WATER RESEARCH SERIES

COASTAL LAGOONS IN EUROPE

Integrated Water Resource Strategies

Edited by Ana I. Lillebø, Per Stålnacke and Geoffrey D. Gooch

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Foreword and book outline

Ana I. Lillebø, Per Stålnacke and Geoffrey D. Gooch (Editors)

THE LAGOONS PROJECT

This book is a major result of the LAGOONS research project (http://lagoons.web.ua.pt). LAGOONS stands for *'Integrated water resources and coastal zone management in European lagoons in the context of climate change'* and was a three-year project (running from 2011 to 2014) funded by the European Commission on the call topic of ENV.2011.2.1.1–1 Lagoons in the context of climate change, under the 7th framework programme (FP7); contract no. 283157.

The key concept of the LAGOONS project was that successful management of coastal lagoons is dependent not only on scientific information, but also on the governance systems in which this knowledge is used at the interface between science, policy and stakeholders, including the local population. The LAGOONS project seeked to address the issues surrounding climate change related 'bottlenecks'. Such events include for instance high precipitation in winter, which can lead to floods and changes in the water quality; and heat waves in summer, which can also result in changes in water quality. In management terms, LAGOONS seeked to contribute to the decision-support methodologies for a coordinated approach to the Water Framework Directive and the Marine Strategy Directive. In addition, LAGOONS proposes actions foreseen in the goals of the Europe 2020 strategy – *A strategy for smart, sustainable and inclusive growth*.

In all, nine research institutes from eight countries participated in the project, and in total, more than 30 scientists, together with PhD and MSc students, contributed to the work. This large group of researchers included many different academic backgrounds, namely climate science, scenario building, modelling, ecology, biology, policy development and economics. For the purpose of this book, we also invited a LAGOONS 'sister' project ARCH (funded in the same EU call) to contribute directly to this book. Others, while not listed as authors, have contributed indirectly but significantly through their research. This large pool of scientific knowledge and experience created a unique possibility to explore and analyse management challenges in coastal lagoons from various angles and entry points.

BOOK OUTLINE

The book focuses on integrated management strategies seen in a land-sea and science-policy-stakeholder perspective, and consists of 22 chapters. The following outline is provided to inform readers from various scientific backgrounds and professional work areas about the various topics discussed in the individual chapters of this book.

Chapter 1 identifies and discusses the pan-European management challenges of lagoons and coastal zones, seen from three different perspectives: governance, environment and modeling. This chapter provides examples of how inter- and intra-institutional interactions influence the implementation of existing laws and regulations; discusses a number of environment-management options seen from a human well-being and sustainable development perspective; identifies major challenges in numerical modelling for solving practical management problems. This chapter is highly recommended for decision makers and managers because it gives an overview of the key issues that should be considered in management.

Chapter 2 provides an overview of the key concepts in the LAGOONS project, given in a management context. It also sets the scene for the following chapters by introducing the project objective, concept and methodology, as well as introduces readers to the four case study lagoons. This chapter is intended as an introduction for all readers.

Chapters 3–10 systematize the knowledge base regarding the physio-geographical background and management story of each of the four case study lagoons. More specifically, **Chapters 3–4** are devoted to Ria de Aveiro coastal lagoon (Portugal), **Chapters 5–6** focus on Mar Menor coastal lagoon (Spain), **Chapters 7–8** are dedicated to Vistula Lagoon (Poland/Russia), and **Chapters 9–10** are centred on Tyligulskyi Liman lagoon (Ukraine). These chapters are intended as supportive information for all readers.

Chapter 11 provides a short overview of trends in climate and land use in Europe that are currently observed and expected in the future, and describes shortly the tools used for creating climate change scenarios, and for impact assessment at the river basin scale. This chapter is recommended as a reference guide for modelers using the eco-hydrological model SWIM.

Chapter 12 provides a short overview of the challenges to improve integrated coastal lagoons modelling in the context of climate change. This chapter is recommended as a reference guide for modelers.

Chapter 13 briefly describes methods and results of climate impact assessment for the four European lagoons and their drainage basins, under a set of 15 ENSEMBLES climate scenarios, within a time horizon until 2100. This chapter is recommended for scientists, decision makers, and managers because it is an overview of the key results under the climate change context.

Chapter 14 describes the methodology used to involve stakeholders in the identification of the main challenges facing the lagoons, and how they contributed to the formulation of possible future scenarios. This chapter is recommended for scientists, decision makers and managers because it is an overview of the engagement of local communities.

Chapter 15 assesses the impacts of potential socio-economic and environmental changes on water quantity and quality in the drainage basins of the four European lagoons. This chapter is recommended for scientists, decision makers and managers, giving an overview of the key results under different possible future socio-economic and environmental scenarios.

Chapter 16 assesses the impact of combined climate change and socio-economic changes in the drainage basins on the water quality of the four European lagoons. This chapter is recommended for scientists, decision makers and managers as it provide an overview of the key responses of coastal lagoons under different possible future socio-economic, environmental and climate scenarios.

Chapter 17 assesses the coastal lagoons response using key bio-indicators and its implications on ecological status in the scope of the Water Frame Work Directive. This chapter is recommended for scientists, decision makers and environmental managers.

Chapter 18 provides an overview of the LAGOONS 'sister' project ARCH: Architecture and roadmap to manage multiple pressures on lagoons. This chapter is intended as an introduction for all readers.

Chapter 19 systematize the results from an integrated vision for ecosystem services given as a environmental SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis and human well-being in a an Pan-European perspective. This chapter is recommended for scientists, decision makers and managers as it gives an overview of the key results combining different scientific disciplines in a multidisciplinary approach, together with the view of stakeholders.

Chapter 20 systematizes the results from the DPSIR (Drivers-Pressures-State-Impacts-Response) framework applied to the society vision for tourism in 2030 in European coastal lagoons. This chapter is also recommended for scientists, decision makers and managers since it is provides an overview of the key results combining different scientific disciplines in a multidisciplinary approach, together with the view of stakeholders.

Chapter 21 provides an overall Pan-European management perspective from various angles and methodological frameworks as well as the overall strategy recommendations from the four case studies. This chapter is highly recommended for decision makers and managers because it gives an overview of the key issues that should be considered in the management of coastal lagoons.

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Behind the finished chapters of this book lie many hours of lively discussions within the research group; but equally important are the discussions with stakeholders and local people in these four case study lagoons. The stakeholder groups combined a wide range of interests and expertise; local fishermen, water managers and policy makers came together, and interacted with us in very productive and rewarding ways during our stakeholder meetings. This interaction has been a great source of inspiration when writing this book.

Thanks also to the Advisory Board for the LAGOONS project which consisted of representatives from international organizations, water, nature and environmental management communities, and research institutes from outside the project. Thanks also to Olga Ameixa, Katrin Knoth, Annelene Pengerud, Inga Greipsland, Attila Nemes and Stefanos Xenarios who have reviewed the first versions of the chapters. Last but not least, the European Commission is gratefully acknowledged for their financial support, and we would also like to express a special gratitude to our Scientific Officers at DG Research and Innovation who have supported us all along the duration of the LAGOONS project.

Aveiro, Ås and Dundee,
February 2015

Chapter 1

Challenges in the policy – environment – modelling management context

G. D. Gooch, A. I. Lillebø, P. Stålnacke, F. L. Alves, M. Bielecka and V. Krysanova

Summary: The management of freshwater, transitional waters and coastal waters poses a number of challenges for policy-makers, decision makers, scientists and other stakeholders. This chapter discusses the management challenges in coastal lagoons seen from the context of three perspectives: Policy, Environment and Modelling. More precisely, the chapter first introduces a theoretical framework for the analysis and then provides examples of how inter- and intra-institutional interactions influence the implementation of existing laws and regulations in the management of lagoons and coastal zones. The chapter then presents and discusses a number of environment-management options for coastal lagoons and coastal zones as seen from a human well-being and sustainable development perspective. The third and final section of the chapter is devoted to the identification of major challenges in numerical modelling as seen from the perspective of a science-management context, with particular focus on the choice of models, data inputs, outputs, and the suitability of a model for solving practical management problems.

Keywords: Ecosystem services, governance, management challenges, numerical modelling, uncertainty.

1.1 THE CHALLENGES FACING THE GOVERNANCE OF COASTAL LAGOONS

Coastal lagoons are complex systems in which freshwater flowing from inland rivers meets the sea, creating a combination of fresh and salt-water and resulting in fragile and complex ecosystems, systems that are also often significantly influenced by human activities. The management of these systems involves a wide variety of institutions and administrative units, as well as knowledge produced by a range of scientific disciplines. The management of coastal lagoons also involves the active participation of the stakeholders involved in the lagoon. In this chapter we examine three central aspects of coastal lagoon management; governance systems, ecosystem management and the use of models to provide input into decision-making. In the following chapters these three perspectives are elaborated and developed, and examples are provided from four European lagoons. Finally, based on the work and results described in the chapters, the book provides recommendations for the management of coastal lagoons which are applicable at European, national, regional and local levels.

1.1.1 Governance systems

The term 'governance' is usually used to denote a form of steering, decision-making and implementation in which the power of formal actors such as governments, political parties and business management is shared and complemented by other actors such as stakeholders, NGO's and consumer organisations. In this context, government is usually associated with the use of command-and-control instruments as policy implementation tools (Pierre, 2000), while governance is more closely related to instruments requiring greater participatory input from the governed. This can be seen especially in relation to the changes seen to be taking place from a system predominantly dominated by formal political institutions, that is, ‘government’, to a system of shared responsibility ‘governance’.

Within water management, governance can be seen as a combination of formal actors and actors from civil society and the business community (Gooch, 2006). While governance can refer to any system that includes these three groups of actors, the need for more effective administration, mainly by international finance and development institutions, has led to a debate over how ‘governance’ can become ‘good governance’. In the context of coastal lagoons, ‘good governance’ can be seen as a process through which the implementation, compliance and effectiveness of agreements, policies and management practices lead to the equitable, sustainable and efficient use of water. The challenge is to identify management systems that protect the sensitive environments of coastal lagoons, while at the same time providing sources of income and livelihoods for the people living around the lagoons.

1.1.2 Interplay – laws, policies, institutions and actors

A central aspect of governance is the role that law, policies and institutions play in influencing the affairs of society (or actors). While these factors are often considered synonymously, more work is needed to ascertain the role and function of each, in order to better understand, firstly, their individual contribution; and secondly, the interplay between different instruments. It is also important to consider how diverse groups of actors interact with law, policies and institutions. Ultimately, examining the interaction between such instruments offers an opportunity to ascertain how individual instruments, or a mix of instruments, best address certain problems and where key decisions about these mixes and instruments are made. While it can be useful to envisage laws, policy and institutions as existing at different spatial levels, the international, national, regional and local, we also need to remember that they are today interconnected. Studies of the influence of law, policy, actors and institutions on coastal lagoon governance therefore need to take into account these spatial levels before continuing with analyses of the ‘modes of connection’ and networks.

An examination of the challenges of coastal lagoon governance and management also needs to include the analyses of the inter-organizational and institutional structures through which law and policy is implemented, an issue which despite a long history of recommendations (Hanf & O’Toole, 1992) still needs more attention. In the case of trans-boundary lagoons such as the Vistula, the situation is even more complicated as there are two different political and administrative systems in place, those of Poland and Russia. It is also important to recognise that both substance and process are central aspects of a governance system. For example, it is not sufficient to look solely at the standard set out within a particular law or policy. In order to consider the issues of implementation and compliance within the context of governance systems, it is necessary to take into account the processes by which such standards are adopted, implemented and adhered to, including who participated in that process and where key policy decisions are made in government (Franck, 1988). Franck maintains that the legitimacy of a rule – measured partly by the fairness of the process by which it was adopted and its determinacy – will affect the compliance pull of a particular rule. The interplay between content and process is therefore important. An analysis of the actors and institutions involved in these processes must therefore complement the study of laws and policies when addressing the challenges facing coastal lagoons.

1.1.3 The existing governance system

A crucial second step within the analysis is to firstly map out the law and policy architecture, as well as the actors and institutions, both at the international and national levels, which are relevant to the case study area. Such a mapping exercise should identify the key legal and policy instruments, establish their relative importance and hierarchy, and consider the connections between instruments. At the international level, it is necessary to understand the degree of commitment that States entered into related to coastal lagoon governance. An analysis of the legal rules and principles contained in the relevant international agreements should therefore also be conducted, alongside an examination of the relationship between them. A second key component of the analysis at the international level is to examine the relevant policy instruments. Such instruments can include declarations, guidelines and working documents, produced by international institutions with a responsibility to implement the legal commitments related to coastal lagoon management. These policies may be overarching in that they may provide the foundations upon which the legal commitments were developed, or they may be specific in that they were developed to support the implementation of a particular legal commitment. The analysis of the challenges facing lagoon management should consider the linkages between different policies, as well as the linkages between the relevant policies and the legal commitments. At the national level, the work should seek to examine the national law and policy framework, in terms of the interrelationship between, inter alia, the relevant national laws and policy instruments. This component of the analysis should also identify the applicable institutions and actors both at the international and national level. At the international level, such institutions might include specific organisations established pursuant to the terms of international agreements, or governmental and non-governmental organisations that support the implementation of the relevant regimes. At the national level, the research should identify the relevant institutions and actors in water management, and civil society groups. The third component of the analysis should seek to examine the frameworks in three key factors that potentially influence implementation and compliance both from a theoretical and empirical case study standpoint, namely a) rule determinacy, b) actor networks and c) administrative capacity. In choosing rule determinacy, actor networks, and administrative capacity, the framework does not intend to be comprehensive in its assessment of factors that might influence implementation and compliance. Rather, the analysis seeks to identify three factors that i) are capable of being examined with limited resources, ii) have been identified in the literature as significant, and iii) are susceptible to policy interventions, either through changes in the existing law and policy framework, or suggestions as to how institutions and/or actors can better utilise that framework.

1.1.4 Administrative capacity and political will

The economic and technical capacities of those responsible for the implementation of law and policy commitments is likely to be an important factor to take into account when examining issues around implementation and compliance (Jacobson & Weiss, 1998). A third key area of the analysis should therefore be to ascertain whether there is sufficient capacity to fulfil the substantive and procedural commitments identified in the above analysis. However, this is one of the most difficult aspects of water management to evaluate. Even in established democracies such as those in Western Europe, the criteria have been hard to formulate (Dimitrova, 2002). Building on the factors outlined above, and the claim that implementation, compliance and effectiveness are three central criteria in water governance, it can be argued that administrative capacity can be seen as the ability to implement an agreement through a process of compliance and effectiveness. As noted, Underdal, (Underdal, 2008) p. 64, identifies three areas of effectiveness, namely output, outcome and impact. However, administrative capacity by itself, while a necessary component of water management, is not sufficient in itself; besides this capacity there has to be the political will to utilise the capacity for implementation. Also, there needs to be a competent and informed management system that takes into account the special characteristics of coastal lagoons.

1.2 THE CHALLENGES FACING ENVIRONMENTAL MANAGEMENT OF COASTAL LAGOONS

1.2.1 Coastal lagoon ecosystems

Coastal lagoons can contain several different types of vegetated habitats, such as submerged aquatic vegetation like seagrasses, and land-water ecotones colonized by salt marshes or mangroves, all depending on the latitude of the lagoon. These shallow inland water bodies can vary from oligohaline (freshwater) to hypersaline, depending on their hydrologic balance (Kjerfve, 1994), and function as nursery grounds for the early life stages, or for the entire life cycle, of many species of fish, crustaceans and molluscs. They are generally very productive ecosystems, and being in the transition zone of freshwater and marine systems, the organic matter fraction from the detrital food web, supporting the *in situ* productivity, can also be exported contributing to the productivity of the adjacent coastal marine areas.

Historically, coastal lagoons have always attracted humans and supported their associated activities. Taking advantage of their geographical location and natural resources, many of these systems have been utilised for fisheries and for collecting materials from plants, algae and animals for direct or indirect human consumption. They have also been used as safe harbours for vessels dealing with maritime trade. The natural capital of coastal lagoons, including the variety of ecosystem services and biodiversity, combined with human capital services as defined by Constanza *et al.* (1997), are therefore essential for human well-being.

1.2.2 Ecological status, ecosystem services and human well-being

One major challenge for the management of coastal lagoons is how to improve human well-being and sustainable development without degrading the environment. Human well-being can be defined as all benefits that '*arises from adequate access to the basic materials for a good life needed to sustain freedom of choice and action, health, good social relations and security*' (e.g., Haines-Young & Potschin, 2013). Also, this concept is closely linked with the concept of ecosystem services, since they represent the contributions that ecosystems make to human well-being. Coastal lagoons provide well-being not only to the people living around the lagoon but also to people living in inland areas, who may also be dependent on the trade and use of goods and services. The human well-being and the economic viability of coastal lagoons depend therefore on the preservation of their bio-physical characteristics, natural resources, biodiversity, land-sea process, landscape and cultural heritage (e.g., Liquete *et al.* 2013). The use of an ecosystem services 'common language' can facilitate comparisons of management alternatives and can be applied in lagoons (Granek, 2010; Haines-Young & Potschin, 2013). The use of the framework is also relevant for the science–policy interface since the well-being of populations and the economic viability of human activities in coastal systems depend on their environmental quality status. There are a number of relevant EU environmental policies (Water Framework Directive – WFD, Marine Strategy Framework Directive – MSFD and Habitat Directive), recommendations (Integrated Coastal Zone Management – ICZM) and strategies (Europe Biodiversity 2020), involving the concept of ecosystem services. For example, the MSFD requires the Member States to apply an ecosystem-based approach to the management of human activities, thus aiming for the sustainable use of marine goods and services. The link between the ecosystem services concept and the WFD is also under consideration, namely in the context of how the ecosystem services approach can help highlight the benefits (societal, economical, environmental) of the WFD (Wallis *et al.* 2012). The Biodiversity strategy for the year 2020, which is closely linked to the Habitats Directive, also has a specific target named Target 2, which aims to 'maintain and restore ecosystems and their services'. The concept of ecosystem services is particularly important in the context of coastal lagoons since it can bridge the gap between the ecosystems ecological and or environmental quality status perspectives and human well-being in a way that is understood by a broad spectrum of users, and it can help to communicate the scientific knowledge relevant for decision-making (Helming *et al.* 2013). Here, the challenge remains, however, as to how to value ecosystem services, how to promote ecosystem services trade-offs, and how to deal with ecosystem disservices, that is, the opposite effect of ecosystem services. Illustrative examples of disservices are changes in agro-ecosystems that promote herbivory and competition for water and nutrients by undesired species (Zhang *et al.* 2007), or environmental changes that favour the prevalence of pathogens affecting humans directly or indirectly (Dun, 2010).

1.2.3 Ecosystem-based management approach

Following the United Nations Environment Programme (UNEP, 2011), ecosystem-based management provides a framework that acknowledges the 'complexity of marine and coastal ecosystems, the connections among them, their links with land and freshwater, and how people interact with them'. It recognizes ecological systems interactions and complexity, and it recognizes that human well-being and ecological status are linked. Following this approach, management must be place-based (e.g., in a coastal lagoon), but must also consider that ecosystem biodiversity, processes and services are interconnected, and that all human multiple activities need to be managed for a common outcome, taking into account inter-sectoral coordination (UNEP, 2011). The goal of ecosystem-based management is to maintain ecosystem productivity, resilience and good ecological status, so that it can provide human well-being. In order to do so, a holistic integrated approach is needed (Atwood *et al.* 2009; UNEP, 2011). Challenges to this approach lie in identifying environmental management priorities, taking into account the way that human activities will affect ecosystems, namely their drivers, pressures and cumulative impacts, their vulnerabilities, the provision of services, and how changes in service provision will affect human well-being (e.g., Granek, 2010).

1.2.4 Vulnerability to climate change and to emergent environmental stressors

Many drivers of pressures occurring within coastal areas, which integrate land-based and marine boundaries, influence the ecological and environmental status of coastal lagoons. Climate change interacts in complex ways with ecosystems making coasts, including coastal lagoons, particularly vulnerable to many of the impacts of climate change (Burkett & Davidson, 2012). Climate change combined with intense human activity imposes additional stress on coastal lagoons, and these disturbances occur concurrently over a range of spatial and temporal scales (Atwood *et al.* 2009; Burkett & Davidson, 2012). While some effects, such as coastal erosion, sea level rise, or floods due to downstream storm surges or upstream runoff, are already evident, further climate change impacts might manifest themselves slowly over decades. Other human-induced stress factors are related to the inappropriate management of water resources, uses and management, land-use, exploitation of resources (e.g., overfishing), and spatial planning. These may induce significant site-specific environmental impacts on coastal lagoons (Atwood *et al.* 2009). Challenges still remain concerning the need to deal with the uncertainty of the cumulative environmental impacts of climate and non-climate stressors (e.g., Burkett & Davidson, 2012).

Additional concerns arise from emergent environmental stress factors, namely pharmaceuticals, nanoparticles, pesticides, industrial chemicals, and personal care products (Daughton, 2005). These substances are being increasingly detected throughout the environment, including coastal lagoons and coastal waters (Munaron *et al.* 2012), and they represent a significant risk to ecosystems and human health (Daughton, 2005). In this matter, there is still a lack of knowledge regarding the chronic effects of these emergent substances, namely the risk of mixtures of these substances (e.g., Munaron *et al.* 2012) and the combined effects of these and other environmental stress factors, including climate change. Therefore, environmental risk assessment remains a challenge. In order to assess these risks and developments, knowledge provided by modelling of possible future trends needs to be provided. These aspects are discussed in the following section.

1.3 CHALLENGES OF USING NUMERICAL MODELS IN A SCIENCE-MANAGEMENT CONTEXT

1.3.1 Why modelling?

Within the fields of water, environmental, climate change and ecological sciences, numerical models are widely developed and used. Studies of environmental pollution and ecological conditions in a coastal zone and river basin require knowledge of the various sources of emissions, and understanding of their transport and transformation processes along a river basin and their impact in the coastal zone. Numerical deterministic bio-physical models are tools that allow a conceptual representation of the physical and geochemical processes related to water quantity and quality in the coastal zone and at the river basin level, combining information on physical characteristics with data on pollution sources and describing process dynamics (Grizzetti *et al.* 2010). The reports of Arheimer and Olsson (2003), Ward *et al.* (1999), Parsons *et al.* (2004), French and Deelstra (2003) give a comprehensive overview of such models, and there exist several web-sites presenting specific modelling toolboxes (BMW, EPA, EURO-HARP, REM). When the models are properly calibrated and validated, they can be applied to run scenarios under changing conditions (e.g., climate, land use, management), and to test the impacts of various mitigation measures providing relevant information for water managers and policy makers.

In the last decade, the management communities have also recognized the need for such models. For example, the EU Water Framework Directive (WFD; 2000/60/EC, 2000) mandates Member States to develop river basin management plans for each river basin district. For example, water quality status needs to be described and sources of pollutants identified and quantified. Furthermore, there must be means by which the authorities can quantify the effects of alternative pollution control options, so that cost-effective measures can be taken. Finally, the involvement of the public and stakeholders requires tools that can more readily illustrate the present pollution situation and the potential for improvement, which can be achieved with various alternative management options. Optimally, such a modelling system could provide additional essential estimates describing economic costs and benefits.

1.3.2 Challenges in modelling

Modelling tools for water systems (river basins, lagoons and coastal areas) of different size and characteristics are well established, with a variety of tools for different spatial and temporal scales. The factors and processes controlling water discharge as well as transformations of various pollutants in soils, groundwater and surface waters have been identified and studied. However, we should always keep in mind that numerical models basically are simplification of real-world situations. There are thus several challenges around the (a) selection of a model for a specific area/problem, (b) input data availability (c) estimation of uncertainty of the model's outputs, and (d) suitability of a model for solving practical management problems. Below we give a brief introduction to some of the main modelling challenges.

1.3.2.1 Selection of a model

There is a wide range of models and all of them have some advantages and limitations, which are usually difficult to assess for others than the modelling experts. In general, 'their complexity increases with the number of processes included and the resolution of predictions, as well as the timing of implementation and the expertise required' (Grizzetti *et al.* 2010). It is not easy to select an appropriate model, since it depends on the question to be answered, resources and available input data. The practical problem is that all these factors should preferably be evaluated prior to the modelling exercise, perhaps even without sufficient knowledge if all the required input data is at place. Ultimately, the choice involves a trade-off evaluating the pros and cons of the candidate models, including its availability at the place and the cost of implementation (e.g., purchase or license costs of commercial tools). Moreover, the heterogeneity, both in terms of spatial and temporal variability, is restraining in the case of regional and large basin estimates. For example, modelling descriptions of the fate and flux of a pollutant, including the underlying hydrological processes, requires a rather detailed understanding of (i) the variability in climate and hydrometeorological conditions, (ii) the absolute and relative importance of point and diffuse sources including data on land use and management practices, and (iii) the relative importance of major hydrobiogeochemical processes involved.

Recent developments in modelling have provided researchers and water managers with improved modelling tools. The application of semi-distributed process-based models for river basins (e.g., Arnold *et al.* 1998; Krysanova *et al.* 1998; Singh, 1995) has proven to be a good compromise between data availability and model complexity, in which the main processes are represented by physically based mathematical equations, while water/matter fluxes are expressed by empirical or conceptual formulations. In physically and process-based modelling the stochastic features and fuzzy logics have become more common approaches to deal with *uncertainties* and spatial variability.

1.3.2.2 Uncertainty

All modelling results have uncertainties, a fact which often has a tendency to be neglected both by the modellers and the end-users. Highlighting uncertainty during communication with end-users increases transparency and enhances the credibility of scientific support to decision making. Each possible uncertainty should be assessed and included in the analyses of modelling results. It has often been argued (see e.g., Grizzetti *et al.* 2010) that there is a need to communicate the whole spectrum of uncertainties, ranging from the uncertainty linked to the choice of a model, to the model representation of the real world, to the input data quality, and the risk that a decision maker is willing to take for solving a particular problem.

1.3.2.3 Data shortage

The choice of a suitable model should also consider the availability of data. A usual limitation is that the model requires a substantial amount of data which is not easily available. Many types of data are usually required for a model (Grizzetti *et al.* 2010), for example:

- physical characteristics of the region of study (such as topography, river network, soils, aquifers, land cover, climate, lakes and reservoirs, etc.),
- information on economic activities related to water quality,
- pollution sources (such as point discharges, agricultural areas and related farming practices),
- time series of measured meteorological parameters (temperature, precipitation, etc.), as well as water quality and quantity observations.

These data, when available, are often collected by different institutions or agencies within the river basin or region, and they are stored using different temporal and spatial scales, which may not suit modelling needs. Another problem in retrieving data is that the modellers may have to negotiate with different environmental agencies or research institutes, and they often struggle in this due to intra-institutional conflicts or barriers. In many cases substantial costs of the data acquisition are also included, often leading to limitations in the purchased data series, which in turn has a negative impact on the quality of the modelling results. Therefore, some compromise between data cost and quality of the results has to be made.

1.3.3 Success stories of model usage in management

The work within the Intergovernmental Panel on Climate Change (IPCC) is perhaps the best example on how models have been used to inform policy. Nowadays, it is a state-of-the-art approach to apply climate scenarios from several sources or a set of regional climate models. Chapters 11 and 12 provide further insight into this issue and show results on the impacts of potential climate change on the lagoons and their catchments. Looking at current practices, we can claim that the mathematical models of water quality have rarely been used to support river basin and coastal zone management and the implementation of water policies. Stålnacke *et al.* (2011) showed that stakeholder involvement at different phases of the modelling process, such as input data preparation, scenario building and discussions of the modelling outcomes, plays a key role in the whole process. Another example of a success story of model usage in management is given in the next section.

THE SUCCESSFUL USE OF SCIENCE-BASED MODELLING – THE BALTIC SEA ACTION PLAN CASE

The HELCOM countries decided as early as 1988 to reduce nutrient loads from all involved countries by 50% by the year 1995 (Helcom, 1994). However, the approach disregarded ecosystem properties and did not take into account the identification of the sectors that should reduce nutrients. In 2007, all the environmental ministers around the Baltic Sea signed and committed themselves to the Baltic Sea Action Plan (BSAP, Helcom, 2007). This can be regarded as a paradigm shift in the policy for the marine protection of the Baltic Sea. Firstly, BSAP included an ecosystem-based approach involving a clear vision on how the sea should look like in the future. Secondly, the mitigation measures and management were shifted from overall load reduction targets (i.e., the Helcom 1994 agreement) and sector-wise management to a more holistic approach with ecological status in focus. Thirdly, the ecological status and load reduction goals for eutrophication (one of four priorities in BSAP) were quantified by scientific modelling. More specifically, the modelling was performed by the Swedish Baltic-Nest Institute within the MARE research programme (Wulff *et al.* 2007). The point of entry was to find simple indicators for the ecological status and then decide on an acceptable 'target' level of eutrophication. The final choice was water transparency (i.e., Secchi depth) since it is understandable for laymen, an integrative parameter and long-term records going back to 1900 exist. Initial estimates of Maximum Allowable Inputs (MAI) of nutrients to reach the eutrophication targets (clear water) were calculated using the NEST-model developed by the MARE Research programme in Sweden. The idea behind the NEST decision support system was to 'develop a user-friendly, computer-based decision support system and to introduce it to managers as a tool for identifying cost-effective strategies to counteract eutrophication of the Baltic Sea' (Johansson *et al.* 2007). The Baltic Sea consists of a series of highly interlinked sub-basins, each with quite different physical, biogeochemical and ecological properties (Wulff *et al.* 2001). Thus, the reduction targets were derived by comparing MAI for each sub-basin with the average nutrient input during a reference period (1997–2003). Successive model runs were carried out reducing P and N loads to the different Baltic Sea sub-basins until an agreement with the environmental targets (i.e., Secchi depth) were reached. First, the loads to the Baltic proper were reduced, then to the Gulf of Finland and the Gulf Riga, and finally to the Danish straits and Kattegat. No reductions were needed to the Bothnian Bay and Bothnian Sea since the targets were already reached by the reduced advective northward flows of nutrients when the targets were met in the Baltic proper. Based on the MAI and agreed allocation principles for dividing the reduction burden between HELCOM countries, nutrient reduction targets were calculated. Based on those, HELCOM Contracting Parties identified priority actions to reduce nutrient loading to the Baltic Sea. It should be stressed that the model calculations in 2007 were based on the best available knowledge at that time and included uncertainties. For example, retention in the drainage basin was not considered. Other uncertainties were devoted to the lack of sufficient river monitoring data (especially time series with sufficient degree of temporal solution) given that the modelling had to be based on the official reporting of load data by the contracting parties to Helcom. Since 2008, work has been ongoing to improve the nutrient reduction scheme, including a further development of the marine model for calculating the MAI. A recent research paper has, with some additional drainage basin and economical modelling, demonstrated that the nutrient reduction goals of 135 000 tons N and 15 000 tons P, as formulated in the BSAP from 2007, correspond to a reduction in nutrient loadings to watersheds by 675 000 tons N and 158 000 tons P when retention is included (Wulff *et al.* 2014).

To conclude, the case of BSAP clearly shows how scientific knowledge and scientific models contributed to an almost total revision of an earlier management policy, and it is a unique example of how research using models and politics can cooperate in defining reduction targets for a marine environment.

1.4 FINAL REMARKS

Water management is influenced by a huge set of challenges, especially in coastal lagoons. Coastal lagoon zones are among the most productive in the world, offering a wide variety of valuable goods and ecosystem services that have always attracted humans, supporting their associated activities and wellbeing. Management of coastal lagoons involves interactions between a wide variety of actors. These consist of the European Union DG.s, national and regional government institutions, local authorities, stakeholder organisations such as farmers' or fishermen associations, and members of the public.

The challenge in the policy-management context is that laws, policies and strategies intended to contribute to the management of the coastal lagoon must be implemented through this complex and often competing institutional architecture. In order for this to be efficient and equitable, overlapping territories of jurisdiction need to be identified and channels of communication need to be developed and maintained.

The challenge in the environment-management context is that without improved knowledge of the dynamics of social – ecological systems, it is almost impossible to design appropriate management tools or even the adaptive intervention experiments needed to inform policy decisions and management strategies. Moreover, the economic viability of human activities in coastal lagoon systems depends on their environmental quality status. Another of the more immediate research challenges is the need to quantify tradeoffs among ecosystem services.

The challenge in the modelling-management context is that models, despite their increased popularity, are faced with uncertainty. This is primarily true in regards to the choice of the appropriate model for the management problem at stake, problems with input data scarcity and accessibility, and consequent model output uncertainty, which is rarely communicated properly to or ignored by the end-users.

> '*Embrace uncertainty by making it apparent, but do not let it distract attention from the things that are known. We often know enough to make an initial choice of direction for action, even if we are uncertain about many details*' (UNEP, 2011).

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Chapter 2

The LAGOONS project in a management challenge context

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Summary: The main objective of the LAGOONS project was to develop science-based strategies and a decision support framework for the integrated management of coastal lagoons and its drainage area. The starting points of the project were that (i) the successful management of coastal lagoons is dependent not only on scientific knowledge but also on the governance systems in which this knowledge is applied, and (ii) the importance of the interface between science, policy and stakeholders (including the citizens).

The focus was on an increased understanding of land to sea processes and the science-policy-stakeholder interface, all in the context of climate change. To achieve the proposed objectives, the multidisciplinary scientific knowledge in the project group was combined and integrated with the knowledge and views of local stakeholders, using a participatory approach. With this innovative approach, applied to four selected lagoons that reflect the diversity of coastal lagoons of the European Member States, we developed integrated scenarios of possible economic development and environmental impacts in the four selected European coastal lagoons. This chapter provides an overview of the key concepts of the LAGOONS project, given in a management context.

Keywords: Coastal lagoons, ecosystem processes, modelling, river basins, science-policy, stakeholders, Water Framework Directive.

2.1 INTRODUCTION

Human activities and well-being, including the global economy, are possible through the diversity of ecosystem services nature provides. In coastal lagoons, benefits provided by ecosystem services can be direct (e.g., fish stocks) or indirect (e.g., floods regulation) through the functioning of ecosystem processes that produce the direct services. This recognised complexity implies, according to us, an Integrated Water Research Management (IWRM) approach as defined by the Global Water Partnership (GWP). This means that IWRM should *'account for a comprehensive, participatory planning and implementation tool for managing and developing water resources in a way that balances social and economic needs, and that ensures the protection of aquatic ecosystems for future generations'*. Sustainable water management and management of lagoons is now the focus of concern for many different groups in society including scientists, politicians, water managers, the public, NGO's, and industrialists (e.g., WssTP – The European Water platform, 2010). However, the societal concerns are diverse, ranging from the effects of increasing demands on the quantity and economic uses of water, to the environmental quality of water and aquatic life. In addition to worries about the effects of global change on the worlds' fresh water resources (Bates *et al.* 2008), there are concerns about the impacts of the expected sea-level rise as reflected through various climate change projection studies (e.g., Jenkins *et al.* 2009), in which lagoons are recognized as highly vulnerable zones.

The 'Millennium Ecosystem Assessment' (MEA, 2005) recognized climate change as possibly the most profound human induced change to the environment. As research contributes to the increased knowledge on climate change, the nature of its impacts and available options for mitigation and adaptation are becoming key concerns. The frequency of extreme weather events has been increasing and directly affecting human well-being (e.g., Kadomura, 1994; Weissbecker, 2011). In general, the frequency of extreme hydrological events is expected to increase, and this will affect all natural and man-made systems as well as human well-being. Climate change is also predicted to have a significant impact on the availability of ecosystem goods and services. Ecological vulnerability and resilience to hydro-climatic shocks such as droughts and floods are critical factors that influence the generation and re-generation of ecosystem goods and services (Smit & Wandel, 2006). Thus, there is a need to study risk and vulnerability associated with natural resources and livelihoods for climate change scenarios and models at various spatial scales. Moreover, there is a need to examine the risk of future losses of ecosystem goods and services, and for using this knowledge to assist in the selection of appropriate mitigation and adaptation strategies. In this context, LAGOONS – '*Integrated Water Resources and Coastal Zone Management in European Lagoons in the Context of Climate Change*' (hereafter LAGOONS) – an EU funded FP7 research project, examined the interaction between climate change and the vulnerabilty and resilience of lagoon ecosystems as well as the impacts on the availability of ecosystem goods and services. We were interested in examining the process through which communities and natural ecosystems are mutually dependant, leading to a strong coupling between social and ecological systems. The interest in understanding the vulnerability of human and natural systems to climate change brought together researchers from a wide range of fields into the LAGOONS project, for example, climate science, scenario building, modelling, ecology, biology, policy development and economics. Furthermore, the main hypothesis of LAGOONS is that successful management of coastal lagoons is dependent not only on multidisciplinary scientific information but also on the governance systems in which this knowledge is used and the interface between science, policy and stakeholder (including the citizens). In LAGOONS, knowledge produced by different scientific disciplines was combined and integrated with local knowledge and the views of stakeholders, using a participatory approach in order to propose reliable integrated scenarios of future possible economic development and environmental conditions in European coastal lagoons. Here, we provide an overview of the key concepts and methodologies used in this project and we give a brief introduction to the four case study lagoons in a management context.

2.2 OBJECTIVE, CONCEPT AND METHODOLOGY

2.2.1 Objective

The main objective of LAGOONS was to develop science-based strategies and a decision support framework for the integrated management of lagoons, based on an increased understanding of land-sea processes and the science-policy-stakeholder interface in the context of climate change.

More specifically, LAGOONS sub-objectives were:

- To create a knowledge base of existing knowledge and data on environmental conditions in the four case study coastal lagoons as well as of relevant laws and policies governing coastal lagoons in a European context;
- To involve stakeholders and policy makers actively from the beginning to the end of the project;
- To conduct quantitative drainage basin modelling and to create scenarios for future developments in land-water interactions in coastal lagoons;
- To present and evaluate these modelling scenarios through a series of three stakeholder workshops in each case study area. These workshops enabled participation outside the scientific community and provided local knowledge and input for the refinement of the scenarios;
- To develop strategies and decision support frameworks for pan-European dissemination and application. This was primarily based on the results of the scenarios as well as on the analysis of legal and policy frameworks, and of the actors and institutions active in coastal lagoon management;
- To up-scale the results produced in the four case coastal lagoons to management recommendations at pan-European lagoon scale.

2.2.2 Concepts and methodology

The LAGOONS multidisciplinary consortium consisted of nine partner institutes from eight different countries (Portugal, Norway, Poland, Russia, Ukraine, United Kingdom, Germany and Spain). These partners have a good background in integrated water resources and coastal zone management, legal policy and institutional analysis, climate change scenarios, hydrological and ecological modelling, ecology, spatial planning, toxicology, and ecosystem services.

The scientific coordination formed the base of the project (Figure 2.1). From the base of the project three main pillars emerged: (i) the stakeholders participation, including an analysis of laws, policies and institutions; (ii) the modelling of key environmental parameters in the lagoons and their catchments, including scenario impact analysis; (iii) the testing of methodologies in the four case lagoons. These three main pillars were connected by the development of a GIS-based knowledge base including a knowledge gap analysis. On the upper part, where the three interconnecting pillars join, the integration and dissemination form an important component, with the aim to produce a support decision framework that should emerge from the obtained results. This enabled us to better understand and manage the dynamics of the relationship between humans and the coastal lagoons in the context of environmental and climate change. In order to develop a decision support framework for coastal lagoons, we choose a bottom-up approach based on four lagoons that were selected based on the following criteria: (i) they must be mearsurable, (ii) they must reflect the diversity of member state coastal lagoons, (iii) sufficient data is available to enable their comparison. Section 2.3 of this chapter summarises the major characteristics of each case study lagoon.

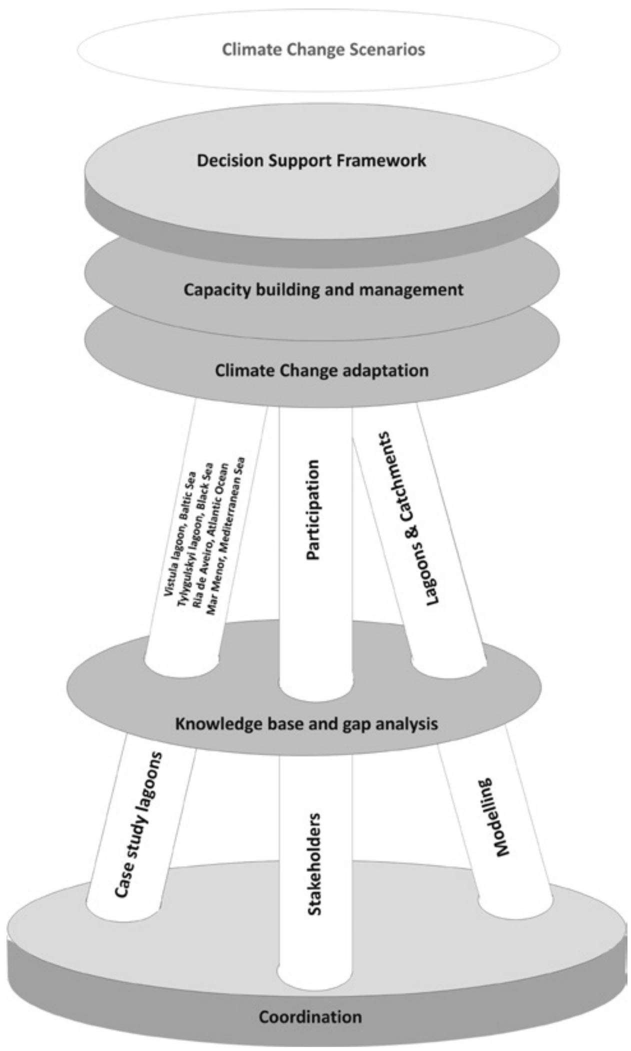

Figure 2.1 Overview of the LAGOONS project structure.

More specifically, LAGOONS had the following major characteristics:

- A dedicated GIS knowledge platform managed the collection of metadata to assure a consistent flow of data and information for the project participants and the external stakeholders;
- In-depth scientific analysis of pressing issues identified by the stakeholders in each lagoon;

- Stakeholders were involved throughout the entire project, ensuring a strong focus on the science-policy-stakeholder interface;
- Focus on the catchment and lagoon interfaces, considering the processes from the catchment to the coast;
- Ecohydrological modelling of the drainage basin and its inputs to the lagoons;
- Hydrodynamical and water quality modelling of lagoon ecosystems;
- Development of scenarios together with local stakeholders (combining qualitative and quantitative scenarios);
- Case study and pan-European analysis of law, policy and institutions;
- Up-scaling of the case study results and dissemination to different audiences (academics, policy makers, stakeholders, including citizens).

2.3 THE CASE STUDY LAGOONS

Four case studies were selected to represent a set of different 'hotspots' coastal lagoons in Europe with a wide and balanced geographical distribution (Figure 2.2) and different characteristics.

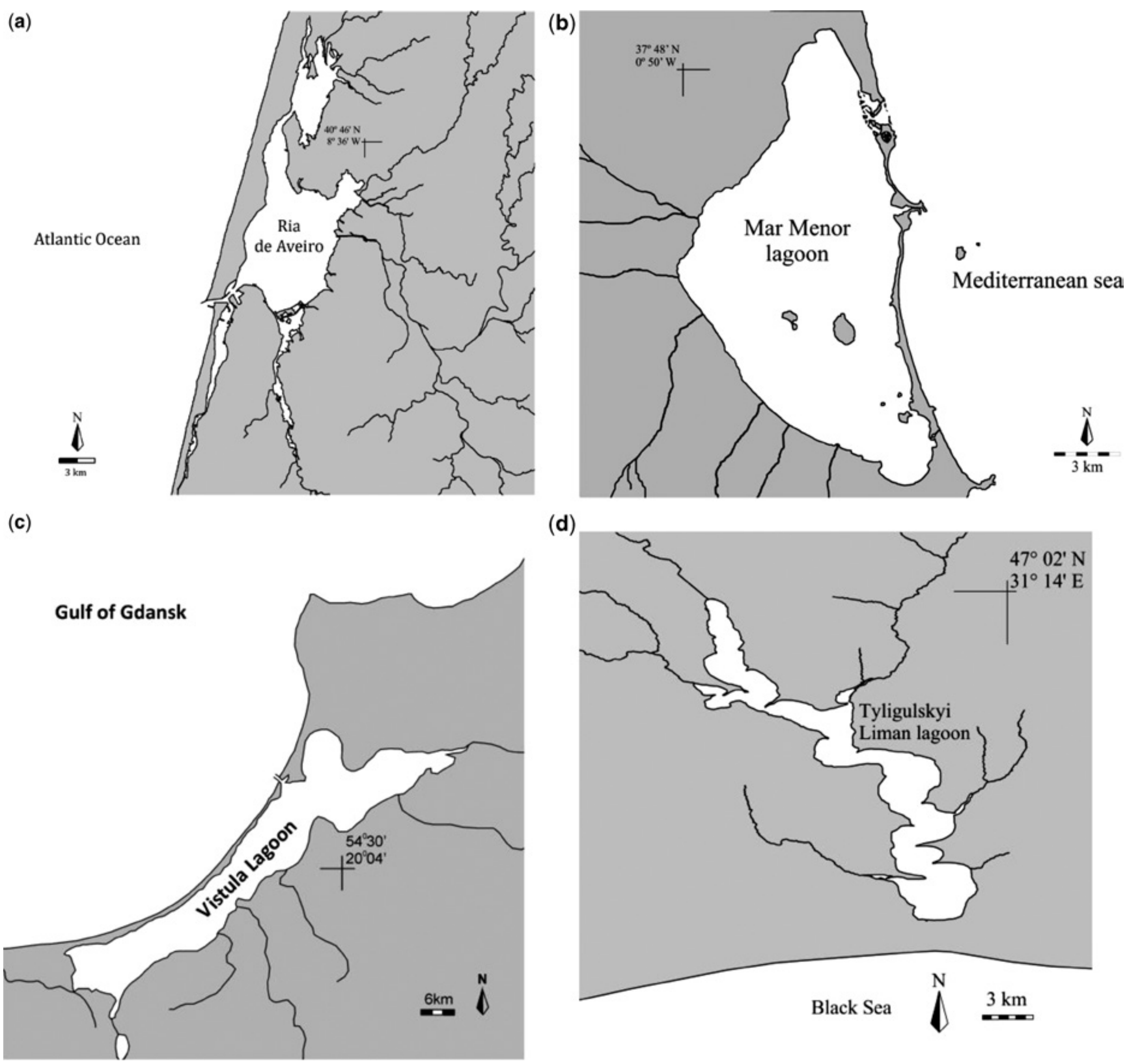

Figure 2.2 The geographical location of the four selected coastal lagoons: (a) Ria de Aveiro, Portugal, (b) Mar Menor, Spain, (c) Vistula (a transboundary system shared by Poland and Russia), (d) Tyligulskyi, Ukraine).

The selected coastal lagoons are:

- Ria de Aveiro Lagoon in the Atlantic Ocean (Portugal);
- Mar Menor in the Mediterranean Sea (Spain);
- Vistula Lagoon in the Baltic Sea (Poland/Russia);
- Tylygulskyi Lagoon in the Black Sea (Ukraine);

Figure 2.2 illustrates the location of the four selected coastal lagoons, whilst table 2.1 summarises their main characteristics. From the case studies summary table in can be seen that different environmental conditions and pressures characterize the selected lagoons. Notably, is that the environmental and especially socio-economic conditions is different in each one of the case study lagoons and their drainage basins. More detailed information regarding each case study lagoon, given as physio-geographical and management stories, can be found in chapters 3 to 10 of this book.

Table 2.1 Summary of the major characteristics of each case study lagoon.

Issue	RIA de AVEIRO	MAR MENOR	VISTULA LAGOON	TYLIGULSKYI LIMAN
Location	Atlantic Ocean (Portugal)	Mediterranean Sea (Spain)	Baltic Sea (Poland/Russia)	Black Sea (Ukraine)
Area & drainage basin (km^2)	83 3.645	135 4.800	838 23.870	170 5.420
Precipitation & Salinity range	1390 (mm) 0–36	300 (mm) 42–47	508 (mm) 0.5–6.5	450 (mm) 5–20
Population (watershed)	353.688 (2011)	99.447	~700.000 (1998)	160.000
Major land uses	Agriculture, Urban Settlements	Agriculture, recreation, tourism (landscape park), urban Settlements	Agriculture, industry, recreation, urban settlements	Agriculture, recreation, tourism (landscape park), urban Settlements
Major activities in the lagoon	Port facilities, industries, fishing aquaculture, salt-production, agriculture, recreational activities, tourism	Port facilities, salt-production, fishing, agriculture, recreational activities, tourism	Port facilities, naval base, industry, agriculture, fishing, limited recreational activities	Recreational activities, tourism, aquaculture, fishing, agriculture
Major fresh water sources (Rivers)	Vouga (67%), Antuã, Boco	Albujón and Ponce wadis	Pregola (41%), Elbląg, Pasłęka, Nogat, Prokhladnaya, Mamonovka, Bauda, Primorskaya and Szkarpawa	Tyligul (65%), Balaichuk, Tsarega
Major water uses in the basin	Hydropower, agriculture, households, irrigation, tourism, industry	Recreation, tourism, fishing, agriculture	Fishing, transportation, limited recreational use	Recreation, tourism, aquaculture, fishing, agriculture, agricultural industry, households
Major lagoon environmental concerns	Droughts and floods events, anthropogenic point sources, historical contamination, coastal erosion, changes in hydrodynamics, seagrasses loss and related ecosystem services	Historical mining contamination of metals, floods, anthropogenic point sources, coastal erosion, eutrophication, jellyfish blooms, seagrasses loss and related ecosystem services	Eutrophication, low hydrodynamics, high turbidity, anthropogenic point sources	Eutrophication, Irregular hydrodynamics, strong salinity fluctuations, high turbidity, anthropogenic point sources, impact on ecosystem services

(*Continued*)

Table 2.1 Summary of the major characteristics of each case study lagoon (*Continued*).

Issue	RIA de AVEIRO	MAR MENOR	VISTULA LAGOON	TYLIGULSKYI LIMAN
End users*	ICNB, INAG, ITP, ARHC, Natural Reserve S. Jacinto Dunes, APA Municipalities, sectoral associations (e.g., farming, fishing, saltpans producers)	Ministerio de Medio Ambiente y Medio Rural y Marino, Estación Náutica del Mar Menor, Autonomic and local administrations, sectoral associations (e.g., tourist, saltpans producers)	Regional Inspectorate for Environmental Protection in Elblag, Sea Fisheries Inspectorate in Gdynia, Association of Marine Cities and Communes, Kaliningrad Centre of hydrometeorology and environmental monitoring, Baltiysk Regional Authorities	MEPU&SAEPO, SCUWE&OPIAWE, Provincial Administrations, Administrations of regional landscape park 'Tyligulskyi', sectoral associations (e.g., farming, fishing, tourist)

**End-users used acronyms:* ICNB-Institute for Nature Conservation and Biodiversity; INAG-Water Institute; ITP-Institute for Tourism; ARHC- Hydrographic Regional Board Intermunicipal Community for Ria de Aveiro; APA- Administração do Porto de Aveiro, S.A.

MEPU&SAEPO – Ministry of Environmental Protection of Ukraine and its regional subdivision – State Administration of Environmental Protection in Odessa Province; State Committee of Ukraine on SCUWE&OPIAWE State Committee of Ukraine on Water Economy and its regional subdivision – Odessa Provincial Industrial Administration on Water Economy.

2.4 THE EUROPEAN POLICY CONTEXT

The main policy context that is of relevance for the LAGOONS project is the EU Water Framework Directive (2000/60/EC) and the activities related to its implementation in the Member States and candidate countries. Indeed, the WFD establishes a framework for protection of inland surface waters, transitional waters, coastal waters and groundwater. The focus of the LAGOONS project was to increase the connection between research and policy, specifically related to transitional and/or coastal waters, by means of the four selected case study lagoons. However, coastal and transitional waters are also affected by the implementation of other relevant EU water legislations, namely the EU Marine Strategy Directive (2008/56/EC), the Integrated Coastal Zone Management (ICZM) recommendation (COM(2007)308 final, 7.6.2007) and the Habitat Directive (92/43/EEC), which is one of the pillars of the Natura 2000 Network of protected areas. In fact, the Annex 1 of the Habitat Directive indicates coastal lagoons as a priority habitat type.

Foreseeing Europe to emerge stronger from the economic and financial crisis, the '*Europe 2020 strategy*', defines '*A strategy for smart, sustainable and inclusive growth*' (COM (2010) 2020, 3.3.2010). Some of the main goals should be attained through research and innovation taking into account climate change; the resilicence of the different EU economies to climate risks should be strengthened and the EU's capacity for disaster prevention and response should be improved to foster sustainable growth. As highlighted in the EU 2020 strategy, climate and resource challenges require joint actions. This means that all member states have to take into account different needs, starting points and national specificities to promote climate change adaptation, capacity building and management. In addition, the Millennium Ecosystem Assessment (MEA, 2005) introduced a new framework for analysing social-ecological systems that has had a wide influence in the policy and scientific communities. However, Carpenter *et al.* (2009) concluded that, beyond the MEA, new research is needed to better understand and manage the dynamics between humans and the ecosystems. In addition, an adaptive management approach is particularly relevant to the challenge of developing a research agenda, in the context of climate change, to support the flow of ecosystem services to enhance human well-being (Steffen, 2009).

The management of transboundary waters has always been a complex and difficult issue, in which national legislation and international conventions meet each other within institutional contexts. Transboundary waters clearly form a special case due to different backgrounds of societies and discrete methods for the estimation of water status. The WFD, while acknowledging the specificity of transboundary waters, does not elaborate on suitable management strategies to involve the relevant countries. Having Vistula lagoon as case study, LAGOONS created a platform that enables the development of strategies for a proper determination of common agreements between national legislation and international conventions, and the formation of suitable institutional contexts.

2.5 THE BOTTOM-UP APPROACH FOR A PAN-EUROPEAN VIEW

To accomplish the LAGOONS objectives – to develop a decision support framework for coastal lagoons in the context of climate change – we applied a bottom-up approach based on four selected lagoons. This required case study scenario analyses in a medium time perspective and an analysis of trends, threats and opportunities, in which the question of compatibility of ecosystem services and social-economic interests was crucial. Such an analysis enabled a proactive approach rather than a reactive one, and the so-called SWOT analysis (Strengths, Weaknesses, Opportunities, Threats) allowed us to do so in a rational and concise manner. This analysis is commonly used to analyse and diagnose the state of the environment in order to define the guidelines for a strategic environment approach. It can be used to analyse the position of environmental conservation and management in comparison with public policies, sectorial strategies and/or programs. As illustrated in Figure 2.3, a comparable SWOT approach has been adopted aiming at a comprehensive overview and assessment of threats and opportunities for an integrated water resources and coastal zone management in European lagoons in the context of climate change, foreseeing human well-being. An example of the application of this analysis is presented in Chapter 20.

Strengths	**Weaknesses**
Ecosystem services Science_policy-stakeholder interface and networks	Economics' resilience Ecological resilience
Opportunities	**Threats**
Eco-innovation Ecoefficiency Ecosystem services trade-offs Capacity building EU Directives context	Climate change Global crisis

Figure 2.3 General SWOT analysis for European coastal lagoons in the perspective of lagoons.

In addition to the SWOT analysis, the generic DPSIR framework (Drivers, Pressures, State, Impacts, Responses), enabled the understanding of the complex relationships between the driving forces on coastal lagoons; their impacts and society's responses to them will therefore be facilitated, and the interlinkages between each of these different interacting components of social, economic and environmental issues were considered. In LAGOONS, changes of the state of coastal lagoons were traced, impacts from anthropogenic activities and climate changes were assessed and evaluated, and potential policy responses identified. The methodological approach combined different scientific disciplines in a multidisciplinary approach, including the existing quantitative-qualitative information from current scientific knowledge, but also the knowledge from the local population. The generic DPSIR framework of analysis, as shown in Figure 2.4, illustrates the coherence across the four coastal lagoon case studies, which was the support for pan-European integration through a bottom-up approach. The scenarios were formulated in order to include anthropogenic deterioration (with climate change impacts, namely extreme weather events) and possible land use changes in the future to develop strategies and methodologies for integrated decision support for stakeholders. An example of the application of this analysis is presented in Chapter 21.

The LAGOONS approach enabled to integrate the stakeholder's views and expectations into the decision support framework and recommendations, as presented in chapter 22. The novel approach proposed by LAGOONS, namely the pan-European integration aspect, ensured that the results were particularly useful; they are aimed at the enhancement of the connectivity between research and policy-making exploiting the recently developed concept of science-policy-stakeholder interface (SPSI) (Gooch & Stålnacke, 2010) and science-policy interface in support of the common implementation strategy of the water framework directive (SPI-CIS). In December 2009, the Water Directors of the EU established an Ad Hoc Activity on Water Science-Policy Interface (Quevauviller, 2010).

2.6 FINAL REMARKS

The conservation and exploitation of critical ecosystem goods and services are influenced by societal needs, development priorities and current state of knowledge. There are several uncertainties regarding the future, however, scenario building and modelling have been recognised as useful tools to assist in attempts to simulate and construct general representations of possible alternative futures foreseeing human well-being.

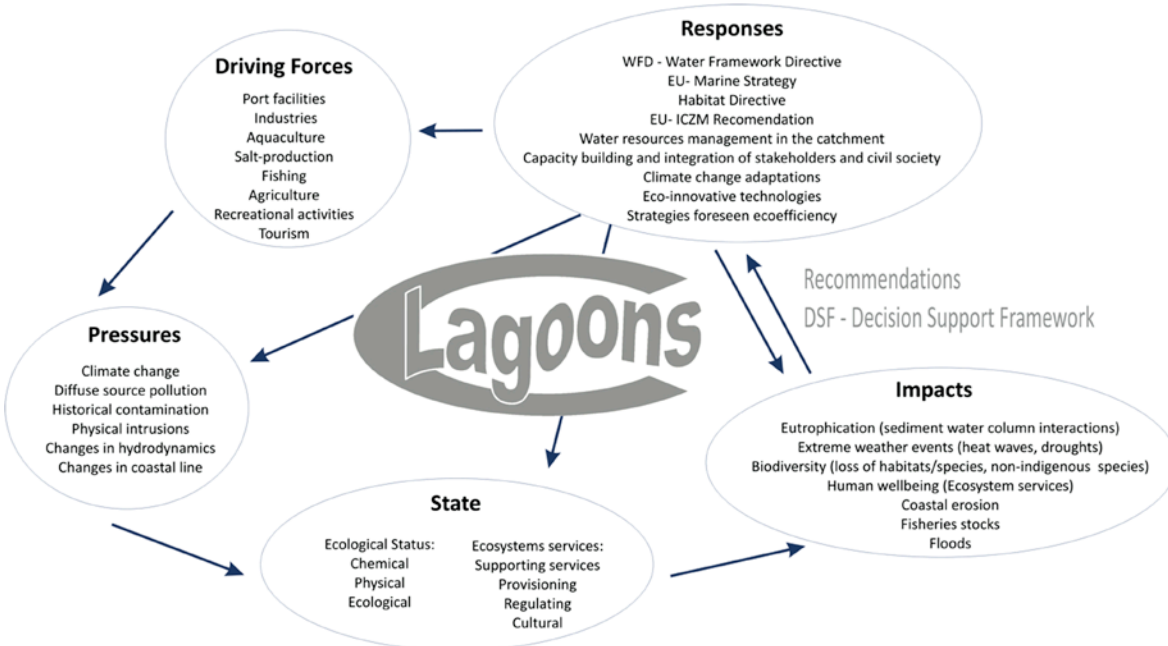

Figure 2.4 A generic DPSIR framework for coastal lagoons and the role of lagoons.

LAGOONS used scenario-building and modelling approaches to try and forecast the combined state of the four case study lagoons and their drainage basins, taking into account observed and predicted changes in climate. As coastal lagoons represent Member States interconnected environments, LAGOONS brought together the participation of end-users and stakeholders (e.g., national/regional parliaments, regional and/or local authorities, social partners and civil society) to work in partnership, by taking action in areas within their interest and responsibility. Finally, as can be seen in the following chapters, LAGOONS proposed actions to tackle bottlenecks of European coastal lagoons in the context of climate change.

2.7 ACKNOWLEDGEMENTS

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Chapter 3

The physio-geographical background and ecology of Ria de Aveiro

A. I. Lillebø, O. M. C. C. Ameixa, L. P. Sousa, A. I. Sousa, J. A. Soares, M. Dolbeth and F. L. Alves

Summary: This chapter systematizes the knowledge base regarding the physio-geographical background and ecology of Ria de Aveiro coastal lagoon. This lagoon is located on the north-west coast of Portugal and is integrated in the Vouga River basin area, which is the main freshwater source into the lagoon. The Vouga River basin is one of the ten hydrographic regions defined in Portugal. This hydrografic region is divided in four main groundwater bodies of which Aveiro Quaternary is the most important in terms of groundwater recharge and water availability. The Aveiro region corresponds to the northern sector of the Portuguese Occidental Meso-Cenozoic sedimentary basin, being characterised by a temperate maritime climate, with warm summers and rainy winters. The geographical location of the Ria and its natural resources contribute largely to its recognised environmental value at national and international levels. This mesotidal shallow lagoon presents unique ecological characteristics, it supports a diversity of life with several classified habitats and it has one of the largest continuous salt marshes in Europe, being also an important area for migratory birds. The Ria's natural capital is an important factor for the development of the region, providing several ecosystem goods and services and contributing to the well-being of the local population.

Keywords: Biodiversity, ecological status, ecosystem services, land use, water demand, water resources.

3.1 INTRODUCTION

The Ria de Aveiro has a complex geologic and human related activity history, carefully recorded since the 16th century. The natural evolution of the lagoon sand spit progressively isolated the ancient bay from the sea, affecting all the related human activities and human health, resulting in a remarkable decline of the local population over 17th and 18th centuries (Abecasis, 1955). In the beginning of the 19th century a permanent artificial inlet was built. Since then, the settled population has shaped the ecosystem by creating salt pans and drainage marshes, opening small channels for navigation, and by creating farmlands such as the smallholdings 'bocage', thus contributing to the increase in habitat diversity and associated biodiversity. The Ria's natural capital is an important factor underpinning social and economic important human activities, contributing to the well-being of the local population and supporting the development of the municipalities in the lagoon area. The Ria de Aveiro's unique environmental, cultural and socio-economic features not only support these high added value economic activities, but are also intertwined with a rich socio-cultural heritage which faces increasing pressures and changes, putting its ecological balance and heritage at risk.

In this chapter, we provide a brief review of the physio-geographical story of the lagoon and basin area, including the physical condition, the climate, the natural resources and land use in the lagoon region. We conclude this chapter with a list of ecosystem services provided by Ria de Aveiro coastal lagoon, followed by some final remarks to make a link between the Ria's natural capital and the next chapter which deals with management framework.

3.2 STUDY SITE DESCRIPTION

3.2.1 Characterization of the Vouga river drainage basin

The source of Vouga River is located in Lapa Mountain, at an altitude of about 930 m. The basin area covers approximately 3 362 km^2, and the river crosses 31 municipalities with a total population of 961, 316 inhabitants (INE, 2012), along 141 km (SNIRH, 2012). The Vouga River estuary is part of Ria de Aveiro coastal lagoon, and the confluence, named Baixo Vouga Lagunar (BVL), forms an area of 3 000 ha with unique characteristics, due to a strong relationship between man, land and water. This area comprises low depth waterways, freshwater wetlands, salt marshes and is recognized as a model of biodiversity and balance between human activities and wild life. The main tributaries of the Vouga River are the rivers Sul, Caima, Antuã and Águeda. The Antuã River forms a sub-basin reaching the Vouga River in the lagoon area. The Vouga River is classified as a Site of Community Importance, over an area of 2 769 ha, contributing significantly to the coherence of Natura 2000 and to the maintenance of the biological diversity within this biogeographic region. The river basin is mostly occupied by forests and farmlands.

3.2.2 Characterization of the Ria de Aveiro lagoon

The Ria de Aveiro (40°38′N, 08°45′W) is a shallow coastal lagoon located in the north-west coast of Portugal and is connected to the Atlantic Ocean through a single inlet (1.3 km in length, 350 m wide and 20 m deep) (Dias & Lopes, 2006). The Ria Lagoon is part of the Vouga River basin area, and is approximately 45 km long (NNE-SSW) and 10 km wide (Dias *et al.,* 2000a). The lagoon forms a unique mesotidal wetland area, characterized by four main channels with several branches forming islands, inner basins and mudflats. In the south, the two narrow and elongated Mira and Ílhavo channels are about 25 km and 15 km long, respectively; in the centre, the Espinheiro Channel is about 17 km long; and in the north, the S. Jacinto-Ovar Channel is about 29 km long. The lagoon's natural capital, including the variety of ecosystem services and biodiversity, is essential for the development of the region and for the well-being of the local population. According to the 2011 census (INE, 2012), the Ria has a population of 353 688 inhabitants in the watershed area.

Ria de Aveiro is a Long Term Ecosystem Research (LTER) site (Lillebø *et al.,* 2011) and is an important site for nature protection. It is part of the Natura 2000 network with one Special Protection Area (the lagoon area with 20 737 ha and the adjacent marine area with 30 642 ha) and one Site of Community Importance, and includes São Jacinto Dunes Natural Reserve, which aims to preserve the coastal dunes.

3.2.3 Hydrological regime

The Vouga River is the most important river discharging into the lagoon, flowing through the Espinheiro Channel and accounting for 80% of the total freshwater input (Stefanova *et al.,* 2014); the remaining 20% comes from smaller rivers, namely the Boco River in the Ílhavo Channel; the Cáster River in the Ovar Channel, and the Mira River in the Mira Channel. Besides the river flows, which influence the physical dynamics in the Aveiro Lagoon, in particular salinity and water temperature, the water circulation is mainly driven by tidal forcing (Dias *et al.,* 2000a; Vaz & Dias, 2008). Tides are semi-diurnal, ranging, at the ocean boundary, from 0.6 m at neap tide to 3.2 m at spring tide, with an average amplitude of 2 m (IH, 2014). The tidal phase lag, relative to the ocean boundary, is in the order of 6 h in the upper reaches of the channels; whilst the water residence time in the lagoon varies from less than 2 days near the ocean boundary, to more than 1 week in the upstream channels (Dias *et al.,* 2000a). The average depth of the lagoon is 1 m, except in navigation channels where dredging operations are frequently carried out to maintain the depths of about 20 m in the ocean boundary and 7 m in the navigation channels (Dias *et al.,* 2000a).

3.2.4 Meteorological characterization

The Aveiro region is characterised by a temperate maritime climate with a warm period between July and September and a cold period between December and February. Rainfall occurs mainly between October and May, with higher precipitation periods in December and January (AMBIECO, 2011). The average annual precipitation in the basin area is 1302 mm (MAMAOT/ARHCentro, 2012), and in the lagoon area 800 mm (AMBIECO, 2011). The annual range of the monthly average temperature is around 10°C in the countryside, and 8.5°C to 9.5°C on the coast (AMRia/CPU, 2006). Adverse weather conditions during winter, such as heavy rainfall, can induce episodic flood events in the freshwater part of the system. In addition, storm surge events (e.g., caused by low-pressure north/northwest of Portugal and high-pressure south/southwest, as well as strong southerly winds) increase the risk of margins erosion and surface saltwater intrusion in the marginal lands of the lagoon (Picado *et al.,* 2013).

3.2.5 Geological and physiographic characterization

The Aveiro region corresponds to the northern sector of the Portuguese Occidental Meso-Cenozoic sedimentary basin. This coast has evolved as sea levels have risen since the Last Glacial Maximum by the accumulation of sand deposits derived principally from the north (Dias *et al.,* 2000b). Geologically speaking , the formation of the lagoon is very recent, starting in the 10th century, when a sandy spit began to proceed southwards from Espinho until the mouth of Vouga River, progressively isolating the ancient bay from the sea (Abecasis, 1955). The topography map, included in Figure 3.1, shows that the coastal plain around the lagoon is very flat, with elevations reaching –10 m; however according to the topography map of that area it can reach elevations up to 1 096 m towards the east and northeast boundaries of the basin (Stefanova *et al*., 2014).

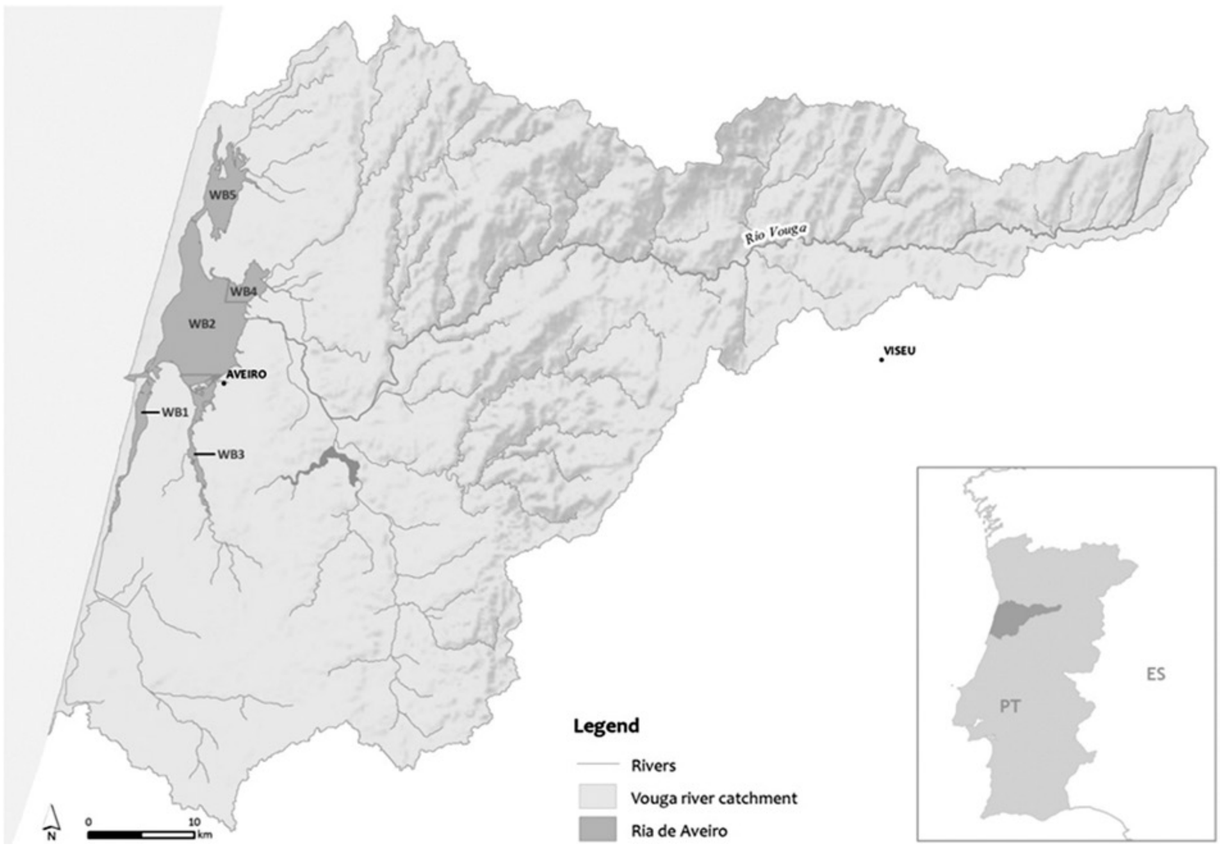

Figure 3.1 The Vouga river basin topography and the integration of Ria de Aveiro in the river basin, with indication of the main freshwater sources into the lagoon, and the lagoon's division into the five transitional water bodies.

3.3 WATER RESOURCES AND QUALITY STATUS

3.3.1 Water resources and demands

The Vouga River basin is part of the hydrographic region no. 4, one of the ten hydrographic regions officially defined with the implementation of the Water Framework Directive (WFD; 2000/60/EC) in Portugal, by the Portuguese Water Law (Act no. 58/2005). This act transposes the European directive to national law, thus laying the foundations and institutional framework for a sustainable water management (see Chapter 4).

The surface water abstractions in Vouga River basin are divided into water abstractions for public consumption (16 abstractions, with an estimated annual volume extracted of 11 hm^3 $year^{-1}$), and abstractions for other uses like agriculture, industry, energy, among other uses (35 abstractions, with an estimated annual volume extracted of 859 hm^3 $year^{-1}$). The majority of the latter abstractions (17 abstractions with an estimated volume extracted of 796 hm^3 $year^{-1}$) are for non-consumptive uses (energy). In total, the estimated water volume extracted from the Vouga River basin is approximately 900 hm^3 $year^{-1}$ (MAMAOT/ARHCentro, 2012).

The Vouga River basin has 4 dams, including Burgães, Cercosa, Várzea de Calde and the Ribafeita. The main use of the Burgães and Várzea de Calde dams is the irrigation of agricultural fields, and the main use of the Cercosa and Ribafeita dams is energy production. Under the framework of the National Programme for Dams with High Hydroelectric Potential, the Ribeiradio Dam it is already under construction and the construction of the Pinhosão Dam is also planned.

In the scope of the WFD implementation, four groundwater bodies have been identified: (I) Aveiro Quaternary aquifer units; (II) Aveiro Cretaceous aquifer units; (III) Bairrada Karst aquifer units, and (IV) Ancient Massif aquifer units (INAG/IMAR, 1997). The Aveiro Quaternary is the most important in terms of groundwater recharge (225 hm^3 $year^{-1}$) and water availability (203 hm^3 $year^{-1}$), followed by the Ancient Massif (groundwater recharge of 144 hm^3 $year^{-1}$ and water availability 130 hm^3 $year^{-1}$) (MAMAOT/ARHCentro, 2012). The majority of the groundwater abstractions in these four groundwater bodies belong to private holders and their main use is agriculture. Other uses include domestic consumption, industry, livestock production, and mixed or undifferentiated uses. However, the highest water volume extracted is from the industry sector. Considering public and private groundwater abstractions the water volume extracted annually is much higher in the former.

3.3.2 Water quality status

Within the implementation of the WFD, a study was published by Ferreira *et al.* (2003), in which sensitive areas and vulnerable zones in transitional and coastal Portuguese systems were identified. The study showed that Ria de Aveiro had a moderate degree of eutrophication and low overall human influence in comparison to other coastal/estuarine systems, and that less than 10% of nutrient inputs were coming from point sources. The improvement of the multi-municipality sanitation waste water treatment plant system, in which most of the households and industrial effluents produced are integrated (SIMRIA, 2014), and which are discharged after being treated to the Atlantic Ocean via the São Jacinto submarine outfall, has improved the water quality. However, some upstream areas still show higher concentrations of dissolved inorganic nutrients, especially nitrogen (Lopes *et al.,* 2007). Back in 2003, Ria de Aveiro was not recommended to be listed as a sensitive area (Directive 91/271/EEC), or vulnerable zone (Directive 91/676/EEC) because the pressures from nutrient loads that could lead to eutrophication were not expected to increase (Ferreira *et al.,* 2003). More recently, in 2012 (MAMAOT/ARHCentro, 2012a), two specific areas were classified as vulnerable zones, 'Zona Vulnerável Litoral Centro' (≅23 km^2) and 'Zona Vulnerável de Estarreja-Murtosa' (≅81 km^2), suggesting that special attention should be given to the water quality status in these areas. Nevertheless, and although the Ria de Aveiro is quite urbanized and industrialized in some areas, it has been recently classified to be in a reasonable good state of environmental preservation. The study leading to this conclusion was done in the scope of the operational programme 'Polis Litoral Ria de Aveiro', reported by AMBIECO (2011). According to the WFD, the Ria de Aveiro Lagoon is divided into five transitional water bodies (Figure 3.1) with the following description and classification: WB1 – A natural (unmodified) water body that includes the Mira Channel and Barra – the connection to the Atlantic Ocean. The water ecological status is 'Good'; WB2 – A heavily modified water body corresponding to the central area of the lagoon. The water potential ecological status is 'Moderate'; WB3 – A natural (unmodified) water body that corresponds to the Ílhavo Channel. The water ecological status is 'Good'; WB4 – A natural (unmodified) water body that includes the Murtosa Channel and the Laranjo Basin. The water ecological status is 'Moderate'; WB5 – A natural (unmodified) water body that corresponds to the Ovar Channel. The water ecological status is 'Poor' (MAMAOT/ARHCentro, 2012a).

3.4 NATURAL RESOURCES

Natural resources comprise the natural capital such as the sea, the lagoon, the river basin and the associated biota as well as all ecosystem goods and services, including all activities that can be practiced enjoying these. Historically, Ria de Aveiro's natural capital has contributed to improve the well-being of the local population. In this context, besides fisheries and marine salt production (see also Chapter 4), there were traditional activities like the harvest of seagrasses and macroalgae mixtures ('moliço') which were used as agriculture fertilizers, or the harvest of rush and reeds used as cattle bedding.

The Ria provides a wide variety of habitats with high biological diversity. It comprises large areas of intertidal sand and mudflats, seagrass meadows and salt marshes, whereas upstream areas of the BVL are characterized by freshwater marshes, forests, open fields and the 'bocage' smallholdings with their typical landscape. These traditional smallholdings measure about 7–8 ha and are bounded mainly by hedges of willows (*Salix* sp.), alders (*Alnus* sp.) and ditches for water regulation, which fragment the landscape and define the boundaries of the property (for more detailed information on agricultural production see Chapter 12). Endemic to the region is the cattle breed 'Marinhoa', which is raised in the BVL marsh area.

The BVL is a transitional system between terrestrial, freshwater and brackish water, being an environmentally sensitive habitat for birds such as the fish-hawk (*Pandion haliaetus*), the purple heron (*Ardea purpurea*), the black kite (*Milvus migrans*), the mallard duck (*Anas platyrhynchos*), and the white stork (*Ciconia ciconia*), among others. It is also an important habitat for mammals like the least weasel (*Mustela nivalis*), the hedgehog (*Erinaceus europaeus*), and the European otter (*Lutra lutra*); for amphibians like the common toad (*Bufo bufo*), the tree frog (*Hyla arborea*), the fire salamander (*Salamandra salamandra*), the marbled newt (*Triturus marmoratus*) and the Iberian painted frog (*Discoglossus galganoi*); for reptiles, namely the Iberian emerald lizard (*Lacerta schreiberi*) and the viperine water snake (*Natrix maura*) (Leão, 2003).

The Ria de Aveiro ichthyofauna is represented by 64 species, several of them with economic importance, which can be divided into four ecological functional groups: i) marine stragglers, species occasionally entering the lagoon with the tides (e.g., *Sardina pilchardus, Sparus aurata*); ii) marine migrants, including the marine species dependent on the lagoon environment for food resources, shelter and nursery grounds (e.g., *Lisa aurata, Dicenthrachus labrax, Platichthys flesus*); iii) estuarine species, including the resident species well adapted to the lagoon (e.g., *Atherina presbyter, A. boyeri*); iv) catadromous (e.g., *Anguilla Anguilla, Alosa alosa*) and anadromous species (*Lampetra planeri*, *Petromyzon marinus*) (AMRia/CPU, 2006).

Cuttlefish and shellfish like clams, shrimps and crabs, also represent a natural value of the Ria de Aveiro with a strong socio-economic role. Another important natural value are worms, which are used as bait in recreational and in commercial fishing (Cunha *et al.,* 2005), e.g., *Diopatra neapolitana,* is used as fresh bait to catch important demersal fishes for human consumption such as seabass (*Dicentrarchus labrax*) and gilthead seabream (*Sparus aurata*). Other relevant polychaetes species used as bait are ragworms (*Hediste diversicolor*) and catworms (*Nephthys hombergii*) (Cunha *et al.,* 2005).

The São Jacinto Dunes Natural Reserve is located on a strip of sand dunes bordered by the Atlantic Ocean and the Ria de Aveiro and covers an area of approximately 700 ha. This protected area was established with the aim of preserving the coastal dunes and its associated flora and fauna. The reserve was divided into three areas differing in their degree of protection: the Strict Natural Reserve which includes the stabilised dune zone and heron-breeding area; the Partial Natural Reserve with limited access, which covers the whole forest area; and the Leisure Reserve, which includes the beach and woods areas (ICNF, 2014). In terms of flora we can find the usual succession in the vegetation seen along the dunes which help in their consolidation. The dunes are bordered by a forested area planted at the end of the 19^{th} century, to prevent the sand from shifting, and consisting mainly of maritime pines (*Pinus pinaster*) and acacias (*Acacia* spp.). In the centre of the protected area, freshwater ponds were made to provide a shelter for anatidae and to help herons (*Egretta garzeta* and *Ardea cinerea*) to become established in the region. The largest of these ponds, known as the Pateira, is the perfect spot for various waterfowl to pay a temporary visit or spend the winter. In the reserve, it is also possible to observe reptiles like the Bocage's wall lizard and the snakes *Malpolon monspessulanus* and *Natrix natrix* and amphibians. Among the mammals, we can highlight *Genetta genetta*, *Vulpes vulpes*, *Crocidura russula*, *Erinaceus europaeus* and *Talpa occidental*.

3.4.1 Land use

The land cover of the municipalities surrounding the lagoon (including Oliveira do Bairro), according to the first hierarchical level of the CORINE Land Cover 2006 nomenclature, is occupied by wetlands (38.38%), water bodies (27.73%), agriculture and agro-forestry (24.43%), forest and natural and semi-natural areas (7.71%) and artificial surfaces (1.75%) (Silva *et al.,* 2011).

3.4.2 Environmental conditions and issues

Ria has been classified to be in a reasonably good state of environmental preservation, having two specific areas that should be considered for specific monitoring programmes and management measures (see sub-section 3.3.2.). The implementation of EU environmental policies has contributed for the reduction of the anthropogenic sources of potentially toxic elements, but, there are still some affected areas: the small basin in the northern part of the estuary (Coroa Basin) (Castro *et al.,* 2006), and the Laranjo Basin, which is a shallow area with 2 km^2 historically contaminated with mercury (Hg) (Pereira *et al.,* 2009). Outside the Laranjo Basin, mercury levels are much lower and below the European threshold concentration for fish and seafood consumption (0.5 mg Hg kg^{-1} for seafood and 1 mg Hg kg^{-1} for certain fish species, EC No. 466/2001). Another study (Sousa *et al.,* 2007) denoted a decrease since 2003 of tributyltin (TBT) pollution – a biocide present in antifouling paints applied to boat hulls, coincident with the EU ban of TBT.

Regarding species richness and biodiversity, the lagoon is composed of a wide range of habitats used as nursery areas for many valuable species. However, the system is also experiencing the presence of exotic species (see Table 3.1). Changes in the system's hydrodynamics since 1990's have altered the tidal prism and increased the water velocity, resulting in the loss of seagrasses, namely in the subtidal areas (Silva *et al.,* 2004) and salt marshes in some areas of the Ria. Previously, seagrass community composition included the species *Potamogeton pectinatus, Ruppia cirrhosa Zostera marina* and *Z. noltei*, but now only the dwarf eelgrass (*Z. noltei*) can be found and mostly restricted to the intertidal areas (Silva *et al.,* 2004). In the BVL, the area of sea rush marshes has also decreased due to prolonged periods of saltwater inundation, and the living hedges are under threat due to surface saltwater intrusion.

3.5 MARINE ECOSYSTEM SERVICES (CICES CLASSIFICATION)

The application of the Common International Classification of Ecosystem Services (CICES) to Ria de Aveiro coastal lagoon, as applied by Maes *et al.* (2014), is presented in Table 3.1. In order to simplify this representation we organized the ecosystems services provided by Ria de Aveiro into 'sections' and 'classes'. The CICES hierarchical classification table can also be seen in Chapter 19 (Table 19.2).

Table 3.1 Ecosystems services provided by Ria de Aveiro.

	Class	Ria de Aveiro
Provisioning	Wild plants and their outputs	Wild glasswort *Salicornia* sp. harvested and sold as a gourmet product.
	Wild animals and their outputs	Fish and shellfish (e.g., lamprey *Petromyzon marinus*, european eel *Anguilla anguilla*, allis shad *Alosa alosa*, spinous spider crab *Maja squinado*, clams *Ruditapes decussates* and *Venerupis corrugata,* cockle *Cerastoderma edule*, cuttlefish *Sepia officinalis*, mussels *Mytilus* spp).
	Plants and algae from *in situ* aquaculture (see also Chapter 4).	Macroalgae farming (red weed *Gracilaria verrucosa,* irish moss *Chondrus crispus,* sea lettuce *Ulva lactuca,* nori or purple laver *Porphyra* spp.*,* velvet horn or spongeweed *Codium tomentosum*)
	Animals from *in situ* aquaculture (see also Chapter 4).	Aquaculture farms of marine fish (e.g., Seabass *Dicentrarchus labrax*) and shellfish (Japanese oyster (*Crassostrea gigas*), the clams – grooved carpet shell (*Ruditapes decussatus*) and the blue mussels (*Mytilus* spp.).
	Fibres and other materials from plants, algae and animals for direct use or processing	Reeds are seasonally harvested; Worms are collected in intertidal mudflats and used as bait; Macroalgae are collected for *in situ* aquaculture.
	Materials from plants, algae and animals for agricultural use	Seagrasses and macroalgae ('moliço') harvesting; Sea rush used as cattle bedding and afterwards as a fertilizer.
	Surface & ground water for non-drinking purposes	The lagoon provides surface water for salt production and forest-fire control, and ground water for inland aquaculture, agriculture, livestock, urban and industrial purposes.
Regulation and maintenance	Bio-remediation & filtration/ sequestration/ storage/ by micro-organisms, algae, plants, and animals	Macrophytes reduce availability of nutrients and pollutants in the sediment and water column; Decomposition/mineralisation processes of plant material mediated by microorganisms; Biological filtration by oysters, clams and mussels in aquaculture and by wild animals.
	Filtration/ sequestration/ storage/ accumulation by ecosystems & dilution by atmosphere, freshwater and marine ecosystems	Bio-physicochemical filtration/sequestration/storage/ accumulation of pollutants by macrophytes; Adsorption and binding of metals and organic compounds in ecosystems, as a result of combination of biotic and abiotic factors; Hydrodynamic dilution of pollutants (tidal action)
	Mass stabilisation & control of erosion rates	Overall, coastal dunes, salt marshes and seagrass meadows contribute to maintain the lagoon integrity.
	Buffering & attenuation of mass flows	Seagrass meadows and salt marshes reduce sediment resuspension and turbidity in the water column, contributing to increase the light availability in the water column.
	Flood protection	São Jacinto dunes, salt marshes and reeds provide resilience to extreme weather events and act as physical buffering of climate change.
	Maintaining nursery populations and habitats	Nursery habitat for fisheries species and commercial invertebrates; Seagrasses, salt marshes including extended areas of reeds, intertidal mudflats, sand flats and salt pans.
	Pest control	Alien species recorded in Ria de Aveiro: manila clam *Venerupis philippinarum*; sand gaper *Mya arenaria*; Asian clam *Corbicula fluminea*; cordgrass *Spartina versicolor.*

	Decomposition and fixing processes	Nitrogen cycling in intertidal mudflats, seagrass meadows and salt marshes.
	Chemical condition of salt waters	The lagoon is divided in five transitional water bodies and their environmental statuses include chemical and biological indicators.
	Global climate regulation by reduction of greenhouse gas concentrations	Global climate regulation by greenhouse gas/carbon sequestration by seagrass meadows and salt marshes, water columns and storage in sediments and their biota; Transport of carbon into oceans.
Cultural	Experiential use of plants, animals and land-/seascapes in different environmental settings	*In situ* bird watching; Visits to the ecomuseum 'Marinha daTroncalhada' salt pans.
	Physical use of land-/seascapes in different environmental settings	Walking, diving, biking, sailing, boating, kite surfing, windsurfing, kayaking, swimming, leisure fishing (angling) and leisure hunting.
	Scientific	Ria de Aveiro is subject matter for research.
	Educational	Natural and cultural heritage of the lagoon are subject matter of education (e.g., guided boat tours in Ria, science activities in the summer with the support of the University of Aveiro, BioRia Environmental trails, Natural Reserve of São Jacinto Dunes, 'Marinha da Troncalhada' salt pan ecomuseum, 'Santiago da Fonte' salt pan (belongs Aveiro University), ship-museum 'Santo André' (an extension of the Maritime Museum of Ílhavo); 'Casa Gafanhoa' municipal museum (testimony of the rural livelihoods of Ílhavo municipality).
	Heritage, cultural	Archaeological sites (e.g., shipwrecks, ship hull, and other isolated findings); Traditional architecture (e.g., 'Palheiros', 'Casa Gafanhoa'); Traditional boats (e.g., 'Moliceiro', 'Bateira', 'Mercantel'); Traditional activities (e.g., salt production).
	Entertainment	Ex-situ experiences through local festivals related with the lagoon's products and activities (e.g. 'Festa da Ria' summer festival with traditional 'moliceiro' boats race; Cod fish festival; Eel and 'ovos moles' from Aveiro; food festival; International marine salt festival; 'FARAV' handcraft festival, Lamprey festival, Allis shad (*Alosa alosa*) festival.
	Aesthetic	Sense of place; Artistic representations of nature (e.g., ceramic tiles, painted shells); Inspiration for some painters and writers, interested in the history and heritage of the lagoon and its users.
	Existence	Enjoyment provided by salt pans, salt marshes, seagrasses and wild species (e.g., lamprey and eel).
	Bequest	Willingness to preserve salt pans, salt marshes, seagrasses and wild species (e.g., lamprey and eel) for future generations.

Note: Only the 'class' categories with existing services are considered in the table, e.g., surface water for drinking purposes is not provided by Ria de Aveiro.

3.6 FINAL REMARKS

Since the 19th century the geographical location of the Ria and the establishment of the permanent connection to the sea contributed largely to the current characteristics of the lagoon, and allowed the settled population in the watershed area to benefit from its natural resources in addition to the provided goods and services. However, human pressure increased during the past decades, imperilling the Ria's natural capital. Even though, Ria has been the focus of considerable research, there are still several knowledge gaps (e.g., the system's resilience to human and climate drivers of change; the implications of these changes in the well-being of local populations; the ecologic and socio-economic value of the provided services, among others). Ria de Aveiro Lagoon and Vouga River basin present unique ecological, environmental, cultural and socio-economic features that not only support high added value economic activities, but are also intertwined with a rich socio-cultural heritage. Together these features underpin human well-being and should be addressed in a multidisciplinary and participatory way. Ria de Aveiro management and governance will be discussed in the following Chapter 4.

3.7 ACKNOWLEDGEMENTS

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Chapter 4

The management story of Ria de Aveiro

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Summary: This chapter systematizes the knowledge base regarding the management story of the Ria de Aveiro coastal lagoon and the surrounding municipalities (Albergaria-a-Velha, Aveiro, Estarreja, Ílhavo, Vagos, Mira, Murtosa and Ovar). The Ria's natural capital is an important factor for the development of the municipalities in the lagoon area. The unique environmental, cultural and socio-economic features support high added value economic activities such as agriculture and livestock, fishing, aquaculture, salt production, industry, tourism, and recreational activities. The Ria de Aveiro is managed within a complex policy and legislative context, with a wide variety of institutions and actors engaged in the use and management of the lagoon. The complexity of the territorial and governance contexts has always been a challenge. Water management associated with spatial planning and territorial management have become, in recent decades, a major target for the different stakeholders (local and regional, public and private). This chapter discusses and presents the legal and institutional frameworks of the Ria de Aveiro.

Keywords: Conflict uses; institutions; legal framework; socio-economic sectors; water management.

4.1 INTRODUCTION

Water management can be considered a complex and interconnected system, particularly in transitional water bodies, since it touches several sectors such as agriculture, economic development, environment and health, and is characterized by the involvement of many organizations, institutions, and stakeholders (Edelenbos *et al.* 2013). The first section of this chapter identifies the main institutions (at national and regional level) responsible, or somehow involved, in water management as well as the policy framework that sets strategies, guidelines and rules for the sustainable use and management of water resources. The second section focuses on the socio-economic and livelihood features of the Ria de Aveiro such as agriculture and livestock, fishing, aquaculture, salt production, industry, tourism and recreational activities, and local population perception of ecosystem services. Finally, the third section addresses the institutions, stakeholders and social groups with direct and indirect interest in the Ria de Aveiro, the main instruments for integrated water planning and spatial planning, and the main use conflicts within the lagoon.

4.2 WATER MANAGEMENT

4.2.1 Water management, institutions and stakeholders

In Portugal, water management is presently enacted by the central government through the Portuguese Environmental Agency (Agência Portuguesa do Ambiente, I.P. – APA). The national water authority is responsible for ensuring the management of the Portuguese water resources; for representing the Portuguese State in water issues at international level and for reporting to the European Commission regarding water related directives. Moreover, the national water authority functions include spatial planning of water resources and demands; water use permits and law enforcement; management of monitoring network; management and application of the economic and financial regime within the hydrographic regions; economic analysis of water uses; and strategic and integrated planning of the coastal zone. At the hydrographic regional level, the APA, I.P. acts through the Regional Hydrographic Administrations.

Economic, scientific, professional and non-governmental organizations are represented in the National Water Council (Government's advisory body for water resources) and in the River Basin District Council (APA's advisory body for water resources to each river basin).

Given the territorial complexity of coastal lagoons – interface areas between water and land systems – and the diversity of uses and activities (both in water and margins), there are several sector-based entities in which APA, I.P. delegates planning, management, licensing or supervision responsibilities. Figure 4.1 summarizes the main thematic areas of management in the Ria de Aveiro and the respective institutional articulation. The articulation between spatial planning tools, Water Law and cross environmental policies is assured by the Regional Coordination and Development Commissions (Comissões de Coordenação de Desenvolvimento Regional – CCDR).

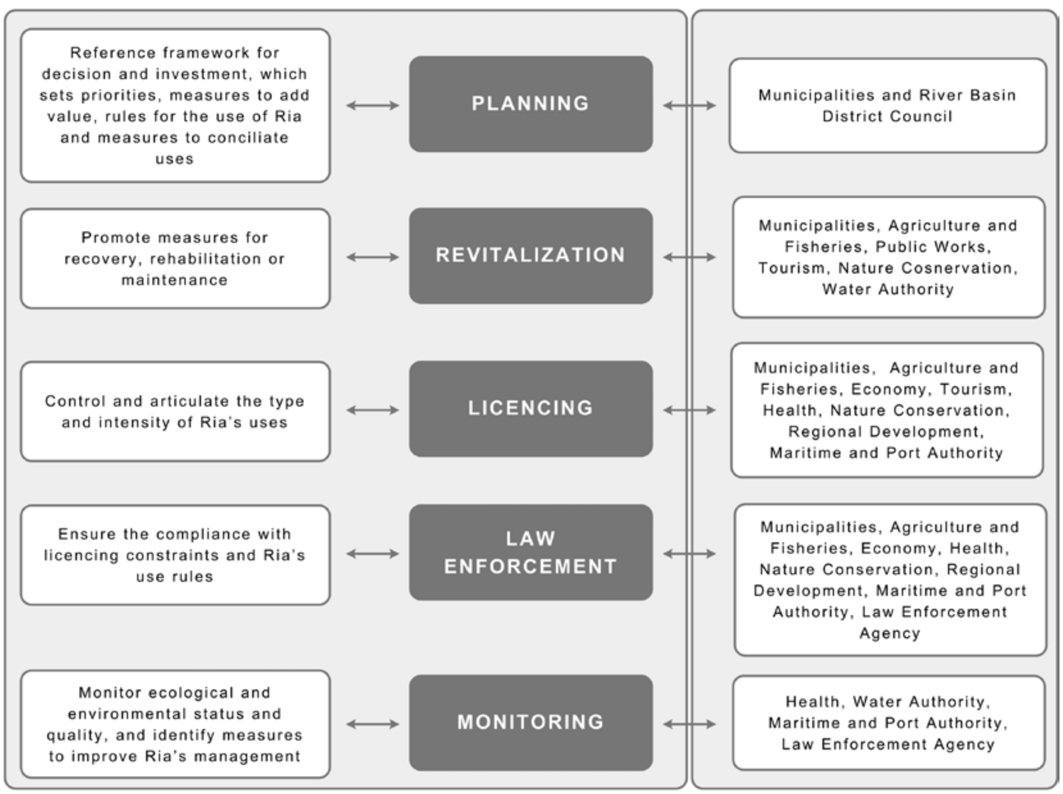

Figure 4.1 Responsibilities of the water authority and articulation with sector-based institutions (adapted from Fidélis, 2011).

4.2.2 Water use rights and laws

Regulation of water uses is undertaken through the Water Law (Law no. 58/2005 of December 29, supplemented by Decree Law no. 77/2006 of March 30), which transposed to the national law the Water Framework Directive (2000/60/EC). The Water Law is the institutional framework that establishes the basis for a sustainable management of water resources (inland surface waters, transitional waters, coastal waters and groundwater). It introduces new concepts and strategies such as the concept of ecological status, which includes chemical, morphologic and biological indicators as a measure for the quality of surface water bodies. The cost recovery for water services and the promotion of public participation in water management are some of the principles addressed by this law (Alves *et al.* 2013). In some domains, the Water Law goes beyond the guidelines of the WFD, particularly regarding the creation of a new instrument, the Estuary Management Plans

(Sousa *et al.* 2011; Fidélis & Carvalho, 2014). This new instrument is a legally binding tool that materializes the territorial contiguity of spatial planning. It focuses on transitional waters, filling the existing gap between coastal and river basin management (Sousa *et al.* 2011).

Other legislative instruments relevant for water resources management are the Water Resources Ownership Law (Law no. 54/2005 of November 15) that defines the Public Water Domain; the Permitting System of Water Uses (Decree Law no. 226-A/2007 of May 31) that establishes the legal regime for the use of water resources; and the Economic and Financial Regime of Water Resources (Decree Law no. 97/2008 of June 11). Other policy sectors should also be considered when reviewing water management such as relations with agriculture and forestry, energy, and tourism, among others, given their strong influence on water quantity and quality, and on the sustainable use of water resources (MAOTDR, 2008a).

4.3 SOCIO-ECONOMIC AND LIVELIHOOD

4.3.1 Agriculture and livestock

The most significant activities, particularly in the northern part of the study area, are milk production and fodder cultivation (maize and ryegrass). Potato is an important crop in the whole area, and in the Bairrada region traditional vineyards (approximately 30 km from the Ria) give a distinctive appearance to the landscape. Rice crop, which once had great importance in the region, is now reduced to small areas in the Baixo Vouga Lagunar (confluence of the Vouga River with the lagoon) and in the sub-tributary river Cértima Valey, although with no economic relevance (DRAPc, 2014).

According to the three last Agricultural Census (1989, 1999 and 2009) there has been a decrease in the Utilised Agriculture Holding (UAH) of each municipality that ranged from 12% to 72%. This represents a loss of approximately 41% of the UAH in the Ria de Aveiro region since 1989 (INE, 2014). The main factors contributing to this decrease are related to road and dam construction, extension of urban perimeters, in addition to the closure of industries and farming decline (abandoned pastures and fields) due to constant loss of income.

Livestock production in the Vouga catchment is characterized by pastures and rearing of poultry and pigs. Regarding the municipalities surrounding the lagoon, there was an overall increase of 23% in livestock units (one livestock unit corresponds to an adult bovine animal) per UAH between 1989 and 1999. However, this trend has been reversed in 2009, which shows a decrease of 12% in relation to 1999 (INE, 2014).

Within this area, there is a region that stands out for its uniqueness in terms of soil productivity, but also landscape and biodiversity: the Baixo Vouga Lagunar. This area comprises a recent agroecosystem characterized by fertile soils managed for purposes of livestock and agricultural production. The farmland is characterized by irrigated fields (rice) and dry fields (maize and wheat). The landscape is characterized by traditional smallholdings, named 'bocage', comprising 7–8 ha bounded by hedges of willows, alders and ditches, which define the property boundaries (Andresen & Curado, 2001).

4.3.2 Port facilities and fishing

Aveiro's harbour is one of the most important Portuguese ports in terms of movement of steel products, liquid loads and mixed cargo containers. The privileged geographic location enables a direct link from the port to the motorway, as well as excellent connections to major roads and the national railway network. It is also one of Portugal's busiest fishing ports accounting for approximately 6% of the total continental fish landings. Most landings are done by Portuguese vessels, although some occasional foreig landings might take place (EC, 2010).

According to the Portuguese Institute for Statistics (INE, 2014), the number of fishermen, motor and motorless vessels registered in the Port of Aveiro has decreased from 2002 to 2012: the number of fishermen decreased by 17%, from 1,798 to 1,501; the number of motor vessels decreased by 3%, from 844 to 819; and the motorless vessels decreased by 25%, from 102 to 76.

The fishing sector is relevant in terms of employment, wealth creation and local socio-cultural identity. Fisheries are the basis of an important and diverse economic activity in Ria de Aveiro, including offshore and inshore fishing, local professional fishing, shell fishing, aquaculture, preparation and processing industry, storage, transport and distribution, and marketing. In the last decade, from 2002 to 2012, the variation in nominal catches increased from 4 to 15 tonnes of migratory (e.g., the European eel) and freshwater fish; from 4,968 to 7,383 tonnes of marine fish; from 87 to 236 tonnes of crustaceans and from 1,357 to 3,367 tonnes of molluscs, both from marine and transitional waters. During this period, the price per tonne remained more or less stable, except for migratory and freshwater fish (that increased about 50%) (INE, 2014).

Collection of shellfish and bait digging activities are common along the shallow subtidal and intertidal flats of the lagoon. (see chapter 3). The relative abundance, the ease of capture, and the growing commercial value make these species an important economic resource. In the present context of a global and national economic crisis, these activities provide work and/or additional income for the local population.

4.3.3 Aquaculture

The Ria de Aveiro provides appropriate environmental conditions for aquaculture and the production of species of commercial importance, namely bivalves (MAMAOT/ARHCentro, 2012). However, due to the economic crisis, major investments in this sector are not expected for the coming years.

In 2010, Ílhavo municipality had 52 licences for aquaculture and Aveiro municipality had 13 (MAOT/INAG, 2012). Seabass (*Dicentrarchus labrax*) is the main species that is produced in extensive or semi-intensive aquaculture earth ponds. These aquaculture ponds result from the conversion of abandoned saltpans. In Mira municipality, turbot (*Psetta maxima*) is farmed in an intensive open aquaculture system (ParquExpo, 2010), and in Murtosa, sole (*Solea spp*) is farmed in super-intensive recirculating aquaculture systems (RAS) (Serradeiro, 2010). These two aquaculture companies contribute significantly to the national production of these species (MAOT/INAG, 2012).

Regarding bivalves, relevant examples of aquaculture production are the Japanese oyster (*Crassostrea gigas*), the clam *Ruditapes decussates* that is produced in the Mira Channel, and the blue mussels (*Mytilus spp.*) in the São Jacinto-Ovar Channel. In Ílhavo Channel, there is one marine macroalgae aquaculture growing macroalgae for human consumption and industry (ALGAPLUS, 2014).

4.3.4 Salt production

Salt production in Ria de Aveiro has been economically important for centuries, but there has been a sharp decline in production during the last decades (e.g., 51,000 tonnes in 1972, 25,000 tonnes in 1982, 5,000 tonnes in 1992 and 500 tonnes in 2002) (Portela, 2006). The number of active saltpans has also decreased in the last decades, and some were converted into earth ponds for aquaculture purposes (Martins, 2005). According to official statistics, there were eight active saltpans in 2013: 'Santiago da Fonte', 'Senitra', 'Peijota', 'Grã-Caravelha', 'Ilha dos Puxadoiros', 'Troncalhada', 'Passã' and '18 Carbonetes'. Some of these saltpans are also directed to other activities: the 'Troncalhada' saltpan, owned by the municipality of Aveiro, was converted into an eco-museum and aims to provide knowledge and interpretation of the territory by maintaining the cultural heritage and demonstrating the practice of saliculture (ECOSAL ATLANTIS, 2011). The 'Santiago da Fonte', owned by the University of Aveiro, is used for research purposes and for education and public outreach; the 'Ilha dos Puxadoiros' is devoted not only to (traditional) production and commercialization of salt, *fleur de sel* and samphire for culinary purposes, but also to nature tourism and leisure (e.g., birdwatching, sport fishing), aquaculture and dissemination of traditional activities through educational visits (Sal do Sol, 2014). The marine salt produced is still regarded as a trademark of the Ria de Aveiro and represents an element of identity for the region. In this context, every year in July, the city of Aveiro hosts an international salt festival.

4.3.5 Industry

The industrial sector currently represents the most important activity in the Aveiro district, with several industrial complexes and factories of recognised national importance. Nevertheless, the number of manufacturing industries in the Ria de Aveiro region dropped from 2,585 to 2,052 between 2004 and 2012. Manufacture of fabricated metal products and food products are the most representative in the region (25% and 19% in 2014, respectively) (INE, 2014). Local specializations include textile and footwear in Ovar, wood and paper in Aveiro, chemical manufacturing in Estarreja, and non-metallic mineral products in Vagos. Ílhavo hosts 60% of the Portuguese fish preparation and processing industries, where salt cod ('bacalhau') is of particular importance, economically and socially.

4.3.6 Tourism and recreational activities

Tourism is a sector with high strategic value to all the municipalities surrounding the lagoon. On the coastline, beach tourism has a long tradition, especially in Ílhavo (Costa Nova beach, since the XIX century, and Barra beach) and Aveiro (São Jacinto beach). Most of the tourists come from Aveiro city and from neighbouring counties. Traditionally, many Portuguese emigrants return during the summer period, spending their holidays at the coastline and in the lagoon area. In addition, these beaches are the closest seaside getaways to some Spanish regions such as Salamanca and Madrid; thus, many Spanish tourists visit Ria de Aveiro during the summer period. Over the past years, the number of guests has increased significantly due to the improvement of the regional touristic offer. From 2002 to 2012, the value has doubled from 78,177to 175,996 (INE, 2014).

The rich natural capital of the Ria de Aveiro, including the Baixo Vouga Lagunar, provides optimum conditions for recreational activities and ecotourism including the traditional 'moliceiro' boat trips, sports activities (e.g., sailing, windsurfing, kite-surfing and kayaking), walking and biking in the diverse landscape (e.g., saltpans, São Jacinto dunes, saltmarshes, farmlands, quays and canals), fishing, and birdwatching (DHV, 2011). Its central geographic location between Lisbon and

Porto and good transport connections make it easily accessible from within Portugal as well as from Spain. Several festivals devoted to local products and traditional activities such as the 'moliceiros' sailing race, take place in the lagoon during summer, as well as several religious celebrations that gather the local population and many tourists.

Fishing and hunting recreational associations are also established in the region. The Recreational Fishing Association of Aveiro and Beira Littoral included 31 local associations in 2011 (www.fppd.pt/). Ria de Aveiro comprises several hunting areas of different types (municipal and associations areas) that have good characteristics for ducks hunting.

4.3.7 Stakeholders perception of ecosystem services

The wellbeing of the local population is largely dependent on the Ria de Aveiro coastal lagoon goods and services. Moreover, the local population has great knowledge about the uses and activities, the historic evolution of social, economic and environmental aspects of the lagoon, and the performance of some management actions.

In fact, the local population of Ria de Aveiro has shown to be aware of the ecosystem services provided by the lagoon (Sousa *et al.* 2013). During the Focus Groups, a deliberative and participatory approach used in the LAGOONS Project in 2012 as a first step for engaging local and regional end-users, participants mentioned several provisioning services such as harvesting of wild animals and plants for nutrition, and harvesting of materials from plants to be used in agriculture (e.g., reeds and seagrasses). Cultural services were also identified, for instance physical and experiential use of plants, animals and landscape through a variety of activities (e.g., walking and biking on the banks, swimming, sailing, recreational fishing), and intellectual interactions with the Ria through science, education and literature, among others. Although stakeholders acknowledged only a few regulating and maintenance services, they clearly recognized the social importance and the regional economic dependence on a healthy ecosystem.

4.4 INSTITUTIONS, LAWS, RIGHTS AND CONFLICTS

4.4.1 Institutions, stakeholders and social groups

Ria de Aveiro is embedded in a complex institutional framework, in which public agencies have different types and levels of responsibilities regarding water management and spatial planning (Fidélis & Roebeling, 2014). As stated above, APA, I.P. plays a major role in the management of Ria de Aveiro. However, because the entire lagoon is classified as Special Protection Area in the scope of the Natura 2000 Network and incorporates a small area of Nature Reserve (São Jacinto dunes), the Institute for Conservation of Nature and Forests (Instituto para a Conservação da Natureza e Florestas, I.P. – ICNF) plays an important role in assuring the conservation and sustainable management of the lagoon.

At the regional level, it is important to highlight the effort made, in 2008, by the eleven municipalities surrounding the lagoon to join their strength to form a regional association, and create an inter-municipal Master Plan (UNIR@RIA) designed and approved for this particular territory (Alves *et al.* 2011), and presently called the Inter-municipal Community of the Aveiro Region (Comunidade Intermunicipal da Região de Aveiro – CIRA). Within its various assignments, CIRA performs the articulation between municipalities and the several services of the Central Administration, particularly spatial planning, nature conservation and natural resources, but also promotes economic, social and cultural development.

In addition to the key agents with legal competences to intervene in the lagoon mentioned in sub-section 4.2.1 (Figure 4.1), there is a large number of stakeholders and social groups with direct or indirect interests in the lagoon such as the Port Authority, the scientific research centres, the municipalities, and the users associations (e.g., fishing, salt producers, farming, hunting, industry, nautical sports).

4.4.2 The national and local regulatory structures

As a result of European and national legal frameworks, Ria de Aveiro is subject to a set of policies, plans and programmes from various government sectors that aim to establish objectives and protection measures (Fidélis & Roebeling, 2014). This sub-section emphasizes the field of water management and spatial planning.

Water planning aims to support and provide guidelines for water protection and management, and the harmonization of water uses, in order to ensure the sustainable use of water resources, and establish environmental quality standards. The main instruments for integrated water planning are:

- the National Water Plan, which defines the national strategy for integrated water management. It sets out the main options of the national water policy, as well as the principles and rules to be applied in river basin management and other planning instruments;
- the River Basin Management Plans, which aim to manage, protect and improve the environmental, social and economic aspects of river basins; and

- the Specific Plans for Water Management, complementary to River Basin Management Plans: the National Programme for the Efficient Use of Water, the Strategic Plan for Water Supply and Sewerage, the National Programme for Dams with High Hydroelectric Potential, and the National Strategy for Agro-Livestock and Agro-Industrial Wastewater.

Regarding the spatial planning of water demands, there are three territorial management instruments that bind the government and privates, whose main goal is to protect and enhance/improve water resources and their uses, which are:

- *the Public Reservoirs Spatial Plans* – provide the appropriate measures to protect and enhance public reservoirs in order to ensure their sustainable use;
- *the Coastal Zone Management Plans* – regulate the uses of coastal resources in order to articulate them with the protection of the biophysical integrity and preservation of the environment and landscape;
- *the Estuary Management Plans* – provide the appropriate measures to protect the estuary water bodies, estuary beds, margins and natural ecosystems as well as to increase the social, economic and environmental value of its surrounding areas. Regarding Ria de Aveiro, the Vouga River estuary management plan has not been made yet.

In addition, and considering the strategic importance of coastal zones at environmental, economic and socio-cultural level, the Portuguese government approved, in 2008, the Polis Littoral Programme (Integrated Operations of Rehabilitation and Recovery of Coastal Areas), which provides a set of specific measures to improve and enhance the coastal areas at risk, as well as degraded natural areas on the coast.

Ria de Aveiro (along with Ria Formosa, Litoral Norte and Litoral Sudoeste) was considered one of the national priority coastal systems for intervention, and the programme has been implemented. These national Operational Programmes focus on nature conservation, while designating areas for economic development.

Figure 4.2 is a schematic representation of the territorial incidence of some of these plans and programmes, showing the complexity of the institutional and legal framework in the Ria de Aveiro region.

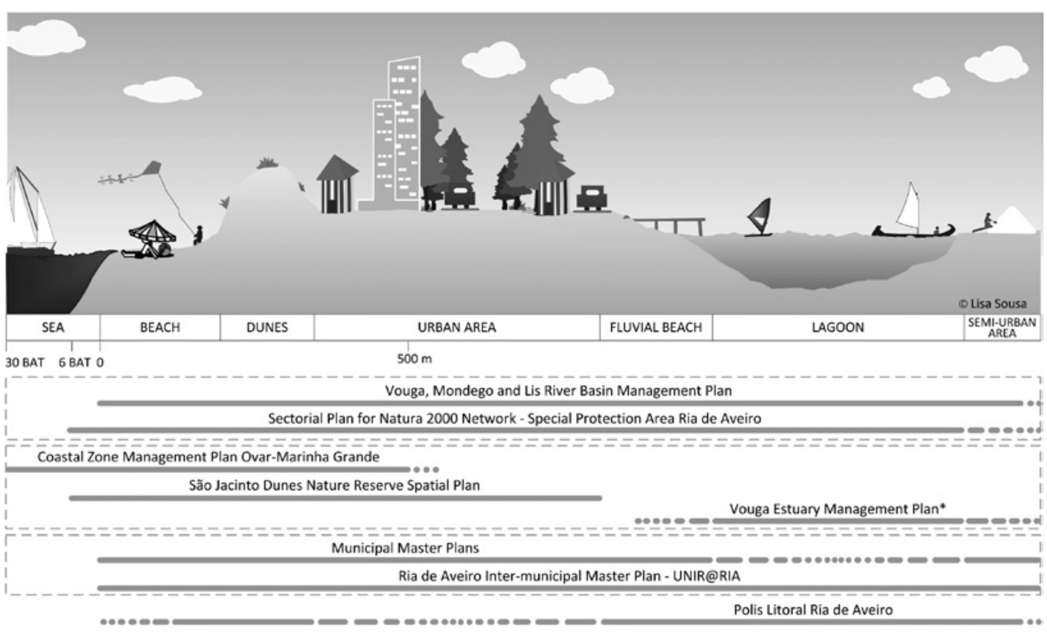

Figure 4.2 Territorial incidence of some of the plans and programmes on the Ria de Aveiro littoral (adapted from Sousa *et al.* 2011).

4.4.3 Use conflicts

In the last decades, Ria de Aveiro has experienced an improvement of the water quality status due to the implementation of wastewater treatment plants and the construction of a submarine outfall that reduced nutrient loads (AMBIECO, 2011). These improvements enabled other uses opportunities that still require an integrated management.

Regarding the management of Ria de Aveiro, we highlight the allocation of financial resources to implement a set of operational measures (more than 150) through the Polis Littoral Ria de Aveiro Programme, which aimed to i) protect, requalify and prevent the risks in the coastal and lagoon area, ii) protect and enhance the natural heritage and landscape, ii) take full advantage of the Ria's resources towards a more competitive and dynamic lagoon from an economic and a social perspective, and iv) promote and encourage the experience of the lagoon (Alves *et al*. 2013). Apart from improving the lagoon's environment, its economic competitiveness and its resilience to natural hazards like floods and coastal erosion, this programme has been important since it involved a strong collaborative work between the central administration and CIRA (Fidélis & Carvalho, 2014). However, despite these efforts, conflicts between uses and activities as well as their impacts/pressures on Ria de Aveiro, are not being addressed as a whole. Meaning that the management of Ria de Aveiro is still sector based and not integrated. In this context, there are several concerns identified by stakeholders (e.g., Sousa *et al*. 2013) and in research/technical reports (e.g., MAOTDR, 2008b; DHV, 2011) that represent a constraint for some activities or uses of Ria de Aveiro such as:

- loss of navigability in secondary channels and access to some quays due to siltation, causing restrictions to nautical sports, professional and recreational fishing;
- siltation will also affect the estuarine beds and their related processes (e.g., nutrient cycling) and communities, some of them with economic value;
- lack of an efficient system of buoys to support navigation in Ria channels;
- lack of infrastructures to support nautical activities (e.g., mooring/anchorage);
- absence of shipyards, particularly for recreational boats;
- deficit of maintenance and degradation of saltpan walls, and consequent change of landscape;
- deficiency of law enforcement, especially regarding fishing activity (including shellfish and bait collecting), which endangers the fish and shellfish stocks and their habitats, and might create problems to nautical sports and recreation;
- changes in the lagoon's hydrodynamic regime (water velocity and tidal range) contributing to the erosion of the banks, salt water intrusion in agricultural fields, modification of the distribution of some habitats (e.g., seagrass beds and saltpans), and low accessibility to some quays during low tide;
- historical contamination of the 'Largo do Laranjo' and 'Esteiro de Estarreja' sediments.

In addition to these pressures, there are some conflicts between activities, for instance (DHV, 2011; Sousa *et al*. 2013):

- conflicts of interest between the economic development and viability of the commercial harbour and other less influential activities, such as fishing and nautical tourism and recreation;
- conflicts between salt production and aquaculture (when not adequately managed), particularly when they are close to each other, once they have distinct water requirements;
- increased conflict between professional and recreational fishing, due to the overlap of the area of activity and the existence of a parallel economy;
- conflict between sailing and kite-surf due to lacking regulations.

4.5 FINAL REMARKS

There has been a growing national effort to adopt a more integrated, adaptive and participatory management of coastal zones (including coastal lagoons), which is reflected in the legislation created for its protection, recovery, management and governance; and in the organizational restructuring.

Nevertheless, and, in spite of the work that has been done in Ria de Aveiro (e.g., the implementation of Polis Littoral Ria de Aveiro and the creation of CIRA), additional efforts have to be made to ensure better coordination and conciliation between the governmental institutions and the different sectors of activities, as well as to safeguard the integration among a variety of planning and management tools. Moreover, Ria de Aveiro is a complex socio-ecological system, being the regional community (from both cultural and economic aspects) strongly connected with the natural capital of the lagoon. This interconnectivity must also be also taken into account in the present and future management of Ria the Aveiro.

4.6 ACKNOWLEDGEMENTS

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Chapter 5

The physio-geographical background and ecology of Mar Menor

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Summary: The Mar Menor, a hypersaline lagoon located in a semi-arid arid region of southeast Spain, is one of the largest coastal lagoons in the Mediterranean, covering an area of approximately 135 km^2. The importance of the lagoon and its salt marshes in terms of biodiversity has been recognised in numerous international protection schemes: it has been listed as a Ramsar International site since 1994; it is considered a Special Protected Area of Mediterranean Interest (SPAMI), established by the Barcelona Convention in 2001; and a Site of Community Importance (SCI) to be integrated in the Natura 2000 Network (EU Habitats Directive). This area is also a Specially Protected Area (SPA) for nesting, migration and wintering of aquatic birds, and is protected by European legislation (Birds Directive 79/409/CEE).

The lagoon and the associated watershed areas comprise a wide variety of natural resources facilitating human use, including large tourist resorts and intensively irrigated agriculture. During the last decades, these human activities have caused substantial environmental changes in the lagoon, namely at the plankton population; replacement of macrophyte species; and undesirable jellyfish blooms.

Although numerous studies have been carried out focusing on the Mar Menor, a better understanding of the consequences of the loss of biodiversity and the increasing eutrophication in the lagoon is still necessary. In addition, the impact of global climate change combined with the previous threats also needs to be addressed in order to develop successful management strategies to protect this valuable ecosystem and the provided services.

Keywords: Biodiversity, eutrophication, Mar Menor coastal lagoon.

5.1 INTRODUCTION

As many other coastal lagoons, the Mar Menor is characterized by its shallow depth, meaning that most of the seafloor lies within the photic zone, which allows benthic primary productivity. As a result, shallow lagoons and bays tend to be dominated by benthic producers such as seagrasses, perennial macroalgae and microphytobenthos, rather than by phytoplankton. In the Mar Menor lagoon, the high benthic macrophyte biomass contrasts with the low phytoplanktonic density and the relative oligotrophy of the waters (Gilabert, 2001; Lloret *et al.* 2005). This fact highlights the existence of a benthic control of the system, since benthic production is more important than planktonic production (Terrados & Ros, 1991; Lloret *et al.* 2008; Lloret & Marin, 2009; Lloret & Marin, 2011).

Due to its location between land and sea, the Mar Menor Lagoon is subject to an elevated rate of dynamic changes in the natural environment that result in high biological productivity and diversity. As a highly productive system, the lagoon shows a marked abundance of macrofaunal species. It also supports fish populations, many of which having great commercial importance, and constitutes an essential area for nest building, migration and wintering of aquatic birds. In terms of biodiversity, the relevance of the Mar Menor lagoon has been recognised in numerous international protection schemes.

The natural resources of the lagoon provide a considerable economic activity as large tourist resorts and intensively irrigated agriculture. However, as many other coastal lagoons, the Mar Menor is considered to be particularly vulnerable to eutrophication and other pollution related environmental problems due to its shallow depth and restricted exchange with the adjacent sea. During the last decades, these human activities in the area have increased the amount of nutrients and other substances entering the lagoon, and prompted diverse changes to the environment. As a consequence of increased inputs, the waters of Mar Menor have experienced rising nutrient levels that have led to changes in the plankton population in the lagoon (Gilabert, 2001; Pérez-Ruzafa *et al.* 2005). These changes have also favoured the proliferation of the jellyfish species *Cotylorhiza tuberculata* and *Rhizostoma pulmo,* with severe consequences for touristic activities in the area (Pérez-Ruzafa *et al.* 2002). Furthermore, modified light conditions of the lagoon waters might have favoured the expansion of *Caulerpa prolifera* at the bottom of the lagoon as well as the confinement of the traditional phanerogam *Cymodocea nodosa* to small patches in shallow areas (Lloret & Marin, 2009). These changes have caused a progressive deterioration of the sediment through the accumulation of organic matter, the subsequent appearance of anoxic conditions, and the production of toxic acid-volatile sulphides; all of which have degraded the water quality in several zones of the Mar Menor Lagoon (muddy bottoms, bad smell, etc.). In addition, the local fishing industry is negatively affected by the decreased population of commercial fish, as these species, mainly Sparidae and Mugilidae, prefer feeding on patches of the phanerogam or unvegetated bottoms, which are now covered by a dense and continuous bed of the macroalga *C. prolifera* (Verdiell-Cubedo *et al.* 2007).

5.2 STUDY SITE DESCRIPTION

5.2.1 Physical conditions of the lagoon and the drainage basin

The Mar Menor is a hypersaline coastal lagoon located in a semi-arid region of southeast Spain. The lagoon occupies an area of approximately 135 km^2 and a total volume of 610×103 m^3 at (Alicante reference seawater level) (Arévalo, 1988). The depth in the lagoon reaches 6.5 m with an average depth of 3.6 m. According to the geomorphological classification of Kjerfve (1986), the Mar Menor constitutes a restricted littoral lagoon relatively isolated from the adjacent Mediterranean Sea. The lagoon is isolated from the Mediterranean Sea by a 22 km long and 100 to 900 m wide sandy bar (La Manga), crossed by three shallow channels (Marchamalo, Encañizadas del Ventorillo y La Torre and El Estacio). In the early 1970s, one of these channels (El Estacio) was dredged and widened to make it navigable. Since then, it has become the lagoon's main connection with the sea. The enlargement of the 'El Estacio' channel led to a substantial increase of water renewal rates from the Mediterranean, as well as subsequent changes in water temperature and in salinity. These changes favoured the colonisation of the lagoon by numerous marine species, as lagoon temperatures and salinities changed to less extreme values (Pérez-Ruzafa *et al.* 1991). Before the dredging of the 'El Estacio' channel, salinity levels in the lagoon reached 52 or above, and temperatures ranged from 6 to over 30°C. Nowadays, salinity ranges from 42 to 47 and temperatures are less extreme ranging from 10°C in winter to almost 30°C during the summer. Water exchange with the adjacent Mediterranean Sea mainly occurs through the 'El Estacio' channel. Small tides, mainly diurnals, are responsible for high frequency dynamics through the channel, but the main force is, by far, the variation in atmospheric pressure (Arévalo, 1988). Winds are responsible for main water circulation within the lagoon, which, on average, shows an anti-clockwise circulation pattern. Water residence time in the lagoon has been estimated as 0.79 yr^{-1}.

The lagoon is situated at the end of a watershed bordered by a group of mountain ranges (Escalona, Algarrobo, Cartagena) that surround the Campo de Cartagena, a wide plain of about 1,440 km^2. Freshwater inputs into the lagoon are restricted to six ephemeral watercourses called wadis (or 'ramblas'). These wide, shallow gullies are generally inactive, but can carry great quantities of water and sediments during flood episodes. The effect of near-impermeable soils and scarce vegetation cover of the watershed areas aggravate the torrential nature of precipitation supplies. Los Alcázares wadi has a diffuse network of channels and reaches the Mar Menor at the town of Los Alcázares. The Albujón wadi constitutes the largest watercourse and drains the adjacent agricultural area of Campo de Cartagena. It drains a surface of 441 km^2, about one third of the total surface of the adjacent agricultural area (Campo de Cartagena). The Miranda wadi presents two main channels that converge diffusely in the El Carmoli salt marsh. The other three wadis that reach the lagoon are the Beal, Ponce and Carrasquilla wadi. These originate in the mountains located south of the Mar Menor Lagoon, and, during episodic rain events, carry metal wastes and mineral deposits from the mining areas located there (Figure 5.1).

The Albujón wadi is the principal watercourse responsible for major inputs of organic and inorganic nutrients that flow into the lagoon (Velasco *et al.* 2006, García-Pintado *et al.* 2007). The principal water source is the drainage from irrigated crops, but sometimes waste-water treatment plants located in the watershed area discharge large amounts of untreated or insufficiently treated water into the channel.

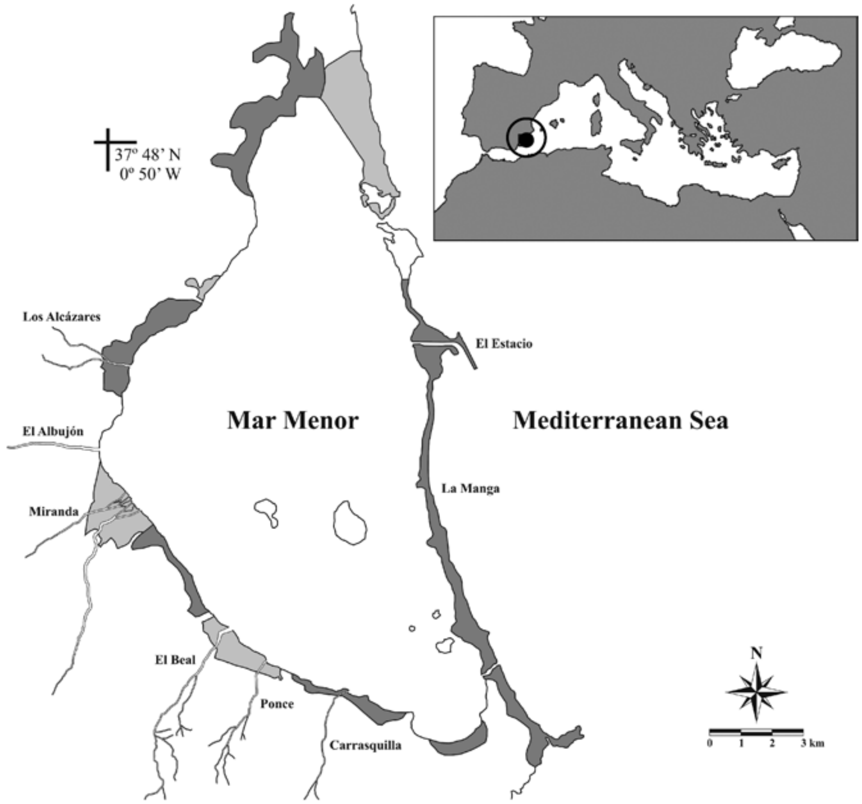

Figure 5.1 Map of the Mar Menor coastal lagoon showing the location of the main urban areas (dark grey), salt marshes (light grey) and watercourses.

5.2.2 Climate

The area presents a semi-arid Mediterranean climate, characterised by warm and dry weather conditions. Mean annual temperatures range from 17 to 21°C. Winters are mild, with temperatures around 10–13°C. Summer temperatures reach values above 25°C.

Precipitation is scarce in the area with low amounts of annual precipitation (<300 mm yr^{-1}), and mainly occurs during storm events in autumn and winter. There is nearly no precipitation during July and August, when maximum evaporation rates are observed.

Wind regimes in the area are dominated by the first and second quadrants with a marked seasonal pattern: westerly winds dominate during the autumn and winter, while winds from the northeast and southeast dominate during the spring and summer.

5.3 NATURAL RESOURCES AND LAND-USE

The Mar Menor lagoon constitutes one of the most unique and studied environments in the region. Its value in terms of biodiversity has been recognised by numerous protection schemes. At a regional level it is a Regional Park and Protected Landscape. It has been listed as a Ramsar International site since 1994; it is considered a Special Protected Area of Mediterranean Interest (SPAMI) established by the Barcelona Convention in 2001; and a Site of Community Importance (SCI) to be integrated in the Natura 2000 Network (EU Habitats Directive). This area is also a Specially Protected Area (SPA) for the nest building, migration and wintering of aquatic birds, and is protected by European legislation (Birds Directive 79/409/CEE).

The high protection status of this coastal lagoon is due to the value of its natural environment. A total of 179 aquatic bird and 46 fish species have been sighted in the area. It also comprises 23 habitats of Community Importance, of which nine are considered a priority.

Many aquatic bird species use the lagoon and its associated salt marshes. Fifty aquatic bird species have been included in Annex I of the Birds Directive 79/409/CEE. Twenty species use the area for nest building. With regard to wintering and migration, approximately 10,000 birds have been estimated during January and 5,000–6,000 during their migration from September to October.

The fish community in the Mar Menor Lagoon is also represented by a large number of species. Many of these species are of commercial interest, such as the Cyprinodontid fish *Aphanius iberus*, since they constitute an important food resource for other species such as aquatic birds; but they also serve as indicators of the overall 'health' of the lagoon environment. Mugilidae fish species are the most important ones in terms of abundance and biomass, but many other species are also represented in the lagoon (Figure 5.2).

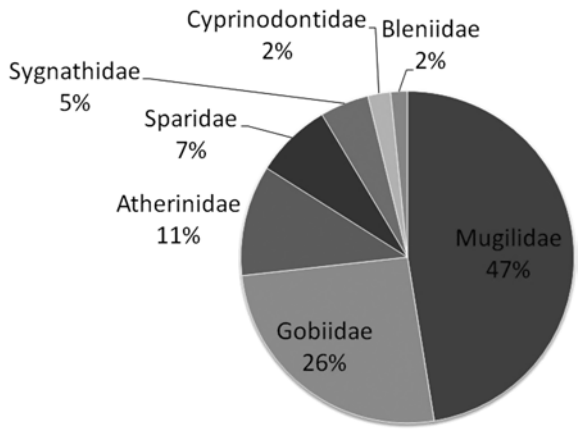

Figure 5.2 Biomass percentage of the main fish families in the Mar Menor lagoon.

Since the appearance of the first neolitic settlements in the area, the Mar Menor has been exploited with increasing intensity as an urban and industrial area as well as for fishing, agriculture, mining, and boating activities, and as a landscape and tourist resource. Military uses are also represented in the lagoon by a military air force base on the western part of the lagoon, close to the town San Javier.

Urban areas that have experienced a large development in order to accommodate the increasing number of tourists that visit the area every summer currently occupy most of the land in the immediate area surrounding the lagoon. The towns of San Pedro del Pinatar in the north, San Javier, Los Alcázares, El Carmolí, Los Nietos and Los Urrutias on the western side, and especially, La Manga, located on the sand bar that isolates the lagoon from the Mediterranean Sea, experience a temporary ten-fold increase of their population every summer. Large tourist resorts are also present in the southern part of the lagoon.

In the watershed area, Campo de Cartagena, intensively irrigated agriculture constitutes the main land use (more than 80%). The area occupied by irrigated crops has increased since the late 70s, after the increase of water resources provided by the Tagus-Segura river diversion.

Natural and semi-natural salt marshes are mainly represented by the salt pans of San Pedro del Pinatar in the north of the lagoon, El Carmolí on the west shore of the lagoon, and Marchamalo in the south.

5.4 MAIN ECOLOGICAL AND ENVIRONMENTAL PROBLEMS

5.4.1 Pollution of the lagoon

High anthropogenic pressure in the surrounding watershed of the Mar Menor has led to an increase in nutrients and pollutants flowing through the watercourses into the lagoon. The lagoon receives drainage inputs from the adjacent watershed, Campo de Cartagena, and presents high levels of organic residues, fertilizer, pesticides and heavy metal pollution. Water pollution in the lagoon is the result of human activities in the area, mainly due to the inputs derived from agricultural drainage resulting from the irrigation of croplands. However, the lagoon also receives some input of urban wastewater that is insufficiently treated, mainly through the Albujón wadi.

The construction of the Tagus-Segura diversion caused both qualitative (changes from dry-crop farms to intensively irrigated crops) and quantitative (increasing area) changes to the local traditional agriculture (Pérez-Ruzafa *et al*. 2002). Further information on the Tagus-Segura water transfer can be found in Chapter 6. Since the overexploitation of groundwater has decreased, changes have led to rising phreatic levels. Such increased drainage-water flow into the wetlands has modified the natural habitat; natural saline steppe, a rare habitat of conservation priority, according to the Habitats Directive, was lost to expanding reed beds, a habitat without interest from the point of view of the directive (http://www.um.es/oserm/salinidad_agua.html). In addition, the Albujón wadi now maintains a regular flux that is fed by groundwater with high nitrate levels, which is responsible for major inputs of organic and inorganic nutrients entering the lagoon (Velasco *et al.* 2006).

The nutrient load is one of the main factors driving the long-term evolution of the ecological conditions of the Mar Menor lagoon, and emerges as a key factor in all relevant scenarios and management options for the Mar Menor site. In the Albujón wadi, nitrate is the predominant form of nitrogen transported. During summer months, it is also common to find high phosphate and ammonium concentrations due to an increased discharge of wastewater (Ruiz & Velasco, 2010). Velasco *et al.* (2006) estimated that the annual inputs into the Mar Menor lagoon from the nearby agricultural area of Campo de Cartagena ranged from 640 to 3,136 tonnes of dissolved inorganic nitrogen, and from 43 to 251 tonnes of soluble reactive phosphorus per year, considering the Albujón wadi as the main contributor. The more evident signals of this eutrophication process are the appearance of a dense monospecific bed of the macroalga *Caulerpa prolifera* (Forskal) Lamouroux that covers most of the lagoon's bottom, and the massive proliferations of two allocthonous jellyfish species from the nearby Mediterranean Sea, *Rhyzostoma pulmo* and *Cotylorhiza tuberculata*. Nowadays, both jellyfish species are considered a plague, affecting the lagoon's image as a tourist destination. The population of jellyfish has been estimated at around 47 million individuals every summer (Pérez-Ruzafa *et al.* 2002). Despite the magnitude and persistence of these inputs, severe and undesirable eutrophication events have not been reported. This fact may be attributed to the role played by the enormous biomass of the *C. prolifera* bed, which has been demonstrated to have effectively reduced nutrient levels in the water column (Lloret *et al.* 2008) and the seasonal filter role of jellyfish. Nowadays, the high benthic macrophyte biomass contrasts with the low phytoplanktonic density and the relative oligotrophy of the waters (Gilabert, 2001; Lloret *et al.* 2005). This fact highlights the existence of a benthic control of the system, since benthic production is more important than planktonic production (Terrados & Ros, 1991; Lloret *et al.* 2008; Lloret & Marin, 2009, 2011).

New urban tourist developments have also generated a degradation of the landscape, loss of biodiversity and fertile soils, as well as serious environmental problems related to waste management, waste water, and traffic, which will require new water treatment facilities and infrastructure. An increase of surface runoff and flood risk has increased the chances of urban and agricultural pollution reaching the lagoon.

Several studies indicated the presence of heavy metals (Zn, Pb, Ar) in the sediments and food chain in the lagoon (Marin-Guirao *et al.* 2005a, 2005b; 2007, 2008). Historical mining activities in the area initiated an increase of heavy metal concentrations in the lagoon's sediments. Although mining activities ceased several decades ago, the El Beal and Ponce wadi carry great quantities of heavy metals, especially after rainfall events. The negative effects of waste from old mining activities are still evident, as scarce but intense rain episodes can transport large volumes of mining waste from the southern mountains into the lagoon. The presence of heavy metals in the food chain constitutes an important concern, not only for animals, but also for human health. Therefore, it seems necessary to keep monitoring the levels of metals in the biota in order to prevent possible metal transfer to humans, since commercial and leisure fishing activities are very popular in the area.

5.4.2 Groundwater pollution and overexploitation

The groundwater in the Mar Menor area shows high nutrient and pesticide concentrations. Intensively irrigated agriculture constitutes the main source of groundwater contamination in this area. In addition, livestock farms are one of the main sources of ammonia that infiltrates the soil. Golf resorts also contribute, by means of fertilizers, that also reach the groundwater.

Most of the groundwater masses in the area are not overexploited due to the increased amount of water available in the area via the Tagus-Segura river diversion. There can be exceptions, however, such as the Las Victorias groundwater mass that is currently overexploited. However, when rates of diverted water are low, water extraction from aquifers increases and the extracted amount of water can exceed the amount of available resources, especially during dry periods. This situation has led to marine water intrusion into the aquifer with an undesirable increase in water salinity and subsequent decrease in water quality.

5.4.3 Impact on protected natural areas

Protected natural habitats give home to a large number of endemic species and provide a habitat for species of interest at a regional, national and international level. However, these areas are threatened by the impact of human activities that occur close to their boundaries including agriculture, mining, and urban development, but also by activities that take place within the protected area such as tourism, fishing, hunting, flowers recollection, noise, and light contamination.

5.4.4 Impact on public domain

The acquisition of public domain marine-land areas by private owners poses elevated risks at times when natural disasters strike the area. Human settlements, especially those related to tourism, have progressively occupied growing areas located close to the ocean that traditionally belonged to the public domain. The urban growth in Murcia is among the most intensive in Spain, which, in turn, is the most intensive in Europe. In the Campo de Cartagena, large areas of irrigated production and traditional crops have been reclassified to urban use. Theses urbanizations have been built close to wadis or on them. Due to the natural characteristics of the drainage area, flat terrains located close to the wadis are at significant risk to flooding during torrential rains events. The characteristic dune systems and broad beaches, typical for La Manga, have been severely damaged by urban development, and over 60% of the area of sand stretches have disappeared over the last 30 years. The public domain is also used to building public services as promenades, sport harbours, artificial beaches and roads.

5.4.5 Increase in surface run-off

Waters from the Tagus-Segura river diversion have yielded a surplus of water resources in the area, and caused a rise in phreatic levels. As a result, some wadis have lost their natural temporary characteristics and now maintain a regular flux of water. This situation has altered plant and animal populations that inhabit the area.

5.5 MARINE ECOSYSTEM SERVICES (CICES CLASSIFICATION)

Table 5.1 summarizes the application of the Common International Classification of Ecosystem Services (CICES) to Mar Menor.

Table 5.1 The ecosystems services provided by Mar Menor.

	Class	Mar Menor
Provisioning	Wild plants and their outputs	Not applicable
	Wild animals and their outputs	The lagoon supports important fisheries of commercial interest (mainly Sparidae and Mugilidae species).
	Plants and algae from *in situ* aquaculture.	Not applicable
	Animals from *in situ* aquaculture.	Not applicable
	Fibres and other materials from plants, algae and animals for direct use or processing	The lagoon supports an important population of *Sipunculus nudus*, a sipunculan harvested and used as a fishing lure by many fishermen. Traditional fishing structures such as Las Encañizadas provide important resources for the area.
	Materials from plants, algae and animals for agricultural use	Not applicable
	Surface & ground water for non-drinking purposes	The lagoon provides water for salt production and bath-houses. Also ground water is used for agriculture.
Regulation and maintenance	Bio-remediation & filtration/sequestration/storage/by micro-organisms, algae, plants, and animals	Seagrasses have the ability to bio-remediate, reducing the availability of pollutants in the sediment and water column (e.g., metals, organic pollutants). Decomposition/mineralisation processes of plant material mediated by micro-organisms; decomposition/detoxification of waste and toxic materials for example, waste water cleaning, degrading oil spills by marine bacteria, (phyto-)degradation, (rhizo-)degradation and so on.
	Filtration/sequestration/storage/accumulation by ecosystems & dilution by atmosphere, freshwater and marine ecosystems	Sequestration and storage of nutrients through incorporation in biomass is performed by seagrasses and algae. Seagrasses accumulate metals and other pollutants (e.g., organic compounds) in their biomass and rhizo-sediment, removing/decreasing its availability in the environment. Biological filtration is performed at Mar Menor through benthic macrophytes.
	Mass stabilisation & control of erosion rates	Lagoon vegetation (halophilic plants, reeds and benthic macrophytes) increases sediment fixation and reduces erosion. The lagoon effectively reduces the erosion of the coastline by storms. The lagoon naturally reduces the amount of sediments reaching the coast and reduces their impact on coastal communities.

Table 5.1 Ecosystems services provided by Mar Menor (*Continued*).

	Class	Mar Menor
Regulation and maintenance	Buffering & attenuation of mass flows	Seagrass meadows and salt marshes reduce sediment resuspension and turbidity in the water column, contributing to increase the light availability in the water column.
	Flood protection	Littoral wetlands in the area contribute to water retention and flash-flood lamination.
	Maintaining nursery populations and habitats	Mar Menor provides nursery habitat for fisheries species and commercial invertebrates (e.g., crustaceans, bivalves). Also provides habitat for important populations of species of conservational interest, such as seagrasses beds, salt marshes including extended areas of reeds, intertidal mudflats, salt pans and coastal dunes. Benthic subtidal and intertidal habitats.
	Pest control	High salt concentration is a barrier for alien species. Allocthonous jellyfish species Rhyzostoma pulmo and Cotylorhiza tuberculata; replacement of the phanerogam macroalgae Cymodocea nodosa.
	Decomposition and fixing processes	Nitrogen cycling in intertidal mudflats, seagrass meadows and salt marshes
	Chemical condition of salt waters	Water dynamics of Mar Menor (WFD indicators)
	Global climate regulation by reduction of greenhouse gas concentrations	The lagoon water body regulates local climate. The important primary productivity in the lagoon and its associated wetlands carries out an important CO_2 uptake and O_2 production.
Cultural	Experiential use of plants, animals and land-/seascapes in different environmental settings	In many areas of the lagoon visitors experience muds for their therapeutic use. Many visitors enjoy the therapeutic properties of bathing in the warm and salty waters of the lagoon. The lagoon is used for recreational activities including birdwatching.
	Physical use of land-/seascapes in different environmental settings	The lagoon is used for recreational activities including swimming, fishing, sailing, windsurfing, kitesurfing, kayaking, biking, walking. The area constitutes one of the most visited tourist destination in Spain.
	Scientific	Mar Menor is subject of important scientific research. The Universidad de Murcia, Universidad Politécnica de Cartagena, IEO, and Centro de Recursos Marinos have an important role in the study of the lagoon.
	Educational	The natural environment of the lagoon has an important value as an educational resource. There are guided tours to the islands, salt pans, and educational programs in protected natural areas.
	Heritage, cultural	The traditional architecture of the bath-houses constitutes a clear example of local cultural diversity.
	Entertainment	Gastronomy, based on the lagoon products is an attraction for visitors. There are several local festivals related with the lagoon.
	Aesthetic	The particular landscape of the lagoon has been always attractive for visitors. The presence of islands within the lagoon is an unique added value to the lagoon landscape.
	Existence	Enjoyment provided by salt pans, seagrasses and wild species
	Bequest	Willingness to preserve salt pans, salt marshes, seagrasses and wild species for future generations.

Note: Only the ‘class’ categories with existing services are considered in the table, e.g., Surface water for drinking purposes is not provided. Explanation on the classification methodology can be seen in Chapter 19 (Table 19.2).

5.6 FINAL REMARKS

The sum of the impacts of mining, agriculture and urban development in the Mar Menor area during the last decades has clearly affected the lagoon ecosystem (Conesa & Jiménez-Cárceles, 2007). Although many studies have been carried out in the lagoon, many of them addressing recent environmental problems (see Cabezas & Martinez, 2009 for a review), there are still some aspects that require efforts in order to better understand the lagoon's response to environmental stressors and the ecosystem's overall functioning.

With the increase of agricultural and touristic activities in the area, the lagoon has developed moderately eutrophic characteristics. Some of the most important symptoms of the changes are the appearance of a dense monospecific bed of the macroalga *Caulerpa prolifera* that covers most of the lagoon's bottom, and the massive proliferations of jellyfish species. The eutrophication process could cause serious changes to the Mar Menor Lagoon, affecting not only its ecological state and biodiversity status, but also its socioeconomic aspects, especially tourism and fishing. There is a benthic control of the system, since benthic production is more important than planktonic production. However, recent studies pointed out that the expected consequences of climate change in the area could have a negative impact on macrophyte production, and therefore increase the risk of eutrophication, and ultimately cause the collapse of the system with the appearance of severe eutrophication events (Lloret *et al.* 2008). A clearer understanding of the consequences of climate change in the area is therefore necessary.

Salinity changes after the enlargement of the El Estacio channel have also affected the traditional fishing activities (Serra-Raventós, 2007; Pérez-Ruzafa, 1989; Pérez- Ruzafa *et al.* 1991). The stocks of traditional species have suffered substantial decrease (Conesa & Jiménez-Cárceles, 2007). This alteration of fish assemblages has also modified the structure of the food chain within the lagoon. It is necessary to improve our knowledge about the effect of this gradual change of the distribution of species on the stability of the ecosystem, and the impacts of urban and tourist development on the lagoon's biodiversity.

The groundwater in the Mar Menor area shows high nutrient and pesticide concentrations and could potentially be overexploited. Management and reduction of groundwater pollution is often a very difficult task. However, environmental education and the improvement of agricultural technologies could help reducing the amount of pollutants that reach groundwater bodies. The acquisition of public domain marine-land areas by private owners has elevated flooding risk, and it has limited space and legal rights to implement larger scale preventive measures. The maintenance of these protected areas requires not only the correct management of human activities, but also rehabilitation measures.

In conclusion, the Mar Menor lagoon ecosystem is under continuous modification due to the impacts of mining, agriculture and urban development. The application of the EU Water Framework Directive, should not consider the Mar Menor lagoon as a 'static' ecosystem, but as one that changes constantly.

5.7 ACKNOWLEDGEMENTS

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Chapter 6

The management story of Mar Menor

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Summary: The Mar Menor Lagoon is managed within a complex legislative and policy context, with a wide variety of institutions, policies and decision-makers. Agriculture and tourism are the two dominant economic sectors. However, attention should also be paid to the fishery sector due to its relevance to the lagoon itself. The main land-use in the Mar Menor drainage basin is agriculture and, more specifically, irrigated lands. Tourism development has increased the demand for recreational facilities resulting in the creation of new infrastructures. The main commercial activities such as urban development and changes in agricultural practices, but also historical mining activities, have increased the pollution input into the lagoon resulting in water eutrophication and a profound change of the ecosystem. Despite the already implemented management measures, in this chapter, we stress the need for a better understanding of the interactions between the processes in the river basin and the lagoon functioning. The 'health' of the lagoon is crucial, and there is a need to develop an integrated strategy for the Mar Menor. More specifically, it is necessary to develop an integrated and holistic management framework with common objectives and guidelines, in order to promote a more sustainable development and protect the environment, natural resources and biodiversity. This is particularly important considering the current and forthcoming consequences of climate change.

Keywords: Mar Menor coastal lagoon, management, human impact, economic activities.

6.1 INTRODUCTION

Since the early 1970s, tourism development in Mar Menor has increased the demand for recreational facilities resulting in the creation of new infrastructures. Other commercial activities such as mining, urban development, and changes in agricultural practices have increased the waste input into the lagoon resulting in environmental changes that have affected the biota and altered the lagoon's environmental conditions (Lloret *et al.* 2005). Urbanisation due to tourism is spreading at the coastline, whilst agricultural activity is expanding inland. During the last ten years, the construction activity targeting the touristic market, has decreased the protected area by 14,000 ha. The area of fertile agricultural land has also decreased by 10% (Schouten, 2003), although the production has been intensified.

The continuous increase of tourist population, particularly during the summer (with increased urban waste water discharge), coupled with a significant increase in the areas of irrigated land has augmented the nutrient load to the lagoon. This has caused significant impacts on the ecosystem. A good example of these impacts is the summer proliferation of jellyfish during recent years (Agnetis *et al.* 2004). While there are a number of probable factors that can contribute to jellyfish blooms in the Mar Menor, jellyfish numbers boomed after extensive habitat modification, mainly due to eutrophication and construction (Purcell *et al.* 2007). In addition to the above, Pérez and Montoro (2008) listed the following general pressures of over-exploitation of the lagoon since the 1960s, which have changed the ecological balance such as tourism; building speculation; high levels of construction, particularly in La Manga; an unbearable human pressure in the summer months; creation of artificial beaches, which necessitated the movement of hundreds of thousands of tons of sand; dredging of the weirs that communicate with the Mediterranean; construction of marinas; thousands of boats navigating on its waters; and the introduction of new species of fauna and flora through channels dredged for the passage of vessels leading to the disappearance of some native species. The most relevant socio-economic and environmental factors in the Mar Menor site, according to Agnetis *et al.* (2004), are shown in Table 6.1.

Table 6.1 Relevant driving forces and impacts in the Mar Menor site using DPSIR framework (adapted from Agnetis *et al.* 2004).

Driver	Impact	Response
Intensification: Increase in total irrigated lands Increase in per hectare input of fertilizers Increase in greenhouses	Hydrological dynamics of the watershed Increased load of nutrients Lagoon eutrophication Summer jellyfish blooms Negative effects on tourist activities Landscape degradation Changes in wetlands associated to the lagoon Changes in biodiversity of wetlands and lagoon	Designation of the watershed as Vulnerable Area to Nitrate pollution Implementation of an Agricultural Good Practices Code Reduction of the area of irrigated lands Re-use of water coming from agricultural drainages
Groundwater desalination for irrigation	Increased load of nutrients into the lagoon Lagoon eutrophication Summer jellyfish blooms	Restoration of natural wetlands Management of natural saltmarshes to treat salty wastewater
Urban and tourist development: Increase in seasonal population New urban developments	Loss of natural habitats Territorial loss of rural habitats Landscape degradation Load of nutrients and pollution Lagoon eutrophication Summer jellyfish blooms Negative effects on tourist activities Changes in lagoon hydrodynamics	Wastewater treatment plans
Climatic change	Increased load of nutrients Changes in wetlands	Restoration of natural wetlands Increase in area occupied by natural vegetation in the watershed

In the following sections, we will give an overview about the main the socio-economical development and the management plans in a water and environmental context.

6.2 SOCIO-ECONOMIC AND LIVELIHOOD ISSUES

In the Mar Menor drainage basin, the municipality of Cartagena has the greatest area and population (390 inhabitants. km^{-2}), followed by the municipalities of Torre Pacheco and Fuente Álamo, and Los Alcázares with a population density of 350 inhabitants per km^{-2}. The total population of this area increases two-fold during the summer due to the strong touristic attractiveness of the lagoon. In the Campo de Cartagena, there are two dominant economic sectors: agriculture and tourism. However, attention should also be paid to the fishery sector due to its relevance to the Mar Menor lagoon.

6.2.1 Socio-economic activities

6.2.1.1 Agriculture and irrigation

The main land use in the Mar Menor drainage basin is agriculture and, more specifically, irrigated agriculture. Most of the area (82%) in the Mar Menor catchment is occupied by arable land, while horticulture, covering 60%, is the most dominant land use. Other important land uses within the agricultural sector are citrus (30%), green houses (6%), and fruit trees (4%). After cropland, heather has the second largest share (11%) of land coverage, mostly occupying areas with higher elevations. The share of forested area is only 1%. Urban areas, especially settlements, make up 3%. Along the northwest coast of the lagoon, most of the area can be identified as settlement. The Campo de Cartagena – Mar Menor is a low-land plain (1,440 km^2) of clay soils dedicated to intensive agriculture with irrigated horticultural, especially for open-fields horticulture (one of the main producers in Europe) crops and greenhouses (mainly melon and lettuce) and citrus fruits. Growing organic fruit and vegetables is a big business in Murcia: 90% of the local production is exported, most of it to Germany, bringing in 55 million EUR annually to the local economy. One co-operative, Hortamira, located in the coastal flatlands outside Cartagena, has 320 producers as members, and around one fifth of its production is organic; though much of the rest is produced under the Integrated Production System, using a minimum of chemical pesticides and herbicides. The co-operative's organic brand 'Pinver' has an annual turnover of 30 million EUR. The warm, dry climate makes the region of Murcia ideal for winter cultivation of broccoli, celery, cabbage, cucumber, lettuce, peas, and citrus fruits like lemon and orange. The annual pepper season alone accounts for up to 3,000 tonnes of peppers, which are processed in Hortamira's factory in San Javier (Food from Spain, 2014). According to the Managing Director for the Modernisation of Farms and Agricultural Training, the modernisation of agriculture in the Murcia region should take into account other available options except for agricultural intensification.

However, the modernisation would require a high quantity and quality of water since, for example, in the Mazarrón, Águilas, Lorca and Cartagena areas tomatoes, a crop highly dependent on water, are grown. An alternative could be early greenhouse crops such as early peach and nectarines, which would be ready in April, or even cherries, if a suitable variety is be available (see: Food from Spain, 2014).

Dry land crops and traditional crops were common some decades ago, but since the Tagus-Segura irrigated system was implemented, open field horticultural crops, citrus trees, and greenhouses have replaced these crops. Traditional agricultural methods used in the past did not rely on irrigation for land cultivation, and had very little impact on the lagoon regarding nutrients, pesticides and other pollutants (Perez-Ruzafa *et al.* 2000). Since the 1970s, the amount of the irrigated agricultural area has increased within the Autonomous Community of the Region of Murcia, particularly in the agrarian district 'Comarca del Campo de Cartagena' (Cornejo & Cano, 2008). Since 1979, the Tagus-Segura river diversion has brought water for irrigation to the Campo de Cartagena, and agriculture in the watershed has changed from extensive dry crops to intensively irrigated crops. The groundwater levels increased, and some previously temporary watercourses maintain a permanent flow into the lagoon' (Velasco *et al.* 2006). The water transfer Tajo-Segura runs from the region of Castilla-La Mancha to the Valencia and Murcia region, and has been severely affected by periods of drought in the Tagus River during the last few years. 'This project was started in 1933, the definitive project was done in 1966, and the whole public works were finished in 1979. Castilla-La Mancha demanded this transfer to be finished in 2015' (Regadíos, 2009).

In the late 70s, the Tagus-Segura River was diverted for agricultural purposes. A main channel 'The Canal Cartagena Field' with a length of 64 km, a capacity of 300,000 m^3 and a maximum flow of 25 $m^3\ s^{-1}$, transports and distributes the resources stored in the reservoir of La Pedrera into each irrigation sector. The diversion generated a profound transformation of the agricultural practises in the Campo de Cartagena that changed from extensive dry crop farming of cereals, olives, almonds and carob beans to intensively irrigated crops. At present, Campo de Cartagena is one of the most productive and profitable agricultural areas in Europe owed to the dramatic increase of water, fertiliser and pesticide use. Irrigated crops represent three quarters of the farms in Campo de Cartagena. Drip irrigation is the main irrigation method, and surface water is the main source, followed to a lesser extent by groundwater, treated wastewater and desalinated water sources. Irrigated agriculture uses a minimum of 6,000 $m^3\ ha^{-1}\ year^{-1}$.

Since 1952, the Community Irrigation Field Cartagena (CRCC) has been the agency responsible for managing water for irrigation in the Campo de Cartagena (www.crccar.org), comprising 41,090 ha and distributing water to 9,444 users. The water resources of the CRCC come from the Tagus-Segura water transfer (122 hm^3), from the Segura basin (4.2 hm^3), from waste water treatment plants (13.2 hm^3), and from the desalination plant of Mojón (2.2 hm^3). Total water resources are 141.6 hm^3, although the real needs are between 180 and 200 hm^3. Hence, the situation leads to a permanent deficit of water resources, mainly due to the great irregularity of the supplies of the Tagus-Segura water transfers.

6.2.1.2 Livestock

Regarding livestock, it is necessary to mention the great importance of pig farming in the study area (40.000 farm pigs), like as in the entire Murcia region (1.700.000 farm pigs).

6.2.1.3 Urban and tourism and recreational activities

The other main activity is the urban-touristic development, which has also caused an increased housing expansion in the area. The current trends of urban and touristic development, especially through the spread of golf-resorts and associated urbanisations, have affected the environmental status of the Mar Menor lagoon. The urban growth in Murcia is among the most intensive in Spain, which, in turn, is the most intensive in Europe (Fernández Durán, 2006). The Soil Law adopted by the regional government in April 2001 that declared all land that is not strictly protected as 'urbanized areas', encouraged this situation. In 2004, the regional government approved the Management Guidelines for the Littoral, declaring 85,000 ha available for potential housing developments. This area is equivalent to 1.1 million new houses. In the Campo de Cartagena, large areas of irrigated production and traditional crops have been reclassified to urban use. Since 2003, the golf-resort model for residential use quickly spread over the Mar Menor watershed. There are around 16 golf-resorts, each one of them including between 800 and 2,000 new houses (Martínez *et al.* 2007). These new residences represent the biggest water demand (≈400 litres per person per day) in the area.

The distinctive environment of the lagoon has been attractive for visitors since the first half of the 19th century. However, a demand in touristic activities has taken place in the area since the early 1970s, characterised by intense urban developments along the lagoon perimeter to accommodate the growing seasonal population. The marked seasonality of tourism in the area (May to September) is profound when comparing the numbers of the permanent local population (about 45,000 inhabitants) with the tourist population that reaches ten times more (about 450,000) during summer months.

The safe shallow bathing area available in the lagoon coupled with numerous outdoor activities such as water sports, golf and other land based activities, as well as the largest open-air mud-therapy area in Europe (the best known being 'Las Charcas de las Salinas' in Lo Pagán) attracts both national and foreign tourists. In an online article published on February 17, 2012, it was stated that Ryanair would bring 2 million tourists to Murcia within three years according to an announcement made by the Regional Minister of Culture and Tourism (tumbit.com, 2014). The new international airport being built in Corvera within the region of Murcia was expected to be opened by July 2012, and to provide the infrastructure for this high influx of tourists. Due to various reasons, however, the airport opening is now delayed until summer 2015.

6.2.1.4 Aesthetic values

Natural landscape as well as traditional uses and structures in the area, constitute one of the most interesting resources in the Mar Menor. Many artists have found a source for inspiration in the Mar Menor lagoon.

6.2.1.5 Fishing and port facilities

An additional environmental conflict is the overexploitation of the lagoon's fish resources. The Spanish Ecological Association, ANSE, recently (Feb 2012) voiced their concern regarding overfishing in the area, and its effect on biodiversity and wildlife. The fishermen nowadays have twice as many fishing nets than in 2007. In addition, a number of illegal fishing incidents have been reported, which has caused some confrontations with licensed trawlers (ANSE, 2008).

Fishing is another economic activity of importance in the Mar Menor, where mainly the Sparidae and Mugilidae species are harvested. Most of the fishing activity is developed in 'Las Encañizadas' on the northern side of La Manga. Due to the widening and dredging of the channel 'El Estacio' in the early 70s, which connects the Mediterranean Sea and Mar Menor, new fish species entered the lagoon coming from the Mediterranean. Presently, the main fish catches are: *Anguilla anguilla*, *Mugil* sp, *Sparus aurata*, *Lithognatus mormyrus*, *Engraulis encrasicolus*, *Atherina* sp., and *Mullus barbatus*. There is a downward trend in the fishing fleet and in the catches, and an increasing trend in the recovery of traditional fishing gear, which is unique to the area 'Las Encañizadas'. It consists of the construction of fences with reeds in the gullets or inlets that connect the Mediterranean Sea with the Mar Menor coastal lagoon. These fences or walls lead to enclosed areas where fish is then harvest by fishermen.

Due to its high biological productivity and the high economical value of its products, the Mar Menor lagoon has been always an attractive location for aquaculture. However, most attempts to develop aquaculture in the lagoon did not go beyond an experimental phase. There is no aquaculture within the lagoon, although there are some facilities in neighbouring marine areas, located offshore (primarily intended for fattening seabass, seabream and tuna).

6.2.1.6 Salt-production

Salt works have traditionally been the main economic activity on the marginal salt marshes associated with the lagoon, although most saltpans have been currently abandoned and refilled for other uses. Nowadays, saltpans are considered as a landscape resource of enormous relevance for the conservation of many species, including aquatic birds that use these areas for nesting, resting areas during migration, and wintering.

6.2.1.7 Mining activities

Mining activities in the Cartagena–La Unión mining district are dated back to the 1st century AD. In the La Unión municipality, which is located in the middle of this mining district, mining of ore deposits containing iron, lead and zinc was the only economic activity for hundreds of years (Conesa *et al.* 2007). The mining activities terminated during the end of the 20th century due to the low commercial value, which brought a socio-economic crisis to this district resulting in the highest unemployment rate (over 20%) within the Murcia region and mass emigration. Owners of the mines are interested in transforming the whole area into a mass tourist centre. However, Conesa *et al.* (2007) pointed out that historic and social aspects should also be considered. Different development options should be considered in order to achieve a more sustainable development approach. The mining activities also led to huge amounts of mining wastes that were transported into the lagoon through the southern wadis of El Beal, Ponce and Carrasquilla.

6.2.2 Wastewater treatment plant infrastructures

During the last decades, the main urban point source of pollution to the Mar Menor was the Los Alcázares wastewater treatment plant, which insufficiently treated the discharges from a population over 100,000 inhabitants during the summer. The partially treated wastewater was discharged into a channel that flows into the Albujón rambla, 2 km upstream of its confluence with the Mar Menor.

The Regional Law 3/2000 of sanitation and wastewater treatment in the region of Murcia created the Regional Entity Sanitation (ESAMUR), which handles the treatment plants in the region. The ESAMUR has established the Integrated Sanitation Plan of the Mar Menor area, with the goal of 'zero discharge' of wastewater to the lagoon. The Segura River Basin Management Authority built the wastewater treatment plant of Los Alcázares in 2008, with a capacity of 22,500 m^3 day^{-1}; it is designed to remove nitrogen and phosphorus, and to provide advanced disinfection. The sanitation plan also contains a plan for the construction of a Mar Menor water collection infrastructure that can catch spillage flow, and direct this to the emissary of the Mar Menor South, which is already built. This water collection infrastructure will prevent flooding and pollutant emission to the Mar Menor lagoon lagoon in case of torrential storms. The continuous incorporation of new facilities and improvement of existing ones, will enhance the water quality and mitigate the direct discharges during the summer season.

6.3 INSTITUTIONS AND MANAGEMENT

Since the 1980s, different plans and initiatives by national and regional administrations have been implemented in the Mar Menor region. The first initiative was taken in 1982, with the objective to reconcile the socio-economic development of the area with the preservation of the natural values of the lagoon. The report 'Study of territorial ordination of the Mar Menor area and its surroundings' is, in fact, the first proposal of guidelines for achieving sustainable development in the area (E.P.Y.P.S.A, 1982). Five years later, The Regional Law 3/1987 'Protection and harmonized uses of the Mar Menor' initiated a dynamic process that aimed at achieving a proper management of the Mar Menor area by means of four planning tools: The Regional Planning Guidelines Area of Mar Menor, The Sanitation Plan for the Mar Menor, the Protection and Harmonized Uses of the Mar Menor, and The Management Plan and Coastal Protection of Mar Menor.

Within the Strategic Development Plan of the region of Murcia 2000–2006, The Sanitation Plan for the Mar Menor and the South Coast, and the Integrated Management of Coastal Lagoon Area, Mar Menor are listed as strategically important. In July 2002, the Spanish authorities proposed a Coastal Area Management Program in the Mar Menor to the Spanish Mediterranean Action Program – United Nations Environment Programme (UNEP-MAP).

In September 2004, the Ministry of Environment presented the A.G.U.A. Programme (Actions for the Management and Water Uses), which aims at improving the management and reuse of water, mainly through the construction of marine water desalinization plants in the Mediterranean littoral; that will increase the supply of water. The full capacity of the desalination plants is not exploited due to the high costs of the treated water.

Under the EU Nitrates Directive (91/676/EEC), the Mar Menor coastal area was designated as Zone Vulnerable to Pollution by Nitrates from Agricultural Sources, by the Order of the Ministry of Agriculture, Water and Environment of 20 December 2001 (BORM no. 301, of December 31, 2001). Later, the Order of the Ministry of Agriculture, Water and Environment of 12 December 2003 (BORM no. 301, of December 31, 2003) approved the action plan for the mentioned vulnerable zone. In 2003 (BORM no. 301 of December 31, 2003) and 2009 (BORM no. 57 of Mars 10, 2009), the corresponding four-year action plan for this vulnerable zone was approved. The plan established the necessary actions to reduce pollution by nitrates from agricultural sources into these aquifers, permitting values of nitrate below a critical limit of 50 mg/l.

Relevant examples of these actions are:

- Monitoring programs for the quality of water used for irrigation;
- Disclosure of the 'Code of Good Agricultural Practice for the Region of Murcia', approved by the Order of March 1, 1998, of the Department of Environment, Agriculture and Water (BORM 85, April 15, 1998), and forced compliance in vulnerable areas;

- Dissemination of indicative plans for irrigation and fertilization on a monthly basis for the different cultures and procedures to adapt to changing meteorological conditions;
- Courses for younger farmers and ranchers;
- Establishment of a Monitoring Commission;
- Established measures for the use of different types of nitrogen fertilizers by indicating the maximum limits of total nitrogen for each species and irrigation system. For example, in the vulnerable zone, it is prohibited to apply organic fertilizer with a nitrogen content exceeding 170 kg per hectare per year;
- The owners of intensive livestock farms in the area must have a management and production plan concerning the application of manure.

The Tagus-Segura transfer is a 'hot' political issue in Spain's intensively cultivated southeast regions. A protest in March 2009 was organised by the Tagus-Segura Transfer Irrigators. Around 500,000 demonstrators were gathered in Murcia along with the Socialist Party and Popular Party members of Valencia, the region of Murcia and Andalucía for the rejection of the decision taken by the community of Castilla-La Mancha to close the Tagus-Segura transfer (Ecologistas en Acción, 2013). Furthermore, the environmental group 'Ecologistas en Acción' claimed that between 5,000 and 10,000 hectares of new illegal irrigation areas have annually been implemented in Murcia, which should be compared to the 192,000 hectares of legal irrigated land (Schouten, 2003). In a recent study, Perez *et al.* (2011) showed that the effect of traditional irrigation systems in NW Murcia and the intrusion of new users, seriously affect groundwater levels and change the structure and robustness of the traditional social-ecological systems, thereby resulting in the emergence of new vulnerabilities.

The water transfer from the River Ebro to Valencia, Murcia and other Mediterranean areas in Spain was included in the 2001 National Hydraulic Plan (NHP). As stated, '*Some Autonomous Communities like Catalonia and Aragón complained about this project as they understood that the River Ebro and its waters were theirs. They said that they needed all the River Ebro´s waters for themselves*'. The 2001 National Hydraulic Plan was never implemented, following a change of government in 2004 and public opposition. Instead, the new government cancelled the Ebro water transfer, swiftly replacing it with the AGUA programme (2004–2008), which predominantly consisted of the construction of water desalination plants and public water reservoirs along the Mediterranean coast (Lopez-Gunn, 2009; Font & Subirats, 2010). While the construction of some desalination plants has gone ahead within the Mediterranean basin during recent years, construction has eased off due to the low economic return of desalination plants (Font & Subirats, 2010).

In October 2011, the Global Water Intelligence (GWI) highlighted that NGO's accused Spain of 'hiding' a river basin plan. It was claimed that Spain's environment ministry had removed a draft of the controversial Tagus river basin management plan from public sight, because it revealed the unsustainability of the 600 million m^3 Tagus-Segura water transfer. The green NGO's noted that the draft contained data showing that annual transfers to the Segura river basin would have to be nearly halved to maintain a 10 m^3s^{-1} (864,000 m^3d^{-1}) flow rate in the Tagus. They claimed that the ministry has breached EU transparency requirements by removing the document from its website only 48 hours after publication (Global Water Intelligence, 2011). The EU Commission announced in June 2011 that they were referring Spain to the EU Court of Justice for breaching two pieces of EU environmental legislation. The EU Water Framework Directive (WFD) requires all member states to publish a management plan for each river district (RBMP's), which should have been fulfilled by 22nd December 2009. Spain was required to produce and adopt a total of 25 RBMP's, but only one had been adopted and communicated (the Plan de gestión del Distrito de Cuenca Fluvial de Cataluña). Therefore, Spain might have to face the EU Court of Justice. The 'Confederación Hidrográfica del Segura' (CHS) is the institution responsible for water management in the Mar Menor site (Agnetis *et al.* 2004).

The ecologist groups (ANSE, WWF) proposed several environmental actions to the Ministry of Environment (regarding the 'Plan of action of the Mar Menor' – 2007) and to the Autonomous Community of the region of Murcia (regarding the 'Plan of integral action of sustainable development of Mar Menor and its influence area' – 2008).

Nowadays, the following environmental actions are implemented:

- To prioritise the restoration of the environment and biodiversity lost during the last decades;
- To recover the natural and social functions of the maritime-terrestrial public domain and the watercourses that drain to the Mar Menor;
- To boost the purchase of property without buildings on land adjacent to the shoreline of Mar Menor, especially close to protected natural spaces;
- To incorporate environmental management measures and harmonize nature conservation objectives with the social and economic development of the Mar Menor area;
- To put in place effective measures for environmental restoration in high urban density areas;
- To coordinate the activities of the different central, autonomous and local administrations;

- To encourage stakeholders to give input to solutions and implementation of actions.
- To stop using natural areas for infrastructure such as wastewater treatment plants, desalination plants, and harbours and to move existing infrastructures out of natural areas;
- To recover traditional landscapes such as windmills, artisanal fisheries, and salt mines that are compatible with the conservation of natural resources.

The ecological importance of the Mar Menor lagoon and its associated wetlands has been recognised by its inclusion in a series of protection schemes at international, national and regional levels which include: Ramsar (since 1994); Special Protected Area of Mediterranean Interest (SPAMI); Site of Community Importance (SCI) to be integrated in the Nature 2000 Network (EU Habitats Directive); Specially Protected Area (SPA) in relation to nest building, migration and hibernation of aquatic birds, protected by European legislation (Birds Directive 79/409/CEE). Under the EU Habitats Directive, the lagoon and wetlands of Mar Menor maintain eighteen habitats of European interest (Martinez *et al.* 2007). Located within the northern end of Mar Menor, the salt flats of San Pedro del Pinatar form the most important wetlands (Regional park 'Salinas y Arenales de San Pedro del Pinatar') in the entire region. The area was declared a Regional National Park back in 1985 and an EU Special Protection Area for bird life in 1998. Stretching some six kilometres south from El Mojón, it is an area of marshes, sand dunes, reed-beds, and salt lakes of international importance. The visitor centre of this regional park has been included in the Migratory Birds for People (MBP) network in December 2011, whose objective is to provide information for and increase the awareness of the general public regarding the importance of protecting migratory birds and their habitats, including the wetlands within the reserve (Centro de Visitantes 'Las Salinas', 2012). Other protected natural areas at the regional level in the lagoon include: the protected landscape of the open space and islands of the Mar Menor; the regional park Calblanque; and rock and eagle mount of Cenizas. The Ramsar Convention (Ramsar, 1971) is also protecting the Mar Menor lagoon. The Convention applies to wetlands and the protection of (primarily) migrating birds. The Ramsar Convention encourages the designation of sites containing representative, rare or unique wetlands, or wetlands that are important for conserving biological diversity. Once designated, these sites are added to the Convention's List of Wetlands of International Importance, and become known as Ramsar sites. The Mar Menor has been designated as a Ramsar site (No. 706) since 1994.

The United Nations General Assembly declared the period 2011–2020 as the United Nations Decade on Biodiversity (Resolution 65/161), which serves to support and promote the implementation of the objectives of the Strategic Plan for Biodiversity and the Aichi Biodiversity Targets (http://www.cbd.int/), with the goal of significantly reducing biodiversity loss.

Given that Spain is a member of the EU, the requirements under both the WFD and the MSFD (Marine Strategy Framework Directive) are of significant relevance to the Mar Menor lagoon. Several efforts have been made in order to implement the commitments established in the WFD, including the creation of a network of surveillance and quality control of coastal waters. The Habitats Directive is one of the pillars of the Natura 2000 network of protected areas, and Annex 1 of this Directive indicates coastal lagoons as a priority habitat type; Mar Menor is part of the Natura 2000 database. The aim of the MSFD is to protect more effectively the marine environment across Europe. Specifically, this directive aims to achieve Good Environmental Status (GES) of the EU's marine waters by 2020, and to protect the resource base upon which marine-related economic and social activities depend. It is the first EU legislative instrument related to the protection of marine biodiversity, as it contains the explicit regulatory objective that 'biodiversity is maintained by 2020', as the cornerstone for achieving GES.

6.4 FINAL REMARKS

A variety of stakeholders and institutions are involved in the use of the Mar Menor resources and its management, a situation that often leads to the appearance of conflicts. The observance and application of regional and national laws and policies in such a complex socioeconomic, institutional and natural environment is often challenging and requires further efforts in order to ensure the rights of the users and the conservation of this particular environment and its biodiversity.

The tensions between competing uses of the water environment (fresh, coastal and marine) in the Mar Menor and the needs of a GES in the lagoon should be further explored. In this context, the following management responses to environmental impacts can be highlighted as the most relevant: i) designation of the watershed as a nitrate vulnerable area; ii) implementation of the Code of Good Agricultural Practice; iii) reduction of irrigated lands; iv) re-use of water coming from agricultural drainages; v) management of natural saltmarshes to treat salty wastewater; vi) building and improvement of wastewater treatment plans; vii) restoration of natural wetlands and increase of the area occupied by natural vegetation in the watershed.

Mar Menor is managed within a complex legislative and policy context, with a wide variety of institutions and stakeholders involved in the use and management of the lagoon. It is therefore necessary to develop a framework of common objectives and management guidelines in order to promote a more sustainable development in the area and protect its natural resources and biodiversity status.

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Chapter 7

The physio-geographical background and ecology of the Vistula Lagoon

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Summary: This chapter describes the physical and geographical setting of the Vistula Lagoon including a general description of the lagoon's drainage basin and the meteorological, geological and physiographic characterization. The chapter also covers issues around water resources and quality, natural resources and marine ecosystem services. The entire chapter serves as an introduction to a more detailed description of current and future issues and problems related to a more sustainable management of the Vistula Lagoon in both a transboundary and climate change context. The most acute environmental problem of the Vistula Lagoon is its significant vulnerability to eutrophication. A second problem is the flood risk in both parts of the lagoon. Another serious problem is the population of cormorants, especially in the Polish part of the lagoon.

Keywords: Land use, water resources, water demands, biodiversity, ecological status, ecosystem services.

7.1 INTRODUCTION

The Vistula Lagoon (Figure 7.1) is the second largest lagoon in the Baltic Sea after the nearby Curonian Lagoon. It covers an area of 838 km^2 and has a drainage basin of 23.870 km^2.

The Vistula Lagoon is shared between Poland, an EU member state (365 km^2), and Kaliningrad Oblast belonging to the Russian Federation (473 km^2). It has a single inlet, the Baltiysk Strait, located in the Russian part of the lagoon. The lagoon has an elongated shape stretching from south-west to north-east a with total length of 91 km. The average width is about 9 km; the widest point measures 13 km. The lagoon's coastline is about 270 km long and the volume of water is about 2.3 km^3. It is a shallow coastal ecosystem. The average depth of the lagoon is 2.7 m and the deepest area located in vicinity of the Baltiysk Strait (Figure 7.2) has a depth of 5.2 meters.

The Vistula Lagoon is separated from the Baltic Sea by the Vistula Spit, a 55 km long sandy peninsula. The spit's dunes are mainly covered with pine and mixed forests, which were planted to reinforce the dunes and to protect the spit's infrastructure from the prevailing winds blowing in from the Gulf of Gdansk. The lagoon exchanges water with the Gulf of Gdansk through the Baltiysk Strait, which has a width of approximately 400 m, a length of two kilometres, and an average depth of 8.8 m. The strait is maintained artificially for navigation purposes.

7.2 STUDY SITE DESCRIPTION

7.2.1 Characterization of the Vistula Lagoon drainage basin

The catchment area of the Vistula Lagoon (Figure 7.3) covers 23.871 km^2 (Silicz, 1975). The largest city in the region is Kaliningrad (around 430.000 inhabitants), located at the Pregolya River mouth in the north-eastern part of the lagoon. Other large towns are: Elbląg (130.000 inhabitants), located in the southern part of the lagoon up the Elblag River; Baltiysk (33.000 inhabitants), situated on the northern side of the Baltiysk Strait; Svetlyi (28.000 inhabitants), located at the northern coast of the lagoon; Braniewo (18.000 inhabitants), situated at the Pasłęka River 8 km from the river mouth (Figure 7.3); and Olsztyn, located ca. 50 km south-east of the lagoon and inhabited by 175.500 residents. Other settlements are smaller than 10.000 inhabitants. In all, the number of residents in the lagoon's catchment slightly exceeds one million.

Figure 7.1 Location of the Vistula lagoon and main discharging rivers (based on Google maps).

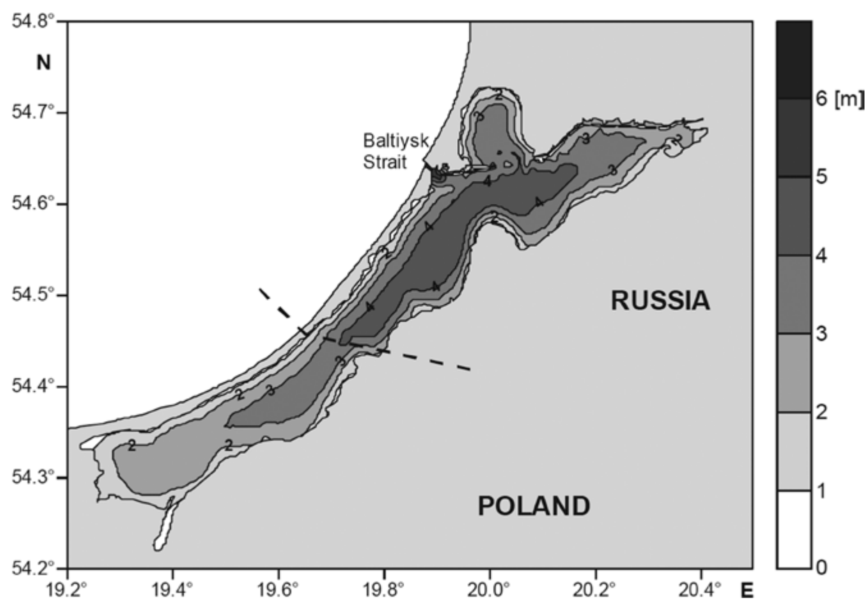

Figure 7.2 Bathymetry of Vistula lagoon (Witek *et al.* 2010).

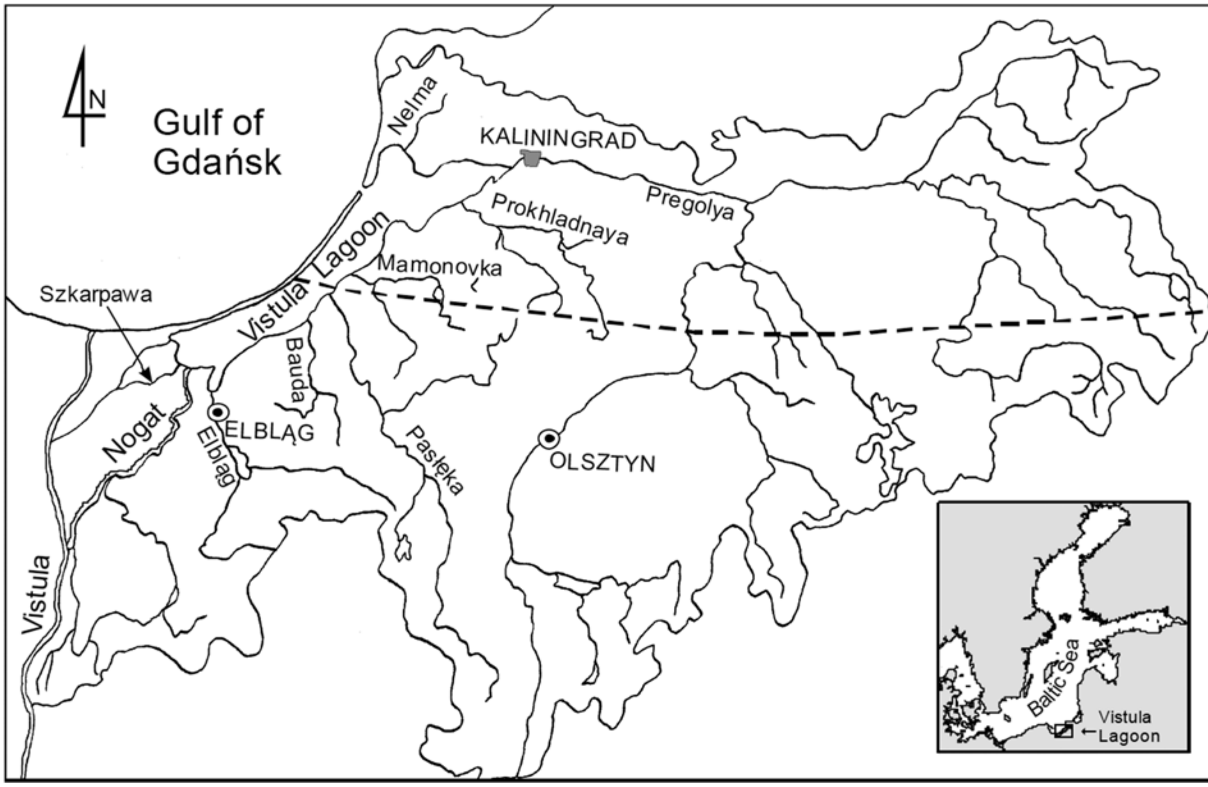

Figure 7.3 Drainage basin of Vistula lagoon (Witek *et al.* 2010).

The main rivers draining in to the lagoon are (Figure 7.3): Pregolya (the catchment area of 15.128 km^2; 63% of the entire area of the Vistula Lagoon drainage basin), Pasłęka (the catchment area of 2330 km^2), Elbląg (1488 km^2), Nogat (1337 km^2), Prokhladnaya (1170 km^2), Bauda (361 km^2), Mamonovka (311 km^2), and Nelma (167 km^2) (Silicz, 1975).

Until about one hundred years ago, the lagoon had been receiving about 50% of the Vistula River waters through a complex net of branches of the river delta. In order to protect the lowland river mouth areas from flooding, an artificial Vistula River mouth was constructed in 1895. In subsequent years, the Nogat River and other branches of the Vistula River delta were closed with locks. Thus, the lagoon was no longer the main recipient of freshwater from the Vistula River and turned into a brackish basin. Nowadays, the Pregolya River discharges much more water to the lagoon than the Nogat River or any other branch of the Vistula River delta. Since the cutting of the connection with the Vistula River, the sediment and suspended matter budget of the lagoon changed significantly. The most vital aspect of this change is the deepening of the lagoon (locally up to 60–80 cm) due to bottom erosion caused by frequent re-suspension of the sediment. More suspended matter is now exported from the lagoon to the Baltic Sea than enters the lagoon with the riverine inflow (Chubarenko & Margoński, 2008).

7.2.2 Characterization of the Vistula Lagoon

The lagoon is a transboundary area, where two huge legal entities meet, the EU (the Polish part) and the Russian Federation (the Kaliningrad enclave). Usually, such arear are subject to multiple issues and problems related to sustainable management of shared areas, and Vistula Lagoon is no exception. The most obvious concern the plans for a large-scale modification of the natural system via the construction of a second inlet to the lagoon at the Polish side to enable the direct ship traffic towards the harbour of Elbląg. The present agreement between the governments of the Republic of Poland and the Russian Federation on navigation within the Kaliningrad (Vistula) Lagoon allows access to the Baltic Sea for any ship from Poland, but the procedure to get a permission to cross the Baltiysk Strait requires a long notice (2 weeks), which significantly restricts the feasibility the enforcement of this agreement.

Secondly, the lagoon is very fragile from an ecological point of view, mainly due to nutrient input sensitivity. Nutrient loads from the large drainage basin and a shallow bathymetry result in very intensive biological processes, which lead to widespread algae blooms in summertime. Considering its depth, the large surface of the lagoon allows for a rapid mixing of the entire water column, even in the case of moderate winds (LAGOONS, 2012). With regards to the transboundary character of the lagoon, the sustainable management of nutrient inputs appears to be the most challenging task. Another reason of concern is the flood risk in both the south-western corner of the lagoon in the Polish part and near the course of the Pregolya River in the Russian part. During north-westerly, northerly and north-easterly winds, large storm surges can develop that attack flood prevention infrastructure in the low lying areas of the Vistula River delta in the Polish part or the Pregolya River in the Russian part. Flood risk problems are not transboundary ones, though.

7.2.3 Hydrological regime

(I) Salinity: Vistula Lagoon has been a brackish system since the end of the 19th century, when it was cut from the Vistula River system that used to deliver large volumes of freshwater. Average salinity of the lagoon is 3.5 PSU (Lasarenko & Maevskiy, 1971), and it may vary from 0.5 PSU at the southern part and the Pregolya River outlet to up to 6.5 PSU at the Baltiysk Strait (Chubarenko, 2008). This is the result of salt water inflows from the Baltic Sea that influence all aquatic areas of the lagoon, including the mouth of the Pregolya River. Seasonal salinity changes are caused by variations in marine and river inflows. Salinity in the lagoon is lowest during the late spring (0.5–4.5 PSU) after the snowmelt (March and April). Between May and August salinity increases to 3.5–6.5 PSU, when the river runoff is lower and the marine influence prevails (Chubarenko, 2008). In autumn, the salinity starts to decrease, and finally, in winter, the ratio between fresh and salt water influxes stabilizes during the ice cover period, and the lagoon comes to an equilibrium between salt- and freshwater processes.

(II) Water temperature: The typical pattern of seasonal temperature variability of water in the lagoon is shown in Figure 7.4. It shows average long-term monthly water temperatures together with maximum and minimum monthly values recorded in 2009. The lack of data for winter months indicates that ice cover usually develops in that period; Figure 7.4 also demonstrates the high annual amplitude of water temperature in the lagoon.

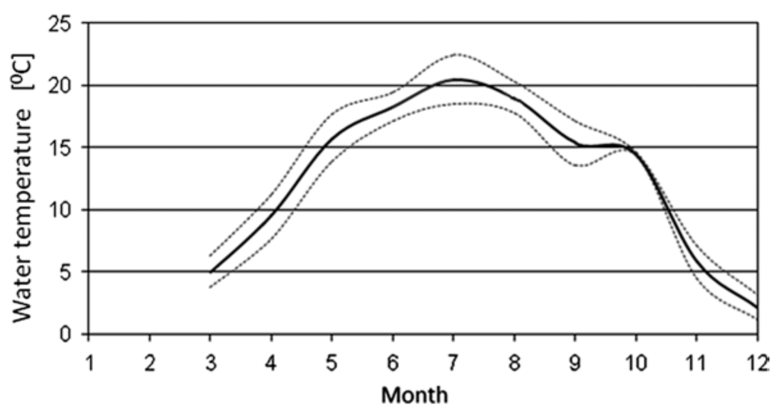

Figure 7.4 Mean water temperature variability in the Vistula lagoon in the period 1998–2008 (Kańska *et al.* 2010).

(III) Water balance: Silicz (1975) estimated that 17 km^3 (80.2%) of water entered the lagoon through the Baltiysk Strait. Riverine inflows amounted to 3.62 km^3 (17.1%). The greatest share is held by the Pregolya River (1.48 km^3). Atmospheric precipitation accounted for 0.5 km^3 (2.4%) and groundwater inflows for 0.07 km^3 (0.3%). Outgoing water masses included 20.48 km^3 of water going to the Baltic Sea (96.9%) and 0.65 km^3 lost due to evaporation (3.1%).

7.2.4 Meteorological characterization

7.2.4.1 Climate patterns (normal vs extreme events)

Winter is normally gentle, with a prevalence of cloudy weather and frequent precipitation. Winds come mostly from the south, south-west and the west, and storms develop on a frequent basis. Winter starts in December, the snow coverage usually appears at the end of the month, and mean daily temperatures are below the freezing point. There can be severe frosts in the middle of the winter season, with temperatures reaching –30°C in extreme cases. The average snow thickness is around 10–20 cm in the coastal zone (LAGOONS, 2012).

The beginning of spring is cold and starts in March. Winds are considerably weaker than during winter months. In mid April, rainfalls are seldom when compared to the winter months; however, the occurrence of fog is fairly frequent. The frosts stop in mid May; however, once every 10–15 years, frosts may occur until late spring and even during early summer. (LAGOONS, 2012).

Summer temperatures are usually moderate and lie around. 15°C at the beginning of June. The mean summer temperature is around 20°C, sometimes 8–17 days are observed with temperatures of 30–35°C, mainly during July and August. Hot weather events are seldom and relatively short. At the end of summer, precipitation increases and heavy showers are the norm.

Autumn is warm, wet and windy. The wet cloudy weather prevails with frequent long-term precipitation. Fogs and stormy winds of western directions are observed. The number of cloudy and rainy days increases. Snow coverage occurs at the end of November, when the air temperature go below the freezing point (LAGOONS, 2012).

7.2.4.2 Precipitation and temperature

Figure 7.5 (left) shows monthly mean annual variability of temperature in the lagoon area. It shows a clear resemblance with respect to water temperature (Figure 7.5), which is the effect of shallowness of the lagoon water body. The right hand side panel shows the average number of days with precipitation per month. The summed annual precipitation usually falls above 700 but below 800 mm; this is more than observed in most of the hinterland. June, July and August are the wettest (60–80 mm), whereas January, February and March are the driest (30–40 mm) months.

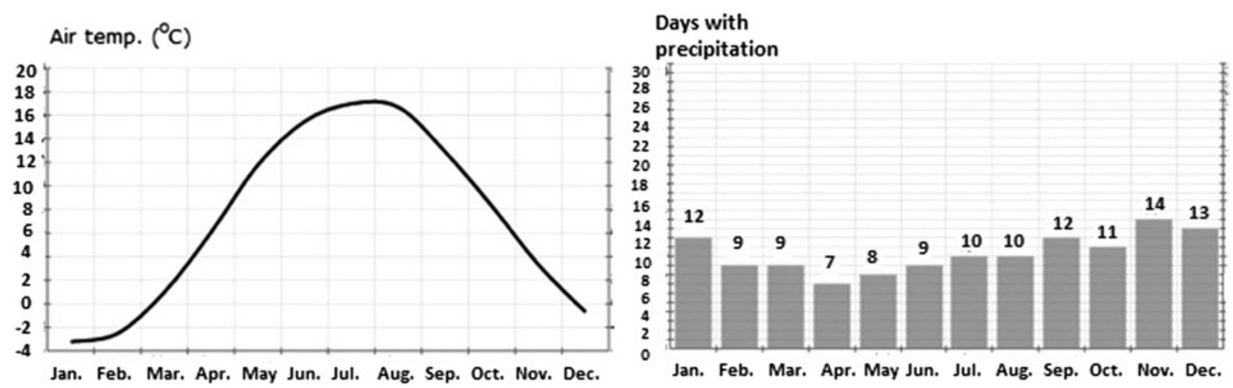

Figure 7.5 Average monthly temperature (left) and days with precipitation per month (source: www.yr.no).

7.2.4.3 Ice cover

Usually, a temporary ice cover is noticed during the winter months. Permanent ice cover is not formed during mild and moderate winters, but, in general, the lagoon is covered with a solid ice cover during the second half of December. Typically, ice melts start in the end of February during mild winters and up to the beginning of April during cold severe winters. On average, the ice cover lasts 67–75 days; during extreme winters it can stay up to 140 days. The thickness of the ice cover can reach up to 60 cm. Satellite imagery allows to trace the melting of the ice cover, which starts in the south-west corner of the lagoon near the city of Elbląg, and then advances to the middle of the lagoon. The ice stays the longest in the Russian part of the lagoon, with the exception of a narrow zone at the Baltyisk Straight, where warmer and saltier marine waters predominate (Kruk, 2011).

The ice cover prevents a mixing of the lagoon water with bottom sediments or depositions from the air, since there is no turbulence caused by winds, and air pollution accumulates on top of the ice layer. At the same time, saltwater from the ocean and freshwater from rivers continue to enter the lagoon. The sedimentation process, undisturbed by wind mixing, allows for absorbing the chemicals present in the water column.

7.2.5 Geological characterization

The recent geological history of Vistula Lagoon started near the end of the lithorine transgression peak, about 6330 BP (Fedorowicz *et al.* 2009). In the first stage, the receding sea uncovered embankment-like formations that were transformed into brown dunes by aeolian processes. This stage lasted for around 1200 years and started about 5000 BP. Brown dunes on the spit and inland peat lands, dated at 3920–3160 BP, are typical for this stage. The second stage lasted from 1200 until 1060 BP; the highest dunes were then formed, exceeding 40 m above the sea level. They are called 'yellow dunes' and were formed during a dry and cool climate with the lowest sea water levels in the Gulf of Gdańsk. The third stage lasted between 1060 and 910 BP. It produced fossil alluvial layers with a 65 cm thick series containing salt-water fauna found 2.5 m below the sea level. It was formed due to seawater intrusions into the Vistula River delta through numerous discontinuities in the spit structure. The discontinuities were caused by rising sea levels and by high water levels in the Vistula Lagoon. The fourth stage has been continuing since 910 BP to date (Fedorowicz *et al.* 2009). The youngest white dunes were formed in this stage. This process was accompanied by slight coastline fluctuations, also, the spit discontinuities were filled.

7.3 WATER RESOURCES AND QUALITY STATUS

7.3.1 Water resources and demands

Water supply fully covers the needs of the lagoon's residents and industry. Water shortages are possible only locally and very occasionally in case of failure of water supply systems. Large cities are supplied either from surface sources or from underground wells; the city of Kaliningrad is supplied with water from the Pregolya River, while Elbląg is supplied from ten underground facilities. Smaller settlements and individual remote households are supplied from underground systems and individual wells.

In contrast to many EU countries, water consumption for agricultural purposes in the Vistula Lagoon area is low. Although exact figures are not known, two pieces of information are remarkable: (1) in Poland, only 8% of the water consumption is spent due to agriculture (W. Majewski, personal communication, 2014), (2) the cultivated area in the Russian part decreased by ca. 50% after the collapse of the Soviet Union (personal communication with a member of local parliament in Kaliningrad, 2014). Those facts point to a rather low intensity of farming activities in the lagoon drainage area. Those data also indicate that water shortages are not likely to occur in the coming decades.

7.3.2 Water quality status

In the Polish part, the implementation of the WFD has lead to significant improvements in water quality in a majority of the rivers. This can be attributed to the construction of waste water treatment facilities in most cities and large settlements. Also, the increase of the prices of artificial fertilizers, after the transition to a market economy, resulted in a reduction of fertilizer inputs. Currently, the system of comprehensive and transparent monitoring of water quality in rivers is being introduced as part of the WFD implementation. The most difficult problem in this regard is the integration of water quality measurements and the records of physical parameters, mainly discharges and precipitation, as two different institutions the Institute of Meteorology and Water Management and Voivodship Inspectorate of Environmental Protection are in charge of those measurements, and they are carried out at different times and with different spatial resolution.

Positive developments are also observed in the Russian part. The construction of a waste water treatment plant for Kaliningrad will soon be completed.

The situation in terms of water quality in the lagoon is much worse. The horizontal distribution of water quality parameters is strongly influenced by hydrological and meteorological factors. One of the most important factors is the exchange of water masses between the Gulf of Gdańsk and the lagoon: nutrients concentrations near the Baltiysk Strait are lower than those in remote parts of the lagoon. The high internal potential for eutrophication is caused by significant sources of nitrogen and phosphorus that have accumulated in the sediments and are now being released (LAGOONS, 2012). Light and nutrient availability are the most important parameters controlling primary production (LAGOONS, 2012). Another contributing factor is the shallowness of the lagoon and the resulting high temperature throughout the entire water column in summer months. The mean annual production in the Polish and the Russian parts of the lagoon was estimated at 300 and 180 g C m^{-2} y^{-1}, respectively. Phytoplankton growth is limited mainly by nitrogen, as phosphorus limitation is only observed during early spring (Witek *et al.* 2010). Three phytoplankton groups, cyanobacteria, green algae, and diatoms, dominate in the lagoon. Blooms of the *Anabaena* genus and *Aphanizomenon flos-aquae* have been observed from June to September in the central part of the lagoon. Cyanobacteria blooms have also been regularly observed in the Russian part.

7.4 NATURAL RESOURCES

7.4.1 Natural resources

The drainage area of the Vistula Lagoon has no valuable natural resources. Recently, test boreholes have been executed near the town of Braniewo in order to identify potential sources of shale gas. Results of those tests are not known in detail. Anyway, if valuable sources of shale gas are found, the economic development of the lagoon area is likely to change dramatically.

7.4.2 Land use

Agricultural areas cover around half of the Russian part of the Vistula Lagoon catchment. Coniferous and deciduous and mixed forests cover 8, 16, and 5%, respectively. More than 22% is used for crop land. Lakes and uncultivated land occupies less than 1%. Urbanized land is 5.5% (LAGOONS, 2012).

The land use structure in the southern hinterland of the Polish part is similar: 42% is arable land, 18% meadows and pastures, and 18% forests. It is somewhat different in the south-east corner, which belongs to the Vistula River deltaic formations: 53% is arable land, 7% meadows and pastures, and 8% forests. This difference is due to greater soil fertility in the Vistula River delta, which favours intensive agricultural production, (LAGOONS, 2012).

7.4.3 Environmental conditions and issues

Despite recent substantial improvements in the purification of municipal wastewater, and the elimination of many industrial sources of pollution, the most acute environmental problem of the Vistula Lagoon is its significant vulnerability to eutrophication (LAGOONS, 2012). According to one of the citizen jury experts, the lagoon is in a permanent status of eutrophication, which means that the elimination of summer algae blooms will be extremely difficult, even if municipal wastewaters are cleaned to the best standards and agricultural inputs of nutrients are kept at the current low levels. On the other hand, the unfavourable appearance of the lagoon's water is the largest impediment for the development of tourist activities on the southern banks of the lagoon for both Polish and Russian parts. It appears that the development of a joint monitoring system for water quality in the lagoon and discharging rivers could be a serious stimulus towards an improved optimum management of the lagoon.

The second problem is the flood risk in both parts of the lagoon. Poland has adopted an EU- supported rehabilitation program of the Vistula River delta, including flood protection infrastructures, known in Poland as 'Żuławy 2030'. This program aims to be a comprehensive management of the delta. However, nowadays it is mainly focusing on rehabilitation and upgrading of levees in the south-east corner of the lagoon, and refurbishment and re-engineering of weirs, in addition to other defense systems preventing backwaters into canals and rivers during storm events. during storm events. The Kaliningrad region is facing the same problems in the Pregolya estuary, but despite similar flood risks in both parts of the lagoon, this problem has no transboundary character.

Another serious problem is the population of cormorants, located near the spit's root in the Polish part. It constitutes Europe's largest colony, which poses severe pressures on local communities and mainly affects the fishing sector (http://www.helcom.fi/BSAP_assessment/ifs/ifs2011/en_GB/Cormorant/). However, it is also detrimental for local forestry, because the huge flock of cormorants amages numerous trees every year, leaving, literally, 'dead forest' behind. Since cormorants are no longer an endangered species, measures to control their numbers must be investigated.

7.5 MARINE ECOSYSTEM SERVICES (CICES CLASSIFICATION)

The application of the Common International Classification of Ecosystem Services (CICES) to Vistula Lagoon, as applied by Maes *et al.* (2014), is presented in Table 7.1. In order to simplify this representation we organized the ecosystem services provided by Vistula Lagoon into 'sections' and 'classes'. The CICES hierarchical classification table can also be seen in Chapter 19 (Table 19.2).

7.6 FINAL REMARKS

In a broader context, Vistula Lagoon can serve as an interesting study area for the research of lagoons in northern Europe. As a transboundary basin shared by an EU and a non-EU country, the lagoon offers a perfect opportunity for studying problems and deficiencies related to tha harmonization of two entirely different legal systems. At this moment, it is noteworthy to underline the positive role of the Baltic-wide treaties and conventions that are binding for all Baltic Sea countries. The most vital document is the Baltic Sea Action Plan, elaborated under the umbrella of the HELCOM convention. It adopted a schedule aimed at achieving acceptable water quality in the Baltic Sea by the early 2020s. In consequence, in the Vistula Lagoon area, numerous water treatment plants have been completed recently, are under construction, or will be built in the near future.

The environmental precariousness of the lagoon should be highlighted. Ecological fragility is the second reason why the lagoon can be a perfect study area, at least in the North-European context. Its importance originates from the fact that the

Table 7.1 Ecosystem services delivered by the Vistula lagoon.

	Class	Vistula Lagoon
Provisioning	Wild animals and their outputs	Fish (e.g., pikeperch, bream, roach, eel, perch, and herring). Wild foods: Gamebird. Edible animal species captured in the wild.
	Animals from *in situ* aquaculture	Aquaculture farms of fish starting in small scale on Russian side only (e.g., sturgeon, trout, cat-fish, eel, tilapia).
	Fibres and other materials from plants, algae and animals for direct use or processing	Common reed is harvested, mainly for thatching and traditional products, during winter.
Regulation and maintenance	Bio-remediation & filtration/sequestration/storage/by micro-organisms, algae, plants, and animals	Sequestration and storage of nutrients through incorporation in biomass is performed by reeds and molluscs. Reeds and molluscs accumulate metals and other pollutants (e.g., organic compounds) in their biomass, removing/decreasing its availability in the environment.
	Filtration/sequestration/storage/accumulation by ecosystems & dilution by atmosphere, freshwater and marine ecosystems	Bio-physicochemical filtration/sequestration/storage/accumulation of pollutants by wetlands; adsorption and binding of metals and organic compounds in ecosystems, as a result of combination of biotic and abiotic factors.
	Mass stabilisation & control of erosion rates	Overall, coastal dunes, forests, meadows, reed beds, macroalgae contribute to maintain the lagoon integrity
	Buffering & attenuation of mass flows	Seagrass meadows reduce sediment re-suspension and turbidity in the water column, contributing to increase of the light availability in the water column.
	Flood protection	The Vistula Spit ensures blockage of wind-wave energy directed from the open Baltic Sea towards the shore and into the lagoon.
	Maintaining nursery populations and habitats	Nursery habitat for fisheries species, extended areas of reeds, coastal dunes. A part of important European migratory birds' corridor. Occurrence of 29 phyto taxa, including 18 submerged, 7 floating-leafs and 4 surfaced species. The macrozoobenthos is dominated by euryhaline marine and freshwater organisms on the Russian side, but on the Polish side these organisms are mostly freshwater species that are typical for eutrophic waters.
	Pest control	Alien species recorded in Vistula Lagoon: for example, cladoceran *Cercopagis pengoi*, polychaete *Marenzelleria sp.*, bivalve *Rangia cuneata*, fish *Neogobius melanostomus*
	Decomposition and fixing processes	Nitrogen cycling in sediments and seagrass meadows, decomposition and mineralization processes.
	Chemical condition of salt waters	The lagoon is a one transitional water body classified based on the chemical and biological indicators.
	Global climate regulation by reduction of greenhouse gas concentrations	Global climate regulation by greenhouse gas/carbon sequestration by terrestrial ecosystems, water columns and sediments and their biota; transport of carbon into oceans (DOCs) and so on

Cultural	Experiential use of plants, animals and land-/seascapes in different environmental settings	The water and wetland area being a part of important European migratory birds' corridor is important for recreation purposes (bird-watching, nature photography, etc.)
	Physical use of land-/seascapes in different environmental settings	Walking, biking, sailing, boating, kite surfing, windsurfing, kayaking, swimming, leisure fishing (angling) and leisure hunting.
	Scientific	Vistula Lagoon has a long history of intense research activities both national (Poland, Russia) and international (bi-lateral trans-boundary Poland-Russia, as well as inclusion in pan-European research).
	Educational	Natural and cultural heritage of the lagoon are the subject matter of education (e.g., ancient water tower building in Frombork illustrating delivery of (running) water to a town in middle ages, local museum featuring cultural heritage and times of Copernicus, view tower with Foucault's pendulum proving the earth's rotation, numerous historical places, churches, buildings constituting past history and architectural values of the area).
	Heritage, cultural	Multicultural heritage: Pomeranian, Prussian, Teutonic Order, Dutch and Mennonites, Swedish, German, Polish, Ukraine, Russian. Historical Cathedral Hill in Frombork with tomb of Copernicus, lots of historical churches and houses around the lagoon (Braniewo, Wielkie Wierzbno, Kadyny with Baroque palace and a park, in the 13th century the Teutonic Knights built a mansion and a grange there, Sacred Heart Church (1681–1683) in Stegna), museums and art galleries (Poland). Ruins of the Balga Castle (Russia). On-shore and off-shore archaeological sites.
	Entertainment	Cultural base including numerous music events, festivals, concerts, dancing tournaments, exhibitions, open air exhibitions, fairs and regional events. Fishing and ice boats races.
	Aesthetic	Genuine gothic architecture in Frombork; steep roofs and massive red brick buildings, highlighting links with the Hanseatic union; a perfect example of urban planning concept in northern Europe with large cathedral situated on a hill dominating the lagoon and its environs. Scenic hills, dunes, forests, meadows as an inspiration for painters, writers and other artists.
	Existence	Polish part of the Lagoon is a NATURA 2000 protected area. Enjoyment provided by nature.
	Bequest	Willingness to preserve NATURA 2000 area and wild species for future generations

Note: Only the 'class' catetfngories with existing services are considered in the table, e.g., Surface water for drinking purposes is not provided. Explanation on the classification methodology can be seen in Chapter 19 (Table 19.2).

lagoon is sensitive to the input of nutrients, and that the amount of nutrients accumulated in the bottom, together with their high potential of re-suspension, poses challenges for a quick and lasting progress regarding water quality.

Finally, the lagoon is important from a socio-economic view point, and still suffer from the change from a centrally planned economy to a market economy. High and persistent unemployment and the migration of young and educated people pose problems that cannot be overcome without extensive governmental intervention. Therefore, the potential construction of the cross-cut through the Polish part of the spit, which is likely to boost the local economy, may become an excellent case study area for economists.

7.7 ACKNOWLEDGEMENTS

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Chapter 8

The management story of the Vistula Lagoon

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Summary: This chapter systematizes knowledge on the management (especially water and environmental) of the Vistula Lagoon. The transboundary feature of the lagoon with one EU country (Poland) and one non-EU country (Russia) adds to the complexity of efficient management of the area. It faces difficulties typical for a transboundary basin, administered by legal entities representing two entirely different legislation systems. The most obvious environmental management problems include overfishing in both parts and the absence of joint monitoring programs of the lagoon. These problems can be attributed to the transboundary character of the lagoon, despite the existence of formal mechanisms of transboundary cooperation between Poland and Russia. There is an obvious gap in practical transboundary cooperation and in cooperation between stakeholders themselves at all levels, both in the Polish and the Russian parts of the lagoon. Other factors include uneven development of different municipalities around the lagoon and different incongruous and divergent sectoral activities. Even though the lagoon is monitored regularly, information on main meteorological, hydrological and water quality parameters for both the Vistula Lagoon itself and the river basins is very scarce and incomplete. There is also a need to identify the interactions (and possible feedback loops) between climatic change and socio-economical development jointly for both countries. This is needed in order to achieve efficient management and assessment of the lagoon's future carrying capacity, especially in terms of discharge of pollutants, predominantly nutrients.

Keywords: Conflicting uses; ecosystem services; institutions; legal framework; socio-economic sectors; water resources.

8.1 INTRODUCTION

The Vistula Lagoon, formerly named in German as Frisches Haff (http://de.wikipedia.org/wiki/Frisches_Haff) was split into Polish and Soviet Union parts after the World War II (WWII). The post-war relocation of population was forced in both the Polish and Soviet parts of the lagoon. Now, after the post-1989 changes that resulted in Poland's admission to EU in 2004, the lagoon is shared between the Republic of Poland and the Kaliningrad Oblast, the latter being an enclave of the Russian Federation. According to the legislations of Poland and Russia, the lagoon waters are legally treated as inland marine waters. Currently, EU regulations and legal instruments are implemented in the Polish part, but not fully harmonized with the Russian legal system. The entire lagoon area is subject to pan-Baltic Sea conventions and treaties, such as the HELCOM Baltic Sea Action Plan (Helcom, 2007). This is very favourable for the lagoon in terms of comprehensive Baltic Sea management, including major marine basins but also lagoons, estuaries and other transitional waters.

The environs of the Vistula Lagoon are not densely populated, less than 15, or between 15 and 30, inhabitants per square kilometer in average for local municipalities. Both the Polish and Russian parts have been suffering from repercussions of a centrally planned economy and there is a general movement of population to cities like Gdansk-Sopot-Gdynia and

Kaliningrad. Such a difficult past have resulted in persistant economic problems, such as high unemployment and inadequate infrastructure. Thus, for local inhabitants, management of the lagoon primarily should target the reversal of the area's economic decline and demographic decline.

8.2 WATER MANAGEMENT

8.2.1 Institutions and water management

International conventions, which are ratified by the Russian Government and EU member countries, comprise the legislative basis for the environmental management in both parts of the Vistula Lagoon.

In Poland, the legal governance of coastal areas follow a hierarchical order, where EU legal instruments (e.g., Water Framework Directive (WFD), Habitat Directive, Natura 2000) are incorporated into national legislation and then implemented by national, regional (provincial) and local authorities. On the other hand, provincial and local authorities voice the interests and needs of local communities during consultations with the Maritime Office that represents the central government. In this way, a combined top-down and bottom-up management approaches (including spatial planning) can be acheived.

In Poland, the spatial planning of marine areas is under the jurisdiction of the relevant Maritime Office (MO). The MOs are agencies of the Ministry of Infrastructure and Development. Any ventures in the territorial sea and the marine inland waters, including lagoons and the exclusive economic zone, must be approved by the MO in charge. The implementation of marine spatial plans is also executed by the MO; for the Vistula Lagoon being the MO in Gdynia. The role of the MOs include also various degrees of jurisdiction in two specific areas of the coastal land, determined by national legislation (Book of Law 03, Book of Law 89). The first area is the technical belt. This belt comprises the area stretching from the shoreline to: (a) 20–200 m landward of the first landward dune foot, (b) foot of landward dike slope, and (c) cliff top. The MOs have full decision power in this zone, so all plans in this belt must be approved by them. The second belt, 1.000–2.500 m wide, is situated landward of the technical belt and is called the protection belt. The MOs have some degree of jurisdiction in this belt. This mean that all proposals on investments, land use change, and so on, must be approved by the MO. In this way, coastal zone development is a result of a compromise between the interests of local authorities and the central administration agency. Thus, the MOs are the most powerful administration agencies of the central government, which integrate water uses with spatial planning, incl. flood risk management.

River basins in Poland are administered by the Regional Water Management Boards (RWMB). They are responsible for the implementation of comprehensive water management (navigation, flood control, implementation of WFD, rehabilitation of degraded sub-catchments, early spring ice flow control) in each basin. The success of integrated spatial management requires a good cooperation between the RWMBs and the MOs in the estuaries.

The third most important actor in the Polish part of the Vistula Lagoon are the Provincial Inspectorates of Environmental Protection. They are in charge of environmental monitoring and provide information on water quality in the lagoon and its tributaries to all actors involved in its management and to the public via Internet.

The main actors in water management issues in the Russian part of the Vistula Lagoon and its drainage area include four federal administrations: the Department on Surveillance at the Sea (former Maritime Inspectorate), the Federal Service for Supervision of Natural Resources for the Kaliningrad Region, the Kaliningrad Office of the Neva-Ladoga Water Basin Administration, and the Kaliningrad Center of Hydrometeorology and Environmental Monitoring. The regional administration, the Service on Ecological Control and Supervision of the Kaliningrad Regional Government, is the fifth management body. Fishery issues are regulated by several different authorities at federal and regional level. Spatial planning in the terrestrial part is coordinated by the Agency on Civil Construction and Architecture. Maritime spatial planning is not yet officially undertaken, but the information basis for such planning is developed by the Atlantic Branch of P.P.Shirshov Institute of Oceanology.

8.2.2 Coastal zone and water use rights and laws

The water use rights and laws are implemented through the institutions described above. In Poland the most vital source of law, from which the most detailed instruments originate from, is the Water Framework Directive (WFD) (EC, 2000). The implementation of the WFD in river basins is one of key statutory duties of the RWMB's, whereas the implementation performance is the duty of the Provincial Inspectorates of Environmental Protection.

Moreover, and as given the previous section, another major management actor is the MO in Gdynia. This powerful agency integrates marine and maritime spatial planning with important elements of environmental management. Spatial planning and water management are interrelated, because the MO is responsible for adaptation to climate change and flood management in coastal areas. Therefore, the MO sets several recommendations aiming at the inclusion of water management in spatial planning. These include:

- the identification of areas less than 2.2 m above the current mean sea level as areas endangered by marine floods in the Vistula Lagoon,
- the determination of minimum ground floor level (datum); usually + 2.5 m,
- implementation of regulation on the construction of basements in high groundwater areas (watertight structures or ban on basement construction),
- minimum dike crest level (datum); to be found in the relevant book of law, where a classification of hydraulic structures and facilities is provided,
- requirements regarding sewage systems, including stop valves preventing backwater of mixed sewage and flood water during inundation periods,
- the prevention of rainwater drainage from flooding during storm surges. These recommendations must be incorporated in the local spatial management plans, which are prepared by the local authorities and consulted with the MO.

The MO has also numerous duties related to environmental water management. One of them is the supervision of the implementation of NATURA 2000 regulations; namely elaboration of the protection plans currently being prepared specifically for the Polish part of the Vistula Lagoon (the entire Polish part is a NATURA 2000 area in terms of both birds PLB 280010 and habitats PLH 280007).

The responsibility for spatial planning in coastal municipalities and communes outside coastal belts is divided among the self-governmental authorities of the municipality and the province. There are two regulatory instruments:

- the ‘study on conditions and directions of spatial management of municipality’ which covers the whole municipality and is indicative; spatial plans on municipality level are drafted by the mayor and are approved by the Municipality Council,
- the ‘local spatial management plan’ that covers a selected area and is an act of local law, which must be consistent with the relevant ‘study on conditions and directions… ‘; the plan is binding for potential investors. Thus, if an area is situated lower than 2.2 m above the current mean sea level, the MO recommendations on ground floor datum, basement restrictions, and so on, apply. Therefore, local spatial management plans provide a space in which government policies (MO) and local authorities intersect and must be formalised. For this reason, they are the most important elements in successful management of coastal communes and municipalities. Municipal and communal authorities are obliged by governmental agencies (e.g., MOs) to draw local spatial management plans, because they facilitate business activities and generate transparency (potential investors read these before considering an investment and comparing locations).

On the provincial level, all studies on conditions and directions of spatial management of municipalities are integrated by the Province Marshal, who drafts the Spatial Management Plan for the province, and the plan must then be accepted by the Provincial Assembly. It has an indicative character. At the national level, a strategic, but not binding document is the ‘Concept of Spatial Development of the Country’ which is elaborated and approved by the government and presented to the parliament. The main conclusions from this document should be taken into account when drafting plans at provincial and municipal level.

According to the Russian Federal Law on Inner Marine Waters, Territorial Sea, and adjacent zone of the Russian Federation (16.07.1998), the Vistula Lagoon belongs to inner marine waters. Therefore, zoning of its shore is made equal to any other marine shore of the Russian seas, or other water bodies (Russian Water Code). The coastal protection zone has a width of up to 50 m, and a water protection zone with the width of 500 m where economic activity is generally prohibited. The main problem, with these general regulations applicable to any water body, is that a marine or a lagoon shore is a changeable system, and therefore the shoreline reference varies over time.

The rules for the determination of the zoning of the shores of the Vistula Lagoon is in principle similar in the Russian and Polish parts (Figure 8.1). However, there is an exception, where the protected zones in Poland are 3–5 times wider than in Russia. This difference in ecological priorities for the Polish and Russian parts is clearly visible in the physical condition of the shore. The shore on the Polish side looks much more natural, and recreational establishments is well organized. On the Russian side of the lagoon, the situation is different, due to less economic activity, and the fact that a big segment of the shore belonged to former military areas (like the Vistula Spit).

The Russian Water Code (www.zakonrf.info) is the main law which regulates activities in the Russian part of the Vistula Lagoon and its drainage area. It is based on water basin principles and has many similarities with the WFD (Alexeev, 2008). The lagoon is considered as a federal property, and belongs to inner marine waters (Russian Federal Law on Inner Marine Waters, Territorial Sea, and adjacent zone of Russian Federation, 16.07.1998). There are no specific maritime planning documents developed so far for the Russian part of the Vistula Lagoon. The lagoon area can be utilized for any economic activity as long as it is in accordnace with all federal laws.

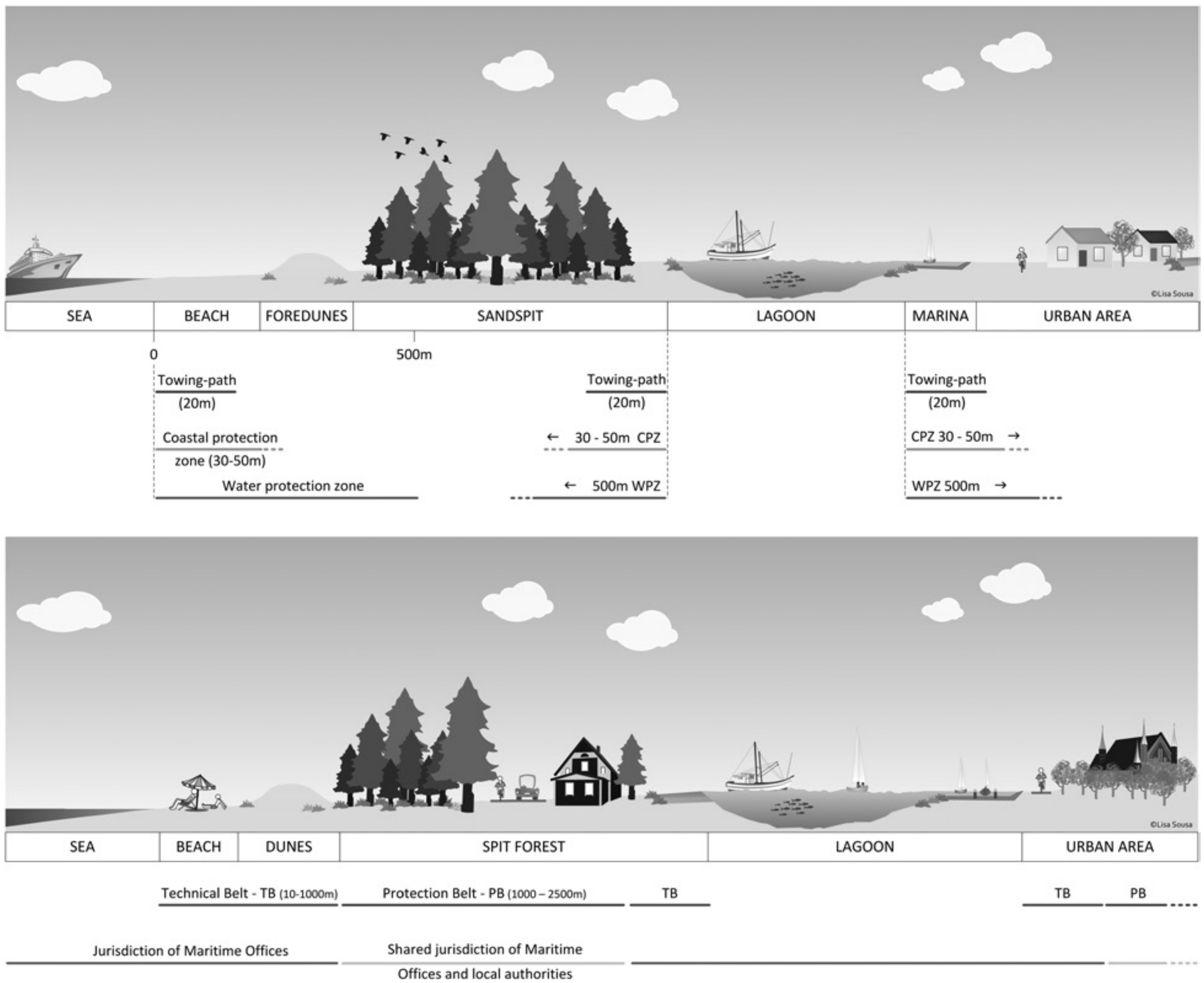

Figure 8.1 Zoning of the lagoon shores on the Russian and Polish sides.

8.2.3 Environmental problems and water use conflicts

The only lagoon inlet and outlet (the Baltiysk Strait) is located in the Russian part. The bilateral Polish-Russian agreement on navigation within the Vistula Lagoon, made after the WWII, did not allow ships from third countries to cross the Polish-Russian border. The present agreement between the governments of the Republic of Poland and the Russian Federation on navigation within the Kaliningrad (Vistula) Lagoon allows access for any ship from Poland to Russian waters and vice versa for Russian ships. However, the procedure to get a permission for access through the Baltiysk Strait require a long notice (2 weeks), which significantly restricts the enforcement of this agreement.

The most acute environmental problem is the eutrophication of the lagoon. This has led to vast and very unpleasant algal blooms in the summer season, making the lagoon area unattractive to most tourists and local inhabitants, thus preventing most recreational uses of the lagoon. The eutrophication problem is partly the consequence of past history, when the lagoon was connected to the Vistula River that discharged large amounts of nutrients into the lagoon. A lot of these nutrients are now found in the sediments, which contributes to a high sensitiveness of the lagoon to additional nutrient inputs nowadays.

Another serious problem is the formation of saltwater wedge near the Pregolya River mouth adjacent to the Kaliningrad City due to influxes of saline water from the Baltic Sea. This results in periodically serious malfunctioning of the water supply systems to the Kaliningrad City.

A source of conflict is related to the management of fisheries and wildlife. Currently, the greatest concern is the high population of cormorants, which consume large amounts of juvenile fish, particularly during the cormorants' breeding season. Cormorants, according to EU regulations, remain under full protection in Poland, despite the fact that they are no longer an endangered species. More detailed environmental characterization of the Vistula Lagoon can be found in Chapter 7.

8.3 SOCIO-ECONOMIC AND LIVELIHOOD

8.3.1 Agriculture and livestock

The current status of agriculture stems directly from the past centrally planned economy, when the agricultural structure basically consisted of large state-owned farms that utilized vast amounts of heavily subsidized fertilizers. This still remain one of the main reasons for the environmental degradation of the lagoon water. The central planning system collapsed in 1989. In the Russian part, only half of the cropland areas are cultivated nowadays in comparison to USSR times (personal communication with a member of local parliament in Kaliningrad, January 2014). In Poland, large farms went bankrupt, and currently the agricultural sector is dominated by small farms, frequently run by elderly farmers.

Agricultural areas cover less than half (46%) of the Russian part of the Vistula Lagoon drainage area. Coniferous and deciduous and mixed forests cover 8% and 16% of the land, respectively. More than 22% is other cropland. Lakes and other non-crop lands occupy less than 1% of total land area. Urbanized areas stand for just over 5.5% of the area. In the Polish part of the Vistula Lagoon drainage area the situation is similar. Arable areas dominate over pastures and forests, with cerals as a dominant crop. Large animal farms are rare.

8.3.2 Port facilities and fishing

The largest transportation hub in the lagoon area is Kaliningrad and the adjacent towns Baltyisk and Svelty (both in Russia). Due to the easy access to the Baltic Sea, this area serves as the most vital access point of the Kaliningrad region enclave to the outside world. There are long-term plans to expand the harbour activities to accommodate the largest vessels that are able to cross the Danish Straits and into the Baltic Sea.

The largest harbour in the Polish part is located in Elbląg. Separated from the open sea, it solely relies on navigation in the Vistula Lagoon and the trade with Russia. This trade is sensitive to general Polish-Russian relations, where conflicts resulted in an almost entire closure of harbour operations between 2006 and 2009. The current traffic in this port is still a small fraction compared to the operations in the mid 1990's, when it was dominated by import of the Russian coal to Poland. For this reason, the development of an artificial cross-cut through the Vistula Lagoon Spit has been considered for the last 10 years, but the final decision is heavily burdened by both political and economical uncertainties. Other harbours in the lagoon are small and are important only locally.

The fishing sector in the Polish part of the lagoon is regulated by the Marine Fishery Act of Parliament (Book of Law 62). One of its provisions is the licensing policy. An annual license is issued by the Regional Sea Fisheries Inspectorate in Gdynia and applications must be submitted by 31st October of the previous year. The second major provision is the threshold for the overall capacity of fishing boats. Currently, there are 52 vessels united in the Fisheries Local Action Group, and today the total number of fishing boats in the Polish sector of the lagoon is around 70 compared to 220 in 2004. This large decline was caused by the falling productivity of the lagoon, collapse of stocking with the juvenile eels programme, and EU-related policies of paying compensations for boat scrapping and profession change.

In terms of biomass, the most important species caught in the lagoon is herring, a fish which usually is caught in (early) spring. Over the last six years, about 1.000 tons of herring were caught in the Polish part of the lagoon. Other species caught amount to 200 tons. In this group the most prominent species are pikeperch and bream. Their catches are limited by the Polish-Russian bilateral commission on fish stocks management. As regards to eel, it is the most precious species, but its landings depend entirely on the stocking programme in the Polish part. Recent levels of fish catches in both parts of the lagoon are available in Psuty (2012).

8.3.3 Industry

Industrial activity is generally concentrated in two major cities of the lagoon, that is, in Kaliningrad City and adjacent towns in the Russian part, and in Elbląg in the Polish part. Kaliningrad has intensive industrial activity which is not limited by the harbour service, mainly small and middle size machinery, food production, electronic instruments, and so on. The Kaliningrad Trade Port, the Kaliningrad and Baltiysk shipyards, oil, soya, coal, gravel, and sand terminals, and harbours of Russian navy bases are located along the Kaliningrad Marine Canal, passing along the northern shore of the lagoon.

In Elbląg, the industry is exposed to competition from the entire EU, which results in serious pressure on the city's economy. The decreasing population and the rather low average income reflect the city's economic difficulties related to a severe reduction of employment in some of the area's key businesses, such as the Alstom factory and the local brewery. For Elbląg, key competitors are located in the nearby agglomeration of Tri-city (cities of Gdańsk, Sopot, Gdynia), where large harbours are located. These large harbours can offer better harbour and transportation services at competitive prices. Thus, it is likely that the present low industrial activity in the Polish part of the lagoon will remain.

8.3.4 Tourism and recreational activities

The tourism-related infrastructure in the Russian part of the lagoon has not been sufficiently developed, hence there is a potential for a significant growth. At present, only angling is developed. Activities related to yachting and beach rest are still to be developed. At present, international routes on internal waterways between Poland and Lithuania through the territory of the Kaliningrad Oblast are practically unused.

In the Polish part, tourism is very unevenly developed. In summer, hundreds of thousands of visitors go to the Vistula Lagoon Spit to enjoy clean and nice sandy beaches of the Baltic Sea. However, they show low interest in the lagoon, since the sea remains the key attraction. One exception is in the south of the lagoon in Frombork Town, due to the tomb of Copernicus that is housed in a local church. However, this attract visitors for a one day stay only, so there is little basis for further development of tourist services (hotels, restaurants). Another problem is that the navigation between the Spit and the southern banks cannot develop sufficiently because of high ticket prices; so thousands of potential visitors of the Spit refrain from visiting the lagoon's southern environs.

Recently, a positive change has been observed after the introduction of visa-waiver schemes between the Kaliningrad Region and northern Poland. This has resulted in an influx of commercial tourists from Kaliningrad, which have generated jobs in local shops and supermarkets. However, most visitors pay only short term visits, so they do not contribute to the development of the tourism infrastructure.

Another important reason why the lagoon is unable to fully exploit its recreational potential is the permanent eutrophication of its waters and the resulting little attractive appearance of the water, caused by resuspension of sediments and algal blooms.

8.3.5 Stakeholders perception of ecosystem services

The Vistula Lagoon used to play a key role as a development asset (fishery, navigation, tourism) for the region (the Vistula Lagoon Region). Nowadays, there are some other and more important sources of growth, and the lagoon is still perceived as an important factor constituting the region; based on self-identification and voluntary co-operation of local communities. This could be seen as an example of cultural services that the lagoon provide in particular their spiritual and historical aspects.

During focus groups and citizen jury meetings (organised by the authors within the LAGOONS project in May-June 2012 and Apr. 2013 respectively) there were many discussions related to the ecosystem services provided by the lagoon. The most fiercely debated issues on the Polish side were provisioning and cultural services such as fishery, tourism and recreation (both summer and winter), and, to some extent, navigation (due to an idea to build an artificial channel to the open sea). Many citizens perceived these services as important assets for the development of the region, in particular for the more remote parts. They proposed to develop high quality tourism based on birdwatching, biking, cross-country skiing and windsurfing. The untapped potential of regular navigation between the Polish and Russian parts was frequently underlined as well.

The discussions also touched upon regulating and provisioning services. In general the stakeholders demonstrated high levels of awareness and understanding of the importance of a healthy and resilient lagoon for the long-term regional development. They supported the need to allocate public funds for water purification and for regulatory measures in the drainage areas aiming at reduction of the nutrient loads. The most controversial issue were the protection of some species (e.g., cormorants) that was claimed to compete with humans for fish and other lagoon resources. Another issue mentioned was the conflicts between development of tourism infrastructure and nature conservation. It was also clear that stakeholders' knowledge on some regulatory services (e.g., some physical and chemical processes in bottom sediments) needs to be strengthened. Their perception sometimes was intuitive and based on general misconceptions.

Following these discussions, it was realized that future management plans should be focused on the role of the lagoon (and its ecosystem services) for enhancement of local development. They should capitalize on the existing perception of the high importance of some ecosystem services in the region, and at the same time strengthen the awareness of local communities with regard to services that need more attention.

The perceptions of the Russian stakeholders were studied during two stakeholder meetings held in 2014. A multi-stakeholder seminar in the Kaliningrad Region entitled 'Local climate change and needs for basin-related adaptation' (Kaliningrad, 21.01.2014) brought together 48 representatives from environmental administrations and research institutes from Kaliningrad (38), Belarus (5), Lithuania (2), Poland (1) and Switzerland (2). The questionnaire undertaken during the meeting showed that the main problems for the Russian part of the lagoon include (all connected with climate change):

- negative influence on traditional agriculture and economical activities due to shifts of seasons, flooding and extreme weather events as a result of climate change;
- intensification of coastal erosion;
- degradation of surface water quality due to warmer weather and increased euthrophication, and less runoff in small rivers;
- negative influence on population health due to climate warming and rise of microbiological activity;
- absence of reliable information about possible climate changes, their consequences and related risks.

A general concern was the necessity of international cooperation in adapting to climate change within transboundary water basins, such as the Neman River Basin, the Vistula Lagoon drainage area and so on.

The Vistula Lagoon Forum (Kaliningrad, 13–14.05.2014) combined participants from Poland (27) and Russia (80), representing regional and local authorities and environmental administrations (29), research and educational organizations (62), real economy sector (14) and public media (2). A resolution was adopted at the forum meeting, in which the great importance of the lagoon to local communities was highlighted, and a suggestion to exclude the Vistula Lagoon from the Hot Spot HELCOM List (HELCOM, 2013). Moreover, the need of climate adaptation measures agreed by both sides (Poland and Russia) was mentioned.

Some of the concerns on the Russian side was related to the salt intrusions into the Pregolya River, as this has a strong influence on the quality of the drinking water. Another issue discussed was the possible construction of a deep marine harbour in the central part of the lagoon.

8.4 INSTITUTIONS, LAWS, RIGHTS AND CONFLICTS

8.4.1 Institutions, stakeholders and social groups

The Polish part of the lagoon is shared by two Provinces (Pomerania and Warmia-Masuria). The former contains the spit and the west bank of the lagoon, the latter the south bank and the city of Elbląg. Such a configuration puts most of the burden related to the management of the Polish part of the lagoon onto the authorities of Warmia-Masuria Province, because the overwhelming part of the catchment and of the population are situated there.

The civil society in the lagoon area is generally weak, being directly attributable to post WWII relocation of population and the subsequent failure of the centrally planned economy. This produced a situation in which many people do not possess the skills needed in a modern economy. This became particularly vivid in the agricultural sector when large state owned farms on both sides of the border collapsed and left many poorly educated farm workers permanently redundant.

A relatively powerful actor in the Polish part of the lagoon is the Fisheries Local Action Group (www.lgrzalewwislany.pl). Fishing still remains an important element of local economy. The Group voices interests of the fishing community, which must comply with strict EU and national regulations on fishing gear, vessels and fish quotas. Also, they act toward curtailment of the number of cormorants in the lagoon area.

A valuable initiative of local authorities of communes situated in the Polish part of the lagoon is the Union of Vistula Lagoon Communes (www.zalew.org.pl). Their main goal is to support near-border eco-tourism. So far, they have prepared materials advertising tourist attractions of the lagoon, which are available at their website. They have also organized several conferences, aiming at the development of transboundary tourism, extending far beyond the currently observed commercial visits.

The remaining relatively influential stakeholder group are also related to the tourism sector and include hotel and gastronomy operators. However, their potential impact remains low because of the virtual absence of longer visitor stays in the lagoon area. The only exception is the Spit, where hundreds of thousands of tourists stay in the summer.

The Russian part of the lagoon is dominated by the city of Kaliningrad, where most economic, cultural, educational and political activities take place. This situation reflects the enclave character of the whole Russian part, which makes Kaliningrad a natural centre of gravity. The concept of development of the Russian part are based on an idea of multidirectional development, including not only a large expansion of harbour activities to provide a gateway for exchange of goods, but also the development of industry and precision engineering, wide tourism and recreational services for Russian tourists.

8.4.2 Cooperation between trans-national partners

During the life-span of the LAGOONS project (2011–2014), several initiatives have taken place in the region of the Vistula Lagoon, including Vila (cross-border Polish-Russian project; http://vilaproject.eu/), ARTWEI (SBP project on local and regional methods for effective management of transitional waters; http://www.balticlagoons.net/artwei/) and HELCOME BASE (supporting implementation of BSAP in Russia; http://helcom.fi/helcom-at-work/projects/base). Additionally, another FP7 project, ARCH, has carried out research including stakeholders' participatory processes for the development of the Vistula Lagoon. Initially, the LAGOONS and ARCH projects had different approaches towards the stakeholders involvement. The ARCH project aimed at the development of 'collaborative roadmaps for local lagoon management' in close interaction with local lagoon managers, policy makers, stakeholders and scientists in a sequence of three local workshops (at each of their 10 project case study sites). This also included inventories of the state of the art, investigations of possible future scenarios, and the development of a framework programme that addresses the crucial challenges. There was no fixed methodology for each workshop, enabling case coordinators to adjust tools and measures to the specificities of a given region (culture etc.). However, it is important to mention that the project focused on the development of a strategic plan that would fit into ongoing strategic management processes in the region, not on the participatory process itself.

Having in mind the experience with the Vistula Lagoons stakeholders (being subject to many ongoing and past efforts), the Polish partners in the two projects – the Maritime Institute in Gdańsk (ARCH) and the Institute of Hydro-Engineering of the Polish Academy of Sciences (LAGOONS) – consolidated their efforts in order to create the best possible synergies. With the agreement of both projects' coordinators, it was decided that the stakeholders' involvement methodology adopted in the LAGOONS should be followed in both projects. However, it was slightly adapted in order to better suit specific needs of the ARCH, for example, consultations of the 'collaborative roadmap for local Vistula Lagoon management'. For this purpose, an additional event prior to the focus groups meeting was arranged. The goal was to inform 'institutionalised' stakeholders about the two projects, the processes and expected outcomes. All participants expressed their interest in the projects' results, and they underlined that they expected results better suited to the regions' needs as well as better tied to the ongoing decision-making processes. A second 'adjustment' of the methodology was the in-depth consultations of the 'Management plan for the Vistula Lagoon Region' at the last workshop for all stakeholders.

Besides various projects carried out in the area, there is also an ongoing cooperation of the Kaliningrad region of the Russian Federation with regions of the Republic of Poland, basically concerning environment protection and management. This is based on two fundamental intergovernmental agreements. The first is an agreement on cooperation of the Kaliningrad region of the Russian Federation and the north-eastern voivodeships of the Republic of Poland dated 22 May 1992 (hereafter Doc.1992). This agreement determine the issues of cooperation regarding the environmental protection in the border areas and the economic use of the border surface and groundwater, including the Kaliningrad (Vistula) Lagoon. The second is an agreement between the Government of the Russian Federation and the Government of the Republic of Poland on cooperation regarding environmental protection dated August 25 1993 (hereafter Doc.1995), which aimed at an improvement of the environmental conditions, improved ecological security and pollution prevention in both countries and the Baltic Sea. This agreement emphasises the implementation of these objectives in border areas by promoting cooperation between local administrations and self-governments, institutions, enterprises and non-governmental organizations regarding environmental protection.

According to Doc.1992, both sides appoint their Commissioners responsible for the coordination of programs and activities aimed at the development of cooperation between the Kaliningrad region and the Polish north-eastern voivodeships. The structure providing implementation of this agreement is the Russian-Polish Council on cooperation of the Kaliningrad region of the Russian Federation and the regions of the Republic of Poland (hereafter – the Council) that was established in 1994. The Council consists of two national parties – Russian and Polish – formed on a parity basis. The Council establishes commissions or working groups. Currently, the Council includes 12 commissions in various areas of cooperation, including the Commission on environmental protection and integrated use of the Kaliningrad (Vistula) Lagoon. The Russian-Polish Council meets annually on the Polish and Russian sides alternately.

One of the Commissions is the Commission on the environmental protection and integrated use of the Kaliningrad (Vistula) Lagoon (hereafter – Russian-Polish Commission). The Commission has been working for 17 years. Currently, the following issues are on their agenda:

- cooperation on the monitoring of surface waters in border areas of the Russian and Polish parts of the lagoon;
- cooperation in the fields of natural resources and environmental protection in border areas of the Russian and Polish parts of the lagoon;
- cooperation on biodiversity conservation, development and management of protected areas, and sustainable forest management in border areas of the Russian and Polish parts of the lagoon;
- cooperation on attracting foreign investments, implementation of international projects and programs on nature resources management and environmental protection.

8.5 MANAGEMENT PLAN FOR THE VISTULA LAGOON REGION AS AN OUTCOME OF THE COOPERATION

A management plan for the Vistula lagoon was created as an expert study of the ARCH project, based on an analysis of several European lagoons and estuaries (Zaucha, Breedveld, 2013). This plan adds the socio-economic dimension to the existing plans and regulations concerning the environment, such as the HELCOM Action Plan or the WFD. The plan was based on available information and analysis of literature (results from the feasibility study entitled 'Vistula Lagoon and its region' (Zaucha, Matczak, 2012), as well as on results from the used stakeholders' methodology of the LAGOONS project. The main idea was to recommend the most promising ways to combine the social, human, economic and natural capital in the region of the Vistula Lagoon, based on an integrated development model elaborated in the ARCH project (Zaucha, 2013). The plan indicate the strategic elements of the main directions of development of the region around the Vistula Lagoon based on a more informed use of the natural capital, that is, the lagoon itself and the ecosystem services it provides and thus provides a footing for the preparation of legally binding documents of national and regional legislation.

Focus groups and citizen juries analyses and discussions have indicated the need for action in the following areas:

- improvement of the natural capital of the Vistula Lagoon;
- targeting public intervention in selected final ecosystem services provided by the lagoon;
- defining the powers and responsibilities for the development of the region and the Vistula Lagoon, and the mechanisms of this development (currently there is no single entity responsible for the lagoon region itself);
- establish an independent mechanism to assess alternative trajectories of development, selection of the most desirable of them, and facilitate structural changes.

The expert knowledge juxtaposed with focus groups and citizen juries results made it possible to list the key (selected) actions proposed in the Management Plan:

- development and implementation of specific standards for wastewater treatment and actions to reduce the inflow of nutrients (and other pollutants) from agriculture and other diffuse sources as an addition to existing quotas established under the HELCOM Action Plan (Helcom, 2007);
- monitoring of the waters of the lagoon aimed not only at meeting the requirements of the EU, but also allowing the identification of the most suitable corrective actions;
- building an integrated tourism programme for the lagoon region;
- signing a contract for the economic development of the region;
- establishing a mechanism for the evaluation of regional development policies (the plan and the implementation of the contract);
- establishment of a new type of governance mechanisms combining different types of authorities, private actors, and both land and sea;
- funding all these from a dedicated regional programme being part of the EU financial perspective 2014–2020 (an idea of territorially dedicated rather than sector-oriented funding).

The plan is currently under discussion with key Vistula Lagoon stakeholders, and it is expected to influence ongoing work on the preparation of the institutional arrangements for managing development funds within the EU financial perspective 2014–2020.

8.6 FINAL REMARKS

In the Vistula Lagoon, both Polish and Russian environmental authorities should plan and coordinate between the countries measures of controlling and reducing nutrients loads from the catchment to the lagoon, which may have a positive impact on the water quality of the Vistula Lagoon. In this context, a system of joint and consistent monitoring of physical and environmental parameters, having the same spatial coverage pattern and the same sampling rates and times of atmospheric, hydrological and water and sediment quality parameters, appears as one of the key common goals to be achieved in the future. On the other hand, it should be realized that the lagoon is a permanently eutrophicated system and improvements of water appearance will therefore be slow, despite improvements pollutants discharged from the catchment.

The presence of high number of cormorants will remain a pressing issue. As this species is no more in extinction – prone their number should be taken under control. It can be done either 'mechanically' by man-made regulation (e.g., shooting birds, scarring them, etc.) or 'smartly' (by determination of fish species that compete for the same food with the cormorants and setting suitable protection periods for them). Mechanical control is difficult from the political and managerial point of view as the Polish part of the lagoon is a NATURA 2000 region. Research is required whether a smart approach by curtailing the catches of predatory species (mainly the pikeperch) in order to reduce the number of juvenile fish as the feeding base of cormorants, will lead to migration of their surplus.

Economic activities in the Polish part may substantially change if the artificial cross-cut through the Spit and a navigational channel to Elbląg harbour are constructed. Current economic analyses estimate that such a venture would become cost-effective in the long-term (decadal) perspective. Also, the research on environmental impact of the cross-cut indicates that environmental footprint on the lagoon and open sea beaches will be of acceptable significance. However, little is known whether new infrastructures will reinvigorate the entire economy of the Polish part of the lagoon, apart from Elbląg city, where positive outcomes would be more obvious. Also, more in-depth economic studies should reveal whether the largest Baltic harbours in Gdańsk and Gdynia, situated just nearby, may easily absorb a potential cross-cut traffic by offering better logistic services, such as motorway access to European transportation network and the resulting faster and cheaper shipment of goods.

The flood risk in low-lying areas is the second engineering and managerial problem in the lagoon. However, the lagoon plays a rather marginal role as such, as any activities will be related to the rehabilitation of existing and construction of new flood defences and not to the functioning of ecosystems, wildlife and habitats in the lagoon. Still, flood risk will remain a serious social and management problem in the area in decades to come, especially in the context of the expected climate change.

8.7 ACKNOWLEDGEMENTS

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Chapter 9

The physio-geographical background and ecology of Tyligulskyi Liman Lagoon

Y. Tuchkovenko, N. Loboda and V. Khokhlov

Summary: This chapter summarizes the knowledge base on the physio-geographical background and ecology of the Tyligulskyi Liman Lagoon. The lagoon is located between the Dnieper and the Danube Rivers and is one of many lagoons in the Ukrainian part of the north-western coast of the Black Sea. The lagoon is connected to the Tyligul River basin, which is the main freshwater source for Tyligulskyi Liman. The natural resources of Tyligulskyi Liman include a unique coastal landscape, a rich flora and fauna, and mineral therapeutic muds. It is also an important place for weight gain, nesting and rest of migrant birds. Tyligulskyi Liman is included in the Important Bird Areas List and is a Ramsar wetland site, primarily due to the waterfowl habitat of international importance. The areas adjacent to the lagoon are mainly used for agriculture. The lagoon's unique characteristics are threatened by anthropogenic and climate change pressures. Numerous artificial reservoirs in the lagoon's drainage basin decreased the river water discharge. During the last decades, water salinity in the lagoon increased considerably due to reduced freshwater inflow from the drainage basin and intensive summer evaporation. As a result, the composition of fresh-brackish and brackish species is being substituted by marine and brackish-marine species.

Keywords: Biodiversity, ecological status, ecosystem services, land use, water demands, water resources.

9.1 INTRODUCTION

This chapter describes the physio-geographical and ecological conditions of Tyligulskyi Liman and its drainage basin. The coast of Tyligulskyi Liman is a natural reserve of Ukraine. It is a unique natural system with numerous natural resources that can be useful for the socio-economic development of adjacent territories, particularly for recreation, eco-tourism, public health, aquaculture, and fishing. In addition, the Tyligulskyi Liman Lagoon provides ecosystem services that can be used for better planning and conservation of the Tyligulskyi landscape park.

9.2 STUDY SITE DESCRIPTION

9.2.1 Characterization of the Tyligul River drainage basin

The Tyligul River is the main source (>90%) of freshwater into Tyligulskyi Liman and has a drainage area of 3,550 km^2 and a length of 173 km (Shvebs & Igoshin, 2003; Figure 9.1). The Tyligul River valley is about 3–5 km wide, while its floodplain is around 300–400 m wide; the latter reaches a width of up to 800 m towards the river's outlet. The river slopes are interspersed with gullies and ravines that reveal Pontian limestone. At the bottom of the slopes, cone-shaped accumulations of debris were deposited as a result of fine material inflow from the ravines. The watershed is characterized by forest shelterbelts, and the slopes are planted with forests. Ravine and valley areas are used as pastures, whereas floodplains are used to grow vegetables, plant gardens and vineyards. More than three quarters of the Tyligul River basin are covered by agricultural land. The existence of a large number of artificial ponds in the catchment area influences the hydrological regime of the river and the lagoon. The northern part of the drainage basin is located in the Northern Steppe and the southern part is located in the Southern Steppe; the latter has a more arid climate. The Tyligul River basin is an area with low *soil moisture*, a condition which is more severe in its southern part.

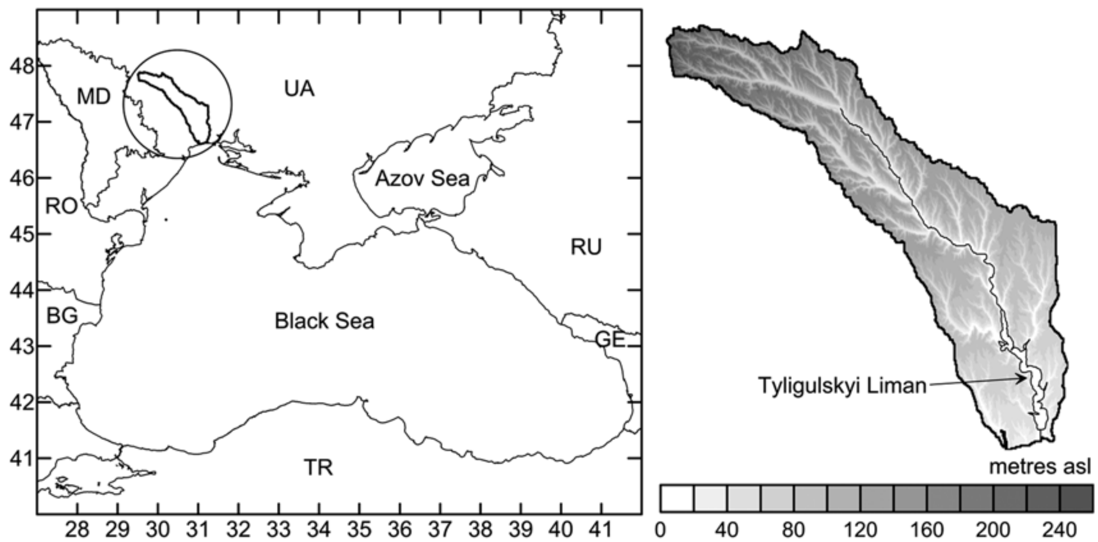

Figure 9.1 Location and topography of the Tyligulskyi Liman lagoon basin area.

According to the hydrogeological zoning (Kamzyst & Shevchenko, 2009), the drainage area of Tyligulskyi Liman is located within the Black-Sea Coastal Artesian Basin. Aquifers are located between the layers belonging to the Quaternary and Neogene System, respectively. The first confining layer beneath the surface consists of marls and clays belonging to the Palaeogene System. The source of the Tyligul River is located at 260 m above sea level; from here, the landscape slowly descends into the coastal plains around the lagoon (see Fig. 7.1).

9.2.2 Characterization of the Tyligulskyi Liman lagoon

Tyligulskyi Liman is located on the Ukrainian coast in the north-western part of the Black Sea, 40 km from the city of Odessa at the border of the Odessa and Mykolaiv administrative regions (46°39.3′–47°05.3′N, 30°57.3′–31°12.7′E; see Fig. 7.1). The lagoon used to be a valley of the Tyligul River that was later flooded by seawater. It is 52 km long and 0.3 to 4.5 km wide. When the water level in the lagoon reaches 6.88 m (PSMSL, 2014), the estimated volume and surface area are 693×10^6 m^3 and 129×10^6 m^2, respectively. The mean depth of the lagoon is 5.4 m. However, the southern and central parts of the lagoon are deeper (10–16 m), and are divided by the shallow water close to the Chylova spit with a depth of only 4–5 m. The maximum depth in the southern part of the lagoon reaches 22.2 m, while the northern part is shallower with depths of up to 4 m.

Tyligulskyi Liman is separated from the sea by a sandy isthmus, which is up to 4 km wide and up to 6.6 km long. The isthmus is the result of wave-induced sand accumulations on the seashore, and has an area of about 14 km^2 and an annual debris accretion of 70×10^3 m^3. In the late 1950s, the isthmus was breached by an artificial channel connecting the lagoon with the sea. The aims were (i) to provide entrance for fish from the sea during spawning season, (ii) to control the water balance of the lagoon. Presently, the channel is 3.5 km long, 20–30 m wide and 0.25–1.5 m deep. Usually, the channel is opened manually during April–May by digging through its sea-side part, and is in use until the end of July–August, when sand accumulates again from the sea-side. Shallow salt lakes of 0.25–1.0 m depth are located in the low-lying areas of the isthmus, and these are fed with water from the channel.

The Black Sea areas adjacent to the lagoon are influenced by the Dnieper and the Southern Bug artificial waterways (the Dnieper-Bug connection). The total freshwater discharge from these rivers can vary from 650 m^3 sec^{-1} during the summer to 2,100 m^3 sec^{-1} during the spring floods. Therefore, the salinity of the sea water inflowing into the lagoon varies from 6–10 PSU in spring to 15–16 PSU in summer.

9.2.3 Hydrological regime

The water regime of Tyligulskyi Liman is determined by the water inflow from its drainage basin, the amount of atmospheric precipitation, the surface evaporation, the water exchange between the lagoon and the sea through the artificial channel.

The total annual surface water inflow into Tyligulskyi Liman is currently estimated to be 24×10^6 m^3. The annual surface evaporation is 93×10^6 m^3, and the input from precipitation is 58×10^6 m^3. Therefore, there is a negative water balance (about 11×10^6 m^3) even in an average year. This imbalance increases significantly in years with low precipitation and high evaporation. When the artificial channel is closed and there is no water inflow from the sea, the water level in the lagoon decreases. When the channel is open, the long-term mean annual amplitude of water level in the lagoon is 0.35 m. The water level rises from January to April and, in the following months, the level decreases, reaching the lowest water level in November. Maximum water levels in the lagoon can reach up to 7.58 m (PSMSL, 2014); this is usually observed in years with very high spring floods (e.g., March 2003). Whenever the connection of the lagoon with the sea is very weak (e.g., if the channel is not dug open or its discharge capacity is small) during a period of few years, the water level can decrease to 7.18 m (PSMSL, 2014) as it was registered during the period from 2006–07.

In the course of one year, the water temperature in the lagoon can vary widely; from −0.1–0.2°C in winter to 30–33°C in summer at shallow water (Polischuk *et al.* 1990). The highest water temperatures are usually registered in July and August. During these months, the diurnal variation of temperature in the shallow areas can reach 6°C. The annual variability of the thermohaline structure in Tyligulskyi Liman is characterized by the development of a seasonal thermocline in May. If hydrometeorological conditions are favourable (decreasing salt levels, intensive surface warming, lack of prolonged storm winds), the thermocline in the deep areas of the lagoon can be maintained until August. For example, by the end of July 2010, the water temperature in the deepest central part of the lagoon reached 28°C near the surface and 8–10°C at a 15 m depth. Nevertheless, in most cases, the sharp seasonal thermocline usually decreases by the end of June.

Another feature of the hydrological regime in Tyligulskyi Liman is the long-term trend in terms of increasing salinity. This increase can be explained by reduced freshwater inflow from the drainage basin and by the accumulation of salt from the sea through the connecting channel. In the 1960s, when the Tyligul River runoff constituted a considerable part of the water balance in the lagoon, the average water salinity was 8.7 PSU, 11.4 PSU, and 13–15 PSU in the northern part, the central part, and the southern part of the lagoon, respectively (Rozengurt, 1974). In the most recent years, water salinity in both the southern and the northern parts of the lagoon has increased to 19–23 PSU in late summer/early autumn. For example, during the period between May–October 2012, the water salinity in the central part exceeded 20 PSU, and reached a maximum of 23 PSU in October.

A certain decrease in water salinity was registered in years with heavy spring and short-term floods. For example, in March 2003, when the water level in the lagoon rose to 7.58 m (PSMSL, 2014), the salinity in the surface layer decreased to 6 PSU. The sharp seasonal pycnocline that followed these events was a result of the low salinity in the surface layer and the high water temperature in the summer, which did not allow a significant decrease of water salinity in the lagoon as a whole. In the late autumn of 2003, the salinity of the surface water layer increased to 17–19 PSU.

9.2.4 Meteorological characterization

The climate of Tyligulskyi Liman is temperate and continental, with low rainfall, short mild winters and long hot summers. Climatic variations can be quite extreme, but the vicinity of the Black Sea moderates summer temperatures and humidity fluctuations. During July and August, the daily air temperature usually exceeds 20°C. Also, there are long dry spells that can last for up to two months. On average, there are 27 dry days with a relative humidity lower than 30% (Passport, 1994). Winter (which lasts for about 80 days) is characterized by variable weather conditions with frequent thaws; daily temperatures can range from −20 to +15°C and precipitation is relatively low (70–90 mm). The coldest period is from 11 January to 10 February, with a monthly mean temperature of −4.7°C. Snow cover occurs on less than 40 days with a mean depth of 50 mm. Frost can penetrate the soil to a depth of 1 m (Passport, 1994).

9.3 WATER RESOURCES AND QUALITY STATUS

9.3.1 Water resources and demands

The results of the water-heat balance model (Loboda & Bozhok, 2014) showed that the mean long-term annual surface freshwater inflow from the drainage basin into Tyligulskyi Liman under natural, undisturbed by water dependent economic activities was 56×10^6 m^3. This value includes the annual runoff of the Tyligul River of 46×10^6 m^3. However, the actual annual runoff of the Tyligul River measured during 1992–2007 was 21.2×10^6 m^3, a value conditioned by the abundance of artificial reservoirs (ponds) in the drainage basin. The ponds are filled naturally with water during the spring floods, that is, thus reducing the river runoff. During the following summer, the ponds act as huge landscape evaporators and the water is permanently lost.

The predominant part of the annual runoff is usually registered during the spring flood period. In years when the snow cover is unstable or missing, the spring flood period can be totally absent. On the contrary, years with accumulation of snow in the drainage area and deep frost penetration result in high spring water discharges.

The subsurface supply of water to the rivers is insignificant, with 8.8×10^6 m^3, and is part of the reason why the rivers are drying out. For example, the downstream section of the Tyligul River runs dry during 90–240 days; particularly during summer and autumn (Passport, 1994). To secure water availability for irrigation, artificial reservoirs (ponds) were created, mainly along the riverbanks. There are 105 ponds down the Tyligul River with a total capacity of 10.2×10^6 m^3. Taking into account the other rivers in the region such as the Balaichuk, Tsarega and Khutorska, the total number of ponds is 140 with a total volume of 14×10^6 m^3. The technical standards of the ponds are very low; for example, the bottom and banks are not impermeable enough to avoid infiltration, self-action weirs often do not operate, and dams are poorly reinforced and partially destroyed. As a consequence, about 80% of these reservoirs dry up. The runoff losses incurred through the filling of the ponds and additional evaporation from their surface result in a decrease of the total water input to the lagoon of about 30–35% (Table 9.1).

Table 9.1 Water resources of the rivers at Tyligulskyi Liman drainage basin under natural and under human activity (until 1989).

Rivers, inflows	**Annual inflow into Tyligulskyi Liman ($\times 10^6$ m^3)**	
	Natural conditions	**With artificial reservoirs**
Tyligul	46.00	33.00
Tsarega	3.90	1.91
Balaichuk	4.10	2.75
Khutorska	0.46	0.00
Lateral inflow	1.60	1.06
Total	**56.06**	**38.72**

Since the late 20th century, the water resources of the rivers are significantly impacted by aridity. Comparing the periods of 1989–2011 and 1953–1988, the mean annual runoff of the Tyligul River decreased by 37%. Thus, human activity (artificial reservoirs in the drainage area) together with climate change result in a decrease in the annual surface water inflow into Tyligulskyi Liman of about 24×10^6 m^3 (see Section 9.2.3).

Given the general shortage of surface water, groundwater is used for drinking and domestic water supply, meeting 92% of the water need. About 150 registered water consumers use groundwater in the Tyligul River drainage basin. They extract 3.62×10^6 m^3 of groundwater, of which 2.93×10^6 m^3 are for drinking and domestic purposes, 0.60×10^6 m^3 are for agriculture, and 0.09×10^6 m^3 are for industry. The groundwater is returned into the Tyligul River without any treatment as there are no waste water treatment plants.

9.3.2 Water quality status

In the case of Tyligulskyi Liman, the methodology used to estimate the quality of surface water was approved by the Ministry of Ecology and Natural Resources of Ukraine (Hritsenko *et al.* 2012). The methods used are based on the calculation of various indices concerning the content of biogenic elements and organic matter content. These methods classify the lagoon as a 'eutrophic β″-mesosaprobic weakly polluted reservoir with a water quality of class 4′. This is due to a high content of mineral and total phosphorus, organic nitrogen, and dissolved organic matter in the lagoon's water. The primary production of organic matter by algae is limited by the low content of mineral nitrogen. The overall ecological condition of the water in the lagoon classified as satisfactory.

According to the E-TRIX index (Moncheva & Doncheva, 2000), the trophic level of the lagoon corresponds to the 'middle' class.

The lagoon's ecological status was assessed using the use of the EBI index (Estuarine Biotic Integrity Index; Deegan *et al.* 1997) and the TFCI index (Transitional Fish Classification Index; Coates *et al.* 2007) based on data on fish assemblages. These two assessments showed that the lagoon is 'Medium' (EBI = 30) and 'Moderate' (TFCI = 33, EQR = 0.58).

The AZTI Marine Biotic Index, AMBI (Borja & Muxika, 2005), defines the assemblages of macrozoobenthos as 'Unbalanced', 'Slightly disturbed' with the ecological status of 'Good', and classifies the lagoon as 'Slightly polluted' (WFD CIS Guidance Document No. 5, 2003). Biotic indices show the negative influence of many factors on the lagoon's ecosystem such as the considerable seasonal and interannual variability of water salinity, the probable summer hypoxia, and the imbalance of the ecosystem with regard to nitrogen and phosphorus content.

9.4 NATURAL RESOURCES

The coast of Tyligulskyi Liman is, to a large extent, characterised by its landscape and rich biodiversity, including wave-cut niches, coastal benches, sandy spits and islands, shallow waters and water meadows, reed beds, steppe areas and woodlots, which offer favourable conditions for biological diversity.

The flora of the lagoon's coast includes more than 650 species of vascular plants. At least 70 plants are dominant in plant associations, and 22 species are in the National and International Red Books. The importance of vegetative cover at the Tyligulskyi Liman coast is mainly due to the representativeness of the steppe zone of southern Ukraine, the occurrence of plant associations registered in the Green book of Ukraine due to their rareness, and to the fact that these species are included in several lists of protected plants of international, national or local importance.

Tyligulskyi Liman is also characterized by a high level of faunal biodiversity. It represents 70% of the habitat for Ukraine's wetland avifauna; during the migration, nesting and wintering period, about 300 bird species can be found here. Among these, 26 species are registered in the Red Book of Ukraine, and three species (*Phalacrocorax pygmeus* (Pallas, 1773), nester; *Haliaeetus albicilla* (Linnaeus, 1758), bird of passage, wintering *Rufibrenta ruficollis* (Pallas, 1769), bird of passage) are listed in the European Red List. During the migration periods in spring and autumn, more than 70 species of wading birds dwell in the lagoon, in shallow waters and reaches (Integrated Land Use of Eurasian Steppes, 2008). The total number of birds varies between 2,000 and 7,000 couples. The population of wintering birds amounts to about 10,000 birds, and migrant birds contribute with about 8,000 individuals (Loieva, 2011).

More than 1,500 species of invertebrate inhabit the lagoon's coast. Twenty-three species of insects are listed in the Red Book of Ukraine, and two species, *Saga pedo* (Pallas, 1771) and *Zerynthia polyxena* (Denis & Schifermuller, 1775), are registered in the European Red List. In addition, seven species of amphibians, seven reptile species, and 31 species of mammals, can be found in the lagoon area; six of the mammal species are listed in the Red Book of Ukraine (Integrated Land Use of Eurasian Steppes, 2008).

A total of 118 species of planktonic algae, 51 species of bottom-living vegetation, including multicellular water-plants and flowering macrophytes, 30 species of meso- and macrozooplankton, 46 species of macrozoobenthos, and 25–30 species of fish are found in the waters of Tyligulskyi Liman (Zaitsev *et al.* 2006).

Tyligulskyi Liman is one of the few wetlands that have preserved its natural seaside landscapes; the ecosystem offers unique conditions for fauna and flora, and the lagoon is of great significance for the maintenance of the region's biological equilibrium.

9.4.1 Land use

Agricultural land occupies about 70–85% in the upper and lower parts of the Tyligulskyi Liman basin area and about 85–90% in the middle part. Around the lagoon, the percentage of arable land varies from 75 to 85% (Atlas, 2002). In the tilled areas, cereals and leguminous crops are prevailing (about 60%), fodder and industrial crops including sunflower and rape account for 20%, while the remaining 20% are comprised of cucurbitaceous species (Atlas, 2002). The typical cereal crop is winter wheat, but areas under winter barley and corn constitute a considerable share. Presently, there are 205 agricultural enterprises registered in the basin area, but only 54 of them cultivate areas of more than 1,000 ha. The slopes near the lagoon are used as pastures for grazing animals (for non-commercial use by local residents).

In the 1990s, numerous suburban, horticultural and gardening associations consisting of small plots of 0.06–0.12 ha adjacent to small buildings (summer cottages) were created along the western coast of Tyligulskyi Liman. During spring and summer, the population of these associations can increase up to 50,000 individuals.

9.4.2 Environmental conditions and issues

Due to the fact that the Tyligulskyi Liman area does not have large cities and large industrial enterprises, the lagoon can, to a large extent, preserve its natural features. However, the natural landscape and environmental conditions are influenced by agricultural practices (see previous sub-section). Soil tillage and grazing in the coastal protective strip and the application of fertilizers and pesticides contribute to the pollution of waters. Severe summer storms can cause an additional inflow of suspended sediments and organic matter into the lagoon. This leads to a reduced water transparency, an increased water temperature in the surface layer, and to the development of eutrophication with all its negative effects.

Additional anthropogenic pressure on the lagoon's ecosystem occurs due to intensive suburban settlements in the territories adjacent to the lagoon. There are now 16,000 suburban horticultural and gardening plots along the western coast of the lagoon. The negative consequences of these activities include the disturbance of the natural landscapes, bird habitats and nesting sites, destruction of unique flora and fauna, formation of landfills along the shore due to a lack of recycling facilities, domestic waste, and discharge of untreated sewage into the lagoon.

The present water management regime has transformed Tyligulskyi Liman into a stagnant reservoir. On the one hand, the water containing biogenic matter and salt flows into the lagoon from upstream rivers and streams, and from the sea through the connecting channel. A small volume of water also flows out to the sea. The significant summer evaporation contributes to water loss in the lagoon. The time of total water renewal from external sources is estimated to be 8 years. This results in long-term accumulation of salt and biogenic matter in the lagoon. At present, the concentration of both mineral and organic phosphorus and organic nitrogen in the water of the lagoon exceeds the concentrations in the upstream surface freshwater (rivers and streams) and the downstream sea water. The ecosystem of Tyligulskyi Liman is out of balance due to the relative share of the two main biogenic elements – nitrogen (N) and phosphorus (P). For example, the ratio of nitrogen and phosphorus concentrations, mgN/mgP, is 1:5 on average for inorganic forms, 14:1 for organic forms, and 4.5:1 for total nitrogen and phosphorus. Thus, the primary production of organic matter is evidently limited by the availability of nitrogen (Zaitsev *et al.* 2006).

As a result of increasing water salinity in Tyligulskyi Liman (Figure 9.2), the composition of fresh-brackish and brackish species has been replaced by marine and brackish-marine species. In comparison to the early 1980s, the percentage of phytoplankton marine species increased from 14 to 64%, marine and brackish-marine macrophytobenthos from 40 to 83%, and marine zooplankton from 40 to 90% (Zaitsev *et al.* 2006; Kovtun, 2012). Only four species of freshwater fish were found in 2013 in comparison to 12 to 25 during the period from 1960–80. The expected climate change can result in an increase of salinity of up to 40–50 PSU by 2050, and in a considerable reduction of water flora and fauna biodiversity (Loboda & Bozhok, 2014).

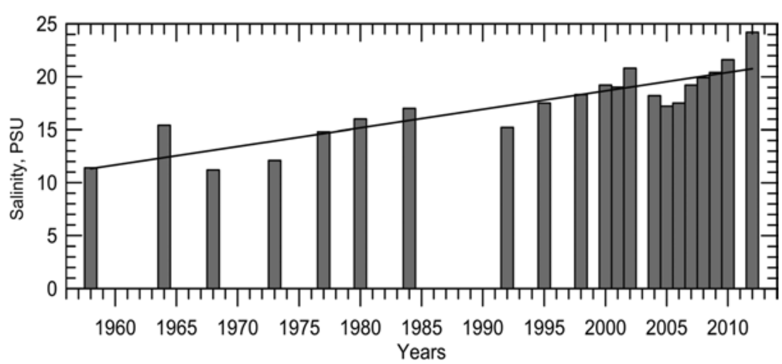

Figure 9.2 Annual mean salinity in the Tyligulskyi Liman lagoon.

Significant storage of biogenic matter in the water and bottom sediments of the lagoon favours a high rate of organic matter production by phytoplankton and benthic macrophytes during spring and summer. When conditions are favourable, phytoplankton biomass in the photic layer can reach 40–160 g m^{-3} (e.g., 2010). The amount of biomass of bottom-living macrophytes in the shallow (2 m depth) coastal area of the lagoon can reach mean values of more than 2 kg m^{-3} during summer. Zaitsev *et al.* (2006) showed that the monthly mean concentrations of oxygen equivalent for the dissolved organic matter can vary from 6.0 to 11.3 mg O_2 dm^{-3}. It was also shown that the representative concentration of oxygen equivalent for the organic matter in the pore water of bottom sediments can reach up to 23–33 mg O_2 dm^{-3}. High content of organic matter in the water and the bottom sediment results in another problem the for lagoon's ecosystem: hypoxia and anoxia in the bottom layer of the deep parts as well as in the shallow parts in hot calm nights due to the 'bloom' of the phytoplankton and the benthic macrophytes. The lack of oxygen causes the death of hydrobionts. Massive fish kills in some parts of the lagoon were registered in the summers of 1999, 2000, 2001, 2006, 2007, 2010, and 2013. For example, in the summer of 2010, about 20 kg of dead fish per square meter were observed in some parts of the lagoon's coast.

The relative isolation of Tyligulskyi Liman from the Black Sea facilitates the preservation of the population of brown algae *Cystoseira barbata* (Agardh, 1820) that vanished in the north-western part of the Black Sea in the 1980s. Among the macrophytes inhabiting the lagoon, the species *Chara canescens* (Loiseleur Deslongschamps, 1810) is listed in the National Red Book, and two species of aquatic flowering plants, *Zostera noltii* (Hornemann, 1832) and *Zostera. marina* (Linnaeus, 1753), are in the Red Book of the Black Sea. The species *Vaucheria litorea* (Agardh, 1820) as well as the red algae *Rhodochorton purpureum* (Lighthfoot) (Rosenvinge, 1900) on the *Cystoseira barbata* (Agardh, 1820) are rare in Ukraine but are still dominant in the Tyligulskyi Liman area.

9.5 MARINE ECOSYSTEM SERVICES (CICES CLASSIFICATION)

The application of the Common International Classification of Ecosystem Services (CICES) to the Tyligulskyi Liman lagoon, as applied by Maes *et al*. (2014), is presented in Table 9.2. In order to simplify this representation we organized the ecosystem services provided by Tyligulskyi Liman into 'sections' and 'classes'. The CICES hierarchical classification table can also be seen in Chapter 19 (Table 19.2).

Table 9.2 Ecosystems services delivered by Tyligulskyi Liman.

	Class	Tyligulskyi Liman
Provisioning	Wild animals and their outputs	Fish (41 species, about 400 tons per year). Unknown quantity of edible mussels can be caught by local residents
	Fibres and other materials from plants, algae and animals for direct use or processing	Reeds are harvested, August through October, to be used in construction as an eco-material.
	Ground water for non-drinking purposes	Domestic and livestock brackish water (salinity lower than 4PSU)
Regulation and maintenance	Bio-remediation by micro-organisms, algae, plants, and animals	Seagrasses have the ability to bio-remediate, reducing availability of pollutants in the sediment and water column (organic pollutants). Decomposition/mineralisation processes of plant material mediated by micro-organisms; decomposition of waste materials for example, waste water cleaning, (phyto) degradation, (rhizo)degradation and so on.
	Filtration/ sequestration/ storage/ accumulation by micro-organisms, algae, plants, and animals	Sequestration and storage of nutrients through incorporation in biomass is performed by seagrasses and algae. Seagrasses accumulate pollutants (e.g., organic compounds) in their biomass and rhizosediment, thus removing or decreasing its availability in the environment. The macroinvertebrate communities perform an important function of organic substance transformation in the 'water column – bed silt' system that determines their significant role in self-purification of the lagoon. They play an important role in the biogeochemical turnover of biogenic elements in the lagoon specifically, removal of nitrogen and phosphorus from the bed silt as well as replacement of biogenic elements from the water environment to a surface through imago of amphibiotic insects. The benthic macroinvertebrates regulate gas regime and texture of soils.
	Filtration/ sequestration/ storage/ accumulation by ecosystems	Biophysicochemical filtration/sequestration/storage/accumulation of pollutants by seagrasses (plants and rhizosediment); adsorption and binding of organic compounds in ecosystems, as a result of combination of biotic and abiotic factors.
	Dilution by atmosphere, freshwater and marine ecosystems	Hydrodynamic dilution of pollutants inflowing into the lagoon with the river and the lateral runoffs, household sewage, sea waters, and precipitation.

(*Continued*)

Table 9.2 Ecosystems services delivered by Tyligulskyi Liman (*Continued*).

	Class	Tyligulskyi Liman
Regulation and maintenance	Mass stabilisation and control of erosion rates	Stabilisation of water level in the lagoon by means of water exchange regulation with the sea through the connecting channel and, as a consequence, the decrease of erosion rate.
	Buffering and attenuation of mass flows	The lagoon acts as a buffer in the case of the lateral and the river runoff impact on the offshore strip. The connecting channel acts as a buffer in the case of sea water impact, wind-induced sea level variations, salt fluxes and sand drift into the lagoon.
	Flood protection	The lagoon is the water inlet during the spring high water and floods and prevents land floods in the basin. In the case of very high spring water, the channel is naturally washed out, and excess water outgoes into the sea.
	Maintaining nursery populations and habitats	Maintaining favourable environment for rare and endangered species of algae and xeropolum.
	Decomposition and fixing processes	Water flow induced erosion of tilled soils in the coastal zone of the lagoon during heavy rains, and humus inflow into the lagoon.
	Chemical condition of salt waters	Salinization of water in the lagoon, inflows of biogens and organics into the lagoon and their accumulation.
Cultural	Experiential use of plants, animals and land-/seascapes in different environmental settings	*In situ* bird watching
	Physical use of land-/seascapes in different environmental settings	The lagoon and the adjacent sea area are used for recreational activities, including swimming, fishing and kiting.
	Scientific	Tyligulskyi Liman is subject matter for research.
	Educational	The natural environment of the lagoon has an important value as an educational resource (tours, out-of-doors lessons).
	Heritage, cultural	Museums, archaeological excavations.
	Aesthetic	Sense of place; Artistic representations of nature; Inspiration for some painters and writers.
	Existence	Enjoyment provided by landscape
	Bequest	Willingness to preserve the Ramsar site for future generations

9.6 FINAL REMARKS

Tyligulskyi Liman has unique environmental features. The landscape park located in the Tyligulskyi Liman area allows the preservation of diverse flora and fauna, representative of the steppe zone of southern Ukraine. However, several unfavourable conditions occasionally occur in the lagoon. For example, eutrophication quite often deteriorates water quality in the lagoon during its summer isolation from the sea, resulting in fish kills and the death of other living organisms. Also, the long-term increase in water salinity in Tyligulskyi Liman has resulted in the replacement of freshwater species by marine and brackish-marine species. The anthropogenic influence often plays a crucial role. The existence of many artificial reservoirs in the drainage basin resulted in considerable runoff losses. Therefore, more participative and sustainable management policies are needed, which will be discussed in Chapter 10.

9.7 ACKNOWLEDGEMENTS

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Chapter 10

The management story of Tyligulskyi Liman Lagoon

O. Gubanova, Y. Tuchkovenko, V. Khokhlov, S. Stepanenko and S. Baggett

Summary: This chapter presents the management aspects of the Tyligulskyi Liman Lagoon. Tyligulskyi Liman is managed under a complex policy and legislative context. Administratively, the territory is managed by the Odessa and Mykolaiv regional state administrations in Ukraine. However, Tyligulskyi Liman is also part of a landscape park. Tyligulskyi Liman is also liable to additional management issues. The lack of coordination between different institutional bodies is the main reason for many conflicts in the Tyligulskyi Liman area. Thus, in this chapter, the stakeholders and social groups of Tyligulskyi Liman are well scrutinized. The contribution of the lagoon to the economic welfare of surrounding communities is currently low. Indicatively, in the last years, fish catches were around 350 tonnes, and mainly comprised of economically low-valued species. However, some considerable socio-economic gains can be made in the future from the use of therapeutic muds. The proper promotion of the scenic landscapes can also contribute to the development of ecotourism. The National Environmental Strategy of Ukraine is described as an appropriate action to amplify a better economic and environmental status in Tyligulskyi Liman.

Keywords: Conflict uses; institutions; legal framework; socio-economic sectors; water resources.

10.1 INTRODUCTION

The Tyligulskyi Liman basin area is located in the Odessa and Mykolaiv administrative regions. The management structure of Tyligulskyi Liman is extremely complicated and is far from being efficient, which is one of the main reasons of poor ecological status in the lagoon. The Water Framework Directive is not currently implemented in Ukraine, and there are many conflicts in the Tyligulskyi Liman area due to the lack of institutional coordination. Tyligulskyi Liman is being used for various recreational activities including fishing and the use of therapeutic muds. The stakeholder groups in Tyligulskyi Liman were involved in the discussion in order to clarify the economic and ecological features of the lagoon, and to provide a better management plan for the Tyligulskyi regional landscape park.

10.2 WATER MANAGEMENT

10.2.1 Institutions and water management

Nature management of Tyligulskyi Liman is distributed between several institutions and their subdivisions (Fig. 8.1). The questions related to the functioning and development of settlements and farms are the responsibility of the district directorates, the elected local councils (Soviets), and the appropriate regional directorates (of economy, of labour and social welfare, of infrastructure development and energy saving, of regional development, of town planning and architecture, of culture and tourism, etc.). Management of the agro-industrial, the transport and the recreational sector is provided by structural subdivisions of the state administration at regional and district levels.

Sharing responsibility in nature management is complicated, for example, the Odessa Regional Directorate for Water Resources is assigned with the control of water resources, while the Central Directorate of the State Committee for Land Resources in the Odessa Region manages land resources. The Odessa Regional Directorate for Forestry and Hunting is responsible for forest resources, while the State Directorate for Protection of Natural Environment in the Odessa Region administers the subjects related to the natural protected areas. Figure 10.1 depicts the current distribution of the administrative units for Tyligulskyi Liman:

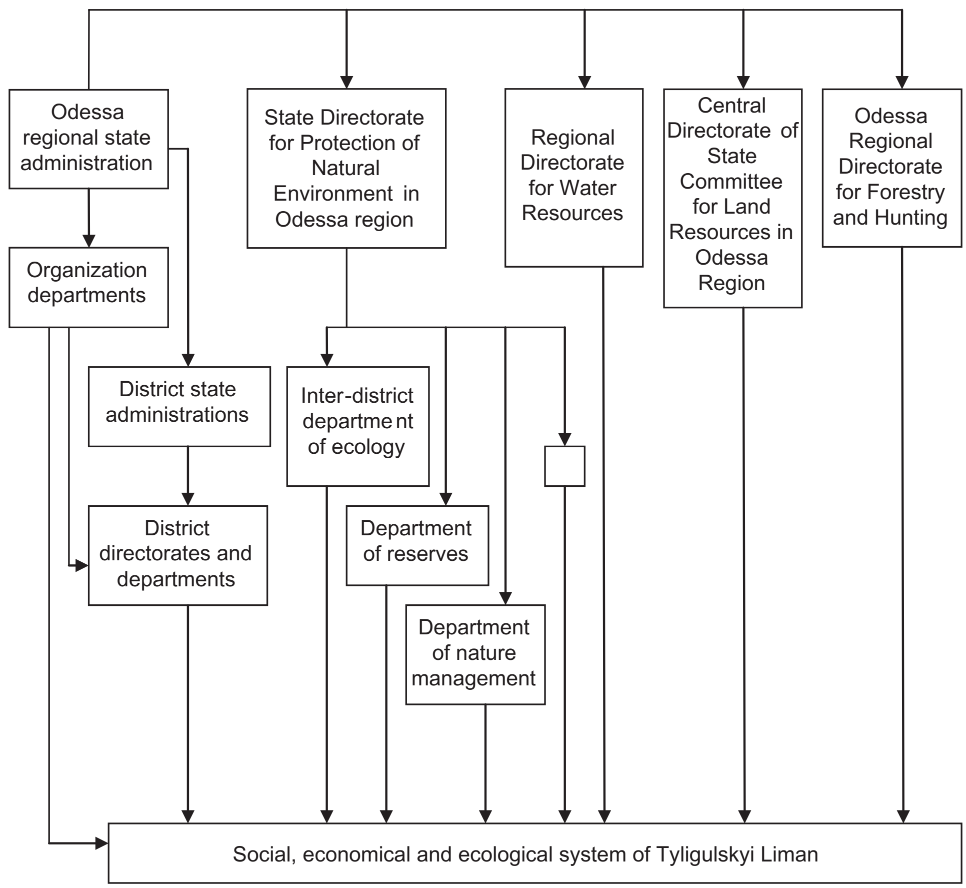

Figure 10.1 Organizational and functional framework of Tyligulskyi Liman management in the Odessa region. (The blank square is related to the opportunity to establish a new institution or to rename an existing institution as a result of changes in the central authorities).

10.2.2 Water use rights and laws

In Tyligulskyi Liman, management of natural resources (including water) is undertaken through the application of the Law on the Natural Protected Areas of Ukraine (1992), the Water Code (1995), and the Land Code (2002). In particular, the Water Code regulates the management of Liman's water area along with the rivers from its drainage, basin as well as artificial reservoirs situated in these rivers.

The Water Code also determines the conditions for land use along the coast of Liman. It assigns a 2 km wide coastal protective strip and a 100 m wide beach zone. The Tyligul River is classified as medium-sized, and the Tsarega and the Balaichuk, which also flow into the lagoon, are classified as small-sized rivers. According to the Water Code classification, the river bank protective strip is limited to 50 m for the Tyligul River and to 25 m for the rest of the rivers in the Tyligulskyi Liman drainage basin.

As the lagoon is part of the landscape park, the law on the Natural Protected Areas of Ukraine determines conditions for the conservation and use of natural resources related to Tyligulskyi Liman. Wildlife shelters and areas can be established without confiscation of land and water from their owners or users. According to the law, there are four kinds of areas with different regimes: (i) protected areas, (ii) areas of controlled recreation, (iii) areas of steady-state recreation, and (iv) economical areas.

As Ukraine is not a member state of the EU, it is not bound by any EU law. At present, the implementation of the Water Framework Directive (WFD) in Ukraine is at an initial stage as part of the integration process. If the integration process continues, all these requirements need to be met in full. At present, for the Tyligulskyi Liman Lagoon and its drainage basin, the basic requirements of the WFD such as the implementation of the basin management model for the catchment, river basin management plans, and programmes for monitoring of water status, are missing.

10.2.3 Water use conflicts

The lack of institutional coordination is the main reason for many conflicts in the Tyliguskyi Liman area (Integrated Land Use of Eurasian Steppes, 2008; Gubanova, 2012; Tuchkovenko *et al.* 2012; Tuchkovenko, 2012; Tuchkovenko Y. & Tuchkovenko O., 2013). These conflicts result from competing interests and expectations of various institutions and stakeholders, which impede the implementation of a sustainable development strategy in the Tyligulskyi Liman drainage basin. Table 10.1 summarizes the conflicts in the Tyligulskyi Liman basin.

Table 10.1 Conflicts Tyligulskyi Liman.

Pressure drivers	State actions	Impacts
Users of ponds and reservoirs in the catchment area	Uncontrolled withdrawal of water from the rivers for filling of both the operating and the abandoned artificial reservoirs.	Considerable decrease (up to 50%) in the fresh inflow of the lagoon. An increase of water salinity in the lagoon. Drying up of the shallow parts of the water area and the wetlands in the Tyligul River floodplain and the upper reaches of the lagoon.
Agro-industrial farms	Agricultural activity	Wash-out of pollutants, biogenic substances, and organics into the lagoon due to tillage of lands in the coastal strip, application of mineral fertilizers, chemical means of plant protection and generation of waste from animal-breeding
Local population, summer residents	Lack of a centralized system for collection of solid domestic wastes and a sewage system.	Pollution of the water and the adjacent land with untreated household sewages and rubbish.
	Application of mineral fertilizers, chemical means of plant protection in the suburban gardening areas.	Wash-out of pollutants, biogenic substances, and organics into the lagoon.
	Unregulated mowing and burn-off of meadow vegetation and reed; illegal cutting of the protected flora. Unregulated cattle grazing on the coastal slopes of the lagoon. Disturbance of habitats and nesting bird sites. Poaching.	Damage to the flora and fauna of the natural protected areas, danger of biodiversity decrease.
	Creation of pits for the extraction of sand and clay; backfill of the gullies; cottage and business site development in the riparian areas.	Disturbance to the natural landscapes.
Holiday visitors	Uncontrolled stay in the territories of the natural protected areas. Disturbance of habitats and nesting bird sites. Littering of the area. Accidental fires.	Damage to flora and fauna of the natural protected areas, danger of decrease in biodiversity.
Industrial fishery	Overfishing in the lagoon exceeding of the established quotas. Irregular water exchange (from April to August) between the lagoon and the sea just to provide entrance for fish from the sea for spawning and fattening.	Significant fluctuation of water levels in the lagoon, instability of the hydroecology regime, danger of biodiversity decrease.

(*Continued*)

Table 10.1 Conflicts at Tyligulskyi Liman (*Continued*).

Pressure drivers	State actions	Impacts
Bodies of state power and local self-government	Division of a unified ecosystem of Tyligulskyi Liman and the adjacent areas into two administrative-territorial units within the limits of the Odessa and the Mykolaiv regions.	Inefficient management of environmental protection, lack of a unified plan for water and environmental management of the lagoon, exhaustion of resources, lack of a unified plan for the monitoring the lagoon's ecosystem and carrying out nature protection measures.
	Water protection zones and coastal protective strips have not been established on location and they are not included in the land management documents.	The nature protection legislation are not met in relation to the restriction of the economic activity within the boundaries of water protection zone, in coastal protective strips and on lands in natural protected areas.

10.3 SOCIO-ECONOMIC AND LIVELIHOOD

10.3.1 Agriculture and livestock

In years with sufficient rainfall, high yields of cereals, vegetables and other crops are obtained from the highly fertile soils (chernozems) of the fields surrounding the lagoon. However, the region has, in recent decades, experienced long and frequent droughts (see Chapter 7.2), which substantially decreased crop yields, and resulted in high inter-annual fluctuations in the gross yield of grains and other agricultural products.

Gardening and viticulture are widespread in the territory adjacent to the lagoon's coast. A large vineyard is located in the Koblevo area near the Black Sea coast.

Previously, dairy and beef farming were the major agricultural activities in the Tyligulskyi Liman drainage basin. However, within the latest decades, livestock farming in the region has declined. The breeding of pigs and sheep, and dairy production is limited nowadays to a few farms and local households. The slopes surrounding the lagoon are used by the local community as pasture for cattle.

Table 10.2 shows some data related to the agriculture and the livestock for the three districts surrounding Tyligulskyi Liman (Odessa Region Statistical Yearbook, 2011; Mykolaiv Region Statistical Yearbook, 2011; Gubanova, 2012).

Table 10.2 Agricultural indicators in the administrative districts surrounding Tyligulskyi Liman.

Indicator	Administrative districts		
	Kominternivskyi	Berezivskyi	Berezanskyi
Area of agricultural lands, $\times 10^3$ km^2	1.141	1.364	1.127
Sown area, $\times 10^3$ km^2	0.819	0.955	0.567
Gross grain yield, $\times 10^3$ tons	124.7	165.3	92.1
Cereal yield, kg per hectare	2,480	2,660	2,260
Livestock population, $\times 10^3$ head:			
cows	3.3	3.1	5.3
pigs	7.3	9.6	5.9
sheep, goats	4.0	2.2	3.7
poultry	783.2	173.5	109.8
Agricultural production:			
meat, tons	6,771	3,534	2,061
milk, $\times 10^3$ tons	13.4	27.6	21.6
eggs, $\times 10^3$ pcs	183,186	15,474	7,538
Profitability of agricultural production, % to laid-down capital	1.9	15.3	28.2

10.3.2 Fishing and aquaculture

Fish productivity (as well as fish fauna diversity) of Tyligulskyi Liman has always been dependent on its hydrological and oxygen regimes and mainly on the salinity of its water. The aim of the channel connecting the lagoon with the sea is (i) to allow fish to enter the lagoon from the sea for spawning and fattening during summer, and for fishing purposes during autumn, and (ii) to control the water-salt balance of the lagoon. The channel has been operated since the beginning of the 21st century with the exception of the period from 2007–2009. The fish catches increased to 309–415 tonnes in 2009–2012, compared to 235 tonnes in the period from 2002–2008. However, these catches were mainly of low-value species, such as *Atherina mochon pontica* (Eichwald, 1831). The data on commercial catches within the latest decade are presented in Table 10.3.

Table 10.3 Fish catches (tons/year) in Tyligulskyi Liman.

Species	Years										
	2002	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Platichtys flesus	—	—	0.14	0.08	0.01	0.02	0.14	0.1	0.2	0.04	—
Atherina mochon pontica	102.8	142.7	256.3	147.2	301.4	252.2	163.2	280.6	315.5	371.3	380.6
Gobiidae	36.50	48.39	37.74	37.05	22.84	24.69	25.4	26.5	25.8	20.0	0.8
Mugilidae	0.01	0.30	7.92	18.53	15.03	0.04	0.4	—	4.1	20.6	0.4
Engraulis encrasicholus	2.0	1.69	—	—	—	—	0.0	1.0	—	—	10.7
Mugil so-iuy	0.9	—	—	1.34	0.4	0.13	0.8	1.0	2.7	3.34	—
Shrimp	—	—	—	0.02	—	—	0.06	0.2	0.4	—	—
Total	142.2	193.1	302.2	204.2	339.7	277.1	190.0	309.4	248.7	415.3	392.5

In the summer of 2010, mass fish kills (*Gobiidae, Mugilidae*) occurred as a result of strong thundershowers between June and July, and high water temperatures from July to August; in some coastal areas, 20 kg of dead fish per square meter (Tuchkovenko & Tuchkovenko, 2013) were reported.

One method to increase the fishing capacity in the lagoon is through the establishment of populations of valuable saltwater species, for example *Mugil soiuy* (Basilewsky, 1855)*, Acipenseridae, Platichthys flesus* (Linnaeus, 1758), and *Gobiidae*. In particular, artificial reproduction and stocking as well as the establishment of self-reproducing populations are considered as the most viable ways to maintain a large population of these species. In the case of aquaculture, the indigenous *Mugilidae* [*Mugil cephalus* (Linnaeus, 1758), *Liza aurata* (Risso, 1810), *Liza saliens* (Risso, 1810)] could substantially increase the fishery biomass (Shekk, 2004).

10.3.3 Industry

Presently, the industrial sector is developed mainly in the Kominternivskyi district of the Odessa region, with chemical industry (Odessa Port Plant) and transport (Yuzhnyi Merchant Seaport). In addition, three main pipelines run through Tyligulskyi Liman: the 'Toliatti–Gorlivka–Odessa' ammonia pipeline (340 tons per hour), the 'Shebelynka–Odessa' gas pipeline (9.2 billion m^3 per year), and the 'Kherson–Snygirivka–Odessa' oil pipeline (19 million tonnes per year).

10.3.4 Tourism and recreational activities

Tyligulskyi Liman and the adjacent areas host considerable recreational activities. A unique coastal landscape as well as its rich flora and fauna enhance the development of responsible 'green' tourism and recreational fishing.

The seaside of the sandy isthmus and the coastal areas of the lagoon are surrounded by very attractive wide sandy beaches. Shallow beaches are found in the bays located in the southern part of the lagoon. In general, the lagoon's beaches are small in comparison to the seafront beaches; their width usually does not exceed 5–10 m and their height is around 0.3–0.5 m.

Various recreational facilities such as campsites, hotels, and seaside health resorts are situated in the vicinity of Tyligulskyi Liman. Moreover, Tyligulskyi Liman has a considerable potential for the development of recreational and therapeutic activities. One of the largest deposits of mineral-rich muds in the Black Sea Region is located at Tyligulskyi Liman, and is estimated at about 15,800 tonnes distributed over an area of 23.2 km^2. The availability of therapeutic muds is a strong factor to enhance the recreational activity in the Tyligulskyi Liman area. The area has the potential to accommodate more than 100,000 guests for therapeutical activities, which could result in a socio-economic gain of up to 1.5 million euros (Stepanov & Stepanova, 2004). Moreover, the processing of muds and brine could offer an additional income source (over 7.5 million euros per year), if made available to the market. Construction costs for a plant with these processing capabilities together with the costs of nature protection measures are estimated to be 1.1 million euros, and the corresponding payback period of these investments is estimated to be 1.5 years (Integrated land use of Eurasian steppes, 2008).

In order to protect the environmental features of the lagoon, two regional landscape parks were created along the coasts and in the water area within the limits of the Odessa Region (39.73×10^6 m^2 of land and 99.81×10^6 m^2 of the water area) and the Mykolaiv Region (34.40×10^6 m^2 of land and 47.55×10^6 m^2 of the water area). Also, some other nature reserves are protected in the nearby area such as the 'Kalynivskyi' botanical reserve (0.92×10^6 m^2), the 'Tyligulska Peresyp' (3.90×10^6 m^2), the 'Kosa Strilka' (3.94×10^6 m^2), the 'Lower Reaches of Tyligulskyi Liman' (1.20×10^6 m^2) ornithological reserves, the 'Kairovskyi' (1.50×10^6 m^2), and the 'Novomykolaivskyi' (3.15×10^6 m^2) landscape reserves.

10.3.5 Stakeholders perception of ecosystem services

Local communities both the residents and the temporary (summer) lodgers, are to a certain extent dependent on the goods and services offered by the Tyligulskyi Liman Lagoon. Moreover, they have a great knowledge of the uses and activities, the evolution of the economic and ecological development of the lagoon, and have undertaken some management actions (Gubanova, 2012).

The local population of Tyligulskyi Liman proved to be quite aware of the ecosystem services provided by the lagoon. During the focus group meetings conducted within the LAGOONS project in September 2013, the participants mentioned several ecological services such as the harvesting of wild animals for nutrition, the extraction of materials from plants (e.g., reeds), the use of groundwater for domestic and livestock purposes, and the conduction of recreational activities (e.g., walking and biking on the banks, swimming, fishing, therapeutic use of muds). They also clearly recognized the economic importance of a healthy ecosystem for the regional economy.

In summary, the stakeholder groups in the Tyligulskyi Liman Lagoon seem to agree on the undertaking of the following initiatives:

- to urgently dredge the connecting channel and to control the sand extraction;
- to clean the Tyligul River bed;
- to draw up an inventory of the natural resources – wild species of flora and fauna;
- to consolidate and to improve the legislation on natural resource management in order to systematize the status of Tyligulskyi Liman;
- to consolidate all the administrative units under one institutional body (e.g., the Tyligulskyi Landscape Park);
- to develop the infrastructure (with priority to roads) for recreational and tourism purposes;
- to develop a tourism industry, which offers many specialized forms of tourism (green, educational, festival, wine, ethnic, health, sports, etc.);
- to implement agricultural practice that takes into account the ecological issues;
- to increase the number of staff of environmental authorities.

10.4 INSTITUTIONS, LAWS, RIGHTS AND CONFLICTS

10.4.1 Institutions, stakeholders and social groups

In a first approach, stakeholders can be divided as follows:

- the authorities of regional, district and local levels;
- the management agents (e.g., a water management institution);
- the local and summer residents;
- the employees of the regional landscape parks;
- the tourists;
- the scientific institutions and public environmental agencies.

All these stakeholders hold an interest in the balanced development of the lagoon and the adjacent areas. At the same time, the stakeholders differ in their interests, and place some pressures on the ecosystem. Table 10.4 below provides the list of institutions and stakeholders identified in Tyligulskyi Liman.

Table 10.4 Institutions and stakeholders in Tyligulskyi Liman.

Institutions	**Type**
Ministry of Environment and Natural Resources	Central body of executive power with the activity directed and coordinated by the Cabinet of Ministers of Ukraine
State Agency of Land Resources of Ukraine	Central executive authority
Odessa State Regional Administration	Regional government
Mykolaiv State Regional Administration	Regional government
Odessa Regional Water Management Department	State budgetary organization
Kominternove district state administration	District administration
Berezivka district state administration	District administration
Berezanka district state administration	District administration
Stakeholders	
Odessa Regional Council	Council
Mykolaiv Regional Council	Council
Koblevo village council (Mykolaiv region)	Council
Tashine village council (Mykolaiv region)	Council
Autonomous bodies of cottage villages	NGO
Ukrainian Association of Protected Areas – UN Development Programme in Ukraine and the Global Environment Facility project.	NGO – But The State Service for Protected Areas of the Ministry for Environmental Protection of Ukraine is the National Executive Agency of the Project
National Ecological Centre of Ukraine (Mykolaiv branch)	NGO
Black Sea NGO Network	NGO
The Centre for Regional Studies	NGO
Ukrainian Hunting & Fishing Association	NGO
Ukrainian Society for Protection of Birds	Nature conservation organization and Birdlife International Partner in Ukraine
Association of Farmers and Private Landowners of Ukraine	NGO
Research Centres	
Tyligulskyi regional landscape park, Odessa region	Research centre
Regional landscape park ‘Tyligulskyi’, Mykolayiv region	Research centre
Ukrainian Academy of Agrarian Sciences	A self-governing scientific organization supported by the State
The A.O. Kovalevsky Institute of Biology of the Southern Seas	Research centre of National Academy of Sciences
Odessa Regional Institute of Public Administration	National Academy of Public Administration, Office of the President of Ukraine, and its Regional Institutes play a central role in training as well as educating government employees and officials
Ukrainian Scientific Centre of Ecology of the Sea	Leading institution of the Ministry of Environmental Protection of Ukraine in the field of marine ecological research

10.4.2 The national and local regulatory structures

According to the recommendations of the pan-European Biological and Landscape Diversity Strategy and the pan-European Ecological Network, Ukraine has approved two laws for the protection of the lagoon. The first law refers to the ‘National program for setting up national ecological network for 2000–2015’ (2000) and the other ‘ecological network’ (2004). Under these laws, the Odessa Regional Council has established the ‘Program for setting up national ecological network in the Odessa Region for 2000–2015’ (Topchiiev *et al.* 2011). According to this scheme, the Tyligulskyi Liman area is part of:

- the Azov-Black-Sea International Natural Ecological Corridor – the southern part of Tyligulskyi Liman with adjacent territories and the isthmus;

- the South Ukrainian State Ecological Corridor – the middle part of Tyligulskyi Liman;
- the Tyligul Regional Ecological Corridor – the Regional Landscape Park together with the Tyligul River main bed and adjacent water protection zones.

The scheme can be considered as a basis for the development of land management, municipal engineering, and economic activity.

Another local act is the 'Strategy of social and economic development in the Odessa region for 2012' that defines strategic lines and plans of natural resources use. This act underscores the need for the preservation of the Black Sea coastal Limans; the development of an integrated system of coastal zone use; strategic planning for the coastal zone development; development of schemes for functional zoning of coastal areas; optimization of coastal zone use according to ecological requirements and local priorities; estimation of impacts and development of an action plan aimed to wards the adaptation to climate change.

On 21 December 2010, the Ukrainian Parliament (Verkhovna Rada) ratified the National Environmental Strategy of Ukraine for the period until 2020. This act analyses the use and protection of natural resources in Ukraine. Also, it sets the aim and the principles of the national environmental policy, strategic aims and goals, tools and stages of implementation of the national environmental policy as well as the expected results for implementation of the strategy. The National Environmental Strategy of Ukraine includes the following actions to be conducted by 2020, which are, without a doubt, applicable to the lagoon:

- to ensure compliance of drinking water quality and treatment of discharged water according to the established norms;
- to justify, preserve and assign the status of protected territories to 15% of the total territory of Ukraine;
- to introduce measures for the prevention of uncontrolled release of genetically modified organisms (GMO), and inform the population on the GMO content in the products, which are produced, imported or consumed in the territory of Ukraine by 2015;
- to reduce greenhouse gas emissions by 20%, in relation to emissions in 1990, and increase the amount of electric power generated from renewable sources by 12.5% of the total amount;
- to conduct decontamination of polluted soils, which significantly impact the surface water quality, and ensure an appropriate level of degraded land reclamation;
- to cease the trend of soil fertility loss;
- to ensure the increase of forested areas to 17% of the total territory of Ukraine;
- to ensure full compliance with the regulations of international treaties on the protection of transboundary water resources.

10.5 FINAL REMARKS

The major management problems in the Tyligulskyi Liman Lagoon are the division of the lagoon administration in two units (Odessa and Mykolaiv Regions), the lack of an integrated coastal zone management system, and the absence of river basin management plans and monitoring programmes. The uncontrolled activities of various stakeholder groups have also impacted the aquatic ecosystem.

Substantial efforts have already been made to mitigate the impacts and provide a better management plan for the protection of the Tyligulskyi Liman Lagoon. The management must be made based on the basin management model, designed in cooperation with all the relevant stakeholder groups.

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Chapter 11

Application of modelling tools and data to assess climate and land use change impacts at the catchment scale

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Summary: This Chapter first provides a short overview of trends in climate and land use in Europe that are currently observed and expected in the future. After that, tools used for creating scenarios of climate change, and tools for impact assessment at the river basin scale are shortly described. The next section presents climate scenarios and the model SWIM used for impact assessment in the drainage areas of four European coastal lagoons: Ria de Aveiro, Mar Menor, Tyligulskyi Liman and Vistula Lagoon. The last section describes data requirements and availability for the impact assessment study in the four drainage areas. The SWIM model was calibrated and validated for the drainage areas of all four lagoons and applied to assess climate and land use change impacts. The results of impact assessment are briefly described in the following Chapters 13 and 15.

Keywords: Climate change, climate scenario, eco-hydrological model, impact assessment, land use change, RCM.

11.1 CLIMATE AND LAND USE CHANGE IN EUROPE IN THE 21ST CENTURY

11.1.1 Observed climate trends

Over the past decades positive trends in temperature and associated changes in precipitation, which have affected water balance components and regional water resources, have been observed worldwide (IPCC, 2007a, 2013). The 4th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007a) reviewed the existing knowledge on climate trends from the beginning of the 20th century, and concluded that the temperature rise will continue. In most parts of Europe, an increase in average annual surface temperature is observed, amounting to 0.8°C over the whole European continent on average over the past 150 years. The analysed data show that the warming in the winter is stronger than in the summer. It is very likely that the observed warming since the middle of the 20th century is due to the increase in greenhouse gas concentrations in the atmosphere resulting from anthropogenic activities. The changes in precipitation are not so consistent, and show more temporal and spatial variability compared to that of the temperature changes. However, during the last decades, annual precipitation in northern Europe has generally increased, while it decreased in most parts of southern Europe. Besides that, other effects have also been reported, such as longer crop growing season, changes in the distribution patterns of species and biodiversity, and retreating glaciers. Impacts of climatic factors, such as heat waves, on human health were also stated.

11.1.2 Expected changes in climate

According to the 4th Assessment Report of IPCC (2007a), potential warming in Europe has a range of approximately 1.5 to 6.0°C by the end of this century. However, the trends may vary noticeably in different regions of Europe. The changes will include not only rising temperature, but also shifting rainfall patterns, less snow in the winter and further melting glaciers. Most simulations of climate models show continued increase in precipitation in northern Europe (most remarkably during the winter season), and decrease in southern European regions (most significantly during the summer). Despite of higher precipitation in northern Europe in winter, snow cover is expected to be reduced on average in extent and also in duration for the total European continent.

11.1.3 Observed changes in land use

The European continent has the highest share of land used by people for agriculture, forestry, settlements and infrastructure (up to 80%, source: EEA, http://www.eea.europa.eu/themes/landuse/intro). Land use changes (between and within the categories) are driven by the increasing demand for living space per capita, trends in economic activities and transportation demand (EEA, 2010). According to the cited report, the area used for agriculture and pastures shows a small decreasing trend, the size of forested areas slowly increases, and urban areas are growing most notably in Europe as a whole. The national trends may be different. For example, the agricultural conversions occur in Spain (conversion of arable land to olive groves and vineyards), Finland (from forest and wetlands to arable land), and Czech Republic (from arable land to pasture); changes in forested areas are concentrated mainly in northern Europe (Finland: net loss of forest and Sweden: some uptake of forested areas), as well as in Portugal (new forested land) and Hungary (transitional woodland creation); and the growth of residential areas is observed in France and western Germany (EEA, 2010).

11.1.4 Trends in land use

It is expected that current trends in land use patterns will continue in the coming 10–20 years. Therefore, some decrease in arable land area was projected in recent EEA studies (EEA, 2007; RIKS, 2010), however the area of permanent crops may not change substantially in Europe. According to these reports, it is also expected that the area of forested landscapes will increase in Europe, by approx. 5% between 2000 and 2020, whereas the share of urban areas will increase by approximately 1% in total. The various trends in land use are expected in the drainage areas of our four coastal lagoons. They are described in more detail in Chapters 14 and 15 below.

11.2 TOOLS USED FOR CREATING SCENARIOS OF CLIMATE CHANGE AND IMPACT ASSESSMENT

The main tools used for creating climate scenarios are global and regional climate models, whereas hydrological and eco-hydrological models are used for impact assessment on water resources. These models are briefly described below. The methods used for the development of land use change scenarios are described in Chapters 14 and 15.

11.2.1 Climate models

In order to investigate regional impacts of climate change, it is necessary to regionalize global climate scenarios simulated by General Circulation Models (GCMs) (Wilby *et al.* 1999; IPCC, 2000). For that, Regional Climate Models (RCMs) are applied, which can be broadly categorized into two main types: physically based deterministic dynamical RCMs and statistical models (Varis *et al.* 2004). Still, both types of RCMs depend on boundary conditions from GCMs for the region under study. Besides that, the outputs of dynamical RCMs are determined by the method of numerical implementation and parameterization of the models, whereas the results of statistical models are dependent on the chosen algorithm. Therefore, the outputs of various RCMs for the same region under the same driving conditions (CO_2 emission, socio-economic pathway) may differ significantly. However, the sensitivity of water balance to relatively small changes in climate parameters may be quite substantial (Lehner *et al.* 2005; Hattermann *et al.* 2008; Huang *et al.* 2010), and the simulated impacts are usually presented with the uncertainty bounds.

Often in the past, when the effects of climate change on water budget and/or water quality were studied, only one regional climate model was used as a driver of the hydrological model. By that, the uncertainty arising from the use of different RCMs was practically ignored (Menzel & Bürger, 2002; Eckhardt & Ulbrich, 2003; Feyen & Dankers, 2009). Therefore, in order to better account for uncertainty in the projection of impacts, the use of ensembles of climate scenarios from different RCMs was suggested (Cameron, 2006; Graham *et al.* 2007). Nowadays, it is a state-of-the-art approach to apply climate scenarios from several or a set of regional climate models driven by different GCMs as input to one or several hydrological models.

11.2.2 Hydrological models

Numerous studies have been carried out in order to investigate the impacts of climate change on water flows and water quality. The common approach is to apply a validated hydrological model driven by the projected climate scenarios for the future in the region under study. Many such studies have applied either conceptual precipitation-runoff models accounting for water balance components (e.g., Menzel & Bürger, 2002; Arnell, 2003; Drogue *et al.* 2004), or more complex process-based hydrological models (Muttiah & Wurbs, 2002; Krysanova *et al.* 2005; Hattermann *et al.* 2008) at the river basin scale.

For example, in Germany, several projects used this approach at the river basin level with an aim to develop strategies that can be applied in the future for adaptation to climate change. The projects GLOWA-Elbe (http://www.glowa-elbe.de) and GLOWA-Danube (http://www.glowa-danube.de) are two examples of integrated studies on climate change impacts in the Elbe and Danube river basins. Besides that, many papers have been published focusing on the impacts of climate change on water fluxes in different river basins (e.g., Mauser & Bach, 2009; Menzel & Bürger, 2002; Krysanova *et al.* 2005). Many studies were also conducted with an aim to evaluate potential impacts of changing climate on water flows in coastal areas and their importance for ecological status of coastal waters (e.g., Najjar *et al.* 2000; Simas *et al.* 2001; Scavia *et al.* 2002; Thanh *et al.* 2004; Qi *et al.* 2009).

A probabilistic framework was applied using an ensemble of four general circulation models, two greenhouse gas emission scenarios, two statistical downscaling techniques, and two hydrological models to assess uncertainties in climate change impact for the river Thames, UK (Wilby & Harris, 2006). A set of climate model outputs was used to drive a hydrological model for impact assessment in the German project KLIWAS for the Rhine, Elbe and Danube basins, applying ensembles of regional climate scenarios for the A1B emission scenario (Nilson *et al.* 2011; Klein *et al.* 2011). A similar approach was used to study potential impacts of climate change on seasonal water discharge and extreme events in terms of floods and low flow for all rivers in Germany (Huang *et al.* 2010, 2012, 2013). The results from a new generation of hydrological climate change impact studies, combining new methods for downscaling and bias correction of climate projections with new methods for large-scale hydrological modelling are presented by Arheimer *et al.* (2013).

11.3 TOOLS USED FOR IMPACT ASSESSMENT IN THE DRAINAGE AREAS OF FOUR LAGOONS

11.3.1 Climate scenarios

Climate impact assessment in the LAGOONS project was performed by using a set of climate scenario data provided by the ENSEMBLES project (van der Linden & Mitchell, 2009). In this project a set of RCMs was run using the boundary conditions created by different GCMs earlier. However, not all possible combinations of RCMs with GCMs were run due to the high cost of simulations as well as time constraints.

All models were driven by the A1B emission scenario which assumes an increasing world population until 2050 up to 8.7 billion people and a decrease of population afterwards. The economy is projected to be globalized and market-orientated with a balanced use of fossil and non-fossil energy resources (Bates *et al.* 2008). For this scenario, the estimate of projected temperature rise on a global scale is 2.8°C, with a likely range between 1.8 and 4.4°C until the end of the 21st century (IPCC, 2007b). The A1B emission scenario can be referred to as an intermediate scenario concerning projections for increasing atmospheric CO_2 concentration and temperature.

The combination of GCMs with RCMs resulted in different climate scenarios. The resolution of the scenarios is 25 or 50 km, and the simulated period is either 1951–2050 or 1951–2100. In this study, only the scenarios with a resolution of 25 km and those that were run until 2100 were considered. The reason is that the resolution of climate input data is very important for eco-hydrological modelling of meso-scale catchments. There are 15 climate scenarios in the ENSEMBLES climate data set that fulfil these requirements on both resolution and the time horizon. The selected 15 scenarios were created by nine European institutes that used six different GCMs to drive eleven different RCMs (see LAGOONS, 2013).

11.3.2 The eco-hydrological model SWIM

The eco-hydrological model SWIM (Soil and Water Integrated Model) (Krysanova & Wechsung, 2000) was developed based on two models: SWAT (Arnold *et al.* 1993) and MATSALU (Krysanova *et al.* 1989). The model is suited for the modelling of hydrological processes, vegetation, erosion and nutrients in meso- to macro-scale river basins with an area ranging from 100 km^2 up to 500,000 km^2.

SWIM is a semi-distributed, process-based eco-hydrological model that includes mathematical descriptions of physical, biogeochemical and hydro-chemical processes and includes some conceptual and semi-empirical elements (Krysanova *et al.* 2005).

The model has a three-level disaggregation scheme: basin – subbasins – hydrotopes, with hydrotopes as sets of units within one subbasin that have the same land use and soil type. It is assumed that the hydrotopes are characterized by uniform process behaviour concerning water flows, vegetation growth and nutrient cycling. These processes are first calculated at the hydrotope level on a daily time step, and then aggregated at the subbasin level, and the lateral flows are routed. Climate parameters are assumed to be homogeneous on the subbasin level. Like the management data, they are external drivers for the processes represented in the model.

Due to its spatial resolution as well as climate and land use considered as boundary conditions, the SWIM model allows the analysis of impacts of climate and land use changes on the major model output variables.

The model's ability to adequately simulate hydrological processes, nutrient dynamics, crop yield and erosion has been thoroughly tested and validated in many river basins over the last 15 years. SWIM has been applied for several river basins of different sizes, first in Germany, and later in other European countries, as well as for river basins in Africa, Asia and South America. Most of the results in terms of modelling performance were satisfactory (Krysanova *et al.* 2015). The SWIM model is still being developed further as new modules are introduced to the model (e.g., a glacier module), and other modules are improved in order to simulate processes better (e.g., in-stream nutrient transport, crop growth or wetland dynamics). New water management measures are also implemented (e.g., irrigation, ponds or reservoirs) in accordance with the particular research need or specific case study characteristics. Some further model developments/adjustments took place in the current project, namely for the water management (ponds, irrigation, water transfer, water abstraction) and water quality (ammonium, phosphorus, oxygen) modules, and a new calibration option for drainage areas consisting of several catchments was implemented and applied (see more details in LAGOONS, 2013; Hesse *et al.* 2015; and Stefanova *et al.* 2015).

11.4 DATA AVAILABILITY FOR IMPACT STUDIES IN FOUR DRAINAGE AREAS

The SWIM model uses spatial data, time series and management data as input. The spatial input data include a Digital Elevation Model (DEM), a land use map, a map of climate stations, and a soil map with soil parameterization (11 parameters for soil layers). In addition, maps of the drainage area boundaries and the river network could be used. The subbasin map can be provided or created based on the DEM.

The necessary time series include a) daily climate data (minimum, maximum and average temperature, precipitation, air humidity and solar radiation), b) river discharge at the gauge stations, and c) measurements of water quality parameters at the gauge stations. Data from one gauge station close to the river mouth is a must, and data from more stations provide an opportunity for multi-site calibration, which makes a study more reliable. The latter two datasets, b) and c), are needed only for the model calibration and validation.

For the parameterization of cropland areas, data on major crops in the region, customary dates of their planting and harvesting, and typically applied fertilization schemes (dates and rates) are necessary. The management data include information on water abstraction, water transfer schemes (inflow and outflow), and data on point source emission of nutrients.

Table 2.2.1 presents an overview of the datasets used for the application of SWIM in the drainage areas of the four lagoons studied in the LAGOONS project. In all four cases, DEM maps originating from SRTM (Shuttle Radar Topography Mission, source: http://srtm.csi.cgiar.org/) were used (not included in the table). Most of the other datasets were case-specific. In all four case study areas some data were missing, or data coverage in time and/or space was problematic. For example,

- there are only water levels measured in the Ria de Aveiro drainage area, and river discharges had to be estimated from those (see Stefanova *et al.* 2014);
- there are no gauge stations in the Mar Menor drainage area, only estimated seasonal dynamics of water flow exist, and thus SWIM had to be calibrated in a quasi-ungauged mode for this drainage area;
- there are no climate stations in the drainage area of the Tyligulsky Liman, where the re-analysis data from the WATCH project (Weedon *et al.* 2010, 2011) had to be used instead;
- no water quality measurements were available for the Pregolya river, which would enable a real calibration for water quality in this largest river in the drainage area of the Vistula Lagoon.

Apart from the above, in almost all cases, water quality data were insufficient in spatial and temporal dimensions to allow a proper calibration of the SWIM model for water quality characterisation. Therefore, in all four cases, the model calibration for water flows, and especially for water quality variables, was a very complicated task. The problematic data are indicated in Table 11.1 by using *Italic*.

Table 11.1 Data availability for climate and land use change impact assessment in drainage areas of four lagoons under study, and areas of weakness in data support (indicated by *Italic* font).

	Ria de Aveiro	**Mar Menor**	**Tyligulskyi Liman**	**Vistula Lagoon**
Observed climate	30 stations; *large gaps in records, especially for precipitation*; *missing solar radiation* was derived with the Hargreaves-Samani method *Sources*: http://snirh.pt/ http://www.tutiempo.net/	5 stations (4 in the catchment), period: 2000–2011 *Source*: SIAM	4 climate and 2 precipitation stations *outside the catchment; poor correlation between precipitation and measured discharge* → WATCH climate data (WFDEI) (Weedon *et al.* 2010, 2011) for 1979–2009 was used	*Climate data with poor coverage in time and space* → WATCH climate forcing data (WFDEI) (Weedon *et al.* 2010, 2011) for 1979–2009 was used
Land use	CORINE Land Cover 2006, Version 13 *Source*: EEA	CORINE Land Cover 2006, Version 13 *Source*: EEA	*No digital data was available* A paper map was scanned and digitized *Source*: DENR, RDILM	CORINE (CLC2000) for the Polish part (*Source*: EEA), Kaliningrad oblast territorial planning scheme (Source: PKO)
Soil map and parameterization	Map from ESDB Soil parameters from SGDBE and *German soil mapping guidelines* (AG Boden, 2005)	Map: *1 km × 1 km raster* (HWSD) Soil parameters from HWSD and *estimated using the German soil mapping guidelines* (AG Boden, 2005)	Map: derived from HWSD data Soil parameters from HWSD and *estimated using the German soil mapping guidelines* (AG Boden, 2005)	Maps: HWSD and SGDBE Soil parameters from maps and *estimated using the German soil mapping guidelines* (AG Boden, 2005)
Observed discharge	Gauges: *hourly/quarterly water levels and flow curve equations* for 3 gauges for 2002–2005 and 1 gauge for 1991–2000 *Source*: http://snirh.pt/	Gauges: *no gauges* *24 survey measurements* for period 09/2003–06/2006 (UM) *estimated seasonal dynamics for 2003* (Garcia-Pintado *et al.* 2006; Velasco *et al.* 2006)	Gauges: one upstream gauge (*1984–1988*) and one downstream gauge (*1984–1988* and 1998–2007) Source: CGO	10 discharge gauges for *different sub-periods* during 1995–2009 Main calibration gauges Lozy (Pasleka river) and Gvardeysk (Pregolya river) *Sources*: IMGW-PIB, KCHEM
Observed water quality	3 gauges: *sporadic measurements (on average once per month)* of NO_3-N, NH_4-N, P_2O_5-P and DOX and water temp. for 2002–2009; *not all parameters at all gauges* *Source*: http://snirh.pt/	WQ gauges: *no gauges* *24 survey measurements of NH_4-N, NO_3-N and PO_4-P concentrations* for period 09/2003–06/2006 *Sources*: Garcia-Pintado *et al.* 2006; Velasco *et al.* 2006; UM)	*3 gauges around the most downstream station Berezovka, which were only rarely sampled during the last 30 years* *Source*: CGO	Gauge Nowa Pasleka at the Pasleka river mouth (2005–2010) (*Source*: PMŚ) average (monthly) values for 9 rivers (mainly for 1998–2000) (*Source*: Mantra-East project) *No measurements for the largest river Pregolya available at all*

(*Continued*)

Table 11.1 Data availability for climate and land use change impact assessment in drainage areas of four lagoons under study, and areas of weakness in data support (indicated by *Italic* font) (*Continued*).

	Ria de Aveiro	**Mar Menor**	**Tyligulskyi Liman**	**Vistula Lagoon**
Point sources	Total N and P loads in t/year with exact location of sources *Source*: APA	1 urban wastewater treatment plant, monthly TN and TP concentrations for 2004–2012 *Source*: ESAMUR	*No data available* Nutrient emissions assumed per capita calculated from population density per administrative unit *Sources*: www.gadm.org/ http://en.wikipedia.org/	*No consistent data available* Data from the Mantra-East (2004) and HELCOM (2012) reports, and partly estimated from population data of cities (LAGOONS, 2012a; Internet)
Agriculture practices	Cropland: corn (major crop) Fertilization: 130 kg N/ha and 30 kg P/ha were estimated from *German literature* (LfL, 2012)	Cropland: water melons, lettuce Fertilization: 150–265 kg N/ha (water melons) and 60–180 kg N/ha (lettuce) depending on the irrigation type; *no data on P fert.* *Source*: BORM	Cropland: winter wheat Fertilization: 9.8 kg/ha N and 2.4 kg/ha P *Source*: LAGOONS (2012d)	Cropland: winter wheat Fertilization: N_{min} 50 kg/ha, N_{org} 22 kg/ha, P_{min} 16 kg/ha were estimated from literature sources (Mantra-East, 2004; FAO, 2003; Burakowska, 2005)
Water management	Water abstraction: from stream for public water supply with exact location *Source*: APA	Irrigation with water from Tagus river (data on annual amounts and location of irrigated area) *Source*: LAGOONS (2012c)	Data on ponds and irretrievable water use provided by case study partners *Source*: IWR-MR, PTR	Water inflow and outflow implemented according to literature data (LAGOONS, 2012a; Robakiewicz, 2010; Dojlido *et al.* 1994)

APA – Portuguese Environment Agency (former Administração de Recursos Hídricos do Centro (ARH Centro))
BORM – Boletin Oficial de la Region de Murcia BORM n°57 (March 10th 2009)
CGO – Central Geophysical Observatory http://cgo.kiev.ua
CORINE Land Cover – Coordination of Information on the Environment http://www.eea.europa.eu/data-and-maps/data
DENR – Department of Ecology and Natural Resources, Odessa Regional State Administration http://ecology.odessa.gov.ua/
EEA – European Environment Agency
ESAMUR – Murcia Sanitation Authority (La Entidad Regional de Saneamiento y Depuración) www.esamur.com
ESDB/SGDBE – European Soil Database http://eusoils.jrc.ec.europa.eu/data.html.
HWSD – Harmonized World Soil Database http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/
IMGW-PIB – Institute of Meterology and Water Management – National Research Institute (Instytut Meteorologii i Gospodarki Wodnej PIB)
IWR-MR – Inventory of water resources in Mykolaiv Region. Mykolaiv, 2009, 184 pp (in Ukrainian)
KCHEM – Kaliningrad Centre for Meteorology and Environmental Monitoring
Mantra-East project – 'Integrated strategies for the management of transboundary waters on the eastern European fringe', Duration 2001–2004
PKO – Government of the Kaliningrad Region http://old.gov39.ru/index.php?option=com_phocadownload&view=category&id=170&Itemid=716
PMŚ – National Monitoring of the Environment (Państwowy Monitoring Środowiska)
PTR – Passport of Tyligul River. Odessa: UkrYuzhGIProVodChoz, 1994, 148 pp (in Russian).
RDILM – Odessa Research and Design Institute of Land Management http://www.landres.od.ua/kontakts.html
SIAM – Murcia Agriculture Information System (Sistema de Información Agraria de Murcia) http://siam.imida.es
UM – University Murcia
WFDEI – WATCH Forcing Data methodology applied to ERA-Interim data www.eu-watch.org/publications and ftp.iiasa.ac.at

Despite all difficulties and data gaps, it was still possible to calibrate and validate SWIM with satisfactory or good results for the drainage areas of all four lagoons and to subsequently apply it for climate and land use change impact assessments (see Chapters 13 and 15 below).

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Chapter 12

The challenges to improve integrated catchment and lagoon modelling in the context of climate change

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Summary: In this chapter our experiences from an multimodel and integrated catchment to lagoon modelling approach is presented with particular focus on climate change impacts on environmental changes. The models were implemented in four European coastal lagoons: the Ria de Aveiro (Portugal), the Mar Menor (Spain), the Tyligulskyi Liman (Ukraine) and the Vistula Lagoon (Poland/Russia). The main challenges concerning the selection of appropriate models, their set-up, calibration, validation and coupling of different models (climate, catchment and lagoon), including problems with data availability, are presented. It is shown that in all case study areas the most restricting issue was the data availability and compatibility within each of the models and between the models. Therefore the main recommendation is the need to improve water quality monitoring systems in the catchments and lagoons, and synchronize in time sampling periods in all areas. Regardless of all expected difficulties, the quantitative approach of using multimodel analysis for indirectly coupled catchment-lagoon models allowed to achieve practically valuable results. In addition, these results showed to be useful to bring possible climate change impacts into the planning process in the scope of the WFD.

Keywords: Climate change, coastal lagoons and catchments, modelling, climate, hydrology, water quality.

12.1 INTRODUCTION

Over the last decades, an increase in temperature and associated changes in precipitation have been observed in Europe and worldwide, and it will continue in future. It is expected a warmer climate and changes in precipitation patterns will influence regional water resources, coastal water bodies and ecosystems. In the context of climate change and in the science policy perspective, sustainable water management and management of lagoons is the matter of concern for many different groups in society (e.g., WssTP – The European Water platform, 2010; Quevauviller *et al.* 2012; Chapman, 2012). The major EU water policy is the Water Framework Directive (WFD) that mandates Member States to develop river basin management plans for each river basin district, covering all surface water bodies from inland to coastal waters, including transitional waters (where lagoons are included). However, when looking at the lagoons management in the framework of catchment and lagoon processes under the context of climate change, also other policies need to be taken into account. In addition, the WFD does not classify climate change as an anthropogenic pressure in the narrow sense that the related impacts cannot be mitigated by current WFD programmes of measures (Quevauviller *et al.* 2012). In fact, climate change is considered an exogenic unmanaged pressure, meaning that it originates from natural drivers, for which local management cannot address the causes of change, being only able to address its consequences (Atkins *et al.* 2011; Elliot, 2011). Nevertheless, the WFD provides a framework to include climate change impacts into the planning process, and scientific impact modelling could be a useful tool that facilitates the simulation of these possible impacts. Thus, there is a need to study the vulnerability of lagoons to climate change and associated risks, based on the application of different possible scenarios and making use of different models at various spatial scales. Although there are a lot of uncertainties regarding the trends of climate change (IPCC 5th Report, 2014) and their effects on the future state of coastal ecosystems, modelling has been recognised as a useful tool (Meier *et al*. 2012) for estimating and simulating likely states of the water quality status of coastal waters in the context of climate change. In this context, the LAGOONS project – 'Integrated Water Resources and Coastal Zone Management in European Lagoons in the Context of Climate Change' (hereafter LAGOONS) – examined the interaction between catchment and lagoon modelling in the context of climate change. The integrated modelling was performed in the following case study lagoons – the Ria de Aveiro (Portugal), the Mar Menor (Spain), the Tyligulskyi Liman (Ukraine) and the Vistula Lagoon (Poland/Russia) (see Chapters 2–10). The aim of the modelling effort within LAGOONS was to simulate responses of the four lagoons to climate change and land use change scenarios. An integrated catchment-to-coast and lagoon modelling approach in the context of climate change was applied. For the climate change scenarios, a set of existing regional climate scenarios, namely from the ENSEMBLES project (http://www.ensembleproject.org/), was used. For the modelling of the catchments, the SWIM model (https://www.pik-potsdam.de/research/climate-impacts-and-vulnerabilities/models/swim) was applied. This is a continuous-time and spatially semi-distributed model, integrating hydrological processes, vegetation growth, nutrient cycling, and sediment transport at the river basin scale. SWIM uses climate and land use data as input and can simulate climate and land use change impacts. The modelling of the lagoons' hydrodynamic and ecological variables was performed by different models adapted to specific conditions of each of the four lagoons (see Chapter 13, Table 13.1). Depending on the case study and data availability, the lagoon – sea/ocean boundary data were provided by different models, and using different approaches in order to estimate the boundary conditions. The main challenges related to that will be presented in the following sections.

12.2 LINKING CATCHMENT-LAGOON MODELS UNDER CLIMATE CHANGE SCENARIOS

In the modelling of the climate change and socio-economic scenarios impact on lagoons it was necessary to assure that for all modelling segments (i.e., modelling of the sea/ocean boundary conditions, modelling of the catchment impact: river discharges and river water quality, as well as atmospheric forcing in catchments and lagoons) the same climate scenarios were applied. The selection of climate scenarios is described in detail in Chapter 11. Next, the results of modelling of each of the segment had to be coupled with the lagoons models and implement as driving forces (atmospheric forcing, riverine loads) or boundary conditions (sea/ocean boundary at the lagoon's inlet). Lagoons models were run including all these forcing and boundary conditions, providing the resulted response of the lagoons to them (Figure 12.1). Socio-economic scenarios were included in the catchment modelling and to some extent in the lagoons modelling in case of bathymetric modifications resulting from dredging or some other human activities in the lagoon area. These scenarios are described in detail in Chapters 15 and 16, respectively.

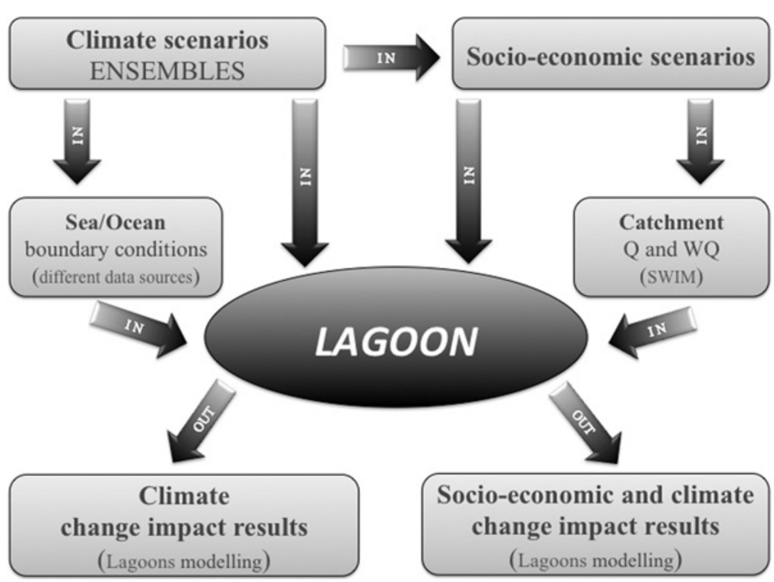

Figure 12.1 General scheme of coupling models and scenarios.

The main challenge of the approach followed was associated with the proper selection of time and spatial resolutions of input/output data for the models and the synchronized transfer of results from one model to another. In this context, it was also necessary to select a set of common variables to be modelled by both the catchment and lagoon models. For example, in order to model water quality and eutrophication processes in the lagoons and considering chemical indicators accepted within the WFD, the lagoon models required at least NO_3-N, NH_4-N, PO_4-P, O_2, water temperature, and salinity as an input from both catchment and the sea/ocean boundary with appropriate time resolution. These requirements were valid both in case of modelling of the scenario impacts on the lagoons, as well as in case of the model calibration and validation. As the calibration and validation was performed based on existing monitoring data, it was possible to extend data sets used as model inputs while taking into account the level of data availability. However, later on during the scenario modelling it was necessary to restrict the data input to the required minimum, as the SWIM model has its own limitations and could not provide all possible input variables (e.g., chlorophyll-a concentrations).

The computational time restrictions were another serious limitation. Thus, in order to manage the lagoon modelling given the very many available climate scenarios it was necessary to use a simplified approach. We restricted the analysis to the selection of typical and extreme years within climate 30-year periods instead of transient modelling of a lagoon behaviour during a full 30-year periods. The selected years were specific for each of the four case study areas, depending on the type of scenarios (i.e., scenario of an extreme event or a scenario based on typical conditions in the scenario period). Such approach was applied only for the lagoon modelling as the SWIM model is computationally more efficient, and was able to provide outputs for full 30 year periods. The selection procedure is described in detail in the D6.3 report (LAGOONS, 2014).

Each of the case study lagoons also had its specific problems which are briefly given below.

In the case of the **Vistula Lagoon**, the multi-model approach was used to analyse the coastal lagoon dynamics on different time-scales, from seasonal variations to climate scale variations (30 years) under natural and anthropogenic forcing. Climate change and socio-economic impacts on the transboundary Vistula Lagoon were analysed using two modelling suits: 1) the Delft3D numerical model, analysing the response of the Vistula Lagoon to climate and socio-economic impacts, and 2) MIKE modelling suite to answer a specific but very important question related to the main urban area on the Russian side (i.e., Kaliningrad city): what will be the impact of climate changes on salt intrusions into the Pregola River, and its impact on the city's drinking water supply?

The greatest challenge for the Vistula Lagoon as a transboundary basin was to collect a minimum of data necessary for calibration and validation of the applied numerical models, both for the catchment and the lagoon. We experienced that some variables have not been monitored on a regular basis over the last years, and the gaps in measured data required estimation, interpolation or extrapolation on the basis of data existing for other rivers. The interpolation or extrapolation also had to be done for time periods with missing data. There were some water quality variables for which measured data were not available at all. Concentrations of these substances were estimated indirectly. Also deposition of inorganic matter was approximated based on measurements at the south Baltic Sea coast (Pęcherzewski, 1975). The coupling of the catchment and lagoon models posed another problem, as the SWIM model could not estimate all the necessary variables for the lagoon modelling; SWIM provided only PO_4-P, NO_3-N, NH_4-N and oxygen. The rest of the essential variables had to be estimated (i.e., data concerning carbon, phytoplankton, ratio between organic and inorganic forms of variables, nitrogen and phosphorus in detritus and remaining organic forms for nitrogen, phosphorus and carbon). Another problem was related to the open boundary at the sea. However, it was possible to use data provided by the ECOSUPPORT project (http://www.baltex-research.eu/ecosupport/) as input. Moreover, some further missing variables (the same as in the case of SWIM model) had to be estimated based on assumptions and field data prepared during calibration and validation.

Another problem with regard to the data quality is that the methodologies of monitoring and chemical analysis are different in the two countries. The data quantity problem for the lagoon can be summarised as the following:

- *Initial conditions*:
  - number of in situ data is insufficient to represent the spatial distribution of the analysed variables (e.g., salinity, temperature) as the monitoring network is rather sparsely distributed;
- *Boundary conditions*:
  - river discharge data coming from in situ measurements are of a different temporal frequency;
  - wind conditions measured at the coast in few locations were extrapolated to the whole lagoon area as a uniform wind field;
  - limited information on water exchange between the Vistula Lagoon and the Baltic Sea;

- Calibration/verification data:
  - decrease of data records in the in situ data base from years 1998–2000 (calibration period) to 2009 (validation period);
  - data from the national monitoring programme (water quality, hydrological and meteorological) were available from only few selected points and very limited continuous data sets were available;
  - no measurements to calibrate water currents.

Estimation of the water level in the Pregolya river was another problem. The model set-up for the combined domain (the lagoon and the river) is very sensitive to water level differences at the lateral boundaries of this domain. The problem is that the catchment model SWIM provide river discharge, but not the water level. Therefore, we had to use information on water level at two open boundaries: in the Pregolya River (near the City of Gvardeysk) and at the Curonian Lagoon mouth of the Deyma Branch.

In the case of the **Ria de Aveiro**, the numerical models Delft3D-Flow (Deltares, 2014a) for hydrodynamics and Delft3D-WAQ (Deltares, 2014b) for water quality were set up and calibrated. This coupled hydrodynamic-transport-water quality modelling suite provided results for a comparative analysis between scenarios within the LAGOONS project regarding water temperature and salinity, nutrients and chlorophyll-a concentrations in the water column. Despite the model shortcomings, the results were regarded as of sufficient level of accuracy taking into account data availability for the lagoon and the surrounding catchment. The responsiveness of the model to external forcings, the very good description of the transport in the water column, its fair reproduction of the annual cycle and range of most of variables, and its fair independence from the initial conditions applied in the model, made the model suitable for different comparisons between scenarios and reference conditions.

However, certain shortcomings were apparent:

i. The description of the bottom boundary as a ‘black box’ was used to calibrate the water column. Thus, oxygen consumption by sediment associated biota oxygen demand could not be validated.
ii. The uncertainty of the model increased towards the heads of the channels for all river-borne variables.
iii. Particulate organic matter (POM) was not modelled at the catchment, and the model did not model explicitly macrophytes, namely seagrasses and salt marshes. This prevented the POM budget to be fully independent from the initial conditions.
iv. The benthic macrofauna was modelled only as a modified forcing function.

Despite the intensive research carried out in this lagoon, one of the major problems for the calibration and validation of this model was data availability. In fact, the water quality data available for model calibration were very restricted and included only monitoring performed in a small number of stations that did not cover adequately all the lagoon main channels. The period of data sampling was not enough to include the lagoon’s response to extreme events. The sampling frequency is too coarse to represent adequately all the temporal scales that define the water quality variability and the date of sampling of the available data did not coincide with the date of sampling of the topo-hydrographic data used to define the model bathymetry. The latter is of major importance as the morphology of the Ria de Aveiro is extremely dynamic, and its hydrodynamics (that is the basis for the local transport of properties) were found to be highly dependent on the lagoon’s geomorphology. Furthermore, there were not monitoring data for the several of the rivers discharging within the lagoon concurrent with the water quality data available, so it was necessary to force the model in the calibration procedure with river discharges and river water quality data predicted by the SWIM model, which induces an extra source of uncertainty.

For the **Mar Menor** case study, the tool selected for both the hydrodynamic and ecological processes was the MOHID water modelling system. Due to its shallow depth, the water column of the Mar Menor displays a good vertical mixing and stratification does not occur. According to these facts and in order to simplify calculations and improve the performance of the models, a 2-D approach was selected.

One of the first problems that arose during the preparation of data and set-up of the model was the lack of accurate bathymetric data in the lagoon, in particular for the three main inlets that connect the lagoon with the adjacent Mediterranean Sea. Two of these inlets, El Estacio and Marchamalo channels, have been highly modified and periodically dredged. The third one, Las Encañizadas, constitutes a natural labyrinth of narrow and shallow channels, not very well described. More accurate measurements of depth and dimensions of these channels are of extreme importance for the future definition and improvement of our model. A re-design of the original orthogonal grid with more detailed spatial information in these inlets would allow a substantial improvement of the hydrodynamic and ecological model results in the future.

Despite the high number of scientific studies carried out in the Mar Menor area, one of the main problems for the calibration and validation of the models was data availability. Long term data series for state variables were scarce and usually incomplete, and contained many gaps. The sampling frequency was also a problem for the model calibration/validation, since most sampling efforts were made on a fortnightly or a seasonal basis, and could not contribute to a proper description of some processes occurring in the lagoon at a finer temporal scale (e.g., storm events).

Recently, some efforts have been made to overcome this problem, including the creation of a monitoring network in the lagoon providing monthly records of salinity, temperature, nutrient and chlorophyll concentrations, and organic and inorganic pollutants in a total of 28 stations spatially distributed in the lagoon. However, it was not possible to use these data for the calibration or validation of the model due to non-existence of a gauge station at the El Albujon wadi that could provide data for the same periods. Despite the low discharge volumes, nutrients and chlorophylls in the whole lagoon are strongly affected by the El Albujon inputs, and detailed freshwater and nutrient input data series from this wadi are of extreme importance for the comparison of modelled data with the observed records for these variables.

Some of the previous studies carried out in the Mar Menor supported the parameterization of some of the processes modelled, such as the studies of Terrados (1991) for *Caulerpa prolifera* photosynthesis, production and nutrient uptake. However, the lagoon still lacks a better description of some processes that determine, for example, phytoplankton and zooplankton dynamics (including jellyfish) and a quantification of nutrient fluxes to and from the organic enriched sediments in the lagoon. Furthermore, particulate nutrient forms have been insufficiently quantified, and their dynamics hardly ever described. However, these particulate forms seem to have an enormous importance for the lagoon's functioning, probably affecting transparency in the water column as well as nutrient fluxes to and from sediments.

For the simulation of hydroecological processes in the **Tyligulskyi Liman** a modified version of the three-dimensional numerical non-stationary hydrothermodynamic model MECCA (Model for Estuarine and Coastal Circulation Assessment, Hess, 1985, 1986, 1989, 2000) supplemented by a biogeochemical unit (Brooks, 2008; Ivanov & Tuchkovenko, 2008).

The major problems during the calibration and validation were related to the ecological model. Unfortunately, data on hydrobiological and hydrochemical observations were distributed extremely irregularly in time and along the lagoon's water area. For example, the majority of hydrochemical observations were carried out in summer months and spatially the biological and chemical monitoring data were to a large extent located at the southern part of the lagoon. Therefore, the annual variability of the hydrochemical and hydrobiological characteristics estimated from the observational data for the period 2001–2010 can be regarded only as a rough approximation of the real long-term average variability. This fact considerably influenced the accuracy of calibration of biogeochemical parameters in the model.

In the course of calibration of the biogeochemical unit, the seasonal changes in water transparency were specified by expert knowledge and in accordance with the available information, since there were only sporadic observational data available on water transparency in the lagoon.

Since the late 1980s, the lagoon has experienced a decrease in freshwater inflow. In order to stabilize water levels in the lagoon, it needs to be refilled annually by seawater through a connecting channel. Currently, this channel is operating during three to four months in spring and summer, when water levels in the lagoon are below sea leve (due to the large evaporation rate). Only in years with a very high spring water level, the lagoon is 'flushed off', and salt, together with mineral and organic compounds of nutrients, are partly washed out into the sea. The positive result of this 'flushing' can be observed during following years, also in changes of the balance of the production-destruction processes in the lagoon ecosystem. In spite of the problems outlined above, the 3-D model results still provide sufficient quality to assess the inter-annual qualitative trends of hydroecological characteristics.

12.3 DISCUSSION

There is one striking and common feature in the environmental and ecological modelling for all case study areas. Not surprisingly this is devoted to the data availability in terms of appropriate quality and quantity. No matter how perfect available modelling suites are and how perfectly they are coupled to each other, their reliability will become limited if information on crucial variables is missing, and when data sets are not consistent in time and space, restricting therefore a proper model calibration and validation.

Moreover, the computational time of 3D and 2D coupled hydrodynamic and water quality numerical models of large water courses is long, and poses a serious problem in case of simulations of long climatic periods. In addition, the preparation of input files and output data processing is highly time consuming, especially in situations when these data are scarce and come from different sources. The modelling in each of the four CSAs clearly showed these limitations which are further discussed below.

The **Vistula Lagoon** is a very dynamic water body both in time and space. Hydrodynamical and water quality processes in the Polish and Russian parts are quite different due to the natural characteristics of each of the parts. Thus, the Vistula

Lagoon modelling efforts go beyond the present data availability with respect to representation of initial and boundary conditions. Although the collected hydrodynamic and water quality data base for the Vistula Lagoon was relatively extensive (e.g., chlorophyll-a, oxygen, nutrients in both Polish and Russian parts), there was a severe lack of data on nutrient inputs from some rivers and streams into the Vistula Lagoon. Another example was the lack of data in the lagoon from the winter season and inconsistencies in data for selected variables. The filling of gaps in time series and spatial extrapolation required a lot of assumptions and simplifications, which resulted in that only 'averaged' results could be given on the environmental state of the Vistula Lagoon.

It is clear that there is a need for a better coordinated data collection both in time and space including intercalibration campaigns between laboratories involved in in situ measurements, and further development of joint monitoring programs, covering the Polish and Russian parts.

In case of the **Ria de Aveiro**, similar data shortages as in the Vistula Lagoon case were also noted, which posed limitations in the modelling work. The following specific recommendations will improve the understanding of the ecosystem functioning of the Ria de Aveiro in case of future modelling:

- i Explicit modelling of the sediments with a set of layers of varying thickness and erodibility. This will increase the understanding of the spatial distribution of the physical properties of the sediments, their organic matter content, and nutrients in the pore water.
- ii Calibrations of water quantity and quality should be improved by establishing more gauging and water quality sampling sites at the several river and stream mouths entering the lagoon. This currently unavailable dataset would depict better data on both flow and quality, and could be also used to better verify the results of the catchment modelling.
- iii Better estimates of the particulate organic matter (POM) inputs from the catchment area are needed since this will improve the initial conditions of POM set for the modelled lagoon. The macrophytes (seagrasses and salt marshes) should be explicitly modelled. This would improve both the POM and the nutrient budget representation in the models.

In the case of the **Mar Menor**, some efforts are still necessary in order to better quantify the concentrations of certain nutrient forms in the lagoon. Some inorganic nutrient forms, such as ammonia and inorganic phosphorus, are usually reported as 'zero' or 'below detection limits' which seems unlikely. Apparently the sampling methods and analyses are not accurate enough to describe their relatively low concentrations. A proper description of all nutrient forms and its dynamics would definitively lead to a better calibration of the ecological model. Moreover, particulate forms of nitrogen and phosphorus also need to be adequately quantified both in the water column and on the bottom, with the remineralisation processes properly described. These processes seem to be extremely important for the lagoon, but have received little attention so far.

Another lesson learnt that requires further research in order to improve the quality of the hydrodynamic and ecological models is the characterization of the influence of storm events on freshwater, nutrient and particulate inputs from the catchment areas. The scarce precipitation and the torrential nature of the very few rain events in the area are the reasons that freshwater and nutrient inputs entering the lagoon mainly occur during these particular events that usually take place for only a few hours, although their effects can last for several days influencing e.g., water transparency, and can have a strong impact on the areas located close to the mouth of the wadis (Marin-Guirao *et al.* 2007).

According to the judgment of experts, a primary future threat for the ecosystem of the **Tyligulskyi Liman** lagoon is not eutrophication, but a tendency towards an increase in water salinity. The salinity increase will lead to a decrease in biodiversity of the lagoon ecosystem, loss of the prospects for aquaculture development, and diminishing significance of the lagoon as a protected natural water body. There are two ways to decrease the rate of salinity increase: (1) to increase the runoff of the Tyligul River by a reduced withdrawal of water for filling numerous ponds and reservoirs in the catchment area; (2) to provide maximum possible flow of the lagoon water, with salts it contain, into the sea.

For the development of scenarios for water quality management in the lagoon, with the water salinity as the main environmental issue, the use of the 3D model for a multi-year run was found to be problematic due to computational limitations.

12.4 FINAL REMARKS

Modelling of the coastal lagoons response to climate changes is still a very challenging scientific problem. There is a lot of information needed to develop a model projection of physical and water quality variables in a lagoon, for example, climate scenario for local atmospheric forcing, water discharge from the catchment and open boundary conditions (adjacent marine/ocean area) varying in time according to the same climate scenario for the atmosphere forcing. Taking into account that the information introduced to the lagoon models is uncertain, also the lagoons' response becomes uncertain, and the problem seems to be hard to solve. Nevertheless, the LAGOONS project showed that regardless to all expected difficulties, the quantitative approach of using multimodel analysis for indirectly coupled catchment-lagoon models allowed achieving practically valuable results. In addition, these results showed to be useful to bring possible climate change impacts into the planning process in the scope of the WFD.

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Chapter 13

Impacts of potential climate change on lagoons and their catchments

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Summary: Climate change is supposed to remarkably affect future conditions of coastal lagoons and their catchments and should be considered in the management plans of these water bodies. This chapter briefly describes methods and results of climate impact assessment for the four European lagoons: Ria de Aveiro (Portugal), Mar Menor (Spain), Tyligulskyi Liman (Ukraine) and Vistula Lagoon (Poland/Russia) and their drainage basins, under a set of 15 ENSEMBLES climate scenarios, within a time horizon until 2100. Generally, all regions show continuously increasing trends in temperature, but precipitation is projected to decrease on the Iberian Peninsula, to increase in the Baltic region, and no clear trend in precipitation was found for the Black Sea area. The results of climate impact assessment show diverse projections of changes in river discharge and nutrient loads as well as in nutrient concentrations in the lagoons, resulting from the applied climate scenarios for the four case study areas. A combined impact assessment taking into account possible future changes in land use and management as well as in climate is recommended for development of adaptation measures appropriate for these vulnerable coastal areas.

Keywords: Climate change impact assessment, ENSEMBLES scenarios, hydrology, lagoons and catchments, modelling, water quality.

13.1 INTRODUCTION

13.1.1 Motivation and objectives of the study

According to the report published by the International Panel of Climate Change (IPCC, 2007), coastal areas will be exposed to serious risks in this century due to climate change, sea-level rise and land use change. The expected changes include a rise in air and sea surface temperatures, a rise in sea level, altered precipitation patterns and runoff from the catchments, as well as larger storm surges (IPCC, 2007). The magnitude of potential impacts would differ considerably in various regions depending on variation in climate parameters, and the impacts have to be investigated to increase adaptive capacity and preparedness of people to future changes. However, there is a consensus on the importance of adequate and proactive management measures for protecting vulnerable coastal zones, especially lagoons and their drainage areas (Anthony *et al*. 2009; Chapman, 2012).

Besides water exchange with the connected ocean, the status of a lagoon highly depends on the ecological situation within its catchment and on water flows and nutrient loads coming with the inflowing rivers. Changes in climate conditions may cause variations in water quantity (e.g. Hirabayashi *et al*. 2008) and quality (e.g. Whitehead *et al*. 2009) characteristics of the rivers draining the lagoons catchment, and may finally affect the ecological and socio-economical potential of the adjacent coastal water bodies.

The main objective of this study was to perform climate change impact assessment for the catchment areas of four European lagoons, and the lagoon's water bodies: Ria de Aveiro, Mar Menor, Tyligulskyi Liman and Vistula Lagoon. For that, different modelling tools were applied for the catchments and the lagoon's water bodies. The model outputs of the catchment model were used as inputs to the lagoon models.

13.1.2 Overview of the applied climate change scenarios

A set of 15 climate scenario data (s1-s15) provided by the ENSEMBLES project (van der Linden & Mitchell, 2009) was used (see Chapter 11). The reference period was 1971–2000 (p0), and climate impacts were evaluated for three future scenario periods 2011–2040 (p1), 2041–2070 (p2) and 2071–2098 (p3).

Before application of climate scenarios for impact assessment, they were analysed and evaluated comparing long-term average monthly and annual temperature and precipitation in three future periods to those in the reference period. By that, so called climate change signals were estimated. The climate change signals for temperature averaged over 15 climate scenarios are similar for all four case studies. They amount to 1.05°C for period p1, 2.16°C for period p2 and 3.16°C for period p3 on average, while for the Tyligulsky Liman catchment the projected raise in temperature is slightly higher than for the other three cases. However, when looking at climate change signals for the 15 scenarios separately, there are significant differences between them: some models project higher increase in temperature, while others project temperature increase that are lower than average.

Regarding precipitation, the projected signals are not so homogeneous in change direction as for temperature, and the uncertainty in regional climate model (RCM) simulations is much larger (Figure 13.1). The agreement in change direction of precipitation is highest for the Ria de Aveiro catchment (14 scenarios agree), followed by the Vistula Lagoon catchment (13 scenarios agree), and lowest for the Mar Menor catchment (9 scenarios agree). Until the end of the 21st century, a consistent increasing trend in precipitation is projected for the Vistula Lagoon catchment, while decreasing trends are projected for the Ria de Aveiro and Mar Menor catchments. The strongest relative decrease in precipitation, on average, is projected for the Mar Menor catchment in period p3 (–18.3%).

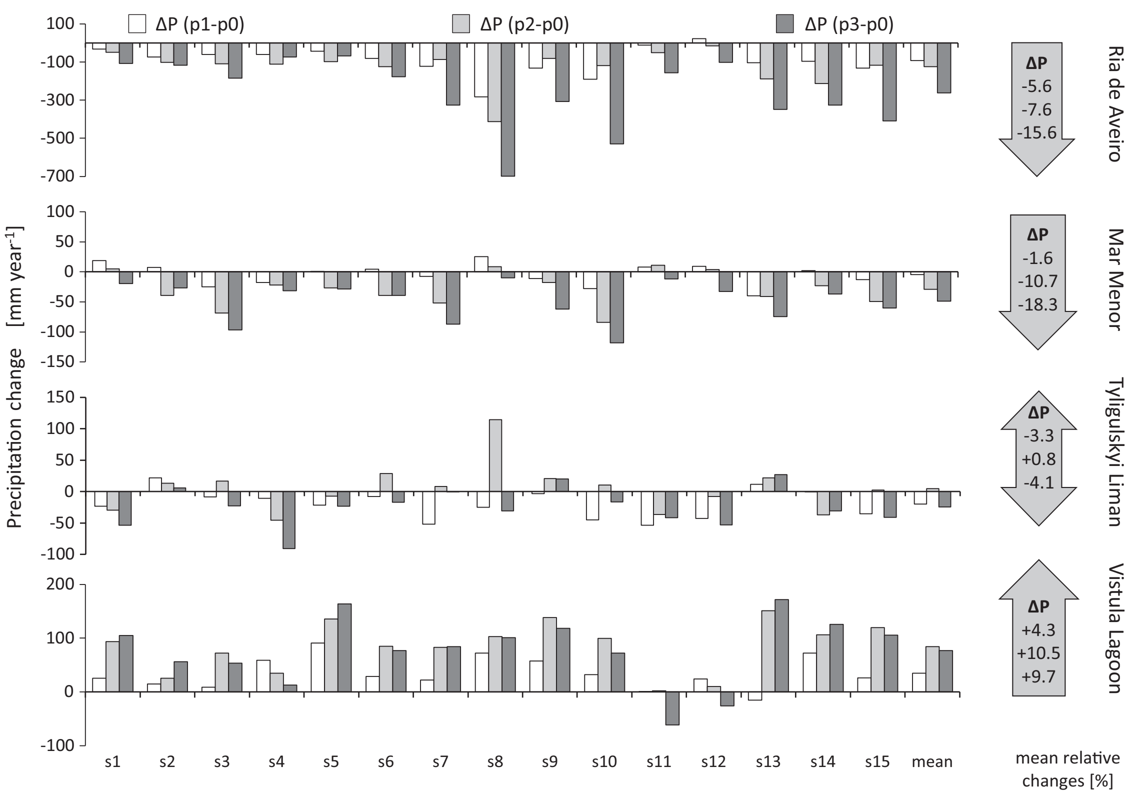

Figure 13.1 Absolute precipitation change signals separately for 15 climate scenarios and on average calculated as differences between the average annual precipitation in the three future periods (p1, p2, p3) and in the reference period (p0) → three bars per scenario (left); as well as average relative changes per three future periods (arrows on the right).

However, in the case of the Tyligulskyi Liman there are largest discrepancies between scenarios from different climate models: some scenarios show a decreasing trend, whereas the others produce increasing trends in precipitation. There are also differences between the three future periods. On average, only small changes in precipitation could be stated in this case. The high diversity in scenario projections regarding precipitation for the Tyligulskyi Liman case can partly be explained by the coverage of the ENSEMBLES scenario data, where the Tyligulskyi Liman catchment is located close to the border of the simulated region.

13.2 METHODS

13.2.1 Modelling approach for impact study in the catchments

A commonly used technique for hydrological impact studies at the catchment scale is to use climate scenarios provided by RCMs as input to hydrological models (Teutschbein & Seibert, 2010). Climate change impact assessment for the catchments of the four LAGOONS case study areas (CSAs) was performed using the eco-hydrological model SWIM (Soil and Water Integrated Model) (Krysanova *et al.* 1998, 2000) as a hydrological tool and the ENSEMBLES climate scenarios as drivers. The model and climate scenarios are shortly described in Chapter 11.

If a hydrological model is intended to be applied for climate change impact assessment it should be first calibrated and validated for the case study catchments. Hydrological calibration of SWIM in all four catchments was a very challenging task. Firstly, this was due to often poor and inconsistent data availability, practically in all four cases (see Chapter 11), and, in addition, heterogeneity of spatial data for the Vistula Lagoon catchment, which is shared by two countries.

The model calibration was done by collecting all possible data, with the support of local case study partners. As a first step, a standard calibration for the main rivers in the catchments was performed. Then the SWIM model was set up for the total drainage areas of the four lagoons and checked additionally using aggregated estimates based on observed data. Despite of all difficulties, the results of model calibration were quite satisfactory in all four cases (compare Report D5.1; LAGOONS, 2013), creating a sound basis for the climate impact assessment.

After calibration and validation of SWIM for water flows and water quality characteristics, all 15 chosen climate scenarios from the ENSEMBLES project were applied to the calibrated SWIM model in four CSAs. The land use and management input data of the reference period were unchanged in the future periods in order to evaluate impact of climate change only. The climate change impacts on water discharge and water quality variables were analysed as an average of all 15 scenarios on the long-term average daily, seasonal and annual basis for the total discharge and nutrient loads entering the particular lagoon. To get an impression of the ranges of uncertainty of future projections, different percentiles of the scenario results, as well as minimum and maximum values, were calculated in addition. For the analysis, the four time periods mentioned above were used. Each of the three future scenario periods was analysed in comparison with the reference conditions simulated by the same scenario set.

The following main variables were evaluated regarding differences between the scenario and reference periods: total water inflow (Q), loads of nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), phosphate phosphorus (PO_4-P), water temperature and dissolved oxygen.

13.2.2 Modelling approach for impact study in the lagoons

For each of the lagoons, a numerical hydrodynamic and water quality model was selected, which provided simulations of main chemical and ecological parameters additionally to the basic hydrodynamic variables (Table 13.1). Boundary conditions for each of the models consisted of the river discharges and nutrient loads provided by the SWIM model; atmospheric forcing was supplied from the same RCMs that have been used by the SWIM model. Each of the case studies also had to provide the data for the ocean/sea boundary, both hydrological (water levels, salinity) and ecological (nutrients, oxygen, chlorophyll concentrations). Details of the models set-up procedures for calibration and validation have been described in the LAGOONS Report D6.1 (LAGOONS, 2012). References and methods used for defining the ocean/sea boundary data of the scenario periods per case study area can be found in the LAGOONS Report D6.3 (LAGOONS, 2014b).

In each CSA, all of the lagoon models were calibrated and validated with the use of available monitoring data. It was a challenging procedure, as the availability of data was limited and data sets contained many gaps and uncertainties. For the calibration of the models at least yearly data sets were used, preferably 2 years. In addition, a separate year was used for the model validation. Regardless of the difficulties with the data completeness and synchronization of the data sets over time (normally monitoring of rivers and lagoons is not coordinated and synchronized over time being a disadvantage during the calibration and validation process) the calibration and validation results were satisfactory enough to apply the models for the simulation of the scenarios. Details are available in the LAGOONS Report D6.2 (LAGOONS, 2014a).

Table 13.1 Models used to simulate hydrodynamic and nutrient processes in four case study areas.

Ria de Aveiro	Mar Menor	Tyligulskyi Liman	Vistula Lagoon
Delft3D-Flow (Deltares, 2014a) ◦ for hydrodynamics ◦ curvilinear orthogonal grid in the horizontal plane ◦ 2D depth averaged version applied *Delft3D-WAQ* (Deltares, 2014b) ◦ for water quality	*MOHID* (Braunschweig *et al.* 2004) ◦ for hydrodynamics and water quality ◦ system in 2D version orthogonal continuous grid defined by squares	*OSENU-MECCA-EUTRO* (Ivanov & Tuchkovenko, 2008) ◦ for hydrodynamics and water quality ◦ modified version of 3D hydro-thermodynamic MECCA model (Hess, 2000) supplemented by a biogeochemical unit	*Delft3D-Flow* (Deltares, 2014a) ◦ for hydrodynamics ◦ curvilinear orthogonal grid in the horizontal and a system of sigma coordinate layers in the vertical plane *Delft3D-WAQ* (Deltares, 2014b) ◦ for water quality *MIKE21* & *MIKE3* (DHI, 2005) ◦ for salt wedge intrusion into Pregolya River ◦ regular grid and flexible mesh

Due to extensive storage demand and computation time, hydrological and water quality modelling for the lagoons could be performed only for shorter periods than for the catchments, and it was decided to select single years (reflecting typical and extreme conditions) for climate change impact assessment. A common procedure for selecting the appropriate climate scenarios was used in all CSAs. It was based on selection of typical years within each of the climatic periods, that is, 1971–2000 or 1981–2010 in case of Ria de Aveiro (p0) – the reference, and 2011–2040 (p1), 2041–2070 (p2), 2071–2098 (p3) for evaluation of climate impacts. Additionally, each of the CSAs defined their case specific extreme scenarios, which could be considered as having the greatest impact on the lagoon (for details see Report D6.3; LAGOONS, 2014b). The extreme scenarios are listed and described in Table 13.2.

Table 13.2 Extreme scenarios selected for CSAs.

	Scenario ID	Climate period	Description of extreme scenarios
Ria de Aveiro	**p01** **p11** **p31**	1981–2010 2011–2041 2071–2098	**Hot summer** – exceptional summer mean air temperature above percentile 95 of the summer mean temperature for the climate period
Mar Menor	**p01** **p11** **p31**	1971–2000 2011–2040 2071–2098	**Hot summer** – Year with the highest average summer temperature
	p02 **p12** **p32**	1971–2000 2011–2040 2071–2098	**Cold summer** – Year with the lowest average summer temperature
	p03 **p13** **p33**	1971–2000 2011–2040 2071–2098	**Wet year** – Year with the highest total annual precipitation
	p04 **p14** **p34**	1971–2000 2011–2040 2071–2098	**Dry year** – Year with the lowest total annual precipitation
Tyligul. Liman	**p01** **p11**	1971–2000 2011–2040	**High-water (moist) year** – with the maximum values of annual precipitation and annual river runoff
	p02 **p32**	1971–2000 2071–2098	**Low-water (dry) year** – with the high average annual air temperature, minimum of precipitation and annual river flow
Vistula Lagoon	**p01** **p31**	1971–2000 2071–2098	**Hot summer** – mild winter of temperatures above 0°C and high temperatures in summer
	p02 **p11**	1971–2000 2011–2040	**Cold winter** – long period of winter temperatures below 0°C

13.3 RESULTS OF CLIMATE CHANGE IMPACT ASSESSMENT FOR THE CATCHMENTS

The results of climate change impact assessment for the four case studies are presented in full in the Report D5.1 (LAGOONS, 2013), for two single case study areas in Hesse *et al.* (2014) and Stefanova *et al.* (2014), and briefly here in Figures 13.2–13.4. Figure 13.2 shows the long-term average changes of total water inflow and nutrient loads entering the lagoons with uncertainty bounds based on results driven by all 15 scenarios for three future periods compared to the reference period. Figure 13.3 visualizes changes in average daily and monthly total water inflows to the lagoons for the far future period p3, also with ranges of uncertainty. And finally, Figure 13.4 gives an impression of the spatial variability of changes in runoff within the entire catchments of the lagoons under study in three future periods compared to the reference period.

The scenario results per CSA are summarized in the following sections. Results for water temperature and dissolved oxygen are not included in Figures here, only in the full report (LAGOONS, 2013).

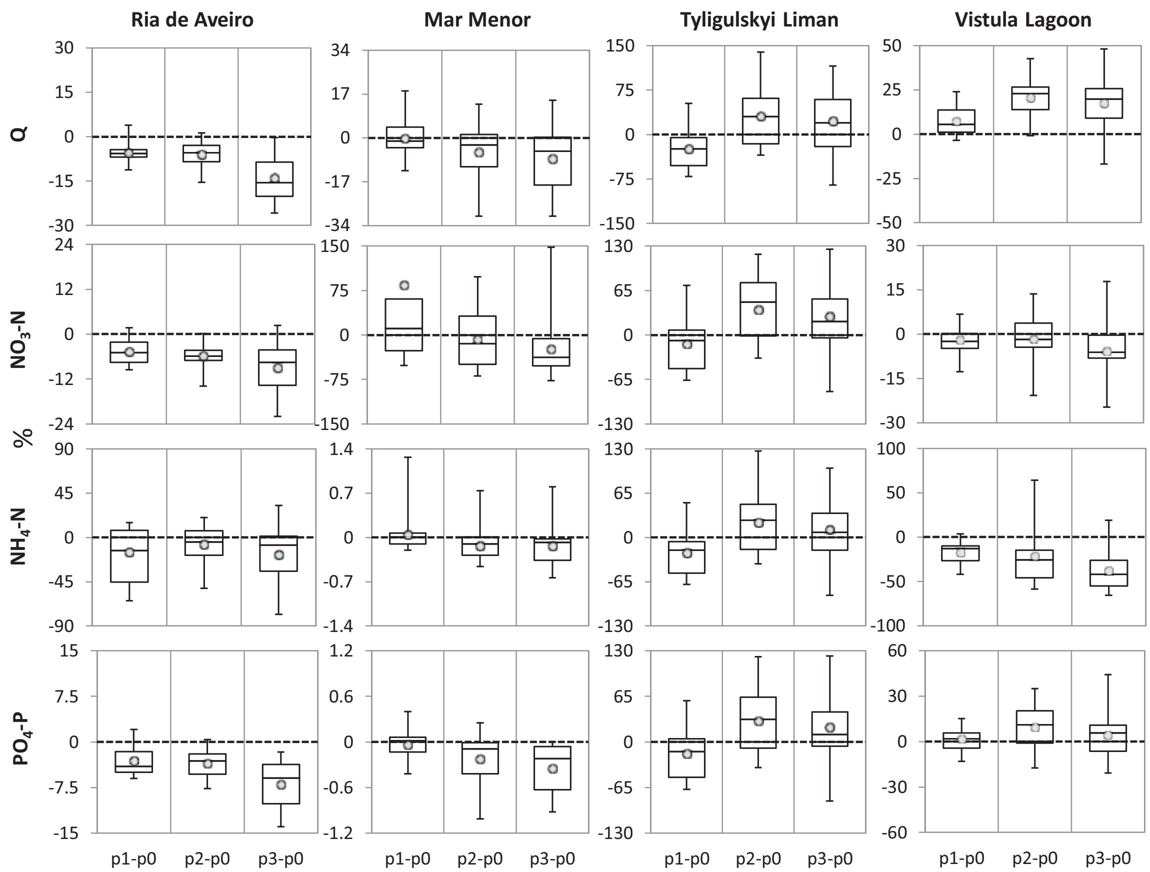

Figure 13.2 Percental changes in total water inflow (Q) and nutrient inputs to the four lagoons simulated with SWIM driven by 15 ENSEMBLES climate scenarios (future periods p1, p2, p3) compared to the reference period (p0). The box plots visualize min/max, 25/75-percentile, median and average (dots) of percental changes per lagoon, variable and period.

13.3.1 Ria de Aveiro

The simulated results of climate impact on water discharge to the Ria de Aveiro show a moderate decrease in the 1st and 2nd future periods (–5 to –7%), which becomes higher by the end of the century (about –15% on average) (Figure 13.2). Though the decreasing trend is very clear when average results driven by 15 climate scenarios are analysed, the uncertainty is high and increasing with time from period p1 to period p3.

The increasing trend in water temperature by 2°C at the end of the century is clear, and agreement between scenarios is high. Dissolved oxygen concentrations show a decreasing trend, which is consistent between scenarios, and rather small. All three studied nutrients, NO_3-N, NH_4-N and PO_4-P, demonstrate the decreasing trends in all three future periods varying between −5% and −9% for NO_3-N loads, between −3% and −7% for PO_4-P loads, and between −6% and −18% for NH_4-N loads on average, but the level of agreement between scenarios varies between periods and components (Figure 13.2).

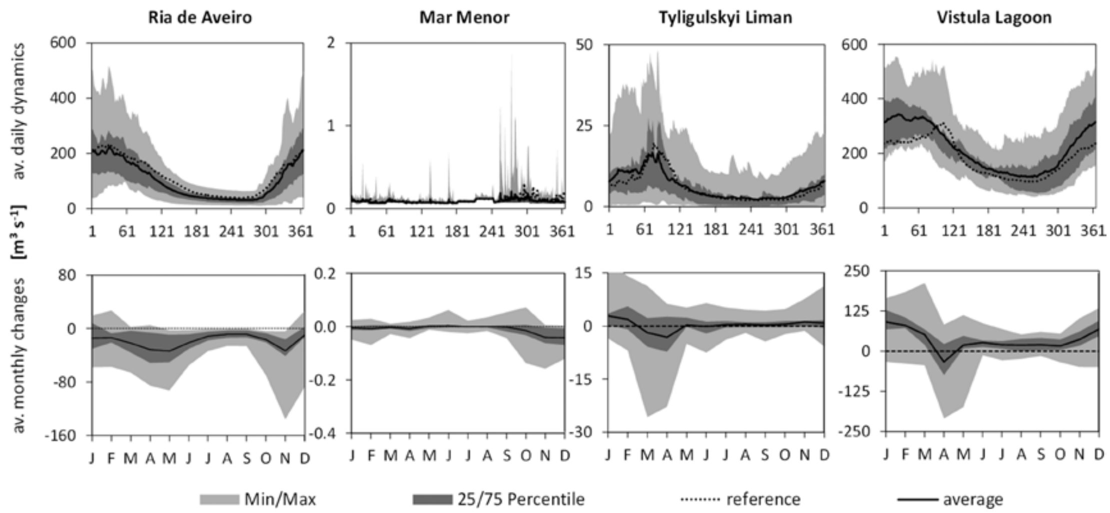

Figure 13.3 Simulated impacts of climate change on total inflow to the four European lagoons for the period 2071–2098 averaged for 15 ENSEMBLES scenarios: the long-term average daily discharges with percentile bands compared to the long-term average daily discharge of the reference period (above), and absolute differences in monthly average discharges compared to those simulated in the reference period (below).

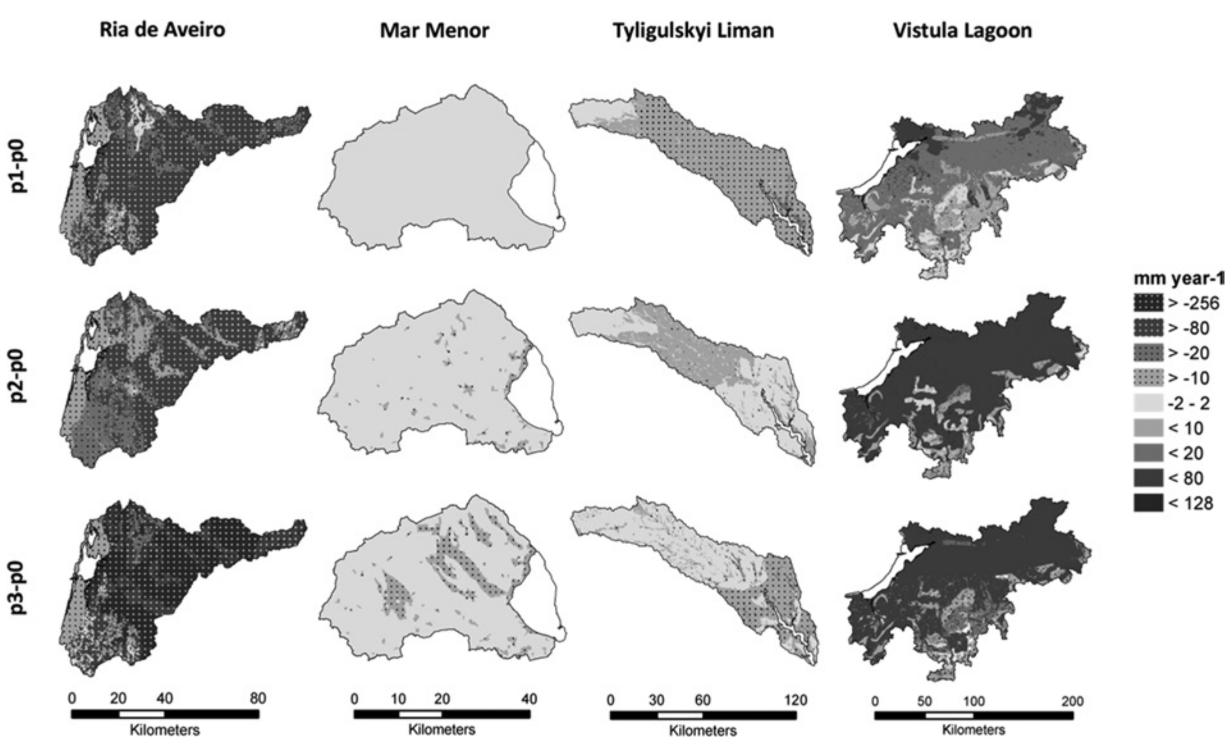

Figure 13.4 Spatial patterns of average annual changes in runoff (surface and subsurface flow) in the lagoon catchments under study simulated under the set of 15 ENSEMBLES climate scenarios (average of 15 mean runoff maps for future periods p1, p2, p3 are compared to those of the reference period p0).

Projected future river discharge to the lagoon has a higher uncertainty in winter months than in the summer season, and a decrease in average water discharges can be detected during the whole year (Figure 13.3). The largest average annual decrease in runoff is obvious in the eastern part of the catchment with higher elevation and reaches −200 mm year^{-1} in wide areas of the catchment in the period p3 (Figure 13.4).

13.3.2 Mar Menor

The impact projections for the Mar Menor catchment are similar to those of Ria de Aveiro, as the climate change scenarios in these two regions have similar trends. The results show a moderate decrease of the average daily discharge to the lagoon by about 10% on average by the end of the century (Figure 13.2). For the 1st and 2nd future periods the scenarios do not agree on a common trend, and on average only a small reduction <5% or a negligible change can be stated. The uncertainty of projections becomes higher towards the 3rd future period.

The water temperature is steadily increasing, and, by the end of the century, an average increase of ca. 2°C is projected. Dissolved oxygen concentrations show a small decreasing trend. Due to one outlying scenario, some increase is projected on average for NO_3-N in the first scenario period, and a decrease of about 20% is simulated for the middle and end of the century (periods p2 and p3) (Figure 13.2). The other two nutrient components, NH_4-N and PO_4-P, are projected to decrease slightly.

Seasonal changes in water flows to Mar Menor show a decrease only in autumn, and the uncertainty ranges are quite moderate (Figure 13.3). As water availability is generally low in this catchment, the average absolute changes in annual runoff are almost not visible in the near future and show differences not larger than −10 mm year^{-1} in the last future periods (Figure 13.4).

13.3.3 Tyligulskyi Liman

The total river discharge to the Tyligulskyi Liman is expected to decline moderately in the scenario period p1 on average, but to increase in the two last periods p2 and p3 (Figure 13.2). These changes do not follow the mean precipitation change signals for the catchment (Figure 13.1) and can be explained by changes in radiation, which influences evaporation and therefore affects the total discharge. Besides, water inflow to the lagoon is strongly influenced by water management (ponds) in this region, which was considered unchanged in the future in order to investigate the ‘pure’ impact of climate change.

Nutrient fluxes reach the lagoon only with flowing water and therefore they show a similar behaviour as river discharge (Figure 13.2). Water temperature and dissolved oxygen are clearly connected to the air temperature dynamics. Rising air temperature leads to an increase of water temperature and an accompanied decrease of dissolved oxygen concentration in the river waters. These trends are increasing over time from period p1 to p3.

Temporal changes in total discharge to the Liman can be recognized mainly in winter and spring time, when warmer winter temperatures influence snowfall and snowmelt processes, which lead to higher winter discharge and lower snowmelt peaks (Figure 13.3). Spatial changes in surface and subsurface runoff more or less reflect the precipitation conditions of the future periods with decreasing runoff in the 1st and 3rd period, but unchanged or slightly increasing runoff in the 2nd period (Figure 13.4). The simulated decrease is highest in the usually drier south-eastern part of the catchment. Resulting from Figures 13.2 and 13.4, increase in average discharge to the Tyligulskyi Liman in the 3rd period is mainly caused by a higher groundwater flow.

13.3.4 Vistula Lagoon

The results of climate impact assessment on water discharge in the Vistula Lagoon catchment show a notable increase in total water flow by 7%, 21% and 18% on average in three future scenario periods (Figure 13.2).

The patterns of change in water temperature and dissolved oxygen are the same as in the three previous cases. The increasing trend in water temperature and decreasing trend in dissolved oxygen concentrations are consistent between scenarios.

Two nutrients, nitrate nitrogen and ammonium nitrogen, demonstrate the decreasing trends in all three future periods varying between −2% and −6% for NO_3-N loads, and between −17% and −38% for NH_4-N loads on average, but the level of agreement between scenarios varies between periods and components. On the contrary, PO_4-P loads are expected to increase slightly, according to the obtained results, by 2 to 9% on average. The uncertainty ranges are moderate (Figure 13.2).

With the exception of April, average monthly discharge is expected to increase in the far future scenario period due to higher precipitation. Changes in total discharge to the Vistula Lagoon are highest in winter time, and on average the snowmelt peak is projected to be totally missing in the future (Figure 13.3). Looking at the spatial distribution of changes in surface and subsurface runoff, the highest increase can be seen for the period p2, while the heterogeneity of changes is highest in the p3 period (Figure 13.4). In general, runoff conditions are highly influenced by the soil type composition, which is more diverse in the southern Polish part of the catchment, as the soil map is based on the European soil data with higher resolution in this region (see Chapter 11).

13.3.5 Discussion of results

In total, the climate change impact assessment provides some useful insights into possible future developments in the four catchments of the lagoons. The results were used by the lagoon modellers to evaluate climate impacts on the lagoon ecosystems.

The conclusion for the **Ria de Aveiro** case study is that water managers and stakeholders have to prepare themselves for decreased water availability in the future, and the focus of adaptation measures should point in this direction, whereas water quality should not be a large problem if land use and current water management do not change drastically.

The message for water managers and stakeholders in the **Mar Menor** is the same as in the Ria de Aveiro case: adaptation measures should focus mainly on water saving technologies. Water, which is scarce already now and has to be replenished by water transfer from another region, may become even scarcer in future. Besides, measures related to reduction of point source pollution and diffuse nutrient pollution from arable land should stay in focus of managers and stakeholders. The simulated average impacts do not show notably increasing nutrient loads. However, they reflect only long-term average dynamics, and hydrological extreme events in future still may have negative consequences on water quality characteristics.

For the **Tyligulskyi Liman** case, the application of combined climate and land use change scenarios is important. Such extended study could provide useful information on how the ponds should be managed in the future. In general, water availability seems to be a problem in this region, and further analysis of water management options together with climate change impacts would be very beneficial. Therefor, more consistent and reliable climate scenarios would be desirable for this region in order to reduce uncertainty of projections.

Though expected changes in climate can be seen as beneficial for the **Vistula Lagoon** catchment, one should not forget about water-related extreme events like floods and droughts, which were not investigated in this study. Therefore, adaptation to climate change is still needed, and measures related to water availability, flood protection, improved sewage treatment and better management practices in agriculture are still important and should be considered for this region.

13.4 RESULTS OF CLIMATE CHANGE IMPACT ASSESSMENT FOR THE LAGOONS

13.4.1 Ria de Aveiro

The modelling of the lagoon's response to the induced changes at the catchment and at the ocean boundaries is expressed in salinity and chlorophyll *a*, NO_3-N, NH_4-N and PO_4-P concentrations. These variables are shown separately for the five transitional water bodies (WB1-WB5) defined for Ria de Aveiro in the scope of the Water Framework Directive (WFD) (EC, 2000) (see Chapter 3), and tested using the nonparametric Wilcoxon-Mann-Whitney test ($\alpha = 0.05$; n = 365).

In the future scenarios, apart from the changes at the catchment boundary, there is a significant rise in median net solar radiation (471–501 Wm^{-2}, $P < 0.001$) from p0 to the end of the century scenario p3, resulting in a more vigorous and widespread coastal upwelling at the ocean boundary (Miranda *et al.* 2013). In the lagoon, water median temperature significantly ($P < 0.001$) decreases by 2–3°C (e.g., from a median range of 16.5–17.1°C to 13.4–14.4°C), whilst the median salinity significantly increases (e.g., WB4 from 19.2 to 23.8 PSU, $P < 0.001$ and WB1 from 30.0 to 31.4 PSU, $P = 0.002$).

The typical year p1 shows a significant increase in median concentration of chlorophyll *a* in relation to p0 in all water bodies except WB4 (Figure 13.5). This increase is largest for WB5 (0.05×10^{-3} to 0.10×10^{-3} mg L^{-1}, $P < 0.001$) and smallest for WB1 (0.03×10^{-3} to 0.05×10^{-3} mg L^{-1}, $P = 0.002$). There are also significant differences in nutrient concentrations in this period, but the pattern is not clear. Comparing the end of the century p3 with p0 typical year, there is a significant rise in median concentration of chlorophyll *a* in the lagoon with exception of WB4 (e.g., WB1 from 0.03×10^{-3} to 0.05×10^{-3} mg L^{-1}, $P < 0.001$ and WB5 from 0.05×10^{-3} to 0.08×10^{-3} mg L^{-1}, $P < 0.001$). In this period, the median concentrations of dissolved inorganic nitrogen (DIN) significantly decrease in all water bodies ($P < 0.01$) with exception of NH_4-N in WB5. In WB4, the median concentration of nitrate (NO_3-N) decreases from 0.59 to 0.47 mg L^{-1}, whilst the median concentration of ammonium (NH_4-N) decreases between 0.01 and 0.02 mg L^{-1} from a median range of 0.04–0.11 mg L^{-1} in p0. The median concentration of phosphate (PO_4-P) changes significantly in the five WB's, but the pattern is not clear ($P < 0.001$).

The extreme Hot Summer scenario for p0 and p1 yielded significant ($P \leq 0.002$) changes regarding the median water temperature and the median concentrations of chlorophyll *a*, NH_4-N, NO_3-N and PO_4-P, but the pattern of change for the present and mid-century periods is not clear. There is no significant change in salinity in this scenario for p0 and p1. For p3, the Hot Summer scenario showed a significant ($P \leq 0.002$) increase in the median salinity values in all water bodies (e.g., from

31.5 to 33.4 PSU in WB2 and from 23.8 to 29.9 PSU in WB4); and a significant decrease in DIN median concentrations (e.g., NO_3-N in WB3 from 0.18 to 0.06 mg L^{-1}). There is no significant change in temperature in this scenario for p3.

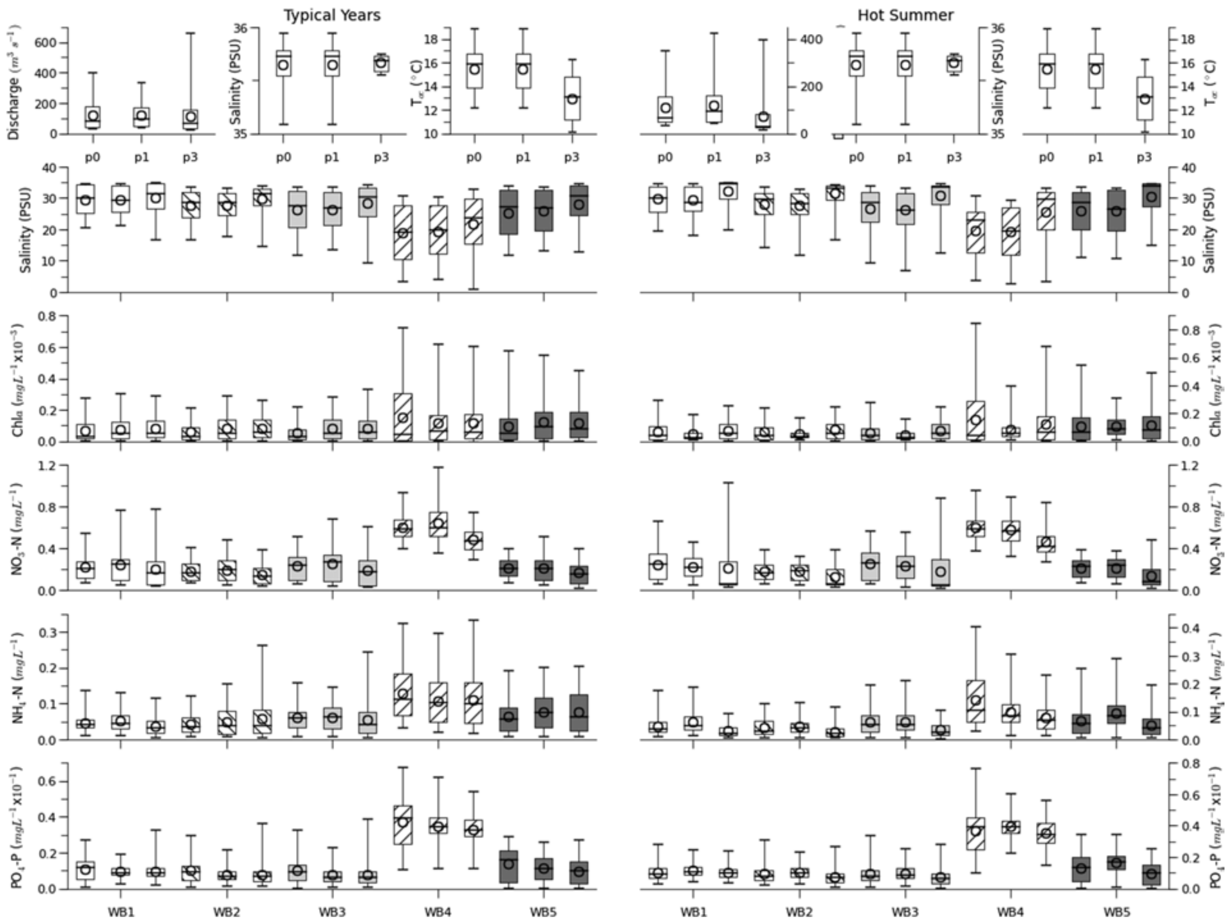

Figure 13.5 Boundary conditions applied in scenarios at catchment (rivers discharges and water temperature) and at sea boundary (salinity) and modelling results in the Ria de Aveiro for the 5 WB's. The box plots visualize min/max, 25/75-percentile, median and average (dots) for each of the typical years of the climate periods p0, p1 and p3 (left pannel), compared with hot summer scenario for each of the climate periods p01, p11, p31 (right pannel).

13.4.2 Mar Menor

The assessment of climate change impacts on the Mar Menor focused on the study of variations of parameters such as water temperature, salinity, NO_3-N, NH_4-N and PO_4-P, chlorophyll *a*, and macroalgal biomass. Despite the existence of certain environmental gradients, mainly characterized by a salinity gradient between northern areas with lower salinities and southern areas with higher salinities and the clear influence of terrestrial inputs of nutrients, results were integrated for the entire lagoon in order to examine major changes in the ecosystem (Figure 13.6).

River discharges were highly variable, but it can be concluded that, in general, freshwater inputs will decrease as a consequence of climate change in the area in all modelled scenarios. An increase in water temperature at the ocean boundary is also expected, as well as a slight decrease in salinity. In the lagoon, water temperatures are also expected to increase, up to 3°C on average by the end of the century, while salinity will display a marked decrease due to the rise in sea levels and the subsequent increase in the amount of water entering the lagoon from the adjacent Mediterranean Sea. These general trends for lagoonal temperatures and salinities can be observed in both typical and extreme scenarios. With regard to nutrient concentrations, the decrease in freshwater discharges will also cause a decrease in nutrient inputs and, therefore, in nutrient concentrations observed in the lagoon. However, higher interannual variations are also expected, particularly for nitrate concentrations. In particular circumstances, such as those occurring during extremely wet periods by the end of the century, nitrate concentrations can peak to values that are 20 times higher than those that can be considered high under current conditions, clearly indicating an impoverishment in water quality and the appearance of a more severe eutrophication process in the lagoon. Accompanying this general slight decrease in nutrient concentrations in the lagoon, a slight decrease in chlorophyll *a* concentrations is also expected, mainly due to the limitation imposed by inorganic phosphorus concentrations.

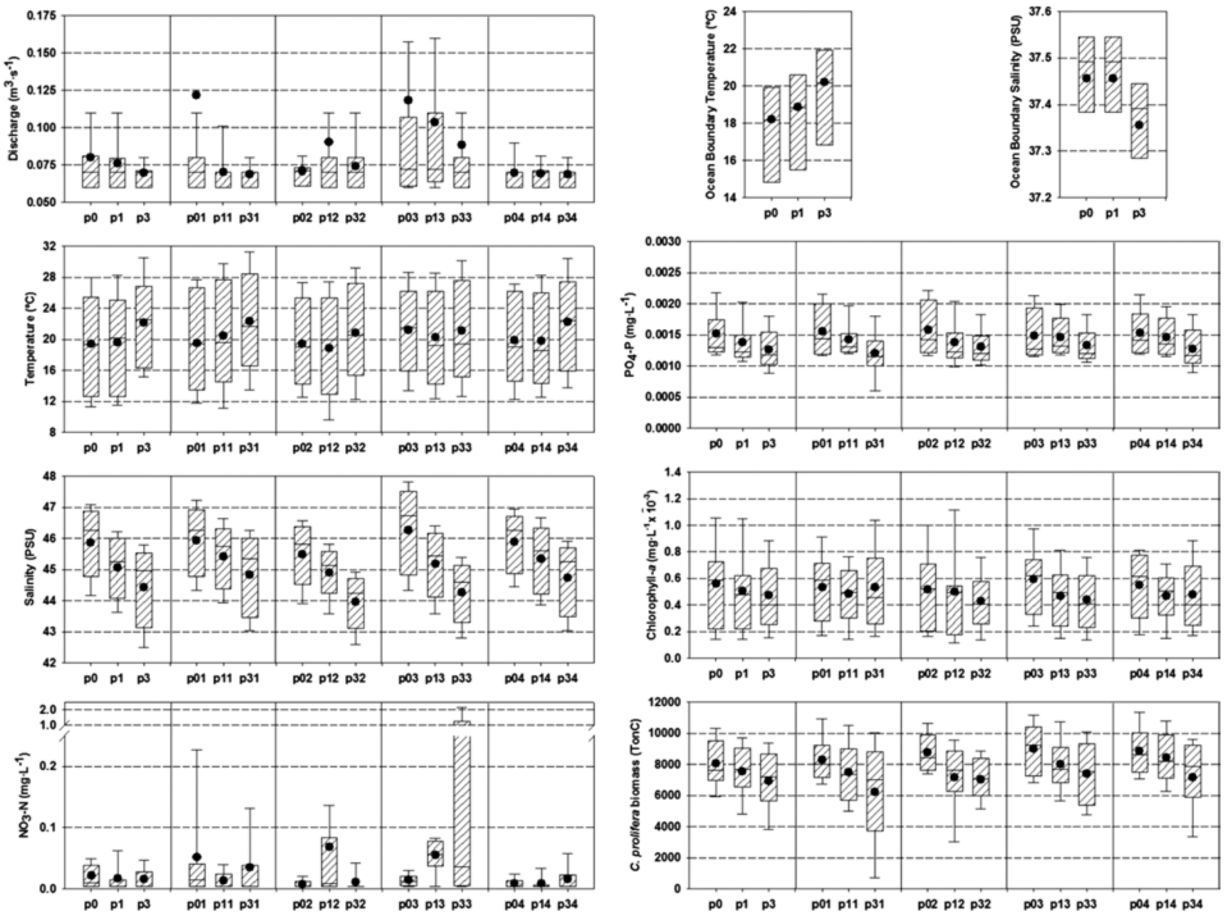

Figure 13.6 Boundary conditions applied in scenarios at rivers (discharges) and at sea boundary (temperature, salinity) and modelling results in the Mar Menor (average values for the entire lagoon). The box plots visualize min/max, 25/75-percentile, median and average (dots) of the calculated variables per scenario.

Probably one of the most dramatic changes that the lagoon will experience, as a consequence of the impact of climate change, is a marked decrease in benthic macroalgal biomass. The increase in water temperatures, particularly during the summer months when temperatures above 30°C are expected, will cause the death of important masses of the macroalga *Caulerpa prolifera*, which populates 92% of the bottoms. This decrease will be particularly evident in the deepest areas of the lagoon and especially during those years with extremely high summer temperatures.

13.4.3 Tyligulskyi Liman

Estimation of the influence of the climate change on Tyligulskyi Liman is performed on the basis of model calculations for typical years, which were singled out with the use of a technique presented in section 13.2.2. The extremes were additionally considered by the volumes of fresh water flow in a year of a particular climate period. Results of the calculations were analyzed for three points of the lagoon, which are located in the deep southern and central parts (St 1, 2), as well as in the shallow northern part St 3 (Figure 13.7). The southern part is influenced by water exchange with the sea through an artificial connecting channel in the period of its functioning (April-June), and the northern part is influenced by fresh water inflow (more than 95%), mostly from the Tyligul River. Generalized information on spatiotemporal variability of basic hydroecological features of the lagoon, such as salinity, phytoplankton biomass, NO_3-N, NH_4-N, PO_4-P, O_2 is presented in Figures 13.8 and 13.9.

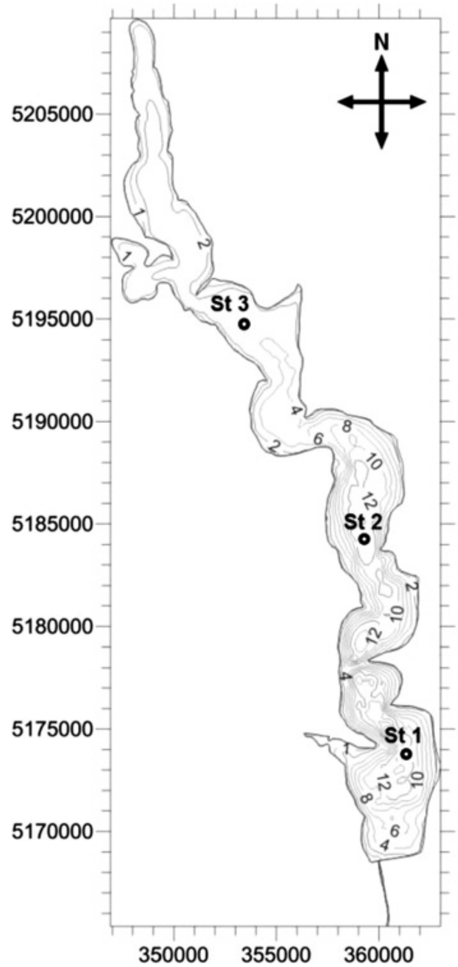

Figure 13.7 The depth map and the location of observation points used for result analysis of Tyligulskyi Liman. On the axes of coordinates marks of grids of the Universal Transverse Mercator system are indicated with a grid of 5000 m, area 36N.

The average long-term results of model calculations testify that the present-day period (p1) is characterized by minor volume of lateral fresh water flow into the lagoon, which results in an increase of water salinity, diminishing concentrations of NH_4-N. This deficit leads to limited primary water-weed production in summer months and an overall biomass reduction and a raise in concentrations of PO_4-P. The deep southern and central parts of the lagoon, the volume of waters in which comes up to 80% of the total volume of waters in the lagoon, pose a considerable damping effect as regards the influence of the river flow (1.5% of the total volume of water in the lagoon). However, even in these parts, salinity is slightly increasing in the course of one year, which probably will result in considerable increases in water salinity over decades. The most intensive increase of salinity takes place in the shallow northern part of the lagoon. Due to the lack of freshwater inflow and intensive evaporation in summer months, the salinity in this area could reach 27 PSU by the end of the year. This salty water eventually reach the central and southern parts of the lagoon, thus contributing to their salinization. The obtained results of hydrodynamic modeling are substantiated by independent calculations using a model that estimates the water-salt balance in the lagoon. According to these calculations, average salinity in the lagoon may reach 30–40 PSU by the end of the period p1.

In the scenario period p2 a considerable increase of lateral fresh water flow into the lagoon is expected. The inflow of mineral compounds of nitrogen will increase together with the flow, which will entail an increase of plant biomass in the lagoon and intensify their «blooming». In spite of an increased utilization of PO_4-P by the water plants, their concentration will also increase on average due to additional input through the river flow. Considerable incidental diminishing in the concentration of PO_4-P is however possible in periods of «flashes» of the biomass, especially in the shallow northern part of the lagoon.

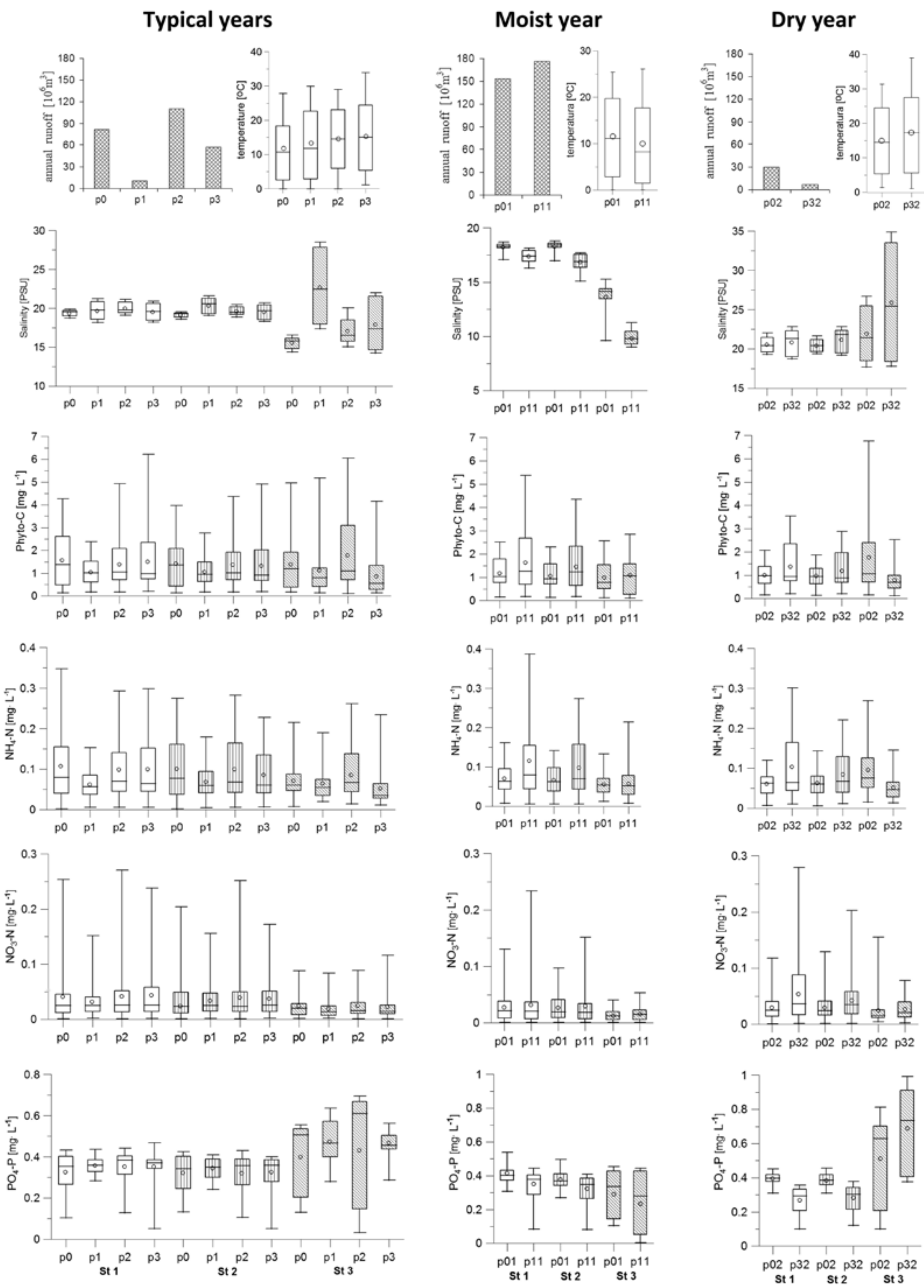

Figure 13.8 Climate variability in the amount of river flow, water temperatures in the Tyligulskyi Liman (factors to disturb the ecosystem) and modelling results at 3 locations St 1, St 2, St 3 in the lagoon. The box plots visualize min/max, 25/75 – percentile, median and average (dots) of the calculated variables per scenario (p1, p2, p3, p11, p32) compared to the reference period (p0 – typical and p01, p02 – extreme).

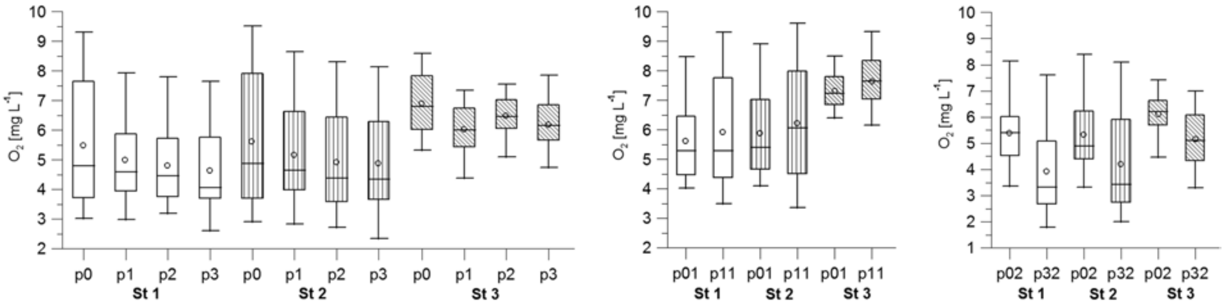

Figure 13.9 Results of modeling the content of dissolved oxygen in the waters of the Tyligulskyi Liman at 3 locations St 1, St 2, St 3.

The scenario period p3 is characterized by a lower river flow as compared to p2 and p0, which is, however, higher than p1. In the same period, the temperature of water and air and, consequently, evaporation from the water surface in the lagoon will attain maximum values. To set off the deficit of freshwater balance, the inflow of salt water into the southern part of the lagoon through the channel will increase. The spatial distribution of phytoplankton biomass in this period will be characterized by maximum values in the southern part of the lagoon and minimum values in the north, where the development of the water plants will be restrained by the lack of NH_4-N.

Parallel to a general tendency of increasing water temperature and phytoplankton biomass in the deep southern and central parts of the lagoon in the 21st century, the oxygen regime will also get worse, and the minima of oxygen in the benthic layer deepens, especially in the central part (Figure 13.9).

Comparison of the calculation results for the extreme years in various future periods provides an insight into their influence on spatial hydroecological descriptions. In the years with the maximum flow (p11) during the period of p1, concentrations of NH_4-N, NO_3-N and phytoplankton biomass in the lagoon will be higher, and the concentration of PO_4-P and salinity will be lower than in an extreme year (p01) in the period of p0. In an extreme year with a minimum flow (p32) concentration of NH_4-N and phytoplankton biomass will be higher, and the concentration of PO_4-P will be lower than in the case of p02, in the deep south and central parts of the lagoon. In the case of the northern part it is quite the contrary. These tendencies become obvious when comparing the extreme years of the periods. In years of a maximum flow (p01) in the period of p0, the concentration of NH_4-N and the phytoplankton biomass diminishes, as compared to a typical year, while it increases in the period of p1 (the year of p11).

13.4.4 Vistula Lagoon

Climate change impact assessment for the Vistula Lagoon was focused on typical and extreme years defined by using methodology presented in section 13.2.2. Results in the lagoon are analysed in four locations (Figure 13.10), representing spatial variability of parameters such as salinity, chlorophyll *a*, NO_3-N, NH_4-N and PO_4-P.

Figure 13.10 Location of selected observation points (PL1, PL2, RU1, RU2) used for analysis of the results for the Vistula Lagoon.

Results of chosen scenarios of typical years (Figure 13.11) indicate that the total river discharge will increase in the future, both as average and maximum values; a similar tendency can be seen for water temperature, while salinity at the open boundary (the Gulf of Gdańsk) will have a tendency to decrease. As a reaction of those changes in forcing, the lagoon salinity will have a general decreasing tendency both in terms of annual average values and salinity annual range. With reference to nutrients, calculated concentrations of NH_4-N and NO_3-N indicate a decrease in Vistula Lagoon (using median and average values as indicators). At the same time, concentration of phosphates is expected to increase for the whole Vistula Lagoon. A simultaneous increase of phytoplankton (expressed by concentrations of chlorophyll *a*) is expected in the PL2 region, while in the remaining part a rather small decrease is predicted.

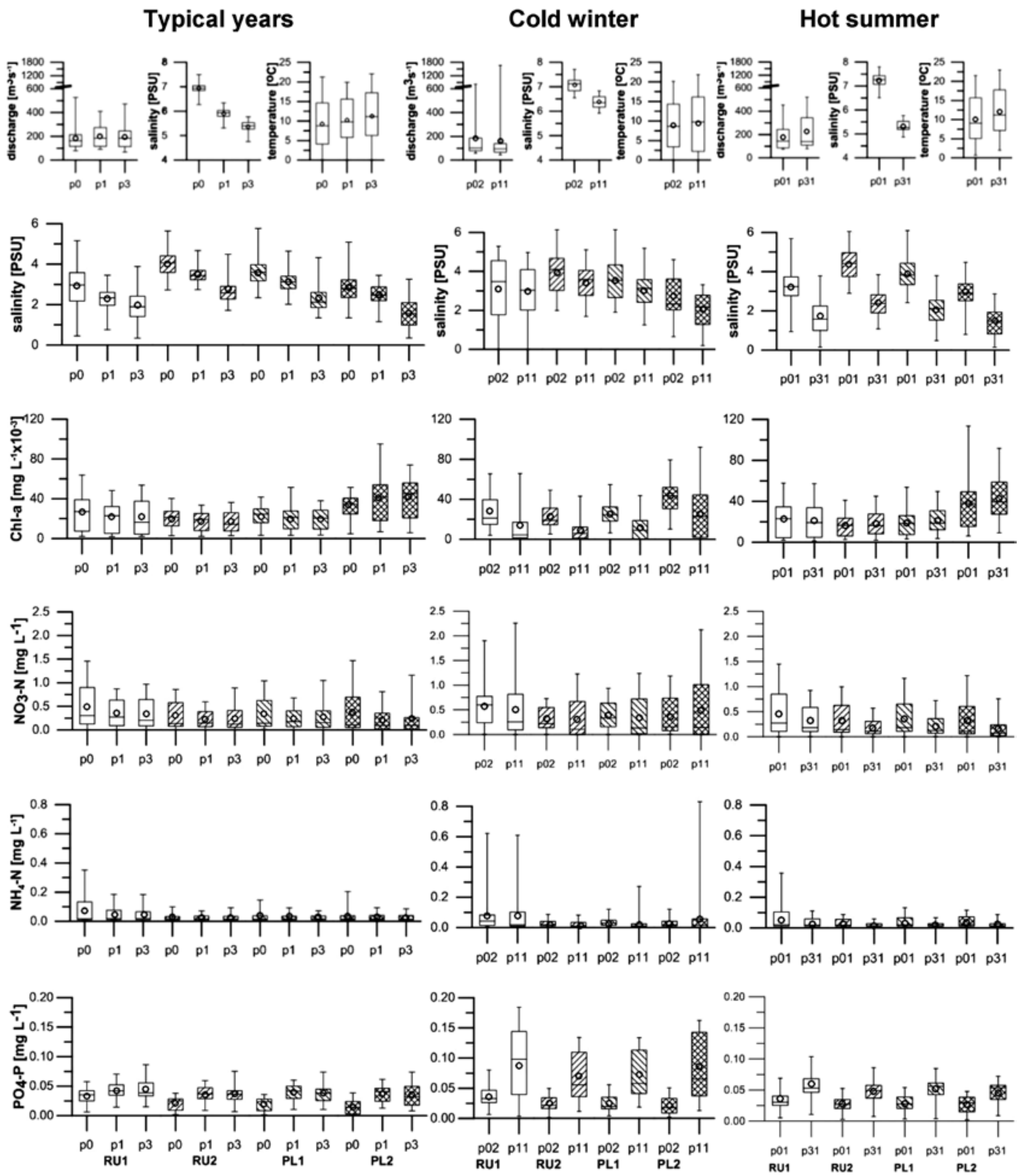

Figure 13.11 First row of plots: boundary conditions applied in the scenarios at rivers (discharges and water temperature) and at the sea boundary (salinity). Next rows of plots: modelling results in the Vistula Lagoon in 4 locations RU1, RU2, PL1, PL2 for salinity, chlorophyll *a* (Chl-a), NO_3-N, NH_4-N, PO_4-P respectively. The box plots visualize min/max, 25/75-percentile, median and average (dots) of the calculated variables per scenario (p1, p3, p11, p31) compared to the reference period (p0 – typical and p01, p02 – extreme).

Growth of phytoplankton is related to environmental conditions. It can be noticed that, in case of the Vistula Lagoon, the concentration of chlorophyll *a* (phytoplankton) is stimulated by water temperature. A simultaneous decrease of concentration of mineral forms of nitrogen (NH_4-N and NO_3-N) leads to an increase of phosphate concentration. In the presented scenarios, nitrogen is a limiting factor for phytoplankton growth which, in addition, limits the use of phosphorous in the Vistula Lagoon and finally limits its increase in water column.

In the scenarios representing years with cold winters (p02, p11), river discharge is expected to decrease, while water temperature is expected to increase. The predicted temperature increase is lower than that expected in typical years. In the lagoon, salinity will have a tendency to decrease, similarly as in typical years, however the range of variation will be higher. With regard to ammonium, nitrate and chlorophyll *a* concentrations, the situation differs from that in typical years. The main reason for differences is due to variations in river discharges, especially in the course of a year. In case of the future scenario (p11), the predicted discharges are very high in April, leading to significant water exchange in the Vistula Lagoon.

In the scenarios representing years with hot summers (p01, p31), the river discharge and water temperature have a tendency to increase in the future, whereas salinity outside the lagoon generally shows a decreasing tendency. The combination of an increase in discharge (by 5%) and a decrease in marine waters salinity (by 30%) results in a considerable salinity decrease (by 45%) in the lagoon. In this scenario, a decrease of ammonium and nitrate concentrations, in parallel with an increase of phosphate and chlorophyll *a* concentrations, is expected (similar to typical year scenarios). Water temperature increase seems to be the dominant factor in this scenario.

In those scenarios an increase/decrease (with connection to locations) in chlorophyll *a* (biomass of phytoplankton) and an increase in phosphate concentrations, and in the same time a decrease in ammonium and nitrate concentrations, are predicted. It is anticipated that nitrogen will be the limiting factor for phytoplankton growth during the whole vegetation period; at present phosphorous is a limiting factor during spring time, while nitrogen is limiting in the remaining vegetation period (Witek *et al.* 2010). Transfer of Vistula Lagoon ecosystem to nitrogen limitation will intensify bluegreen algae blooms as a consequence of an availability of phosphates in the water column and a possibility to assimilate atmospheric nitrogen by bluegreen algae.

13.4.5 Discussion of results

The moderate changes in freshwater and nutrient inputs from the catchment together with the short flushing times of **Ria de Aveiro** results in a limited variation of both nutrients and chlorophyll *a* between present and future scenarios. Therefore, the differences highlighted above will tend to reflect the interannual variability more than a sustained change between climate periods. On the other hand, the exposure to changes at the oceanic boundary will increase due to the rise in sea level, which is expected to increase the exchange between the lagoon and the ocean. An example of this is the projected drop of water temperature and rise in salinity. Projections for the Northwest Iberian coast for the end of the century point to a rise in coastal upwelling caused by the increase of equatorward winds. The enhanced exchange between the lagoon and the adjacent continental shelf will incorporate more of the deep water than before, leading to cooler and saltier conditions. The Hot Summer scenario showed that, although there was no significant change in water temperature, the low freshwater input usually associated with exceptionally hot weather would favour the rise in salinity in the Ria de Aveiro.

For the **Mar Menor**, the climate change impacts are expected to have severe consequences in major hydrodynamic and water quality parameters defining the current functioning of the lagoon. The rise in sea level is going to cause a marked decrease in water residence times. In this hypersaline lagoon, and despite the parallel increase in water temperatures (and therefore evaporation rates), this will be translated into a decrease in salinity, since this parameter is mostly defined by the amount of water that enters the lagoon from the Mediterranean Sea and not by the amount of freshwater inputs, which are extremely low and are expected to decrease. A similar event occurred during the early 70s after the enlargement of El Estacio channel, and caused the colonization of the lagoon by Mediterranean species as salinity ranges became less extreme. This future 'Mediterraneanization' of the lagoon might have unexpected consequences for the functioning of the entire lagoon and the support of valuable ecosystem processes and services.

Equally (if not more) important is the expected impact on *C. prolifera* distribution and survival. As predicted by Lloret *et al.* (2008), the increase in summer temperature as a consequence of climate change will cause a deleterious impact on macroalgal beds in the Mar Menor. The impact goes beyond the death of huge masses of algae and will have a profound effect on the ability of the benthos to process nutrients and, therefore, on ecosystem resistance to eutrophication (Lloret & Marin, 2009; Lloret & Marin, 2011). Although our models predicted a recovery phase for *C. prolifera* biomass after the summer in the modelled scenarios for the last years of the century, this situation is very unlikely to happen, since other 'undesirable' macroalgal species are likely to occupy the empty niche, limiting *C. prolifera* re-colonization and causing the collapse of the system.

For the **Tyligulskyi Liman**, the biodiversity and fish productivity during the period p1 will be endangered by the gradual increase in water salinity up to the mean values of 30–40 PSU. The increase will arise from the reduction in the freshwater inflow into the lagoon. Nevertheless, the mineral nitrogen will limit the production of organic matter by algae. During the period p2, the increasing freshwater inflow will diminish the problem of increased water salinity. However, the additional input of mineral nitrogen will enlarge the primary production of organic matter; as a result, the eutrophication with all its negative effects such as hypoxia and anoxia will occur. High evaporation rates will be registered during the period p3. This will result in inflow of sea water together with the mineral nitrogen that can deteriorate ecological conditions in the southern part of Tyligulskyi Liman.

For the **Vistula Lagoon** the climate change impacts are expected to have moderate consequences for hydrodynamics and water quality parameters in typical years. The expected salinity decrease in the lagoon, mainly due to salinity reduction in the sea and temperature increase in combination with moderate changes in loads, will result in keeping similar ecological status of the lagoon. More pronounced consequences can be expected in extreme cases. After a cold winter, spring floods can be expected leading to a significant water exchange in the lagoon which result in an increase of $P0_4$-P concentrations. In years with hot summers when both river discharge and water temperature are expected to increase, the latter seems to be the dominant. It can be expected that joint decreases of salinity, ammonium and nitrate concentrations can lead to a limited growth of phytoplankton during the whole vegetation period. Transfer of the ecosystem to nitrogen limit will intensify bluegreen algae blooms, being a consequence of phosphate availability in the water column and nitrogen in the atmosphere.

13.5 CONCLUSIONS AND RECOMMENDATIONS

Whilst the projected changes in the catchment yielded unsubstantial changes in the **Ria de Aveiro**, changes at the ocean boundary seems to affect the lagoon in terms of temperature and salinity, narrowing the gap for these variables between the Ria and the adjacent shelf. This rise in salinity is felt mainly at the lower end of the range not affecting the current classification of the water masses in relation to their mean salinity (presently three salinity intervals are considered for transitional waters: less than 5; between 5 and 25 and above 25). The national water management authorities are currently revising the delimitation of the existing water masses (APA, 2014). Although salinity is not the only parameter to be considered, future revisions should take into account the salinity results projected here.

In the **Mar Menor**, the transformation of agricultural practices from extensive dry crop farming to intensively irrigated agriculture favoured the colonization of the lagoon by the macroalga *C. prolifera*. Despite the role carried out by the macroalga in controlling nutrient concentrations in the water and, therefore, limiting phytoplankton densities in the lagoon, macroalgal beds also caused a transformation of lagoonal bottoms that currently present enormous organic matter and nutrient contents. If predicted impacts of climate change become real, the whole ecosystem is likely to collapse, not only as a consequence of the impact on the cited role carried out by the macroalga, but also by the release of nutrients stored in the lagoonal sediments. To avoid this extremely undesirable scenario and the appearance of severe eutrophication in the Mar Menor, it is highly recommended to start decreasing nutrient inputs entering the lagoon.

In the case of **Tyligulskyi Liman**, the shallowest northern part of the lagoon is influenced most by the climate changes. The ecological indicators in the southern part of the lagoon are influenced by the volume of water inflow through the connecting channel. The volume is highly impacted by the evaporation rate and intra-annual variability of freshwater inflow.

In case of the **Vistula Lagoon**, a cumulative effect of an increase of freshwater discharge and a salinity decrease in the Baltic Sea will lead to a considerable drop in both the annual average value and the annual range of salinity in the Vistula Lagoon. This tendency will be observed in the whole lagoon, as desalinisation of the Baltic waters governs the salinity dynamics in vicinity of lagoon inlet, whereas the increase of freshwater inflow causes salinity reduction at the remote parts of the lagoon. A general decrease in salinity in the Vistula Lagoon will lower the threat of both intrusion of saline water upstream the Pregolya River and blocking of the intakes of Kaliningrad City drinking water supply system. With regard to water quality in the future, concentrations of chlorophyll *a* and phosphate are expected to increase, while nitrate nitrogen and ammonium are expected to decrease. In addition, it is expected that nitrogen will be the limiting factor for phytoplankton growth in the whole vegetation season.

In general, climate change impacts affect lagoon ecosystems from both catchment and ocean borders. Changing water amounts entering the lagoon from the land and sea sides, generally expected higher evaporation rates as well as warmer water temperatures due to rising air temperature cause changes in salinity level and species composition and therefore affect the ecological status of the water bodies. Changed climatic conditions influence nutrient processes in the soils of the landscape (more runoff can intensify leaching and erosion followed by an increase in nutrient amounts entering the lagoons and vice versa; nitrogen transformation processes are temperature and soil water dependent), accompanied by important effects on the ecosystem services of the lagoon's ecological system. From this study it can be seen that the impact degree differs spatio-temporally depending on the location of the observation points relative to the in- and outflows within the lagoon, as well as on the location of the lagoon itself within a climate zone with special climate change signals and typical water regimes of the inflowing rivers.

However, just as climate changes can have remarkable effects on water resources and their benefits for the human society, the human society itself is an important co-designer of the future conditions of these vulnerable coastal areas, too. It cannot be expected that future development will take place without any changes in human behaviour, land use pattern or economic conditions. Therefore, a following combined assessment, taking into account possible future climate and socio-economic changes, is strongly recommended. This would help to identify probable future risks and threats more realistically, and to virtually test possible adaptation measures to climate change impacts.

13.6 ACKNOWLEDGEMENTS

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Chapter 14

Engagement of local communities and integrated scenarios: building qualitative scenario storylines and their quantification

S. Baggett and G. D. Gooch

Summary: This chapter describes how stakeholders were involved in the identification of the main challenges facing the lagoons and how they contributed to the formulation of the qualitative scenarios. It also explains the methodology used to quantify certain socio-economic aspects of the scenarios. The chapter demonstrates that a combination of focus groups, Citizen Juries and workshops can be used to provide informed input into discussions on the desirable or undesirable future of a lagoon.

Keywords: Citizen Juries, focus groups, participatory methods, scenarios, stakeholders.

14.1 INTRODUCTION

As stated earlier in this book, the basic concept of the LAGOONS project was that knowledge produced by different scientific disciplines needed to be combined and integrated with local knowledge and stakeholders' views in order to produce integrated, participatory scenarios (supplemented by science modelling inputs) of possible future trends and conditions in coastal lagoons. During the LAGOONS project active engagement of local stakeholders and policymakers was achieved through a three stage participatory process, consisting of: focus groups followed by Citizens' Juries (CJs) followed by a final stakeholder workshop, in each of the four case study areas. This participatory process enabled the: ability to provide the participants with a chance to put forward their present concerns and their future hopes for the lagoon; incorporation of the drivers, concerns and issues identified through local stakeholders input into the scenarios formulated; consideration of combined local community and overall policy interests in the evaluation and final adjustment of the models and scenarios used.

This chapter addresses the work conducted by the chapter authors regarding:

- How issues relating to the Case Study Area (CSA), proposed by participants and recognised during the focus group and CJs participatory processes, were initially analysed and categorized post engagement, following the principles of Driver – Pressure – State – Impact – Response (DPSIR) methodology.
- How stakeholders' inputs through focus groups and CJs helped form and were incorporated into the crafting of scripts of qualitative scenario storylines, written for socio-economic and environmental scenarios to 2030.
- How each of the scenario storylines was subsequently used as a guide for values that could be ascribed to present day socio-economic, demographic, land use and other data when projected to 2030. This data was subsequently used as a basis for CSA scenario modelling (see Chapters 11, 12, 15 and 16).
- How guidance and training was provided for the production of written and visual material used for the final stakeholder workshop based on the above outputs.

The chapter also describes how the results of the modelling of the different scenario alternatives were then translated into outputs which could be of use for policy recommendations for future water resource management. This process was initiated during the final stakeholder workshops through a process of back-casting and the participatory methodology envisaged a continuation of these discussions after the final workshops were conducted in the case areas. Based on the alternative scenarios produced, policy trajectories and alternatives were identified and the policies and management inputs needed to either achieve desirable futures or avoid undesirable ones were discussed. This method is known as back casting, the process through which desired or undesired possible futures are first formulated, followed by an analysis of the policy paths and options necessary to achieve or avoid these futures. By first formulating these possible futures the necessary policy instruments needed to reach or avoid them can be examined and discussed (Falkenmark, 2004; Robinson, 2003). The methodology provides a technique for informed social learning by stakeholders, scientists and policy makers and offers a valuable input into decision and policy-making in water resource management.

14.2 ENABLING ACTIVE ENGAGEMENT AND INPUT OF LOCAL PARTICIPANTS USING A THREE STAGE PARTICIPATORY PROCESS

The principles driving the active engagement and participation of local stakeholders and communities in water management issues are now widely recognised, justified and accepted, both in legal and procedural terms (Baggett *et al.* 2008). There are a number of benefits to be gained by providing local participants with the opportunity to have input into how water can be used sustainably in the future and the planning required to achieve that aim. The benefits of local inclusion is due, not least, to their familiarity with how local water as a common pool resource is used and their different, possibly conflicting, views and interests surrounding the sharing or apportioning of that resource (Rieu-Clarke *et al.* 2010). The three stage participatory process (focus groups > CJs > final stakeholder workshop) used during the project enabled and provided a) participants with a chance to put forward their present concerns and their future hopes for the lagoon; b) incorporation of the drivers, concerns and issues identified through local stakeholders input to be included into the scenarios formulated; c) consideration of combined local community and overall policy interests in the evaluation and final adjustment of the models and scenarios used; and d) an increased willingness to accept changes as these were based on the participatory process described in this chapter.

A preliminary stakeholder and social group mapping exercise was conducted first, in order to aid identification of the respective key stakeholder groups (e.g., fisheries groups, community based organisations, farmer associations, industry representatives, conservation groups) within each of the four CSAs. The key group information was collected via two main routes: (i) a desk top literature study; and (ii) consultation with the CSA partners key group, who were familiar with the case areas and could provide insights into the selection of stakeholder groups. This served as a starting point for the further investigation of whom the main stakeholder groups were per CSA and why.

14.2.1 Focus groups

Focus groups are a popular form of qualitative tool, whereby a small group consisting of usually eight to twelve individuals are guided through a discussion by a trained moderator (Gooch *et al.* 2004). The aim of focus groups is to initiate discussion between the participants so as to get beyond superficial answers and to uncover insights on their attitudes or behaviour regarding a particular product or issue. Focus groups also provide a social context for discussions and provide insights into the social construction of the debates. Focus groups were the first form of active stakeholder engagement used during the process to ensure stakeholder involvement in the project and gain preliminary views. A focus group may, in the context of a lagoon, have a common interest as they are either residents living within particular vicinities on the shores of the lagoon or may have a common but also specific interest, as in the case, for example, of fishing, agriculture, conservation, business or tourism (Baggett *et al.* 2013). Prior to running the focus groups preparation work included preparing and training the CSA project members on why and how to run focus groups. This consisted of a two day training workshop, organised by the chapter authors, where CSA project members were initially introduced to what focus groups were; why and how they were conducted and recorded, followed by several sessions where they took part in simulated focus groups and were given the opportunity to play the different roles of moderator, facilitator or participant.

Several focus groups were held in each of the four case study areas to elicit views from a broad set of CSA stakeholders. The focus groups were conducted within the participants' locality, in a setting where they would be comfortable discussing the focus group's stated purpose. The number, location and type of focus groups held per lagoon were as follows:

- Aveiro = 9 (residents; students/researchers; council members; recreational hunters and fishermen; mixed activity; fishing sector; shipping; marine harvesting of salt, reed etc.).
- Mar Menor = 6 (ecologists; seniors; students/researchers; business owners, fishermen; farmers and stockbreeders).

- Tyligulskyi = 7 (farmers; fishermen; hunters; landscape park employees; Odessa residents; tourists and tourist sector employees)
- Vistula (*Poland only*) = 6 (teachers; fishermen; hotel owners/operators; gastronomy sector; local authorities; social activists).

The following excerpts are examples of the type of issues brought up by focus group participants during their discussions:

Ria de Aveiro: *'the involvement of ordinary citizens in the activities of management and development of Ria is very important for their pedagogical nature' . . . 'the problem that gathered more consensus among participants was the strong currents that are felt in the channels of the Ria de Aveiro. The increased velocity of water causes the disappearance of some species of fish, sea grasses and reeds, giving rise to silting and destruction of the seabed of the Ria'.*

Mar Menor: *'In terms of future they suggest a better management of the urban develop, for . . . Mar Menor is already overcrowded and there is no need to build. They also suggest a change in the production systems, the agriculture, which is now based in irrigation; this always [has] been a land of dry crops, and that carries several problems'.*

Tyligulskyi Liman: '*Illegal sand mining is still one of the most important factors affecting the faunal diversity (and not only). . . .There is a structural unit of the regional environmental agency in Kominternivskyi district, but there is no sufficient forces and means at his staff to stop the chaos there (as well as that of the 3–4 workers)'.*

Vistula Lagoon: *'Water (In the lagoon) is dirty. Even though field fertilizing is less intensive and the resultant influx of nutrients went down considerably, the water starts blooming in mid-July, so bathing is no longer possible and beaches grow empty . . . Flood management of the lagoon is inadequate and wrong; in case of backwatering (storm surge) Tolkmicko, Suchacz, Elbląg are flooded. Better flood protection is required. In the 70s drainage ditches were cleaned regularly – nobody gives a damn about it nowadays!'*

Focus group participants were also asked to identify on a map of the lagoon, via the use of coloured stickers, aspects of concern (black stickers) and positive aspects (grey stickers) in relation to the lagoon, as shown in the following examples, Figure 14.1). This spatial analysis consisted of a clustering of the positive (grey spots) and less positive aspects (black spots) for each session per lagoon. Star markers on the maps denote the location of the focus group.

Data collected and recorded by the project's CSA members from participants' deliberations within each focus group held were summarised and then translated from their original language into English. These translations enabled the subsequent post analysis and categorisation of the contents so as to assess what the main messages were from a) individual focus groups; and b) all FG participants per CSA grouped together. Analysis of the contents of the focus group material was also used to make an informed choice on the following elements required for the next step in the participatory process that is, CJs regarding the:

- Relevant driving forces and their influence on each of the lagoons, as identified by the participants.
- Fields of expertise that needed to be addressed and represented during the next phase of the participatory process that is, CJs, in order to increase knowledge of the driving forces and to enable informed input into the scenarios constructed later in the project.

Analysis of focus group outputs helped identify the primary driving forces for each lagoon and the main topics that needed to be covered by expert witnesses during the CJs.

14.2.2 Citizens' Juries (CJs)

The second form of stakeholder engagement used during the LAGOONS project was in the form of CJs, a method of engagement and deliberation which is based on the format used for criminal courts in the UK or US (Blamey *et al.* 2000; Kenyon, 2005; Davidson & Elstub, 2014). A CJ usually last two days and consists of between 12 to 24 randomly chosen citizens, who listen to the evidence presented by a range of 'witnesses' who are all experts in their particular field. The witnesses each present their case, to the jury, regarding their specific interest or concerns associated with the (in this case) lagoon in question, which may be a competing or conflicting interest in relation to the other witnesses present. The jury can also question the witnesses. After all the evidence has been presented members of the jury are provided time to think individually about the evidence provided by each of the experts and also deliberate amongst themselves, before presenting their 'verdict' back to the witnesses and the moderator. The 'verdict' provided by a CJ, based on the information presented to them by the expert witnesses, are informed choices regarding policy matters, unlike the verdict provided by juries in a court of law, where the verdict is either guilty or not guilty.

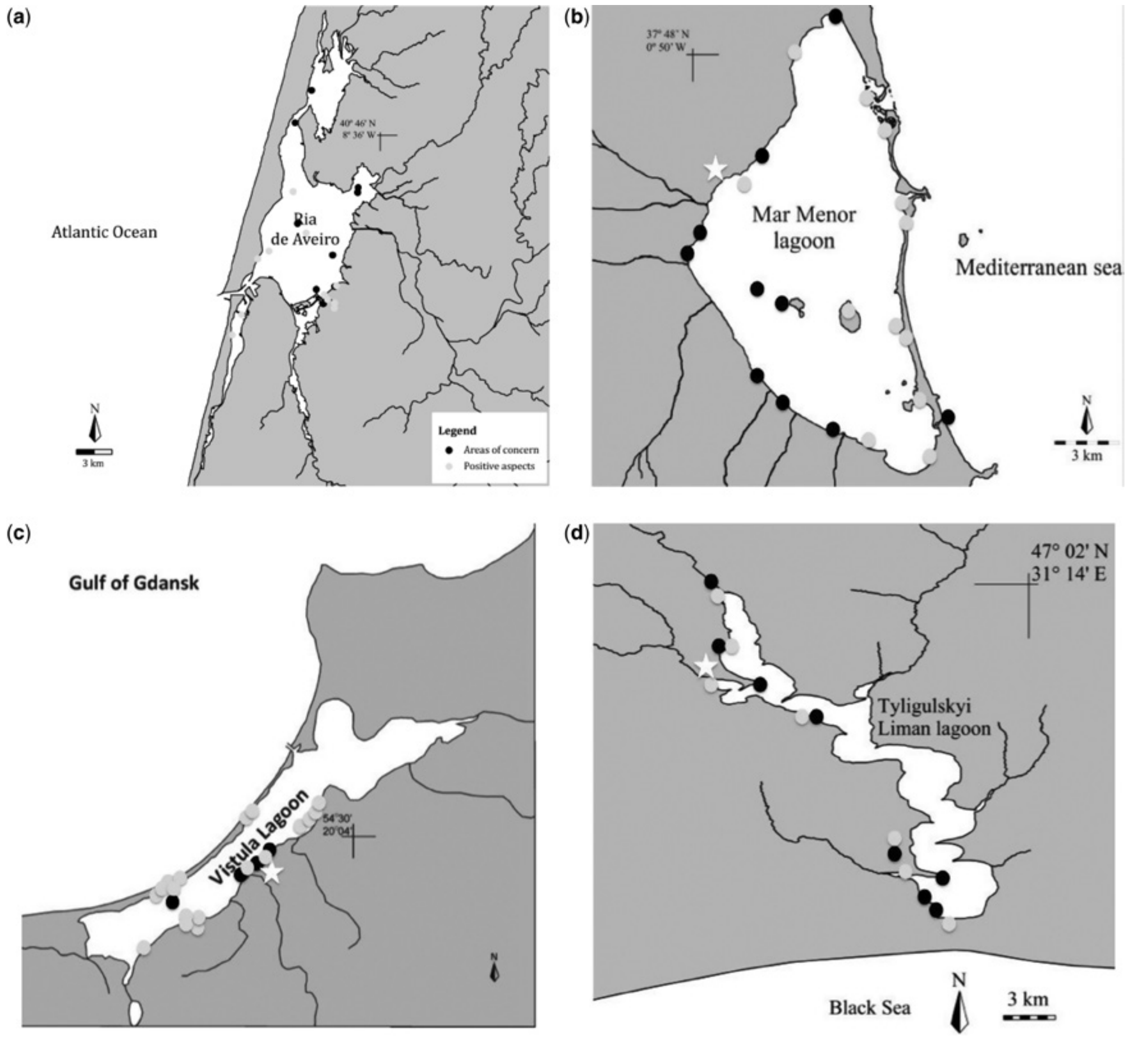

Figure 14.1 Example of the maps with the indication of the aspects of concern (black stickers) and positive aspects (grey stickers) for (a) Ria de Aveiro; (b) Mar Menor; (c) Vistula lagoon; and (d) Tyligulskyi Liman.

Prior to running the CJs a two day training workshop was provided for the predominantly scientific project members of the CSAs, prepared and run by the chapter authors, in preparation for conducting the CJs in the CSAs. This training session provided CSA project members the opportunity for: learning how to run, moderate and record a CJ meeting in their CSAs through the use of a simulated CJ and role playing exercises; A final discussion on the focal question to be put forward to the jury to assess and provide recommendations for: selecting and assembling the jury; which topics needed to be covered by expert witnesses; dates and resources required.

In this instance the jury, consisting again of local stakeholders, was asked to:

(i) Consider future developments (either positive or challenging, according to the participants) of the CSA lagoon in question during the next 15–20 years;
(ii) Provide a series of recommendations in an attempt to promote the future development of the lagoon according to the jury's criteria.

14.3 BUILDING AND FORMING THE SCENARIOS

Combining qualitative and quantitative methods and materials are increasingly being called for and developed, particularly in the sphere of environmental planning (Varho & Tapio, 2013). An array of methods and tools that collect and combine deliberative and analytical dimensions are being used worldwide for this purpose in an attempt to inform the progressions required for future water planning (Stratton *et al.* 2011) and bridge the gap between the dimensions of scientific endeavour, stakeholder input and decision making (Liu *et al.* 2008). One of the qualitative/quantitative methods that can be used for this is qualitative scenario storylines coupled with quantitative modelling (Alcamo, 2009). Possible future changes and their consequences due to the impact of human pressures on the natural environment, along with possible societal responses to environmental change, are increasingly explored and assessed through the use of scenario storylines (Rounsevell & Metzger, 2010) Scenarios are not predictions about the future; they instead provide a limited number of possible future alternatives, based on assumptions made regarding the interaction and relationship of key actors, social processes and physical systems, which explore and test possible future developments and strategies (http://climwatadapt.eu/scenarios). The concept of using scenarios as a means of assessing possible futures was first used for industrial (Shell, 2003) and military purposes (Alcamo & Ribeiro, 2001) and there are now a number of areas where scenarios have been developed and applied, see, for example (Gallopin & Rijsberman, 2000), (Heijden, 2000), (Kok *et al.*2006), (Allouche *et al.* 2008). The most appropriate use of scenarios is likely to explore situations where complexity and uncertainty levels are high (Wollenberg *et al.* 2000; Schoemaker, 1993). Developing and considering alternative scenarios has therefore become a popular tool in a number of research and management fields, not least for water resource management (Wright *et al.* 2012; Alcamo & Gallopin, 2009; Allouche *et al.* 2008). Water resource scenarios provide a means of formulating possible policy and management options and alternatives, desirable or undesirable, for future water resource management and often start with the formulation of qualitative storylines (Alcamo, 2001) (Allouche *et al.* 2008).

Based on the Driver – Pressure – State – Impact – Response (DPSIR) framework (Agnetis *et al.* 2004) (Borja *et al.* 2006) the: driving forces; relative issues associated with those drivers; and possible responses within each case study area were initially identified through the participatory process and transformed into loosely aggregated DPSIR tables (Table 14.1). The content of rows are not attributed to any particular driver as there may be several associations across the table that have an effect on a particular feature listed within the table (Baggett *et al.* 2013). An increase or decrease in some features is denoted by an upward or downward pointing arrow respectively. The first drafts of the storylines, created for each of the case study areas, were based on the study and analysis of the results of the focus groups and the DPSIR table. Second versions of these storylines were then produced which incorporated further qualitative information, based on the results of the CJs.

A major task in the construction of scenarios is: defining the number and character of the scenarios to construct; choosing a suitable timescale. Only using two scenarios is often considered unsuitable, as this tends to lead to an 'either or' situation, whereas three scenarios can lead to a preference for the middle option, as the other two may be considered extreme (Schwartz, 1998). Four scenarios is a common choice and in the case of the LAGOONS project four future scenarios were constructed per CSA. 'Business as usual' scenarios represent the future as we believe it will develop from our starting point (often the present), if future developments are not influenced by a change in policies, radical changes in the economy or political interference. It is customary to include a 'business-as-usual', or baseline scenario in environmental studies, and this was also the case here.

The formation of the scenarios used by the project were guided by the driving forces and issues identified in the focus groups and CJ held per lagoon and analysed by the authors. The timescale chosen for the scenarios constructed was 2013–2030, providing a timescale that ran far enough forward into the future to provide alternative plausible scenarios, but not so distant that the stakeholders could not relate to it. A number of versions of the scenario axes were suggested, applied and broadly discussed within the research group prior to deciding on a version that could accommodate the main issues identified. The axes finally decided upon were economic development and environmental quality, providing four different possible futures. This provided the following four different perspectives to use as a base for building storylines that reflected the varied effects of environmental and economic factors on human wellbeing and livelihoods:

- *Business as Usual (BAU)* – attempts to describe how the future could develop based on known changes and past trends, without any major deviation from present arrangements regarding economic growth or environmental quality.
- *Managed Horizons* – provides an alternative future where both economic and environmental factors are positively used to provide tangible human benefits but are co-managed in a way that not only does no harm but may also benefit the environment.
- *Set Aside* – may not provide direct tangible increases in benefits to the residents of the CSA but may provide indirect economic and environmental benefits to the area predominately through the value of and payment for ecosystem services and through ecological conservation.
- *Crisis* – where both economic decline and environmental degradation of the study area impact on the well-being and livelihoods of the CSA residents and severely affect any economic, social and environmental recovery of the lagoon.

The following section provides examples of the type of content incorporated into the qualitative scenario storylines. For the sake of simplicity, not all alternative scenarios have been described for all case areas. Instead, a selection of scenarios is provided which serve as examples.

Table 14.1 Example of DPSIR table produced for forming qualitative storylines – Ria de Aveiro (Baggett *et al.* 2013).

Driver	Pressure	State	Impact	Response
Economy	Channel dredging	↓ Seagrasses	↓ Traditional employment/activities	Better overall regulation, law enforcement
Fishing/shellfish	Sediment dynamics (erosion/deposition)	↑ Pressure on fish/ shellfish species	↑ Parallel economy	Improve procedures for monitoring biotoxins and lead
Tourism	Water velocity	↑ Bait digging	Locals' income variability	Unique local management structure
Port activities	Land salinity; surface salt water intrusion.	Impoverishment of sediments bed	Management conflicts	Improve public participation
Downturn	↓ Infrastructure investment	↓ Reeds	Invasive species impact on lagoon environment and local economy	Stimulate stakeholders and end-users engagement
Climate	Illegal fishing gears	↑ Siltation	Changes in seagrasses beds ('moliço') and hydrology	High-end/ sustainable tourism including traditional activities
Uncoordinated management	Competition between harbour and local fishermen interests	↑ Margin erosion	↑ Seagrasses nursery function	Better promotion of produce
Traditional activities	Professional vs. recreational fisheries	↑ Water quality	Sense of isolation	Appropriate sustainable infrastructure/ transportation
Agriculture	Historical industrial pollution (e.g., Largo do Laranjo)	Tidal high change	Loss of agriculture land	Integration of local fishermen and port interests
Recreational hunting and fishing activities	Temporary ban on shellfish harvesting due to biotoxins	↑ Water velocity	↑ Air temperature Avanca	Structures to control currents and water velocity
	↑ Local unemployment	↓ Traditional activities	Cormorant impact on aquaculture farms	Increase role of University of Aveiro
	Invasive species	↑ Bivalve health	Excess growth of *Eichhornia crassipes*, (Common Water Hyacinth) in freshwater channels;	Conclude Baixo Vouga dike
	↑ Motorboats	↓ Public transport (ferry & speedboat)	Large stork colonies impact on prey population	Promote the balance between freshwater and saltwater
	↑ Drinking water price	Salinization of cultivated fields		Small channels restoration
		↓ specimens for recreational fishing and hunting		Traditional activities recovery
		Environmental imbalance due to mismanagement		

14.3.1 BAU for Ria de Aveiro

Portugal has been a member of the European Union for 44 years. The resident population of Aveiro has increased by six percent. Employment however has continued to slowly decline, with more than one third of 15–64 year olds out of work with the under 25s accounting for more than 50% of the unemployed in the area. Traditional employment and associated activities within the local population also continues to fall. People in the area are more and more reliant on obtaining other forms of employment, but the likelihood of securing another job in a different economic sector due to economic decline is also uncertain. These economic changes are also due in part to the changing hydrological dynamics and increased water velocity within the lagoon which impacts the sea grasses, reeds and the natural and nurturing environment of the lagoon's sea bed and surrounding land and can no longer provide a steady reliable income for local populations. The total area available for agriculture has decreased by 10% since 2009.

Competing demands on the lagoons' resources between the interests of the harbour and the local fishermen is prominent. There is also a high level of concern shown by the professional fishermen due to the impact of recreational fishermen, the use of illegal fishing gears, increasing pressure on fish and shellfish stocks and the long term impact of intensive bait digging. Inadequate supervision of these activities by the responsible entities. Some level of historical industrial pollution in Largo do Laranjo is still present. For specific periods there is a temporary ban again on shellfish harvesting in the entire lagoon area due to the presence of biotoxins produced by harmful algae blooms (HAB).

Although, water quality status, according to WFD chemical indicators, continue to improve, ecological conditions in the lagoon continue to deteriorate due to the lack of structures to control the currents and water velocity. Failure to finish the Baixo Vouga dike further promotes the erosion of the lagoon's banks and saltwater intrusion of the surrounding land. A number of invasive species (namely clams) have established populations within the lagoon, while the seagrasses populations of the lagoon and its associated fauna are in decline. Level of investment is low and the overall management of the lagoon and its surrounding areas are uncoordinated between the municipalities with very little stakeholder and end user engagement and input. In general regulations are poorly enforced. Public transport in the form of ferries and speedboats in the region is sparse, with some areas on the lagoon being difficult to reach other than by personal transportation or taxi. The potential for sustainable tourism and eco-tourism across the whole lagoon area is high and the numbers of visitors overall has increased, but there is also low investment and planning in this sector. There has been an increase of 65% in total environmental protection expenditure since 2011.

14.3.2 Set aside for Vistula Lagoon (Poland)

The resident population has decreased by 20% and employment in the region has increased by 5% percent. Job opportunities are stable across a number of sectors and the outflow of people – particularly the younger skilled generation has slowed down. The required infrastructure for the area has improved and any further improvements which may be required are closely monitored and assessed helping to further initiatives, investment and promotion while maintaining overall sustainability and conservation of the area. Flood management and drainage issues are on-going through supervision and monitoring, carried out jointly by all the local authorities.

Conservation of the lagoon as a Natura 2000 site is well monitored and maintained for any changes. The total agricultural area has decreased by 50% due to set aside, providing essential recuperation of natural resources that in turn generate indirect income through the ecosystem services provided to the region. The local administration actively includes local stakeholder involvement when policies and planning for the lagoon possibly need to be revised. This is coupled with improved inter-municipality cooperation between the local authorities and communities regarding some larger or more widespread issues that could affect the lagoon including potential funding or investment bids. The need to resolve the regulatory imbalances and lack of communication channels between Poland and Russia regarding a number of issues as with, for example, fisheries, are underway and some benefits due to this are already evident. Agro-tourism and eco/sustainable tourism is a growing form of tourism attracting a number of longer term visitors. The number of wastewater treatment plants and sustainable farming practices has steadily increase addressing demand and water quality is very good with algal blooms now becoming a rare event.

Traditional fish stocks are improving (e.g., eel, pike-perch, and salmon) and poaching is kept to a minimum due to heavy fines, increased local awareness of its impact and the introduction of designated no access areas retained for conservation and replenishment of stocks. The number of cormorants living and nesting in the lagoon are regularly monitored and checked. A number of schemes are in place for restocking for example, with juvenile eel and so far are successful with some schemes being run in direct cooperation with the Russians. Local access to the S22 road leading up to the Russian border is improving. There are varying opinions, in favour and against, the plans for a cross-cut across the Spit to gain access directly to/from the sea from the Polish side.

14.3.3 Populating the qualitative scenario storylines with numerical data

The drivers identified in the qualitative storylines were sub-divided into constituents that could be quantified through the use of Eurostat (http://ec.europa.eu/eurostat/data/database) and other statistical compilations. Actual socio-economic, demographic and land use statistical data available on the Case Study Areas (CSAs) were extracted and manipulated by the authors to offer quantified changes to complement the qualitative descriptions provided in each of the sixteen scenario storylines (four per CSA). The first task was to identify the base-line figures and to extrapolate future trends for the 'business as usual' scenarios. These were calculated on the basis of developments during the last 10 to 11 years, depending on the time series for

Table 14.2 Example from Ria de Aveiro on how the qualitative scenarios where transformed to quantitative scenarios.

Drivers	Indicator	Data Source	Code	Baseline	BAU (2030)	Crisis	Managed Horizons	Set aside
GDP	GDP (PPS index)	Eurostat 2011	NUTS 1	77% of EU avg	–10%	–50%	20%	10%
Tourism	Total nights spent	Eurostat 2011	NUTS 2 PT16	5988216	9%	–40%	30%	9%
	No of bed places	Eurostat 2011	NUTS 2 PT16	107297	–5%	–25%	5%	–5%
Numbers	Vouga river drainage basin ppn	Census 2011		961316	6%	–30%	12%	–15%
Numbers	Ria inhabitants	Census 2011		353688	6%	–30%	12%	–15%
Numbers	Total resident ppn	Eurostat 2011	NUTS 2 PT16	2325000	6%	–30%	12%	–15%
	Total ppn	Europop 2008	NUTS 2 PT16	2409000	6%	–30%	12%	–15%
Demography	Crude popn growth rate %	EuroPop 2008	NUTS 2 PT16		3%	–15%	5%	–5%
	% total ppn 65 or over	Europop 2008	NUTS 2 PT16	20.50	10%	30%	0%	15%
	Employment rate 15–64 yo – %	Eurostat 2011	NUTS 2 PT16	66.10	–10%	–40%	15%	–20%
	Unemployment rate total yo %	Eurostat 2013	NUTS 1	17.60	10%	30%	–15%	20%
	Unemployment rate <25 yo %	Eurostat 2013	NUTS 1	42.10	50%	75%	–50%	50%
	Area total land use sq. km	Eurostat 2009	NUTS 2 PT16	28188	–5%	–5%	–5%	–5%
Agriculture	Area agriculture total sq. km	Eurostat 2009	NUTS 2 PT16	8416	–10%	–15%	0%	–50%
Agriculture	Area agricultural excl fallow, kitchen sq. km	Eurostat 2009	NUTS 2 PT16	4619	–25%	–50%	0%	–50%
Agriculture	Utilized area ha	Eurostat 2005	NUTS 3 PT161	26720	–25%	–50%	0%	–50%
	Fallow & abandoned land sq. km	Eurostat 2009	NUTS 2 PT16	3619	25%	50%	0%	50%
Agriculture	Crops (cereal & rice) yield 100kg per ha	Eurostat 2009	NUTS 2 PT16	43	30%	–20%	50%	30%
Agriculture	Irrigation – ha total irrigable & irrigated	Eurostat 2007	NUTS 3 PT161	21620	0%	–30%	15%	–15%
Agriculture	Utilised agricultural area organic in ha	Eurostat 2007	NUTS 2 PT16	36680	100%	–25%	125%	75%
Agriculture – livestock	Live bovine animals	Eurostat 2011	NUTS 2 PT16	195600	–15%	–30%	0%	–50%
Forest	Forestry sq. km	Eurostat 2009	NUTS 2 PT16	12563	0%	–20%	0%	20%
Hunting & fishing	Hunting & fishing sq. km	Eurostat 2009	NUTS 2 PT16	16	–5%	0%	5%	–20%
Settlements	Popn density inhabs/km^2	Eurostat 2011	NUTS 2 PT16	82.4	5%	–20%	10%	–10%
Heavy environmental impact	Heavy env impact sq. km	Eurostat 2009	NUTS 2 PT16	1165	10%	40%	–20%	–50%
Services & residential	Services & residential sq. km	Eurostat 2009	NUTS 2 PT16	2125	5%	0%	20%	–5%
	No visible use sq. km	Eurostat 2009	NUTS 2 PT16	3903	15%	30%	–5%	50%
Environmental protection expenditure – total	Percentage of GDP	Eurostat 2011	NUTS 1	1.38%	65%	–40%	200%	400%

the data. Where possible European Union (EU) NUTS3 data were used, otherwise NUTS2 data were utilised. NUTS data is the Nomenclature of Territorial Units for Statistics produced by the EU and NUTS3 provides data at smaller geographical scales than NUTS2, which in some cases is only provided at the country level. In some cases, for example expenditure on environmental protection, only country level data were used as data was only available at that level. However, other indicators reflecting the main drivers identified required more local data, for example, fishing levels and aquaculture activities. BAU scenarios for the year 2030 were then calculated using a continuation of these trends during the coming 17 years.

Quantification of the other three alternative scenarios were calculated using analyses of conditions in the case areas and the depiction of the future provided in the corresponding qualitative storylines. Examples of the variables used and calculated can be seen in Table 14.2. The quantitative data used related to a number of corresponding features depicted in each of the storylines. The percentage changes provided in each of the scenario columns per CSA (Table 14.2) is the change seen in the corresponding baseline figure provided per attribute listed in the table. Some of these variables were used as the basis for quantitative modelling (see Chapters 15 and 16) and some included in the final refinement of the scenarios, before presentation in poster format to the stakeholders at the final workshops.

14.3.4 Final workshops

The final workshops were discussed at a training session attended by project participants and led by the authors, where different formats for presentation and the ways that data and project results could be discussed. Due to the large amount of data generated in the project the presentations prepared for the final workshops needed to select only a small amount of this data. It was therefore decided that only data representing significant changes in the state of the lagoons or of the socio-economic status of the populations living around them should be used

The primary objectives of the final stakeholder workshops were to provide participants the opportunity for:

- Open discussions, deliberations on and assessment of the four different scenarios presented by the project.
- Putting forward suggestions and recommendations regarding actions that in the participants' minds could be taken to either enhance or deter possible outcomes in relation to a particular scenario presented, or provide a preferred or alternative scenario for the future of the CSA. The content and layout of two scenario posters used during at the final workshop in Mar Menor and in Tyligulskyi Liman are provided as examples (Figure 14.2).

During the final workshops participants were actively engaged in deliberations and forthcoming with their suggestions. Participants provided recommendations regarding actions that in their minds could be taken to either enhance or deter possible outcomes in relation to a particular scenario presented, or provided a preferred or alternative scenario for the future of the CSA, for instance in:

- Mar Menor participants did not have any preferred scenario as their view was that all four scenarios presented had both good and bad points. They provided a comprehensive list of recommendations, based on the scenarios presented, for their own preferred alternative scenario that addressed the following five main areas: agriculture; natural areas; the maritime domain plus fisheries management; water management; tourism.
- Ria de Aveiro participants selected the two scenarios 'Managed Horizons' and 'Set-aside' as a starting point to discuss the most desirable scenarios for the year 2030. However, the participants thought the ideal scenario should be a fifth scenario built on these two scenarios and provided an accompanying list of recommendations on how to achieve that goal.
- Tyligulskyi participants unanimously chose the 'Managed Horizons' scenario, but with the following additions concerning: (i) the need for a gradual transition from the present forms of economy to alternative forms; (ii) addressing ecologically risky activities within the Tyligulskyi lagoon area, that in a number of instances also provide very little in the form of income (e.g., low productivity land); (iii) further recommendations on how to achieve the scenario's aim.

14.4 DISCUSSION/CONCLUSIONS

The participatory process conducted during the LAGOONS project was used to provide stakeholders the opportunity for contributing their input into the process of developing and delivering possible scenarios for the future management of the CSAs within the project. Stakeholder opportunity for input culminated in the final stakeholder workshop, where they took part in open discussions, deliberations on and critical assessment of the four scenarios presented to the participants. These scenarios were formulated and based on: (i) analysis of FG and CJ outputs and subsequent production of qualitative storylines and population of storylines with numerical data; (ii) land use and climate change modelling; and (iii) lagoon modelling of the scenarios, presented to the participants.

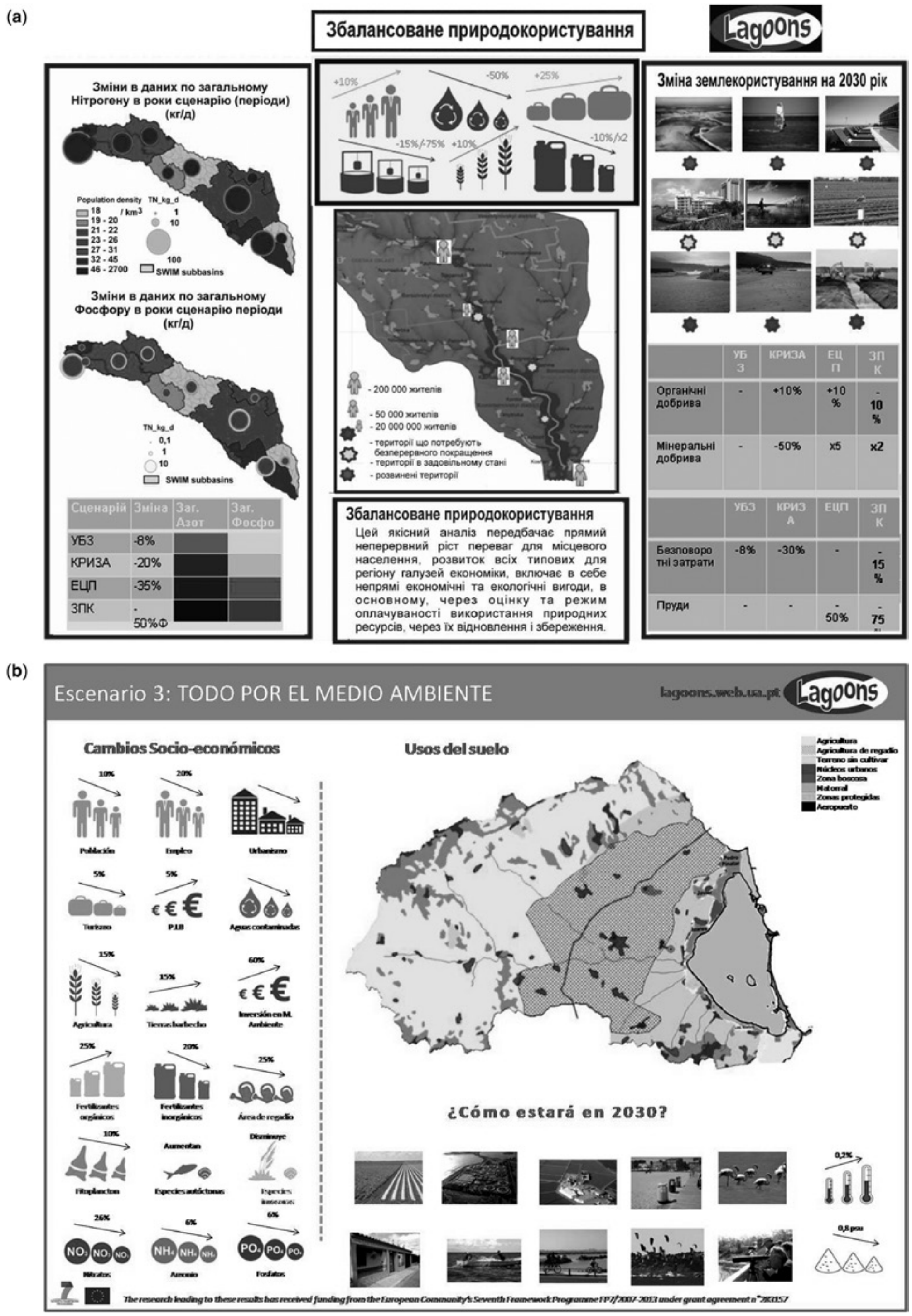

Figure 14.2 Scenario posters used at the final stakeholders workshop (a) Mar Menor; (b) Tyligulskyi.

The objective of the formation and evaluation of the scenarios used and presented by the project at the final stakeholder workshops was to further the provision of knowledge and information required for future water management and policy making in the case areas. This was achieved by combining the output of stakeholder and public deliberative participation along with scientific knowledge, statistics and data based on the qualitative storylines, providing scenarios that were formed through integrated and participatory means.

The initial process of building and developing the scenarios and presenting the scenarios to the stakeholders at the final workshop ultimately provided a set of ideas and recommendations regarding the actions that could be taken to either achieve desired outcomes or deter unfavourable ones by adopting corresponding strategies.

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Chapter 15

Potential impacts of socio-economic and environmental changes in four European lagoon drainage basins

A. Stefanova, V. Krysanova, C. Hesse, S. Turtumøygard, L. P. Sousa and J. A. Soares

Summary: In this study we assessed the impacts of potential socio-economic and environmental changes on water quantity and quality in the drainage basins of four European lagoons. In each case study, four specific qualitative scenarios and narrative storylines were translated into quantitative scenarios, and these were applied to the eco-hydrological model SWIM. We analysed the model outputs in terms of changes in the total freshwater and nutrient (NH_4-N, NO_3-N and PO_4-P) inputs to the Ria de Aveiro (Portugal), Mar Menor (Spain), Tyligulskyi Liman (Ukraine) and Vistula Lagoon (Poland/Russia) as well as alterations in groundwater recharge and actual evapotranspiration rates in the lagoons drainage basins. Depending on the economic development and environmental awareness assumed for the different scenarios and case study areas, the implemented land use and management (concerning agriculture and water) changes showed quite diverse impacts on water resources in terms of tendency (increase/decrease) and impact intensity (high to low impact) for the various components under study.

Keywords: Eco-hydrological modelling, land use and management change, water availability, water quality.

15.1 INTRODUCTION

Socio-economic and environmental changes such as changes in population size, land use patterns, agricultural practices (cropland and livestock) and sewage treatment can affect water resources in river basins and coastal areas by direct influence on water flows and nutrient cycling, as by increased or decreased water abstraction and emission of nutrients from point sources. Changes in the hydrological cycle may have negative consequences for society due to the changed water availability and quality. Therefore, monitoring, analysing and mediating the possible negative environmental consequences of socio-economic changes and, simultaneously, sustaining the usage of essential regional resources is a major priority for policy makers around the world in general, and in coastal areas in particular.

The potential impacts of socio-economic changes have to be assessed in addition to climate change, and in combination with this because their influence on certain hydrologic components may be stronger or even have antagonistic effects than the climate change impacts only. Due to space limitation, in this chapter, we will only show the impacts of socio-economic changes. The climate change impacts for the four lagoon drainage basins are presented in Chapter 13.

So far, the attention of researchers has mostly been focused on investigating land use change scenarios, which partly considered also agricultural practices, for example ploughing methods (Scanlon *et al.* 2008) and their impacts on water resources. There are many published studies, which have explored the impacts of land use change separately, (e.g., Schilling *et al.* (2008), Farley *et al.* (2008)), in combination with climate variability (Favreau *et al.* (2009)), or in combination with climate change (Van Roosmalen *et al.* (2009), Muñoz-Arriola *et al.* (2009), Wagner (2013)). Moreover, Levy et al. (2004) investigated the integrated impacts of future changes in climate, CO_2 concentration, and land use on natural ecosystems and in the terrestrial carbon sink. Other studies have dealt with land use change impacts on water quantity and water quality (e.g., Hesse *et al.* (2008), McMahon *et al.* (2008), Hesse *et al.* (2012)).

The studies on land use change impact done for the Rhin basin (drainage area 1716 km^2) and the Saale basin (24.130 km^2) in Germany (Hesse *et al.* 2008, 2012) have demonstrated how nutrient load reduction can be achieved. The results showed differences between nitrogen and phosphorus loads: nitrate nitrogen was more sensitive to changes in fertilization regime and crop type composition, and for phosphorus as well as for ammonium nitrogen decreased emissions from point sources (sewage treatment plants and industrial effluents) gave the largest load reduction.

The assessment of potential impacts of socio-economic and environmental changes at the drainage basin scale in the four LAGOONS case study areas can be used in the design of future development strategies in the regions under study. The intercomparison of four case studies in this context is beneficial, because it may provide a wider picture of possible environmental implications under various socio-economic and climatic conditions.

15.2 APPLICATION OF SCENARIOS

This section describes the implementation of four different socio-economic and environmental scenarios to the drainage basins of the Ria de Aveiro (see Chapter 3), Mar Menor (see Chapter 5), Tyligulskyi Liman (see Chapter 7) and Vistula Lagoon (see Chapter 9). It includes a short description of the approaches used to translate the qualitative scenarios into quantitative ones, as well as an overview of the applied scenarios for each case study area. The methodology used for impact assessment is briefly discussed in the last section of this chapter.

15.2.1 Translation of qualitative scenarios into quantitative scenarios

For the purpose of modelling and the assessment of potential changes in water quantity and quality for the four lagoon basins, the storylines and qualitative scenarios presented in Chapter 14 for each case study area were translated into quantitative scenarios with short names: Business as usual (BAU), Crisis (CRI), Managed horizons (MH) and Set-aside (SET). The modifications of the standard SWIM input data (see Chapter 11) comprise two main parts: i) the development of new land use maps and ii) changes of some input parameters for the SWIM model.

The new land use maps were created using a GIS tool. The reference land use grid of each lagoon basin was processed taking into account several factors. The most relevant criteria for changing land use patterns were: soil quality (in terms of water holding capacity), distances to the lagoon and urban areas, morphology of the basin, extent of existing irrigation systems (for Mar Menor only), and rainfall distribution.

Figure 15.1 shows the distributions of the major land use classes in the four catchments for the reference conditions and for each of the four scenarios. The assumptions made for transferring the defined changes into new land use maps are listed in Table 15.1. Examples of new scenario land use maps, one per case study area, are shown in Figure 15.2.

The changes made in the input data for SWIM concerning water management and agricultural practices, were derived based on the assumptions described in Chapter 14. The long-term average annual changes in point sources were estimated using the data on alterations in population sizes, tourism, and level of sewage treatment. Changes in the rates of water abstractions (Ria de Aveiro and Tyligulskyi only) and discharges such as treated effluents from waste water treatment plants (Ria de Aveiro and Mar Menor only) were also calculated using the information on population and tourism. In the case of Mar Menor, changes in the irrigated area were implemented as modifications in the hydrotope structure of the catchment. The irrigation zone of Campo de Cartagena was reduced by excluding areas furthest away from the major irrigation channel and increased by adding areas closest to the same channel. In this way, the share of agricultural hydrotopes within the irrigation zone was reduced/increased according to the numbers defined by local experts for each of the four scenarios. In the case of Tyligulskyi, the effective volume of existing ponds in the catchment was reduced based on recommendations of local experts for the two scenarios seeking environmental sustainability (MH and SET). The agricultural practices for all scenarios and all catchments remained unchanged, with the exception of the amounts of mineral and organic fertilizers that were applied. Table 15.2 summarizes the relative changes in management settings as implemented in the input data for SWIM.

15.2.2 Methodology

The SWIM model (compare Chapter 11) was applied for each lagoon basin, and it was calibrated and validated for daily discharges, and nutrient loadings using empirical data. After this, the SWIM model was run with the reference land use map and the reference management settings, as well as with the four socio-economic and environmental scenarios (four different land use maps in combination with four different management settings) using the same set of forcing climate data. For the assessment of potential impacts, the long-term average annual changes of various water quantity and quality variables for each case study area and each scenario were estimated by calculating the differences between the scenario and the reference model outputs. The results are briefly presented in the next chapter.

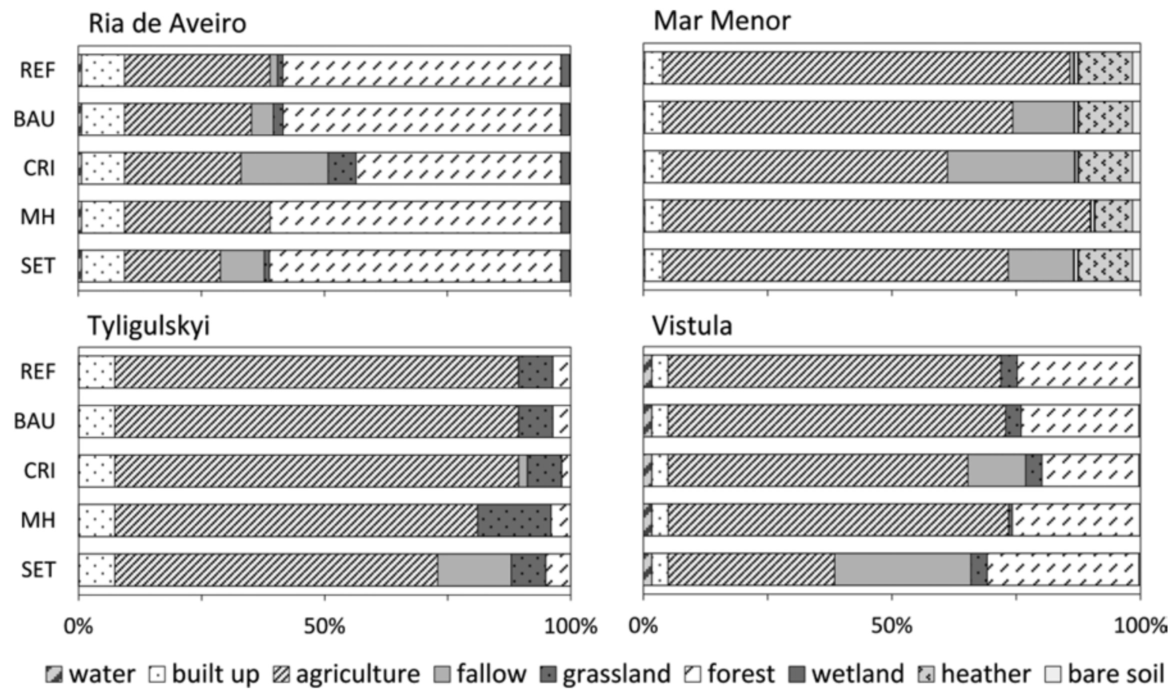

Figure 15.1 Land cover distribution for the reference conditions (REF) and four scenarios (BAU: Business as usual, CRI: Crisis, MH: Managed horizons and SET: Set-aside) for the four case study areas.

15.3 POTENTIAL IMPACTS OF SOCIO-ECONOMIC AND ENVIRONMENTAL CHANGES FOR FOUR LAGOON BASINS

This section shortly presents the model outputs on potential impacts of socio-economic and environmental changes on water quantity and quality in the drainage basins of the Ria de Aveiro, Mar Menor, Tyligulskyi and Vistula lagoons. Water quantity impacts were assessed by long-term average annual trends of major water fluxes. Water quality impacts were evaluated using relative changes of nutrient loads (NO_3-N, NH_4-N and PO_4-P) to the four lagoons.

15.3.1 Impacts on water quantity

The water quantity assessment was based on changes in total freshwater inflow to the lagoons as well as actual evapotranspiration and groundwater recharge rates in the different basins. Some results of the assessment are presented in Figure 15.3.

The smallest percentual change in water discharge was noted for the drainage basin of **Ria de Aveiro**. The land use and management changes hardly influence the water inflow from the catchment, except for the CRI scenario. In this scenario 20% of the forested area is converted to fallow (compare Figure 15.1 and Figure 15.2), which noticeably reduces evapotranspiration. This decrease leads to an increase of runoff generated in the basin and, consequently, to an increase in total inflow to the lagoon. The impacts of changes in water management are negligible for one main reason: water management (reservoirs, wells, irrigation, etc.), under the reference conditions, does not have hydrological relevance for the area and, thus, even changes of 30% (e.g. for water discharges under the CRI scenario) have only very little impact on water resources in the basin.

In the **Mar Menor** basin, the total inflow to the lagoon increased around 15% for both the BAU and MH scenarios, which assume an increase in population size and tourism. The municipal water supply in this basin is ensured mainly through the Tagus-Segura interbasin water transfer system, which is a 286 km long pipeline connecting four different Spanish river

Table 15.1 Assumptions made for the implementation of the defined land use changes and the development of a new land use map for each scenario. (BAU: business as usual, CRI: crisis, MH: managed horizons and SET: set-aside) and each case study area.

BAU	CRI	MH	SET
Aveiro			
Agricultural land (–10%) converted primarily to fallow and also to some extent to grassland; changes on areas close to main river (Vouga) and to the major tributaries (e.g., Aguéda River)	Agricultural land (–15%) and forest (–20%) converted primarily to fallow and to some extent also to grassland; deforestation mainly in central part of drainage basin; abandoned agricultural land in similar areas as in BAU scenario	Fallow and grassland converted to forest (+2.5%); conversion mainly in the 'Bocage' area and partly at mountainous areas close to the basins borders	Agricultural land (–30%) and grassland (–10%) converted primarily to fallow and to some extent also to forest; conversion of agricultural land as in BAU scenario and of grassland areas as in MH scenario
Mar Menor			
Agricultural land (–14%) converted to fallow, primarily in areas with low precipitation rates and outside the irrigation zone, and secondly on soils with low water holding capacity	Agricultural land (–30%) and forest (–20%) converted to fallow; for agricultural land same assumptions as in BAU scenario; deforestation close to urban areas and on soils with low water holding capacity	Fallow (–100%) and heather (–5%) converted to agricultural land, primarily inside Albujon basin and irrigation zone, secondly on soils with high water holding capacity; Heather at high elevations converted to forest (+5%)	Agricultural land (–15%) converted to fallow, primarily in areas closest to lagoon, secondly on soils with low water holding capacity and outside irrigation zone; Heather at high elevations and at largest distance to urban areas converted to forest (+10%)
Tyligulskyi			
No changes	Forest (–50%) closest to urban areas converted to fallow	Agricultural land in northern part of a conservation corridor along Tyligul River converted to forest (+10%), remaining agricultural land (–9%) in corridor converted to grassland	Agricultural land (–20%) in corridor along Tyligul River converted to fallow and to forest (+40%); afforestation primarily in most northern areas on soils with low water holding capacity
Vistula			
Fallow, grassland, forest and wetland on soils with high water holding capacity converted to agricultural land (+1.4%)	Agricultural land (–10%) converted to fallow, primarily on soils with low water holding capacity, secondly on areas with largest distance to lagoon; Forest (–20%) closest to urban areas converted to fallow	Fallow converted to agricultural land (+2%), primarily on soils with high water holding capacity, secondly on areas closest to lagoon; Fallow on soils with low water-holding capacity converted to forest (+5%)	Agricultural land (–50%) converted to forest and fallow, primarily on soils with low water holding capacity, best part of former agricultural land (with highest water holding capacity) changed to forest (+25%), rest converted to fallow

basins: the Tagus, the Júcar, the Segura and the Guadiana. The sewage water is treated in the Mar Menor drainage basin and discharged via a channel to the Mar Menor. Therefore, an increase in population leads to higher effluent rates from the waste water treatment plant and, consequently, to an increase in total inflow to the lagoon. For the CRI and SET scenarios, population and tourism are assumed to decreas and, therefore, less effluent would be discharged into the Albujon wadi (the main river in the drainage basin). Consequently, the inflows to the Mar Menor show a decreasing trend for these two scenarios. The trends in groundwater recharge and evapotranspiration rates reflect the changes assumed for the irrigated area. If the irrigation zone is narrowed around the main water supply channel, less additional water is added to the system and less water is available for evapotranspiration and groundwater recharge, thus, both components are decreasing. If the irrigated area is extended, an upward trend for groundwater recharge and evapotranspiration can be observed.

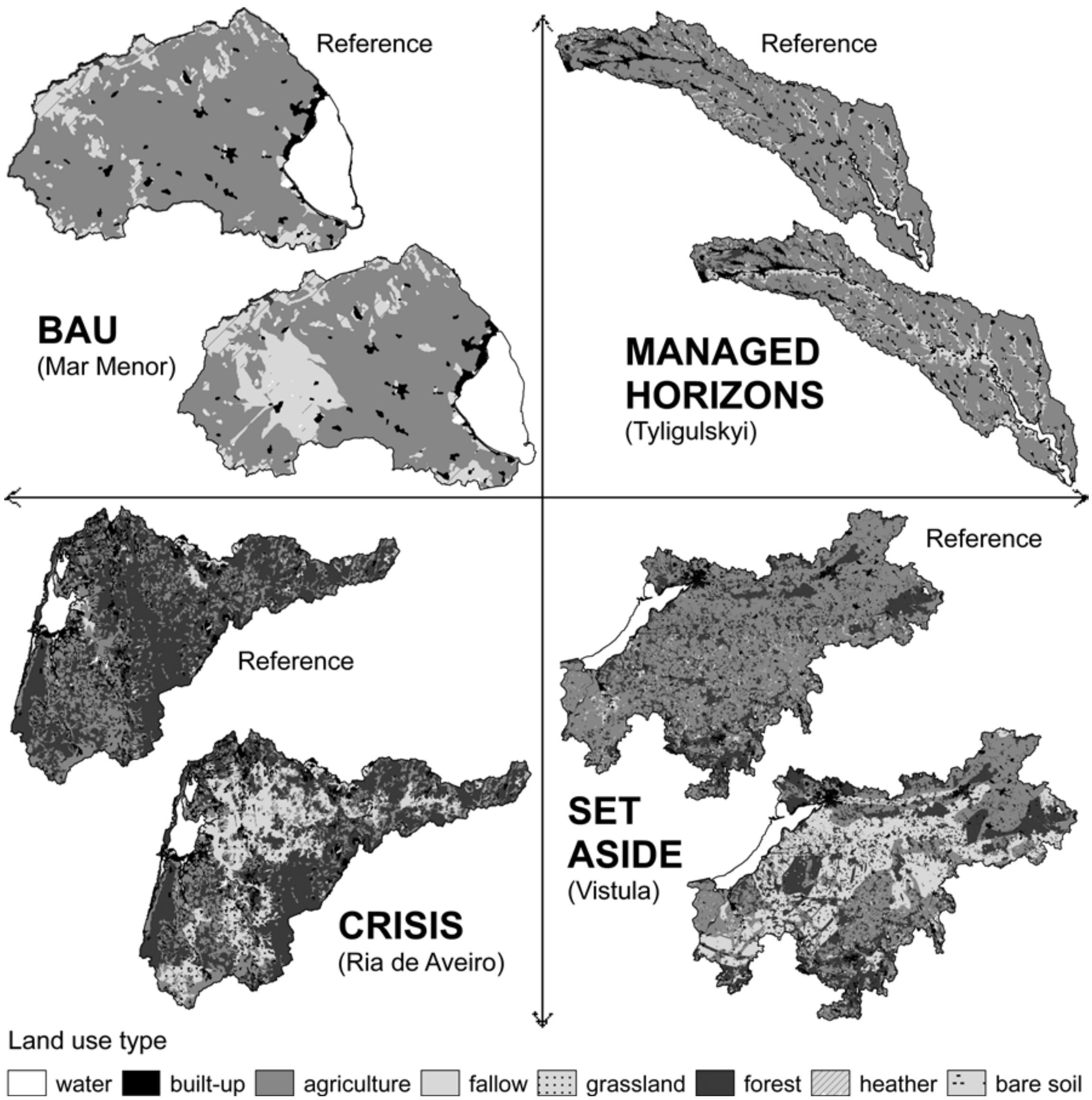

Figure 15.2 Example of land use maps showing the reference land use and one scenario map per case study area- the BAU scenario map for the Mar Menor, the managed horizons scenario map for the Tyligulskyi, the crisis scenario map for the Ria de Aveiro and the set-aside scenario map for the Vistula lagoon drainage basins.

In the drainage basin of the **Tyligulskyi Liman**, the total freshwater inflow increases for all four scenarios. The simulated changes are induced through a combination of various factors. A reduction of the effective volume of the irrigation ponds

(MH and SET scenarios) leads to an increase in river discharge just as a decrease in abstracted water (all scenarios except MH) or the conversion of forested areas into fallow (CRI scenario only). The conversion of certain areas into forest (MH and SET scenarios) leads to a decreasing groundwater recharge and higher evapotranspiration rates at the same time.

Table 15.2 Relative changes (in %) of model settings for point sources, fertilization and water management under four scenarios. (BAU: business as usual, CRI: crisis, MH: managed horizons and SET: set-aside) for the four case study areas.

	Ria de Aveiro				Mar Menor			
	BAU	CRI	MH	SET	BAU	CRI	MH	SET
Point sources	–2	+7	–8	–18	+24	–7	+34	–6
Min. fertilization	+5	–20	–15	–20	–	–20	–15	–20
Org. fertilization	–10	–20	–15	+20	–	–20	+15	+20
Discharge/ abstraction	+6	–30	+12	–15	+28	–20	+10	–10
Irrigation	no irrigation				–22	–45	+5	–25
	Tyligulskyi				**Vistula**			
	BAU	**CRI**	**MH**	**SET**	**BAU**	**CRI**	**MH**	**SET**
Point sources	–8	–20	–50	–35	–10	–30	–40	–35
Min. fertilization	–	–50	+5	+2	–	–10	+100	+10
Org. fertilization	–	+10	+10	–10	–	–10	+300	–
Abstraction	–8	–30	–	–15	–	–	–	–
Ponds	–	–	–50	–75	no ponds			

The total inflow to the **Vistula Lagoon** shows an increasing trend for the BAU and CRI scenarios and a decreasing trend for the MH and SET scenarios. The impacts on water quantity are influenced by land use changes only, as alterations in water management were not assumed for any of the scenarios. Deforestation and afforestation have the highest influence on water fluxes in the drainage basin. An increase of forested areas in the MH and SET scenarios contributes to an overall decrease of discharge and groundwater recharge, as well as to an increase in evapotranspiration. In the BAU and CRI scenarios, deforestation reduces evapotranspiration and increases total inflow and groundwater recharge. In the CRI scenario, however, the overall trend (average over the whole basin) of groundwater recharge is decreasing. This is, because, in this scenario, in addition to deforestation, large areas of agricultural land are would be abandoned and converted to fallow. Fallow has lower groundwater recharge rates, due to a lower vegetation cover and an increased proportion of surface runoff.

15.3.2 Impacts on water quality

The relative changes in nutrients loadings to the lagoons for each of the four scenarios are presented in Figure 15.4.

Similar as for water quantity, land use change and altered management have very little impact on water quality characteristics in the **Ria de Aveiro** case study area. However, some decrease in total nutrient loads to the lagoon can be observed for all parameters and all scenarios. Nitrate nitrogen (NO_3-N) and phosphate phosphorus (PO_4-P) show the strongest decrease (up to 14% for the SET scenario). These two nutrient components are generated mainly by diffuse pollution from agricultural land, and their reduction is a result of the decrease of agricultural land and fertilization amounts. Ammonium nitrogen (NH_4-N) originates primarily from point sources and only to a minor extent from diffuse pollution. The assumed changes in point sources for the four scenarios are rather small, which, in total, leads to a much weaker depletion of NH_4-N compared to NO_3-N and PO_4-P.

In the basin of the **Mar Menor** there are no common trends among scenarios, neither among nutrient components. Nitrate nitrogen decreases in all four scenarios, but the decrease in the SET scenario is the strongest (66%). Although the assumed reduction of agricultural land, irrigated area, and mineral fertilization for this scenario were nearly the same as for the BAU scenario, the impacts on NO_3-N loads to the lagoon are much stronger. The reason for this is the conversion of agricultural land into fallow, preferably on areas close to the lagoon. These changes act as a buffer strip along the lagoon, which retains the nutrients inputs from diffuse pollution. The other two nutrient components (NH_4-N and PO_4-P) are more dependent on changes in population and tourism and hence on changes in point sources. They show an increase in the BAU and MH scenarios, as a result of an increased pollution level from the waste water treatment plant.

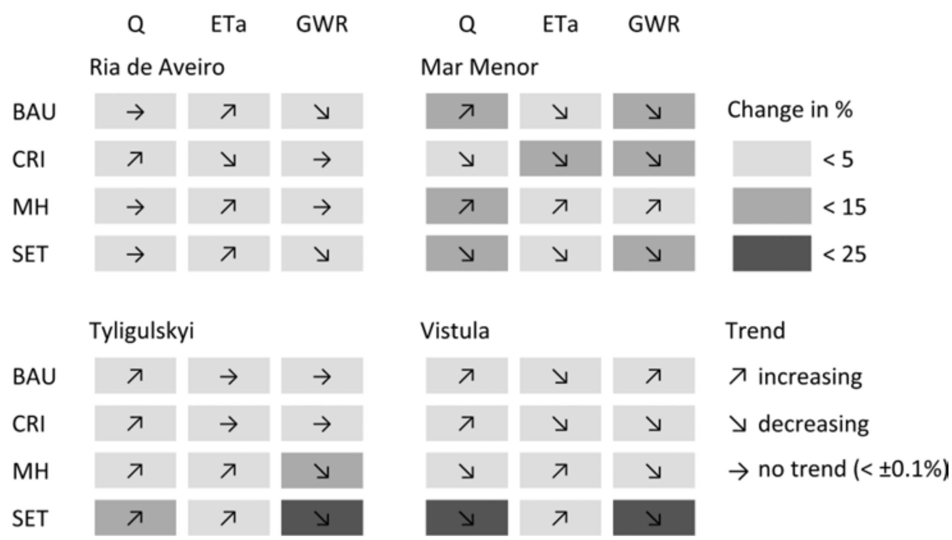

Figure 15.3 Trends in total freshwater inflow to the lagoon (Q), actual evapotranspiration (ETa) and groundwater recharge (GWR) in the lagoon basins under each scenario (BAU: business as usual, CRI: crisis, MH: managed horizons and SET: set-aside) and for each case study area.

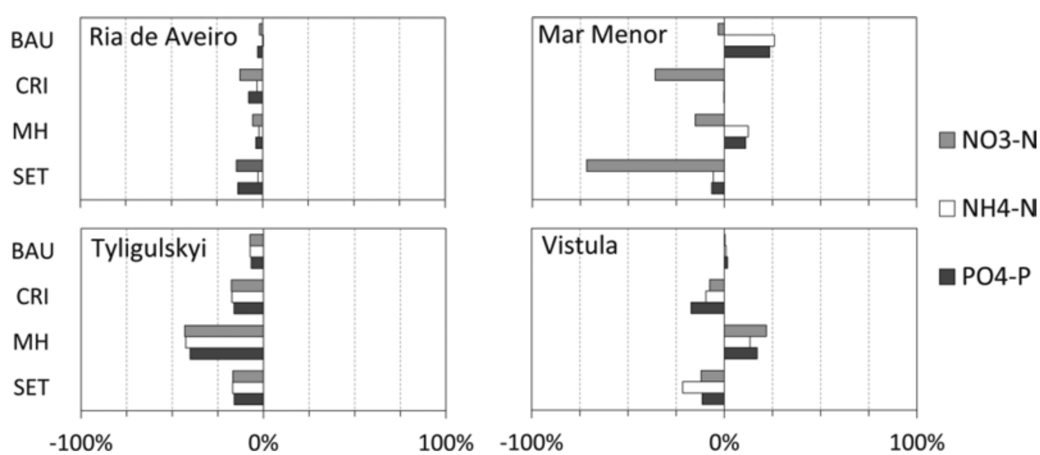

Figure 15.4 Relative changes of total NO_3-N, NH_4-N and PO_4-P loads to each of the case study lagoons under each of the four scenarios (BAU: business as usual, CRI: crisis, MH: managed horizons and SET: set-aside).

The nutrient loadings to the **Tyliguskyi Liman** are strongly influenced by the operation of ponds, as it is already the case for water quantity, but also by the pollution from point sources in the catchment. All three water quality parameters decrease under the four scenarios. The reduction of nutrients is the strongest for the MH scenario, which has the most favourable combination of changes in point sources, diffuse pollution (fertilization and buffer strip along the major river) and ponds management. In contrast to the other drainage basins in our study, the differences between reduction levels of NO_3-N, NH_4-N and PO_4-P are minor, because the regulation of water flows (with dissolved nutrients) through ponds is a prevailing factor in this case.

In the case of the **Vistula Lagoon**, changes in diffuse pollution (area of agricultural land and amount of fertilizers) have the strongest impact on water quality. Nutrient loads are reduced in the CRI scenario, in which lower fertilization amounts and a moderate reduction of the agricultural land are assumed, as well as in the SET scenario, in which slightly higher fertilization rates and a 50% reduction of the agricultural area were defined. The nutrient loads increase in the MH scenario, in which more area is cultivated and, in addition fertilized with much higher rates of mineral (+100%) and organic (+300%) fertilizers. For the BAU scenario the changes in nutrient loads are negligible.

15.4 CONCLUSIONS AND RECOMMENDATIONS

In summary, it can be concluded that the impacts of socio-economic and environmental changes on water quantity and quality were only minor for the drainage basin of the Ria de Aveiro, moderate for the Vistula Lagoon, and quite significant for some scenarios in the Mar Menor and Tyligulskyi Lagoon basin. The latter two are strongly influenced by human activities such as an all-year-round cultivation of irrigated horticulture in the Mar Menor basin and the operation of numerous ponds in the drainage basin of the Tyligulskyi Liman, which explains their strong vulnerability to land use and management changes.

Contrary to possible expectations, the more environmentally friendly scenarios (MH and SET) did not always lead to an improvement in water quality or an increase in river discharge. In the cases of Mar Menor and Vistula, a growing economy and the associated increases in population, number of tourists, and amounts of applied fertilizers per hectare under the MH scenarios led to a decrease in water availability and the deterioration of water quality. At the same time, poor economic conditions and less care about the environment, as defined under the CRI scenarios, led to lower nitrate nitrogen loads to all four lagoons. This improvement of the ecological conditions is the result of reduced fertilization rates in combination with the abandonment of agricultural land. The SET scenario led to less nutrient loads in all four catchments, however looking at total inflow to the lagoons or groundwater recharge in the catchments, the effects are different, depending on other local factors. Based on the changes assumed in this study, it can be stated that the measures and impacts related to the economic development or degradation of the region are clearly stronger than the measures and impacts related to its environmental attitude (towards environmental sustainability or towards environmental degradation).

Nevertheless, the results form a good basis for decision makers, and demonstrate nicely the complexity and uniqueness of each lagoon drainage basin.

In addition to this study, it is recommended to analyse the impacts of land use and management change in combination with climate change. In some cases, climate change may intensify some trends and mitigate others. It can have an opposite effect on certain outputs and completely reverse the direction of change. Furthermore, some changes which were evaluated as positive for the drainage basin, may have negative effects on the lagoon. It is therefore necessary to assess those impacts in an additional lagoon oriented study, before further conclusions can be made.

15.5 ACKNOWLEDGEMENTS

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Chapter 16

Lagoons impact integrated scenarios

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Summary: The impact of combined climate change and socio-economic changes in catchments of four European lagoons: Ria de Aveiro (Portugal), Mar Menor (Spain), Tyligulskyi Liman (Ukraine) and Vistula Lagoon (Poland/Russia) is presented. The influence of four possible socio-economic scenarios on the lagoons' water quality is discussed. The response of the four lagoons to different scenarios was moderate to small. In all cases, Set Aside and Crisis scenarios resulted in some reductions of nutrient concentrations, whereas Managed Horizons and Business As Usual scenarios resulted in an increase of nutrient concentrations. The greatest changes (up to 25%) were predicted in the Vistula Lagoon and the least in the Tyligulskyi Liman (less than 5%) and the Ria de Aveiro (from 8% to –21%). Need for implementation of some adaptation measures is recommended in case the least favourite scenario happens.

Keywords: Climate change impact assessment, socio-economic impact assessment, lagoons and catchments modelling, hydrology, water quality.

16.1 INTRODUCTION

Lagoons constitute important buffering zones between catchments and the sea with respect to water quantity and quality. Due to this fact, they are subject to multiple impacts such as all loads that come from catchments (nutrients, pollutants, floods), but also with impacts from the climate (precipitation, air temperatures, winds, solar radiation) and sea/ocean (storm surges, tides, varying salinity and water temperatures, as well as nutrients and pollutants). Therefore, it is less surprising that so many different influences upon one water basin may result in many ecological problems in the lagoon, and require careful mitigation measures in order to ensure its good water quality and quantity.

Modelling results of how the lagoons may cope with multiple stresses originating from climate change impacts and socio-economic and environmental changes in the catchment will be presented here.

A common procedure for selecting four socio-economic and environmental scenarios was used for all lagoons. Models of all four lagoons were run with the same set of scenarios, with story lines specific for the area and described in Chapter 14. All socio-economic and environmental scenarios were developed for the year 2030, using a typical year from the period 2011–2040 as the climatic input to the models.

16.2 APPLICATION OF SCENARIOS AND THEIR IMPACT ON LAGOONS

This section describes results of application of the socio-economic and environmental scenarios to four lagoons, that is, the Ria de Aveiro, the Mar Menor, the Tyligulskyi Liman and the Vistula Lagoon. Their impacts on water discharges, salinity, nutrients and chlorophyll-*a* changes are discussed. Moreover, modelling results from the socio-economic and environmental scenarios were compared with the modelling results for the typical climatic year selected from the period 2011–2040 (p1), not including any socio-economic and environmental changes since period p0.

16.2.1 The Ria de Aveiro

The typical year for the 2011–2040 period is very similar to the reference typical year for the period from 1981–2010 in terms of atmospheric forcing. Ocean and atmospheric boundary conditions, together with the bathymetry, were kept unchanged from the reference scenario for the 2011–2040 period (p1 climate scenario, Chapter 11). The changes operated in the model were mainly forced by changes at the catchment level (for more details see Chapter 13). The single exception to this was a simulation of chronic leakage in a submarine outfall in the crisis scenario, where expenditure in maintenance was considered sparse (for more details regarding the scenario story lines, see Chapter 14). This, however, had a negligible impact on the modelling results.

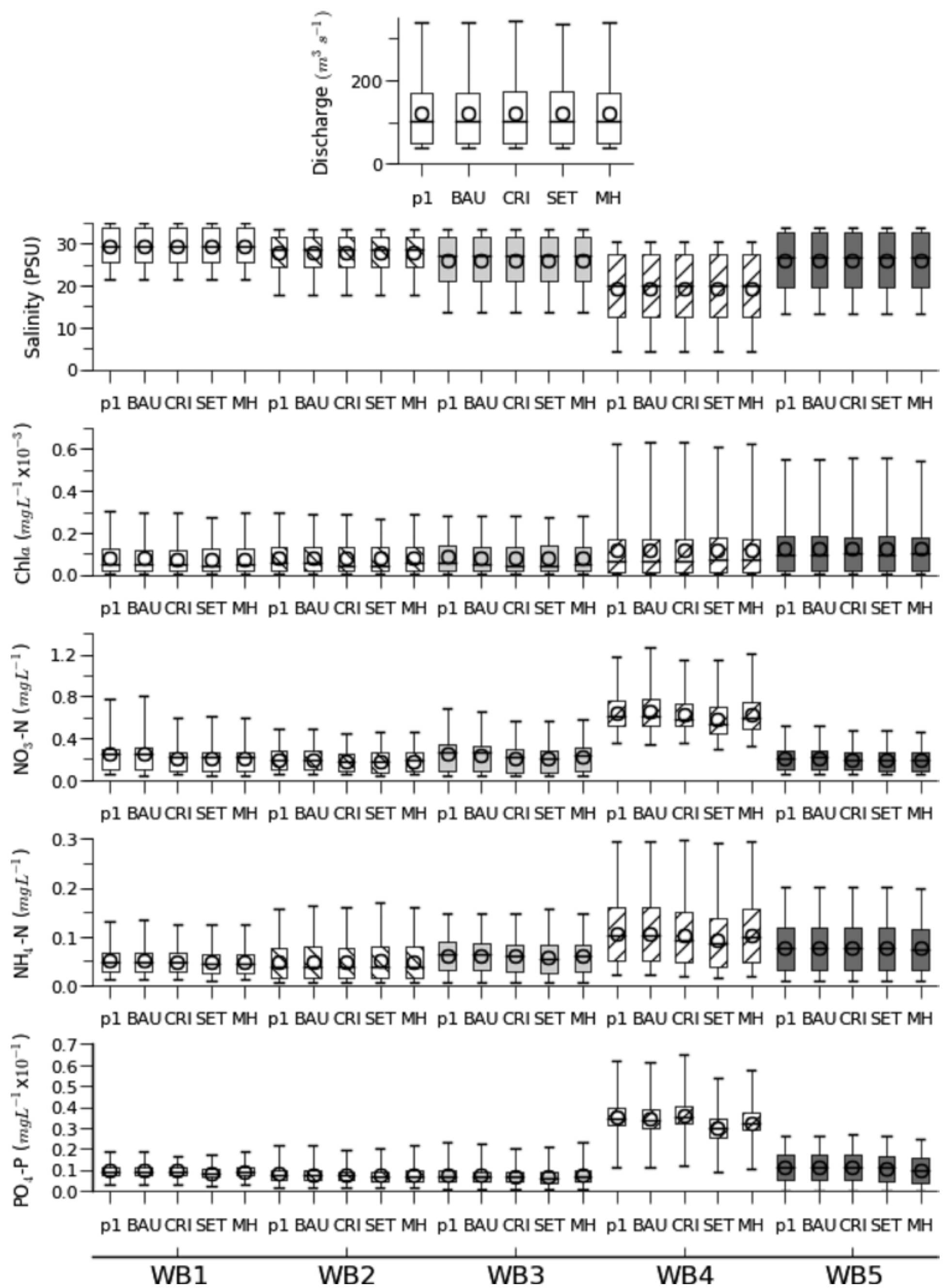

Figure 16.1 Boundary conditions applied in scenarios at rivers (discharges) and modelling results in Ria de Aveiro for the five WFD water bodies WB1-WB5. The box plots show min/max, 25/75-percentile, median and average (circles) of the calculated variables per scenario (BAU, CRI, MH, SET) compared to the reference period p1.

The results are presented in Figure 16.1 separately for the five transitional water bodies (WB1-WB5) defined for the Ria de Aveiro in the scope of the Water Framework Directive (WFD, 2000/60/EC) (for a detailed description of each water body see Chapter 3). Overall, changes in land use in the catchment resulted in negligible changes in total freshwater volume discharged into the lagoon (<1%). This resulted in unchanged salinities for all water masses and socio-economic scenarios. In the Business As Usual scenario (BAU), land use in the catchment expresses the projection of the current behavioural trend to the period of 2011–2040. This is reflected in a very small change in total nutrient load, with a maximum drop of ~3% for PO_4-P at the catchment-lagoon interface (range for p1 between 0.01 and 0.06 mgL^{-1}). The consequences of these changes for the BAU scenario are not enough to produce changes in the lagoon, neither for nutrient concentration nor for chlorophyll *a*.

The Crisis scenario (CRI), which corresponds to the abandonment of 50% of agricultural land and a population drop of 20% at the catchment, produces a decrease of ~12% of the total NO_3-N input from the catchment (reference range between 0.4 and 1.2 mgL^{-1}) and a decrease of ~7% of PO_4-P. Figure 16.1 shows that this scenario has the effect of lowering the high end of the NO_3-N concentration in all water masses of the lagoon, yet, no visible change occurs as a consequence of the drop in PO_4-P.

The Set-Aside scenario (SET) simulates an increase of forest area (20%), a decrease of livestock (50%), and a conversion of 50% of agricultural area to fallow. Heavy impact industries also fall by 75% and organic farming increases by 75%. This produces conditions for a drop in nutrient input from the catchment: ~12% for NO_3-N and ~14% for PO_4-P. Such changes lead to a decrease in concentration for all nutrients inside the Ria de Aveiro for this scenario, most notably for the WB4 water body, which includes the Murtosa Channel and the Laranjo Basin.

The Managed Horizons scenario (MH) corresponds to an increase of 125% in organic farming and 50% in irrigation and cereal crops, but no change in total agricultural land. Heavy impact industries drop by 20% and population increases by 10%. These changes result in a decrease of ~8% in NO_3-N and ~4% in PO_4-P loading at the lagoon-catchment interface. These values are not enough to qualitatively change the nutrient balance in the lagoon. Table 16.1 summarizes the relative changes occurring in the lagoon for each scenario and water body, and Table 16.2 presents the range of those changes for each scenario.

Table 16.1 Relative changes [in %] per WFD water body in Ria de Aveiro compared to the period p1: salinity and concentration of chlorophyll-*a*, NO_3-N, NH_4-N, PO_4-P (* – value between –1 and 1).

		Salinity	Chl-*a*	NO_3-N	NH_4-N	PO_4-P
WB1	BAU	*	–1	2	*	–2
	CRI	*	–2	–14	–3	–1
	SET	*	–2	–15	–5	–10
	MH	*	–2	–13	–4	–4
WB2	BAU	*	–1	–1	2	–2
	CRI	*	–1	–10	*	–3
	SET	*	–3	–10	2	–8
	MH	*	–2	–6	*	–3
WB3	BAU	*	–1	–3	*	–2
	CRI	*	–2	–17	–3	–5
	SET	*	–3	–21	–5	–6
	MH	*	–2	–12	–2	–1
WB4	BAU	*	*	3	*	–2
	CRI	*	*	–2	–5	3
	SET	*	*	–10	–13	–15
	MH	*	*	–2	–2	–7
WB5	BAU	*	*	*	*	–1
	CRI	*	*	–8	*	–1
	SET	*	–1	8	*	–6
	MH	*	*	–10	–2	–10

Table 16.2 Relative changes [in %] of discharge and concentrations of Chl-*a*, NO_3-N, NH_4-N, PO_4-P (range of changes) in each of the scenarios, compared to the period p1 (2011 – 2040) (* – value between –1 and 1).

	Discharge	Chl-*a*	NO_3-N	NH_4-N	PO_4-P
BAU	[*, *]	[*, *]	[–3, 3]	[*, 2]	[–2, –1]
CRI	[*, *]	[–2, *]	[–17, –2]	[–5, *]	[–5, 3]
SET	[*, *]	[–3, –1]	[–21, –8]	[–13, 2]	[–15, –6]
MH	[*, *]	[–2, *]	[–13, –2]	[–4, *]	[–10, –1]

16.2.2 The Mar Menor

In Chapter 13, the impact of climate change on hydrodynamics and ecological status was discussed in detail; here, the analysis concentrates on the joint influence of climate change in a typical year in the near future (p1) and the influence of four possible socio-economic scenarios (discussed in Chapter 14).

Temperature, salinity, and water level variations at the connection with the Mediterranean Sea were assumed the same in all analysed scenarios. The basic difference between modelled scenarios regards changes in freshwater and nutrient inputs due to changes in land use in the drainage basin. Despite the differences in freshwater inputs, lagoonal salinity is not expected to vary significantly among the different scenarios due to the small influence of discharges in this particular lagoon. The general decreasing trend predicted for salinity in p1 can be assumed for all the socio-economic scenarios, since this variable is mostly defined by the balance between water exchanges with the adjacent Mediterranean Sea and evaporation rates within the lagoon. The general decreasing trends in nutrient and chlorophyll-*a* concentrations and *Caulerpa prolifera* biomass are also applicable to all modelled scenarios, although certain differences can be observed when scenarios are compared to the typical year of that period (p1).

Changes in land use defined in the BAU scenario promote a certain increase in discharges entering the lagoon. Slight increases in NO_3-N and PO_4-P are expected when lagoonal concentrations are compared to p1. As a consequence of these increased nutrient concentrations, slight increases in chlorophyll-*a* can also be observed. *C. prolifera* biomass displays a slight decrease when compared to the typical year of the analysed period (Table 16.3, Figure 16.2).

Table 16.3 Relative changes [in %] in discharges, concentrations of NO_3-N, PO_4-P, Chl-*a*, and *C. prolifera* biomass compared to the period p1.

Scenario	Discharge	NO_3-N	PO_4-P	Chl-*a*	*C. prolifera*
BAU	24.12	9.10	1.04	4.21	–0.25
CRI	0.28	–8.08	–0.03	0.11	–0.09
MH	11.26	6.67	0.51	1.74	–0.07
SET	–8.18	0.46	–0.26	–1.84	0.16

For the CRI scenarios, no major changes are expected, except for a decrease in NO_3-N concentrations. Despite the dramatic changes in land use and the reduction of water resources available for irrigation defined in this scenario, little changes are expected concerning water quality and ecological status of the lagoon (Figure 16.2, Table 16.3).

The MH scenario predicts an increase in discharges mostly caused by an increase in the use of water resources defined in this scenario, while land uses resemble those of the reference period. A slight increase in NO_3-N and PO_4-P, as well as chlorophyll-*a* concentrations, is predicted, while *C. prolifera* biomass is not expected to change substantially (Table 16.3, Figure 16.2).

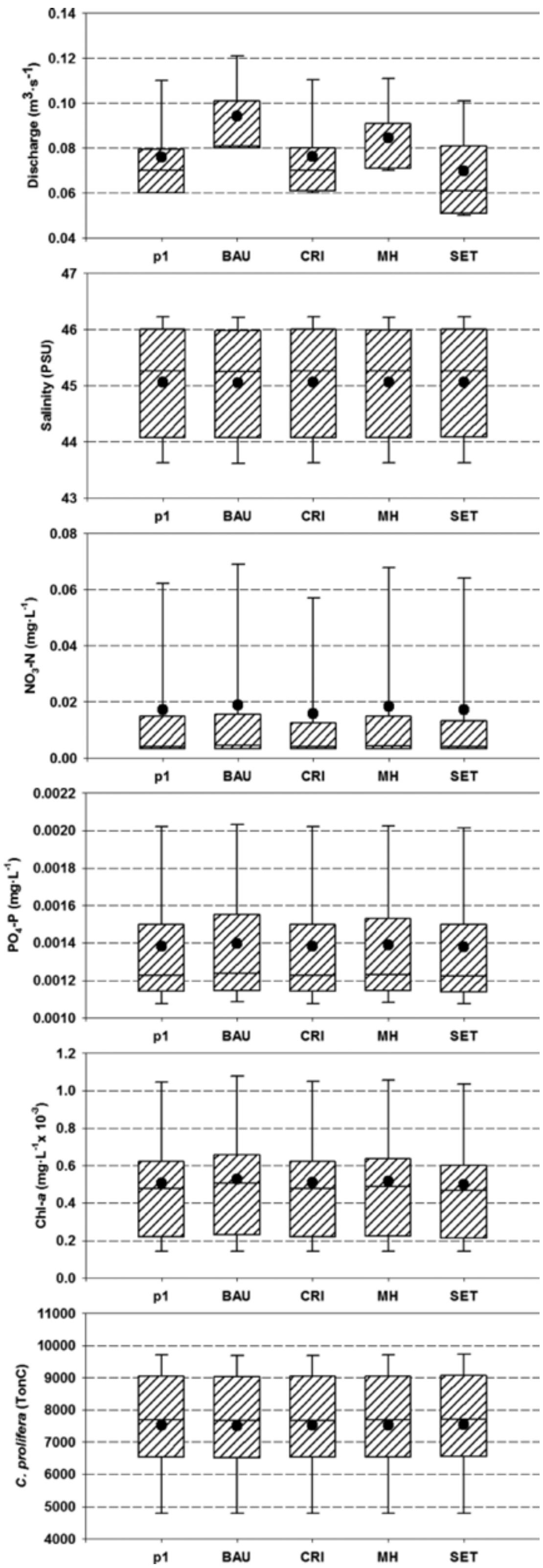

Figure 16.2 Boundary conditions applied in scenarios at rivers (discharges) and modelling results in Mar Menor. The box plots visualize min/max, 25/75-percentile, median and average (dots) of the calculated variables per scenario (BAU, CRI, MH, SET) compared to the historical reference period (p0) and the typical year for 2011–2040 (p1).

The SET scenario predicts changes in land use and the availability and use of water resources that will cause a reduction in water discharges entering the lagoon. Although this reduction does not seem to have an immediate effect on NO_3-N concentrations in the lagoon, which are expected to be the same as in the typical year of that period, PO_4-P concentrations are expected to decrease, and, therefore, chlorophyll-*a* concentrations will be slightly reduced as well. In this scenario, a slight increase in *C. prolifera* biomass is also observed (Table 16.3, Figure 16.2).

16.2.3 The Tyligulskyi Liman

The ecological status of the Tyligulskyi Liman can be influenced by socio-economic conditions in its drainage area as well as a regime of water exchange between the lagoon and the sea through the artificial channel. The socio-economic factors such as land use and water management, define the values of freshwater and biogenic matter inflow. During the last decade, the water exchange with the sea purposed mainly to compensate the deficit of freshwater balance in the lagoon and, as a result, to stabilize its water level and to prevent its shoaling. Under climate change, the use of the channel for fishing purposes was secondary. Therefore, the runoff of water and biogenic matter from the lagoon's drainage area and the regime of water exchange with the sea, are two factors that make it possible to control the ecological status of the Tyligulskyi Liman to some extent.

In this chapter the joint impact of climate change in the nearest future (the typical year for the period p1; 2011–40), together with four possible scenarios of land and water use as well as different conditions of water exchange with the sea, are considered. The hydrometeorological conditions in the lagoon's drainage area and on the sea border of the channel were assumed to be the same in all scenarios. The changes in the runoff of water and biogenic matter due to the different land and water use conditions in the lagoon's drainage area were varied in all scenarios. Figure 16.3 and Table 16.4 show main model results. In Figure 16.3 the phytoplankton biomass (mgC) is presented instead of chlorophyll- *a*, as the model was calibrated based on the observation data of the raw biomass of phytoplankton. The observations suggest that the ratio of mg Chl- *a* /mgC varies considerably during the year. The approximate ratio of mg Chl- *a* /mgC = 0.021 can be used. In the same figure also the annual runoff is presented instead of discharge, because the non-zero (and relatively high) river water discharge into the Tyligulskyi Liman for the scenarios p1, p02, p32 is predicted only during few months.

As it is noticed in Chapter 13, the period p1 is characterized by minimal long-term values of lateral freshwater runoff (just 1.5% of the lagoon's water volume). This feature predetermines the model results. In spite of drastic measures, the impact of socio-economic scenarios in the lagoon's drainage area becomes apparent in its shallow northern part that is the main (more than 90%) recipient of the Tyligul River runoff.

All scenarios consider a increase of river runoff into the lagoon: BAU and CRI – due to a decrease of population and, as a consequence, the reduced water use, MH and SET – due to the 50% and 75% decrease of artificial reservoirs on the lagoon's drainage area. The rate of water salinity increase will slow down, if the latter two scenarios are realized.

The primary production of organic matter in the Tyligulskyi Liman is limited by mineral nitrogen. For the scenarios CRI and MH, the inflow of mineral nitrogen from the drainage area will decrease. These changes will result in the decrease of the mean and most probable concentrations of NH_4-N, NO_3-N, and algae biomass, as well as in the increase of PO_4-P concentration in the northern part of the lagoon. An insignificant increase of mineral nitrogen and algae biomass can be observed in the central (scenario CRI) and southern (scenario MH) parts of the lagoon. For the scenario SET, the inflow of mineral nitrogen into the lagoon will increase up to the values that are representative for the typical year of period p1. Excluding the decreasing water salinity, the model values of the ecological characteristics will return to those, which are representative for the typical year of period p1.

As mentioned above, the water exchange between the lagoon and the sea through the connecting channel can also regulate the ecological conditions in the Tyligulskyi Liman. The channel is mainly used to refill the lagoon with sea water; due to high evaporation rate, the salt is accumulated in the lagoon. The intra-annual variability of the lagoon's water balance was preliminarly analyzed to determine an acceptable operating regime of the channel. The analysis showed that the channel must be operated during a whole year to ensure the salt water outflow from the lagoon to the sea. This scenario is referred to as p1S.

Figure 16.4 shows that the rate of the salt accumulation can be decelerated under the scenario p1S, just like in the SET scenario. Also, the amplitude of salinity variations will decrease in all parts of the lagoon, which positively affects the lagoon's ecological status. Nevertheless, the year-round water exchange with the sea will influence the ecological characteristics of the lagoon in different ways. The concentrations of NH_4-N will decrease in the southern and northern parts of the lagoon, and will increase in the central part. The concentrations of PO_4-P will decrease in the southern and central parts of the lagoon and will increase in the northern part. The mean and most probable concentrations of algae biomass will significantly decrease in the northern part of the lagoon, and will not change in the southern and central parts. Results in Table 16.4 confirm that the most preferable scenario is the one, in which the channel provides the year-round water exchange between the lagoon and the sea. This provides the greatest decrease of water salinity and other hydrochemical parameters.

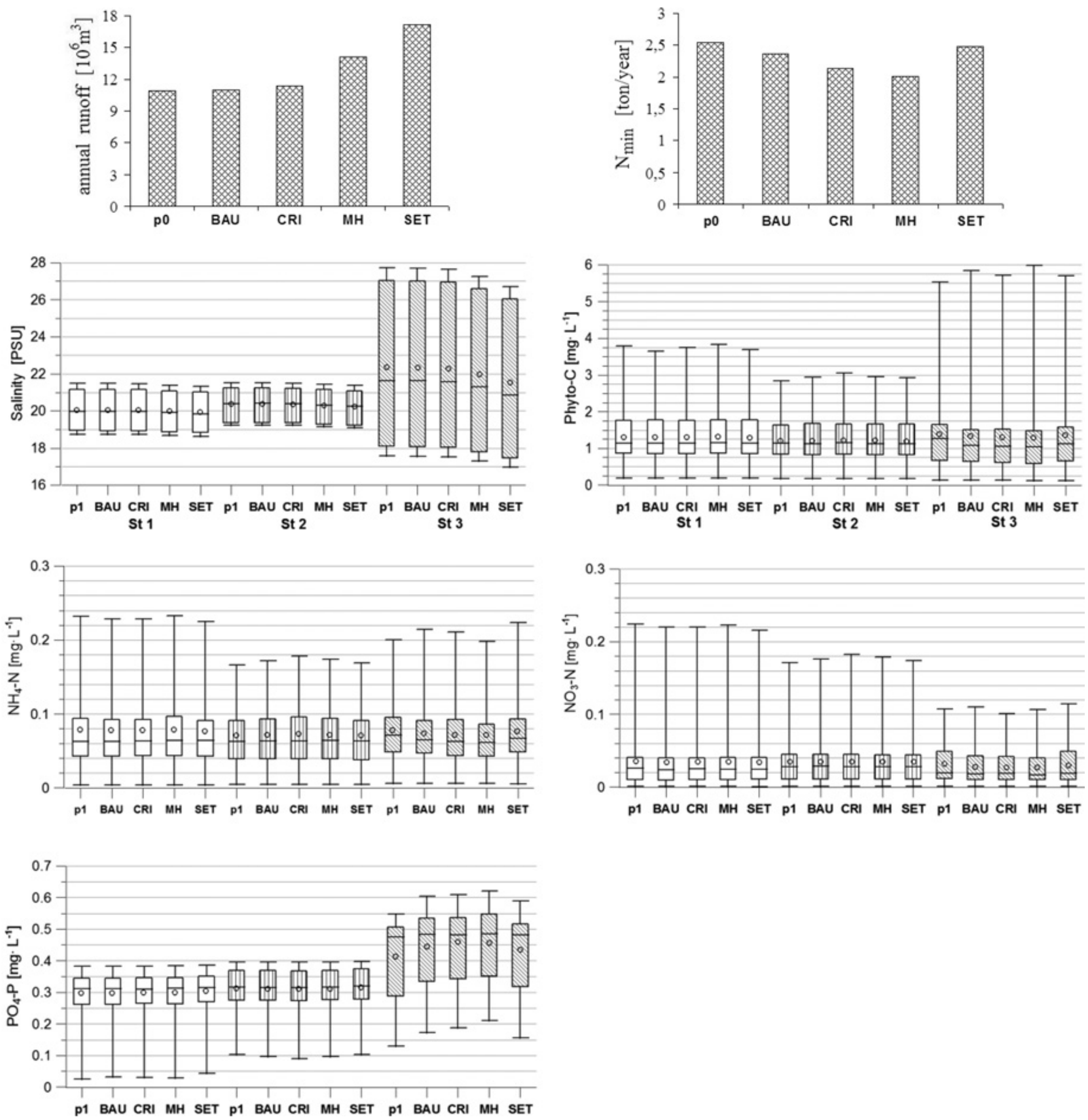

Figure 16.3 Boundary conditions applied in scenarios at rivers (annual runoff and mineral nitrogen load) and modelling results in Tyligulskyi Liman in three locations St 1, St 2, St 3. The box plots visualize min/max, 25/75-percentile, median and average (dots) of the calculated variables per scenario (BAU, CRI, MH, SET) compared to the reference period p1.

Table 16.4 Relative changes [in %] of discharge, concentrations of Chl-*a*, NO_3-N, NH_4-N, PO_4-P and salinity in each of the scenarios compared to the period p1 (2011–2040).

Scenario	Discharge	Chl-*a*	NO_3-N	NH_4-N	PO_4-P	Salinity
BAU	0,90	–0,56	–3,62	–0,56	1,51	–0,02
CRI	4,05	–0,22	–3,18	–0,28	2,13	–0,11
MH	28,61	–0,58	–3,19	–0,58	2,15	–0,60
SET	56,65	–1,14	–2,70	–1,04	2,36	–1,18
p1S	0,00	–2,32	–9,19	–2,12	–2,29	–2,78

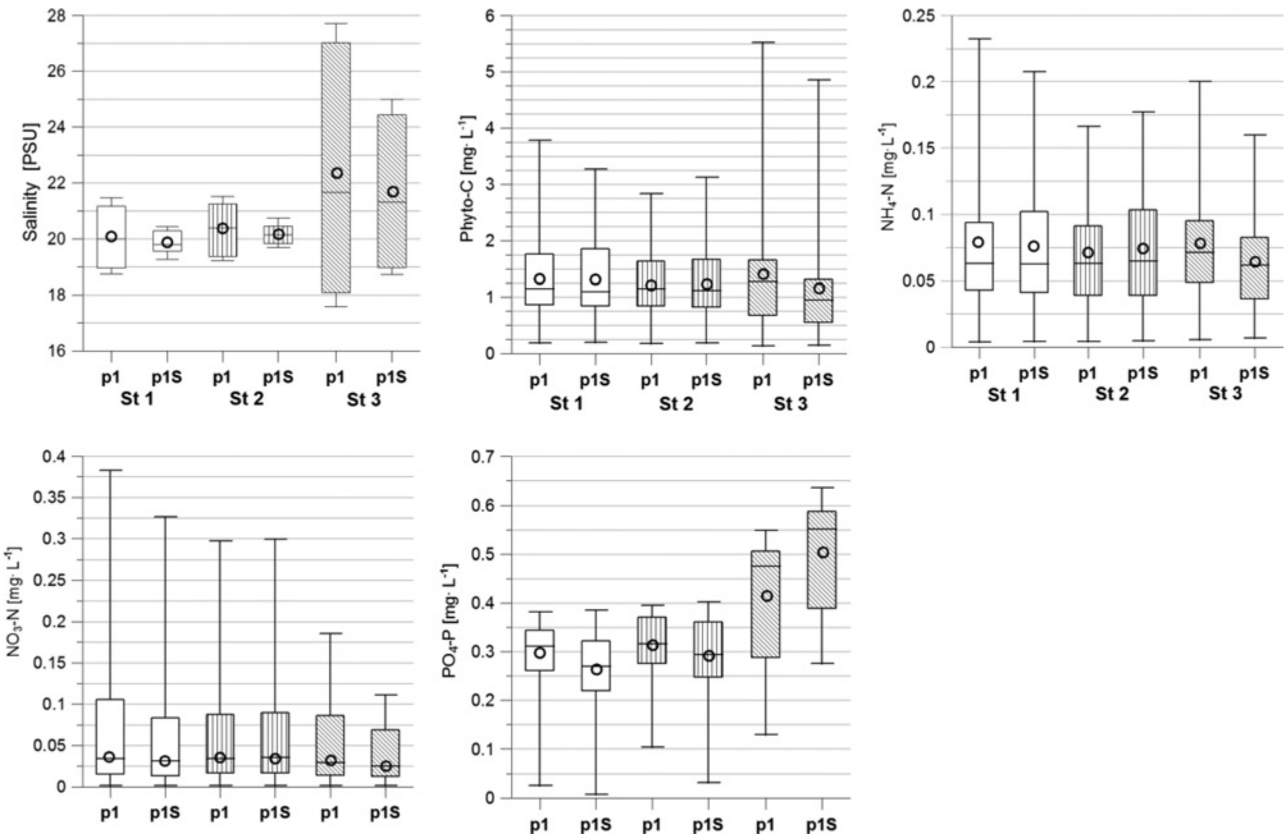

Figure 16.4 Model results of salinity and ecological characteristics in Tyligulskyi Liman in three locations St 1, St 2, St 3. The box plots visualize min/max, 25/75-percentile, median and average (dots) of the calculated variables for scenario p1S compared to the reference period p1.

16.2.4 The Vistula lagoon

Changes in hydrodynamics and ecological status of the Vistula Lagoon discussed in this chapter are a result of possible climate and socio-economic impacts, the latter are reflected through land use changes. In Chapter 13 the impact of climate change is discussed in detail; here, the analysis concentrates on a combined influence of climate change in a near-future period 2011–2040 (p1), together with four possible land use scenarios (discussed in Chapter 14).

Salinity and water level variations at the connection with the Baltic Sea, as well as initial water temperature in the lagoon, were assumed to be the same in all analysed scenarios. The basic difference between the scenarios concerns modified volume and quality of riverine waters due to changes in land use in the drainage basin.

Land use in the BAU scenario resembles very much that in the reference period (p1, see Chapter 13), resulting in similar concentrations of analysed parameters. Compared to the results of scenarios for the climate change, the socio-economic scenarios predict a small decrease of NO_3-N and NH_4-N, while the largest change can be expected for PO_4-P; the concentration of which will increase by 7.12% (Figure 16.5, Table 16.5).

In the Crisis scenario (CRI), the agricultural land (–10%) and forest (–20%) closest to urban areas will be converted to fallow, leading to minor changes in discharge and a small decrease in concentrations of NO_3-N, NH_4-N and PO_4-P. From a Vistula Lagoon ecosystem point of view, the expected changes in the water column can lead to an improvement of water quality status. Results of calculations suggest that, due to reduced agricultural and industrial activities, the most pronounced relative changes can be expected for PO_4-P (Figure 16.5, Table 16.5)

In the MH land use scenario, fallow will be converted to agricultural land (+2%) or to forest (+5%), leading to minor changes in river discharges. Concentrations of all parameters will increase, the most pronounced will be the increase of NO_3-N concentration. The obtained results (based on the assumptions presented in Chapter 14) show that this scenario will be the most unfavourable for the Vistula Lagoon ecosystem. As a consequence, the MH scenario will lead to the highest increase of phytoplankton in relation to all socio-economic scenarios considered (Figure 16.5, Table 16.5).

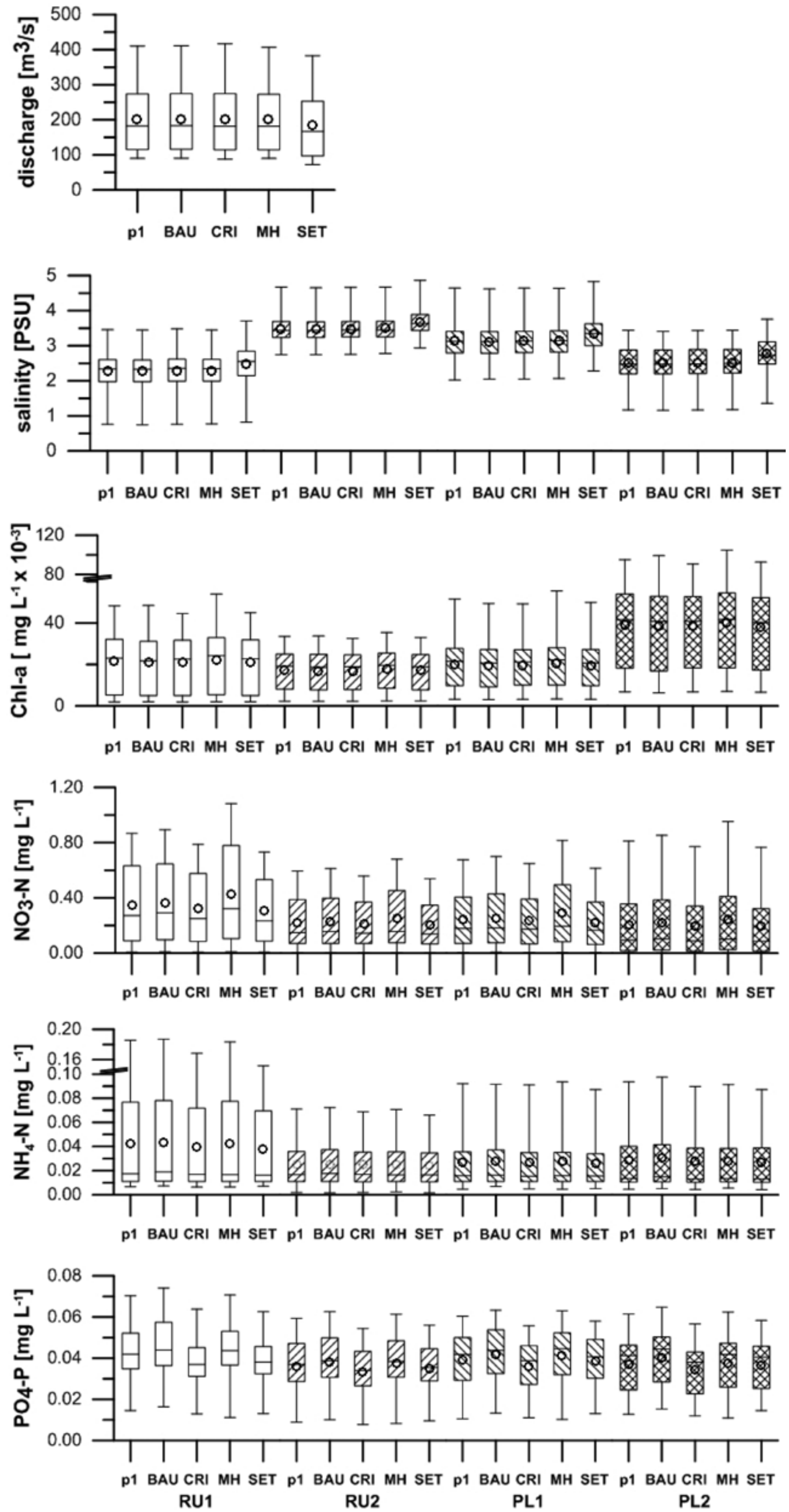

Figure 16.5 Boundary conditions applied in scenarios at rivers (discharges) and modelling results in the Vistula Lagoon at four locations RU1, RU2, PL1, PL2. The box plots visualize min/max, 25/75-percentile, median and average (dots) of the calculated variables in a scenario (BAU, CRI, MH, SET1) compared to the reference period p1.

Table 16.5 Relative changes [in %] of discharge and concentrations of Chl-*a*, NO_3-N, NH_4-N, PO_4-P in each of the scenarios compared to the period p1 (2011–2040).

Scenario	Discharge	Chl-*a*	NO_3-N	NH_4-N	PO_4-P
BAU	0,26	–2,31	4,44	2,92	7,12
CRI	–0,33	–0,18	–9,51	–6,27	–14,73
MH	–0,71	5,08	24,82	2,77	13,19
SET	–7,63	–5,25	–23,60	–5,52	–7,63

The SET scenario is characterised by the largest difference in land use compared to the reference period, leading to a reduction of discharge. As a consequence, concentrations of all parameters will decrease; the largest decrease can be expected for NO_3-N. From the point of view of the Vistula Lagoon ecosystem, the SET scenario is the most favourable. However, it should be mentioned that the obtained results are based on available data and modelling assumptions, taking into account the most recent scientific achievements (Figure 16.5, Table 16.5). A better understanding of natural processes may result in a modification of presented predictions.

It is important to mention that all parameters retain the same quality class as in the reference period (p1).

Such a conclusion indicates that changes in the Vistula Lagoon ecosystem will proceed relatively slowly.

16.3 CONCLUSIONS AND RECOMMENDATIONS

Changes considered in the four scenarios for land use in the catchment draining into the **Ria de Aveiro** produce mild changes in the total nutrient load entering the lagoon. The Ria de Aveiro is a mesotidal lagoon with short flushing time, subjected to semidiurnal and fortnightly cycles of water level and currents. The lagoon's tidal regime serves as an equalizer for nutrient concentrations promoting flushing when nutrient inputs rise, and maintaining a base level through resuspension of the benthic nutrient sources by tidal currents.

Currently, the ecological status of the Ria de Aveiro transitional water bodies (WB) in the scope of WFD, which includes the chemical and biological indicators, is as follow: WB1 and WB3 are classified as 'Good', WB4 as 'Moderate', and WB5 as 'Poor'. WB2 is a heavily modified water body corresponding to the central area of the lagoon with a 'Moderate' potential ecological status (MAMAOT/ARHCentro, 2012). The changes projected by the proposed scenarios are not relevant for the nutrient balance in the lagoon, and chlorophyll-*a* shows no change from the reference conditions. Thus, under these scenarios, the lagoon is not expected to change its current water chemical status.

The analysis of climate driven changes in the **Mar Menor** lagoon presented in Chapter 13 predicts a deleterious impact on *C. prolifera* distribution and survival, as previously stated by Lloret *et al.* (2008), causing an alteration in the ability of the benthos to process nutrients and, therefore, on ecosystem resistance to eutrophication (Lloret & Marin, 2009; Lloret & Marin, 2011). To avoid this extremely undesirable scenario and the appearance of severe eutrophication in the Mar Menor lagoon, it is highly recommended to decrease the amount of nutrients entering the lagoon.

Despite the general decreasing trend in nutrient concentrations observed for the p1 scenario as a consequence of climate driven changes, the different socio-economic scenarios display clear variations in the amount of nutrients entering the ecosystem, and are also reflected in a variation of nutrient concentrations in the lagoon. In this context, the BAU and MH scenarios predict increases in nutrient inputs and concentrations (and even slight increases in chlorophyll-*a* concentrations), and should not be seen as desirable scenarios for this particular area. The cumulative effect of increased nutrient inputs throughout the years could accelerate the appearance of eutrophication in the area and aggravate its consequences. It seems clear that, in order to avoid the undesirable impacts of the increase in economic activities described in these two scenarios, more effective management measures are necessary such as a reduction of the amount/type of fertilizers used for agriculture and a more effective wastewater treatment to reduce inputs. The CRI scenario predicts a certain reduction in nitrate concentrations. However, this reduction does not seem to be reflected in an immediate improvement of water quality parameters in the lagoon, which remain practically the same as those predicted for that period. The marked changes in socio-economic activities and land uses defined in this scenario are not sufficient to effectively reduce the amount of nutrients entering the lagoon. The SET scenario seems to be the most desirable scenario for this area. It predicts a substantial reduction in nutrient inputs and, even though nitrate concentrations in the lagoon seem to remain the same as expected in that period, water quality in the lagoon displays a slight improvement. Changes in agricultural practices as well as the continuous efforts in the management of water resources defined in this scenario, seem to be very effective measures for the improvement of water quality in the lagoon, and prevent future undesirable eutrophication events. Furthermore, the abatement of agriculture in an area immediately surrounding the lagoon seems to be a very effective management strategy that could be applied in other socio-economic scenarios in order to reduce inputs.

Owing to the low lateral freshwater runoff into the **Tyligulskyi Liman** during the period p1, the impact of the scenarios with different land and water uses (even in the case of drastic measures) will only be apparent in the shallow northern part of the lagoon. In case the MH and SET scenarios are to happen, the practical realization of these scenarios requires both considerable expenses and a solution for numerous socio-economic problems.

As a rough approximation, the scenario p1S that provides the year-round water exchange between the lagoon and the sea, is most preferable, due to its relative simplicity and cheapness. However, it has to be additionally investigated as the observations on the variability of ecological characteristics in the sea water near the inlet of the channel are missing.

In case of the **Vistula Lagoon**, eutrophication is presently the most important issue. In this context, all changes leading to reduced concentrations of nutrients are desirable. Taking this into account, the SET scenario will have the most positive impact on the lagoon in comparison with other scenarios being analysed. Also, the CRI scenario predicts a positive impact on the lagoon. The MH scenario will have the worst impact on the lagoon due to the predicted significant increase in nitrate and phosphate concentrations, along with the increase of Chl-*a* concentrations. As a result, more intensive algal blooms should be expected if such a scenario becomes reality.

Based on the obtained results, it is recommended to modify the land use composition in order to ensure an increase of natural retention, as well as a reduction of land fertilization. Environmentally friendly agriculture should be promoted in the Vistula Lagoon drainage basin.

In general, the lagoons' responses to socio-economic scenarios were moderate to small. The greatest changes (up to 25%) were predicted in the Vistula Lagoon and the least in the Tyligulskyi Liman (less than 5%) and Ria de Aveiro (from 8% to –21%). In all lagoons, changes in nutrient concentrations and chlorophyll- *a* were minor and did not exceed 25%. In case of the Mar Menor and the Vistula Lagoon, the MH scenario happened to be the least desirable one. The next least desirable scenario was the BAU. The SET and CRI scenarios were the most desirable scenarios with the greatest nutrient reductions in all lagoons.

16.4 ACKNOWLEDGEMENTS

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Chapter 17

LAGOONS response using key bio-indicators and implications on ecological status (WFD)

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Summary: The Water Framework Directive (WFD 2006/60/EC) requires member states to assess the ecological quality status (EcoQS) of coastal lagoons. This chapter briefly describes the recent environmental changes of the four European lagoons Ria de Aveiro (Portugal), Mar Menor (Spain), Tyligulskyi Liman (Ukraine) and Vistula Lagoon (Poland/Russia); provides a description of the main benthic habitats identified according to the sediment type, presence of macrophyte meadows, salinity and benthic macrofaunal assemblages; and assesses their EcoQS, by means of the M-AMBI index. Results show that a high proportion of the Ria de Aveiro habitats were scored as 'High EcoQ' status. According to the disturbance classification of the M-AMBI index, most of the benthic habitats of the Mar Menor lagoon were classified as 'Good EcoQ'. The shallow sandy habitats of the Tyligulskyi Liman lagoon were classified as 'High or Good EcoQ', but the deepest areas were impacted by periodic anoxia events. In the Vistula lagoon, the benthic biocenosis present in mixed muddy and sandy sediments were classified as 'Moderate EcoQ', while the muddy habitats were classified as 'Poor EcoQ'.

Keywords: Coastal lagoons, Water Framework Directive, M-AMBI index, benthic habitats, benthic assemblages.

17.1 INTRODUCTION

There is an increasing need for reliable detection of environmental disturbance due to anthropogenic pressures in marine environments (Crain *et al.* 2008; Underwood, 1994). Coastal industrial and urban development has lead to an increase of pollution and impacts on coastal and transitional waters, producing changes in the structure and functioning of benthic communities. In response to concerns about environmental degradation, many nations have enacted new legislations to counteract existing anthropogenic impacts. In Europe, two key directives for aquatic systems include the Water Framework Directive (WFD 2006/60/EC) and the European Marine Strategy Framework Directive (MSFD 2008/56/EC). However, where both directives overlap, the MSFD is only intended to apply to those aspects that are not already covered by the WFD. The WFD requires member states to assess the ecological quality status (EcoQS) of surface water bodies; the EcoQS is a numerical value between zero (Bad status) and one (High status). This range is divided into five classes of EcoQS: 'High', 'Good', 'Moderate', 'Poor' and 'Bad'.

The WFD includes metrics of the macrobenthic community, such as the level of diversity and abundance of invertebrate taxa, and the proportion of disturbance-sensitive taxa. The range of biotic indices developed in response to the WFD includes the Azti-Marine Biotic Index (AMBI, Borja *et al.* 2000) and the multivariate AMBI (M-AMBI, Muxika *et al.* 2005, 2007). Although the AMBI can present weaknesses in the inner part of estuaries or when the number of species is very low (see Borja & Muxika, 2005), the addition of a multivariate species richness and Shannon diversity component to the AMBI, called multivariate-AMBI (M-AMBI (Borja *et al.* 2004; Muxika *et al.* 2007)), has allowed for a broader application within the WFD in different countries (Borja *et al.* 2007, 2009). The M-AMBI uses two simple metrics based on well-known ecological theories, Shannon and Wiener's species diversity (H') and richness index (S), combined with a third variable, the AMBI, which relies on a very large knowledge-base about the ecology of individual species: the AZTI list (<http://ambi.azti.es>).

The objective of this chapter is to assess the EcoQS of four European coastal lagoons (Ria de Aveiro, Mar Menor, Tyligulskyi Liman and Vistula Lagoon) using the M-AMBI, and to analyse this index response to anthropogenic pressures *vs* natural variability.

17.2 THE BENTHIC COMMUNITIES IN EACH CASE STUDY LAGOON

Coastal lagoon benthic communities play a key role in environmental health and biodiversity, contributing to provided ecosystem services and the well-being of the surrounding populations. For each case study lagoon, data was gathered as follows: Ria de Aveiro data is based on several sources (AMBIECO, 2011; http://www.biorede.pt/; Rodrigues *et al.* 2011; Nunes *et al.* 2009; and team personal observation); Mar Menor lagoon data is based on the cartography elaborated by the Geographical and Environmental Information System (SIGA) available at www.carm.es and on fieldwork by the University of Murcia; Vistula Lagoon data was provided by the National Marine Fisheries Research Institute (Poland); Tyliguskyi Liman lagoon data was provided by the Odessa Branch of the Institute of Biology of Southern Seas of the National Academy of Sciences of Ukraine.

17.2.1 Ria de Aveiro benthic habitats and species richness

Six major benthic habitats were identified according to: i) the presence of the main macrophyte species (including macroalgae, seagrasses and salt marshes), ii) the salinity system classification of Venice (McLusky & Elliott, 2004), and iii) the benthic assemblages (the five main affinity groups (A, B1, B2.1, B2.2 and C) identified by Rodrigues *et al.* (2011)) such as seagrass and macroalgae meadows, euhaline sandy habitats, polihaline-mesohaline muddy sand habitats, mesohaline-oligohaline muddy sand habitats, oligohaline-limnetic muddy sand habitats, and salt marshes (Figure 17.1). The spatial distribution of species biomass and of species richness is plotted in Figures 17.3 and 17.4, respectively.

17.2.1.1 Seagrass meadows and macroalgae

This habitat is mainly located in the Ovar and Mira channels, having an associated faunal community with high species richness and abundance. The majority of the most important species in this group were amphipods and isopods (Rodrigues *et al.* 2011). Silva *et al.* (2009) indicated that intertidal zones vegetated by vascular plants and macroalgae correspond to ca. 5% of the total area of Ria. Presently, the most representative seagrass species in Ria is *Zostera noltei*. Regarding macroalgae, *Gracilaria* was the most abundant and was present in most of the areas with *Z. noltei*; *Ulva intestinalis* was the most frequent species in areas without *Z. noltei*, but with a low biomass density; *Ulva lactuca* had a comparatively lower abundance, but was occasionally present with high biomass density (Silva *et al.* 2009).

17.2.1.2 Euhaline sand habitat

Characterized by high hydrodynamics due to strong intertidal influence, this habitat had one of the lowest mean species richness (7.2 spp. m^{-2}) and abundance (1300 ind. m^{-2}) values of the lagoon. The most important species are *Spisula solida*, *Microphthalmus* sp., *Pisione remota* and *Pomatoceros triqueter* (Rodrigues *et al.* 2011).

17.2.1.3 Polihaline-mesohaline muddy sand habitat

This habitat had a high mean species richness (16 spp. m^{-2}) and abundance (7900 ind. m^{-2}). The most important species for/in this habitat were *Tharyx* sp. *Tubificoides benedii, Pygospio elegans, Capitella* sp., *Heteromastus filiformis* and *Scrobicularia plana* (Rodrigues *et al.* 2011).

17.2.1.4 Mesohaline-oligohaline muddy sand habitat

This habitat is characterized by a high abundance (7900 ind. m^{-2}) and species richness (9.1 spp. m^{-2}). The most representative species are *Alkmaria romijni, Streblospio shrubsolii,* oligochaetes and *Hediste diversicolor* (Rodrigues *et al.* 2011).

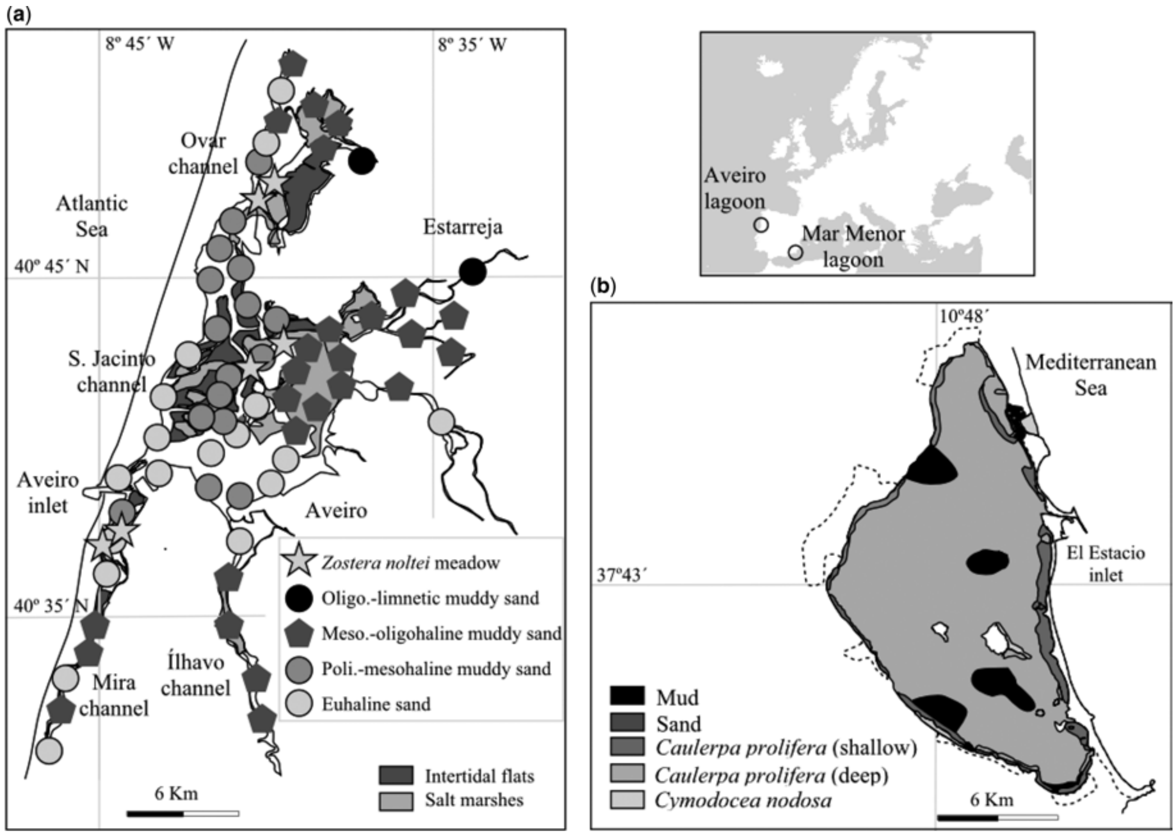

Figure 17.1 Ria de Aveiro and Mar Menor lagoons. Classification of major benthic habitats based on the sediment granulometry and the presence of benthic macrophytes. (A) Ria de Aveiro lagoon, main habitats (modified from Rodrigues *et al.* 2011; Nunes *et al.* 2008); (B) Mar Menor lagoon, main benthic habitats. Note: The positions of the represented symbols are only an indication, they do not intend to represent the exact location or area of distribution.

17.2.1.5 Oligohaline-limnetic muddy sand habitat

This habitat corresponds to the innermost upstream sites of the channels with sediments with high percentage of organic matter, except in the Ílhavo and Ovar channels. The mean species/taxa richness was the lowest of all habitats (less than 4 spp. m^{-2}) as well as the mean abundance (2500 ind. m^{-2}). The most important species was the bivalve *Corbicula fluminea* (Rodrigues *et al*. 2011).

17.2.1.6 Salt marshes

The low marshes are dominated by *Spartina maritima*, whilst the high marshes are dominated by *Juncus maritimus* (for a more detailed description of salt marshes composition, see Chapter 3).

17.2.2 Mar Menor benthic habitats and species richness

According to the classification of major sediment types and the presence of the main macrophyte species and their distribution, five major habitat types can be defined in the Mar Menor lagoon: muddy sediments, sandy sediments, *Cymodocea nodosa* meadows, *Caulerpa prolifera* in shallow areas, and *Caulerpa prolifera* in deep areas (Figure 17.1). The spatial distribution of species biomass and of species richness are plotted in Figures 17.3 and 17.4, respectively.

17.2.2.1 Muddy sediments

This habitat clearly dominates deeper areas of the lagoon occupying most of its surface (note: rocky habitats, although present in the Mar Menor lagoon, are scarce and their presence is limited to small areas mostly close to the islands).

17.2.2.2 Sandy sediments

This habitat is found as a narrow band along the lagoon perimeter. This band becomes wider in La Manga, the sand bar that isolates the lagoon from the adjacent Mediterranean Sea.

17.2.2.3 Cymodocea nodosa

This phanerogam habitat is restricted to small patches in the shallowest areas, with 800 to 1500 shoots per square meter and a positive net recruitment (Marin-Guirao *et al.* 2005b).

17.2.2.4 Caulerpa prolifera

This macroalgae covers approximately 90% of the lagoon's bottom forming a dense monospecific bed. Its biomass represents approximately 18,000 tonnes in dry weight and its distribution per area is quite homogeneous (around 100–150 g DW m^{-2}), although there are some differences between shallow areas with lower biomass per area, and deeper areas that display higher biomass (Lloret *et al.* 2008). These differences are also responsible for notable differences/dissimilarities in the sediment characteristics and invertebrate communities that inhabit these habitats (Marin-Guirao *et al.* 2005a; Lloret & Marin, 2011).

17.2.3 Tyligulskyi Liman lagoon benthic habitats and species richness

According to the classification of major sediment types and the presence of the main macrophyte species and their distribution, four major habitat types can be defined in the Tyligulskyi Liman lagoon: macrophyte meadows, sandy sediments, muddy sediments and muddy-sandy sediments (Figure 17.2). The spatial distribution of species biomass and of species richness are plotted in Figures 17.3 and 17.4, respectively.

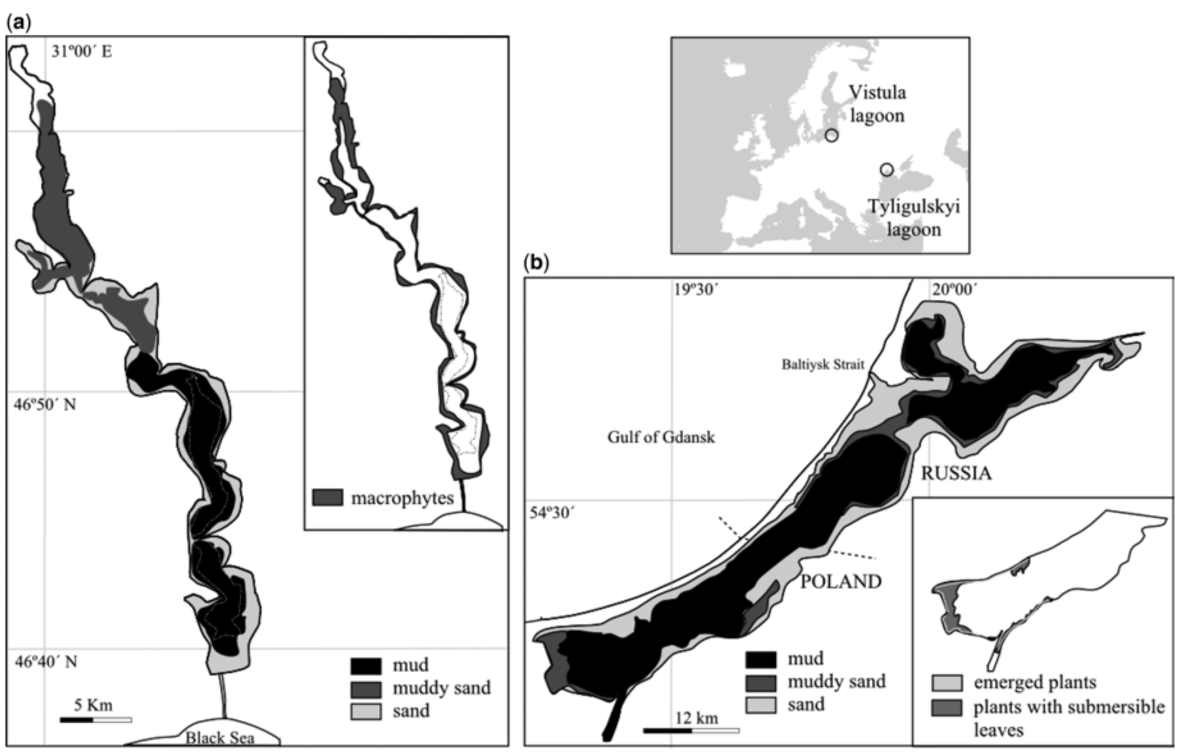

Figure 17.2 Tyligulskyi Liman and Vistula lagoon. Classification of major benthic habitats based on the sediment granulometry and the presence of benthic macrophytes. (A) Tyligulskyi Liman lagoon; (B) Vistula lagoon (the map of the macrophytes covers the Polish part of the lagoon only). Vistula lagoon maps modified based on Gajewski (2010). Note: The positions of the represented symbols are only an indication they do not intend to represent the exact location or area of distribution.

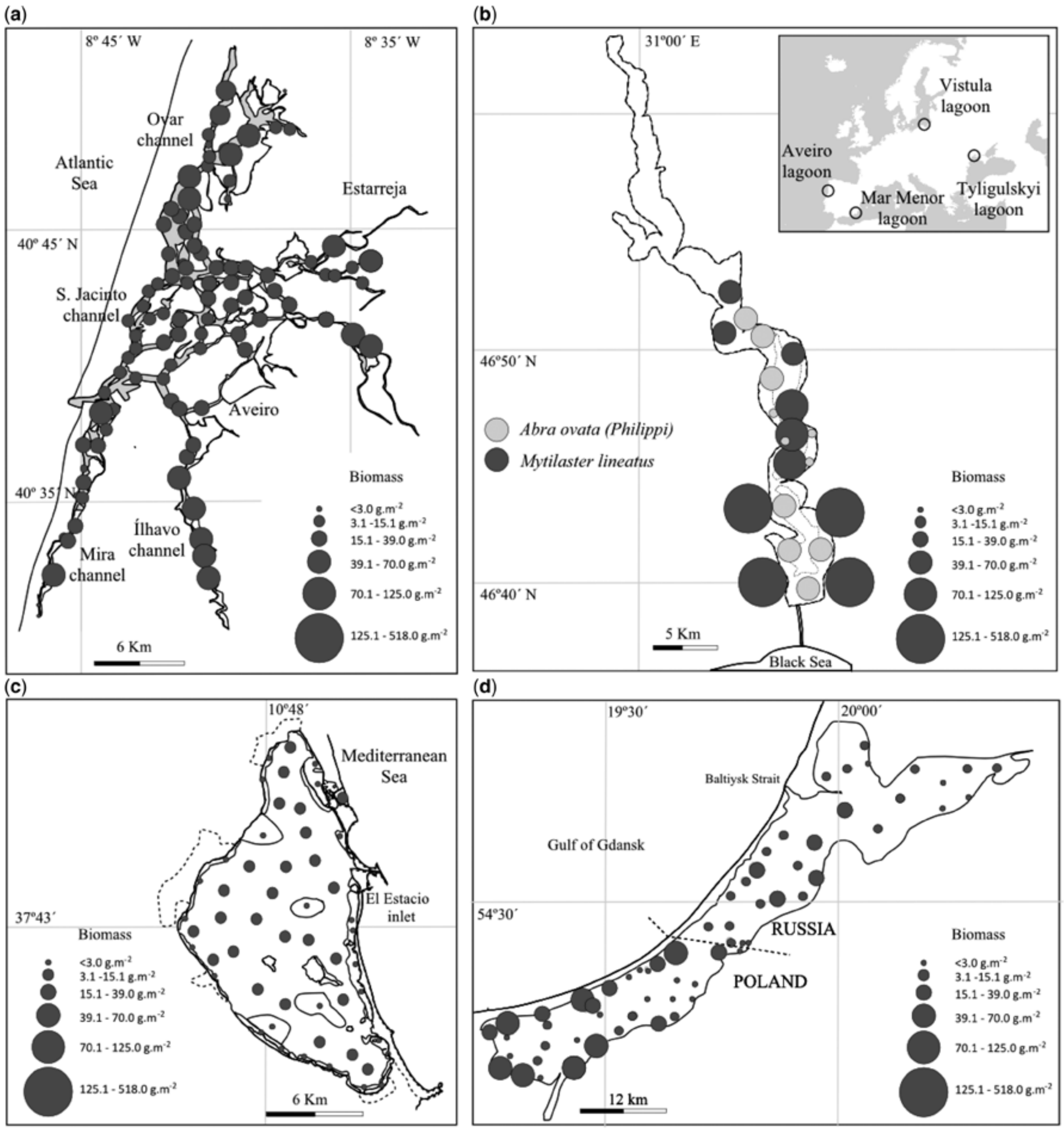

Figure 17.3 Macroinvertebrate biomass distribution in Ria de Aveiro (A) Tyligulskyi Liman (B), Mar Menor (C) and Vistula lagoon (D). In Ria de Aveiro and Mar Menor lagoons, the biomass is referred to the total invertebrate biomass. In Tyligulskyi Liman lagoon is represented the biomass of the bivalves *Abra ovata* and *Mytilaster lineatus*. In Vistula lagoon is only represented the biomass of the non-indigene polychaeta *Marenzelleria* spp.. Note: The positions of the represented symbols are only an indication, they do not intend to represent the exact location or area of distribution.

17.2.3.1 Macrophyte meadows

This habitat is composed of seagrass species (*Ruppia spiralis*, *R. cirrohosa, Zostera noltei* and *Z. marina*), Magnoliophyta species (*Ceratophyllim demersum*, *Myriophyllum spicatum*, *Phragmites australis, Potamogeton pectinatus* and *Typha angustipholia*), and macroalgae (77 species). The salinity of the lagoon waters has the strongest influence on the macrophyte species composition. The southern, deeper half of the lagoon is characterized by the most stable water salinity (salinity: 15–22) and it is here that the greatest species diversity of the macrophytes is observed. In the northern half of the lagoon, depending on the availability and intensity of the Tyligul river runoff, the water salinity during the annual cycle can vary from 0 to 24. As a result, macrophyte species variety in the northern part of the lagoon is almost two times lower than in the southern part.

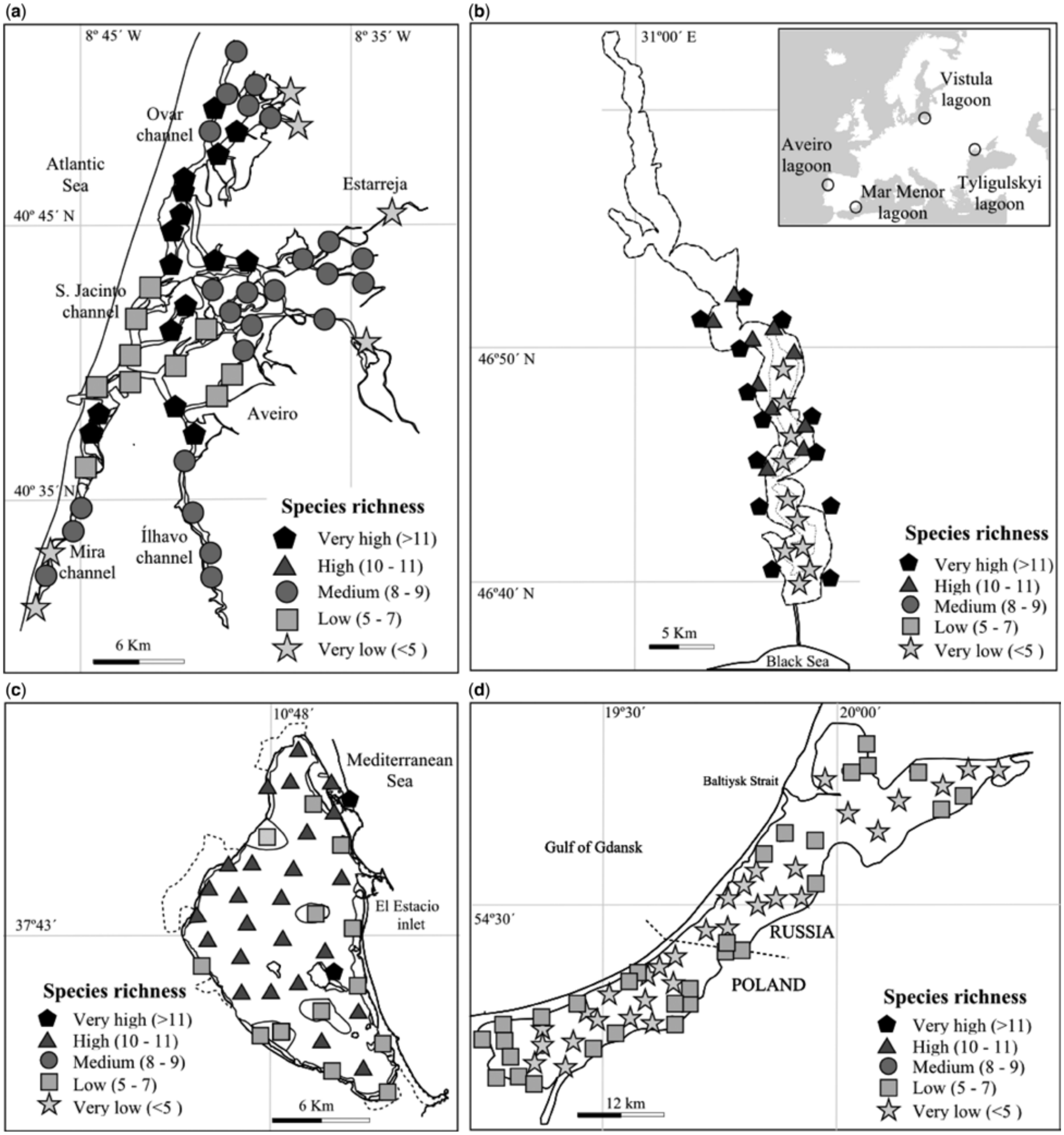

Figure 17.4 Species richness distribution in Ria de Aveiro (A) Tyligulskyi Liman (B), Mar Menor (C) and Vistula lagoon (D). Species richness was calculated as the medium number of invertebrate species per m^2. Note: The positions of the represented symbols are only an indication, they do not intend to represent the exact location or area of distribution.

17.2.3.2 Sandy sediments

This habitat has a higher mean species richness (10.3 spp. m^{-2}) and abundance (20,700 ind. m^{-2}). The most representative species between 0 and 0.5 m depth are the amphipod *Pontogammarus maeoticus*, and the insect larvae *Chironomus salinaris, Chironomus* sp., *Clunio marinus, Cricitopus vitripennis, Eristalis* sp.. The most representative species between 0.5 and 1.3 m depth are *Hediste diversicolor, Polydora cornuta, Hydrobia acuta, Mytilaster lineatus, Cerastoderma glaucum, Abra ovata mollusks, Sphaeroma pulchellum, Idotea baltica basteri, Gammarus aequicauda* and *Chironomus salinaris.*

17.2.3.3 Muddy sediments

This habitat has low mean species richness (6.4 spp. m^{-2}) and abundance (11,500 ind. m^{-2}). The reason for this is the influence of oxygen deficit in the benthic waters, which emerges in the summer period. The more representative species in muddy sediments between 1.3–13.0 m depth are *Hediste diversicolor, Polydora cornuta, Hydrobia acuta, Mytilaster lineatus, Abra ovata* and *Chironomus salinaris*.

17.2.3.4 Muddy-sandy sediments

There is no information about this habitat, but its sediment granulometry composition and the salinity fluctuations due to river runoff suggest that the species richness and abundance could be lower than those in shallow sandy habitats.

17.2.4 Vistula Lagoon benthic habitats and species richness

Based on the classification of major sediment granulometry composition types as well as the spatial distribution and domination structure of the benthic fauna, the following main habitat types can be identified in the Vistula lagoon: Macrophytes, muddy sediments and sandy sediments (Figure 17.2). The spatial distribution of species biomass and of species richness is plotted in Figures 17.3 and 17.4, respectively. Macrophyte habitats can be subdivided in macrophyte habitats with submerged rooted plants (photic mud and sand sediments characterized by submerged rooted plants) and macrophyte habitats with emergent vegetation (photic mud and sand sediments characterized by common reed (*Phragmites australis*)).

17.2.4.1 Macrophyte habitats with submerged vegetation

Submerged plants and the ones with floating leaves cover the largest areas of the bottom in the western part of the Vistula Lagoon and in the nature reserve Elbląg Bay. Their communities are much less developed in the central and eastern part of the Vistula Lagoon, where they usually assemble in the vicinity of the emergent plant communities. The elodeids and nympheids do not occur in the northern part of the Vistula Lagoon. The total area of the bottom covered by the submerged plants and plants with floating leaves is about 28.8 km^2, which corresponds to 9.5% of the Polish area of the lagoon (Kruk-Dowgiałło, 2010).

17.2.4.2 Macrophyte habitats with emergent vegetation

The emergent water plants occur at a major part of the Polish coastal zone of the Vistula Lagoon (Plin´ski, 2005; Chubarenko, Margon´ski, 2008; Kruk-Dowgiałło, 2010). The diversity is low, including only four species (*Phragmites australis, Scirpus lacutrsis Acorus calamus* and *Typha angustifolia*). Common reed (*Phragmites australis*) is the most common species (76% of coverage) and often forms single-species dense and extensive patches. The total area occupied by helophytes is about 6.5 km^2, which corresponds to 2.1% of the Polish area of the lagoon (Kruk-Dowgiałło, 2010). The largest patches and the most diversified in terms of species are localized at the western and south-western coast of the Vistula Lagoon. Helophytes do not occur in the north-eastern part of the Vistula Lagoon along the section from Krynica Morska to the country border, characterized by a high cliff coast.

17.2.4.3 Muddy sediment habitat

There are two main characteristic features of the Vistula Lagoon macrozoobenthos: the domination of euryhaline organisms of marine and freshwater origin and the important share of the non-native species in the total number of macrobenthic taxa (Żmudziński, 1996; Jabłońska *et al.* 2013; Jażdżewski *et al.* 2005). Taking into account the taxonomic composition, abundance and functional structure of macrofauna two main assemblages were distinguished and characterised below: Muddy sediments in shallow areas (1.4–1.9 m), characterized by domination of *Marenzelleria* sp. followed by Oligochaeta nd. and *Chironomus* f.l. semireductus. There is a domination of facultative suspension/deposit feeders (*Marenzelleria* spp.), then deposit feeders. Important share of deeply burrowing bioturbators (*Marenzelleria* up to 30 cm); Muddy sediments in deep areas (2–3.6 m) with domination by *Chironomus semireductus* and then Oligochaeta nd. and *Marenzelleria* spp. There is a domination of deposit feeders (*Chironomus semireductus* and Oligochaeta), as well as facultative suspension/deposit feeders (*Marenzelleria* spp.).

17.2.4.4 Sandy sediment habitat

(0–2.0 m). – Two assemblages of macrofauna characterize this habitat; one dominated numerically by *Marenzelleria* and another dominated by midge larvae (Chironomidae). In terms of functional structure, the facultative suspension/deposit feeder (*Marenzelleria)* and deposit feeders (Chironomidae) dominate.

17.3 THE ECOLOGICAL QUALITY STATUS (ECOQS)

17.3.1 The M-AMBI index

The EcoQS for the four lagoons was assessed by means of the M-AMBI (Borja *et al.* 2009). The M-AMBI is a combination of the proportion of 'disturbance-sensitive taxa' through the computation of the AMBI index (Muxika *et al.* 2005), species richness (it uses the total number of species, S), and diversity through the use of the Shannon–Wiener index ($\log_2$), which overcame the need to use more than one index to evaluate the overall state and quality of an area (Zettler *et al.* 2007). These parameters are integrated through the use of discriminant analysis (DA) and factorial analysis (FA) techniques to determine the position of the sample along a scale linking the 'High' and 'Bad' reference stations (i.e., station EQR – Ecological Quality Ratio – values are expressed as values between 1 and 0). In the current study, reference conditions were set using the highest and lowest values in the datasets for each of the metrics used the calculation of M-AMBI (Borja *et al.* 2009). The EQR scale is divided into five Ecological status (ES) classes (i.e., High, Good, Moderate, Poor, and Bad) by assigning a numerical value to each of the class boundaries allowing ES to be assigned to samples (Muxika *et al.* 2007b). The result varies between 0 and 1, with 1 indicating the best quality. Four thresholds define five categories on this M-AMBI scale: 'High' >0.77, 'Good' 0.77–0.53, 'Moderate'0.53–0.38, 'Poor' 0.38–0.20, and 'Bad' <0.20, identified by/through intercalibration with other methods during the WFD intercalibration exercise (Carletti & Heiskanen, 2009).

The AZTI Marine Biotic Index or AMBI index is based upon the proportions of five ecology groups (EG) to which the benthic species are allocated:

$$\text{AMBI} = [(0 \times \%\text{EGI}) + (1{,}5 \times \%\text{EGII}) + (3 \times \%\text{EGIII}) + (4{,}5 \times \%\text{EGIV}) + (6 \times \%\text{EGV})]\ /100$$

with EG I being the disturbance-sensitive species, EG II the disturbance-indifferent species, EG III the disturbance-tolerant species, EG IV the second-order opportunistic species and EGV the first-order opportunistic species (Grall & Glémarec, 1997; Borja *et al.* 2000). Calculation of the AMBI index was made with the use of AMBI_v5.0_2012 (AZTI – Tecnalia, www.azti.es) software. The index produces a final score on a continuous scale from 1 to 6 (7 in azoic sediments), and five categories define benthic community health (Borja *et al.* 2000): 'Undisturbed' (<1.2), 'Slightly disturbed' (1.2–3.3), 'Moderately disturbed' (3.3–5), 'Heavily disturbed' (5–6) and 'Extremely disturbed' (>6).

17.3.2 A comparative view of EcoQS in the four lagoons

The Ria de Aveiro was the lagoon with a better EcoQS overall score (Figure 17.5). The benthic habitats with high salinity and strong intertidal influence were classified as 'High EcoQS' (Euhaline sandy habitats, Polihaline-mesohaline muddy-sand habitats and Mesohaline-oligohaline muddy-sand habitats). These habitats are also characterized by a high diversity (H´ = 2.8–3.6). The AMBI index shows a predominance of the species of the groups I (disturbance-sensitive species), II (disturbance-indifferent species) and III (disturbance-tolerant species). The macrophyte meadows also showed 'High EcoQS' values with high proportions of disturbance-sensitive species (group I). There was a gradual decrease of EcoQS towards the upstream areas of the channels, where salinities are low due to the freshwater input from the rivers and the drainage channels in the Mira channel. The mesohaline-oligohaline muddy-sandy habitats were classified as 'Good-Moderate EcoQS', while the oligohaline-limnetic muddy-sand habitats were evaluated as 'Moderate' to 'Bad EcoQS'. In addition, Nunes *et al.* (2008) performed a more detailed study restricted to the historical contamination in the 2 km^2 Laranjo basin area close to Estarreja (Figure 17.5), concluding that macrobenthic community structure changed significantly along the mercury gradient (for a more detailed information regarding the Hg historical contamination see Pereira *et al.* (2009)). Results showed that the increase of mercury contamination was associated with reduced total abundance, lower species diversity dominance of taxa tolerant to mercury (Nunes *et al.* 2008).

According to the disturbance classification of the M-AMBI index, a major part of the Mar Menor lagoon can be classified as 'Good EcoQS' (Figure 17.5). The muddy unvegetated sediment and *C. prolifera* covered area are both characterised by sediments with very high silt-clay contents (up to 90% in some cases). These sediments also display very high organic matter contents that favour the appearance of anoxic conditions below the sediment-water interface, and the release of toxic methane and acid volatile sulphide compounds, which, in turn, may affect the survival of some sensitive macrofaunal species. Sandy unvegetated sediments and *C. nodosa* covered areas, restricted to shallow areas of the lagoon, were classified as 'High EcoQS' according to this classification. The colonisation of the Mar Menor lagoon's bottom by the macroalga *C. prolifera* and the subsequent organic matter enrichment of the sediments have promoted a certain degree of disturbance of the benthos. However, the existence of the monospecific bed of the macroalga might also be supporting a complex macroinvertebrate community above the sediment-water interface, therefore favouring a higher/better benthic ecological status in the lagoon, as previously stated by Lloret and Marin (2011).

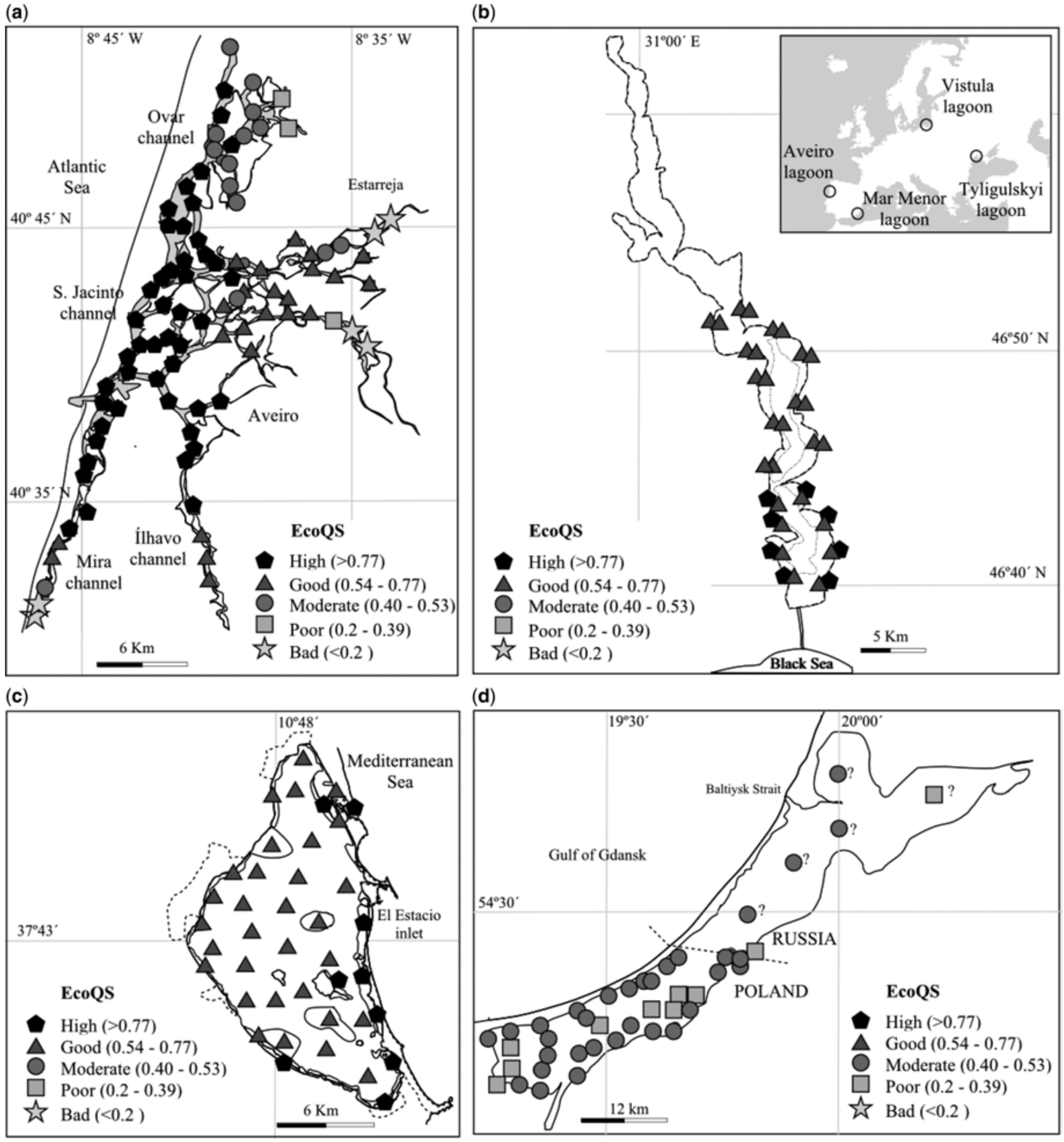

Figure 17.5 The ecological status (EcoQS), calculated with M-AMBI index, in Ria de Aveiro (A) Tyligulskyi Liman (B), Mar Menor (C) and Vistula lagoon (D). In the Ria de Aveiro lagoon EcoQS was recalculated from Rodrigues *et al.* (2011). M-AMBI index of Vistula lagoon was calculated with the invasive species classified in the ecology group V (EG V). Note: The positions of the represented symbols are only an indication, they do not intend to represent the exact location or area of distribution.

The marked extension of macrophyte meadows and sand habitats in the Tyligulskyi Liman lagoon explains the notable species richness (10.3 spp. m^{-2}) and abundance (20,700 ind. m^{-2}) of these well-oxygenated shallow sediments (Figure 17.5). However, the muddy deeper sediments exhibit a low mean species richness (6.4 spp. m^{-2}) and abundance (11,500 ind. m^{-2}) due to oxygen deficit during the summer period. In general, all shallow habitats were classified as 'Good EcoQ', but the area closer to the inlet that provides communication with the Black Sea was assigned as 'High EcoQ'.

Vistula lagoon has the lowest species richness (mud, S = 4.2; muddy sand, S = 6.8; sand, S = 5.7) and diversity (mud, H´ = 1.04; muddy sand, H´ = 1.83; sand, H´ = 1.13) of the four lagoons (Figure 17.5). The most abundant ecological group in the muddy sediments was the disturbance-tolerant species (EG III), while in the sandy and mixed sediments the disturbance-indifferent species from EG II group prevailed. Based on the values of the M-AMBI index, it may be concluded that the lowest disturbance level characterizes the benthic biocenosis in mixed and sandy sediments, while the highest level is typical of the muddy sediment fauna. A similar rating of the disturbance level was obtained on the basis of the diversity indices (H′ and S). However, a second analysis of the M-AMBI index was done with a new classification of species, where the invasive species were re-classified in the ecology group V (EG V) or the first-order opportunistic species (Grall & Glémarec, 1997; Borja *et al.* 2000) (e.g., *Marenzelleria* spp.). The results of the second analysis modified the mixed and sandy sediments to 'Moderate EcoQS', and the muddy habitats to 'Poor EcoQS' (Figure 17.5). It should be stressed that 'poor status' in the muddy sediments is mainly an effect of domination of invasive polychaete: *Marenzelleria* spp. (see Figure 17.3).

17.4 DISCUSSION

The highest benthic diversity and biomass of the four European lagoons Ria de Aveiro (Portugal), Mar Menor (Spain), Tyligulskyi Liman (Ukraine) and Vistula Lagoon (Poland/Russia) were located in macrophyte habitats and shallow sandy habitats. However, these habitats have decreased in the four lagoons mainly due to hydrodynamic changes and eutrophication processes. In Ria de Aveiro, changes in the system's hydrodynamics have altered the tidal prism and increased the water velocity (Picado *et al.* 2010) resulting in the loss of subtidal seagrass meadows, and reducing the intertidal meadow extension and biodiversity of Ria de Aveiro (Silva *et al.* 2004). Along the lagoon salinity gradient and tidal prism, the polihaline-mesohaline muddy sand and mesohaline-oligohaline muddy sand habitats are characterized by a higher abundance and species richness.

In the Mar Menor, the higher water renewal rates from the Mediterranean due to the El Estacio channel and an agriculture derived eutrophication process, have favoured the proliferation of jellyfish and the expansion of the macroalga *Caulerpa prolifera,* confining the traditional phanerogam *Cymodocea nodosa* to small patches in shallow areas. The macroalga *C. prolifera* covers approximately 90% of the lagoon's bottom as a dense monospecific bed with a high species richness and low biomass of associated fauna.

The Tyligulskyi Liman lagoon suffers a gradual hypersaliniation associated to intensive water management in the drainage basin, which has decreased the volume of surface runoff of fresh waters and deficient seawater inflow into the lagoon through the artificial canal. Also, the salinity of Vistula lagoon has increased as result of the Vistula River regulation and changing its course at the beginning of the 20th century as a result of frequent flooding. In addition, there is a considerable process of eutrophication with high primary production (ca. 300 and 180 g C m^{-2} a^{-1} in Polish and Russian part, respectively) (Renk, 2001; *et al.* 2001; Aleksandrov, 2004) and frequent cyanobacteria blooms (Andrulewicz *et al.* 1994). Consequently, the range of macrophyte habitats has been drastically limited (particularly in the Polish area), which is very disadvantageous for fish that use these plants as a spawning substrate or as a fry nursery area.

Regarding the EcoQS for the four lagoons, a high proportion of the Ria de Aveiro habitats were scored as 'High EcoQS'/'High EcoQS'. According to the disturbance classification of the M-AMBI index, most of the bottoms of the Mar Menor lagoon were classified as 'Good EcoQ'. The shallow sandy habitats of the Tyligulskyi Liman lagoon were classified as 'High' or 'Good EcoQ', but the deepest areas were impacted by periodic anoxia events. In the Vistula Lagoon, the benthic biocenosis present in mixed muddy and sandy sediments were classified as 'Moderate EcoQ', while the muddy habitats were classified as 'Poor EcoQ'.

17.5 FINAL REMARKS

The results for the four lagoons using key bio-indicators and the disturbance classification of the M-AMBI index, suggest the following recommendations for management of European coastal lagoons:

- Artificial changes to the systems' hydrodynamics should be avoided, since this could alter the tidal water velocity and change the salinity. Also alteration of freshwater input from the rivers or wadis could modify the salinity of the lagoons. These changes decrease the biodiversity and the singularity of coastal lagoons;
- It is necessary to reduce the eutrophication process and, especially, to prevent anoxia events;
- The shallow habitats (macrophyte meadows and sandy habitats) are especially sensitive to environmental impacts, because they contain a higher diversity and productivity;
- The management of coastal lagoons should take into account the singularity of each lagoon (species composition, salinity gradients, etc.);
- The M-AMBI index should be modified to reclassify the invasive species as first-order opportunistic species to assess the EcoQS.

17.6 ACKNOWLEDGEMENTS

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Chapter 18

ARCH: Architecture and roadmap to manage multiple pressures on lagoons

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Summary: The ARCH research project aims to overcome the boundaries between the multiple scientific disciplines involved in the management of lagoon and estuary systems. The central objective of the ARCH research project is to develop participative methodologies in collaboration with the involved managers, policy makers, and stakeholders to manage the multiple problems affecting lagoons in Europe using ten different case study sites. This will generate realistic solutions and provide roadmaps for their implementation at the lagoon scale. Important components towards this goal include (i) the promotion of an integrated research approach, (ii) the employment of a true participatory process, and (iii) formulating realistic strategies towards sustainable lagoon management.

keywords: Coastal zone management, multidisciplinary science, stakeholder involvement, workshop methodology.

18.1 INTRODUCTION

The European Commission has taken the lead to promote Integrated Coastal Zone Management (ICZM) to balance the management of lagoon and estuary systems. This initiative provides an opportunity to enable stakeholders in the development of management strategies with a basis in both evidence-based science and current policy. The challenge for implementing existing science and policy is the lack of integration and interpretation between the two. The ARCH research project (EU-FP7, 2011–2015) aims to overcome this limitation by consciously minimizing the boundaries between the multiple scientific disciplines as well as by developing participative methodologies to be implemented at ten different case study sites throughout Europe (Figure 18.1).

Lagoons, estuaries, and fjords are characterised by the transition from land to coast and the boundary of land and water, including the transition from fresh water to salt water. They represent highly dynamic systems in both social and natural/physical aspects because of their natural characteristics and human uses (fisheries, tourism, harbour activities, etc.). They are complex social-ecological systems with different kinds of responses and time-place relationships (Folke, 2006). The complex character of the system makes it difficult to predict how the system will respond to policy measures. Subsequently, we can call this type of problem a complex policy problem. Complex policy problems are characterised by the systemic and persistent character of the environmental problem, many interdependencies, a diversity of stakeholder interests, and many different views on the problem. For these complex, often called 'wicked problems' (Rittel & Webber,1973; Jentoft & Chuenpagdee, 2009; Patterson *et al.* 2013), we need a new approach that is aimed at integration of scientific knowledge, stakeholder involvement, and collaborative knowledge production (Slob & Duijn, 2014). These three elements are at the centre of the ARCH-project.

The central objective of the ARCH research project is to develop participative methodologies in collaboration with the involved managers, policy makers, and stakeholders to manage the multiple problems affecting lagoons in Europe. This will generate realistic solutions and provide roadmaps for their implementation at the lagoon scale to ensure their legacy.

Important components towards this goal include (i) the promotion of an integrated research approach, (ii) the employment of a true participatory process, and (iii) formulating realistic strategies towards sustainable lagoon management.

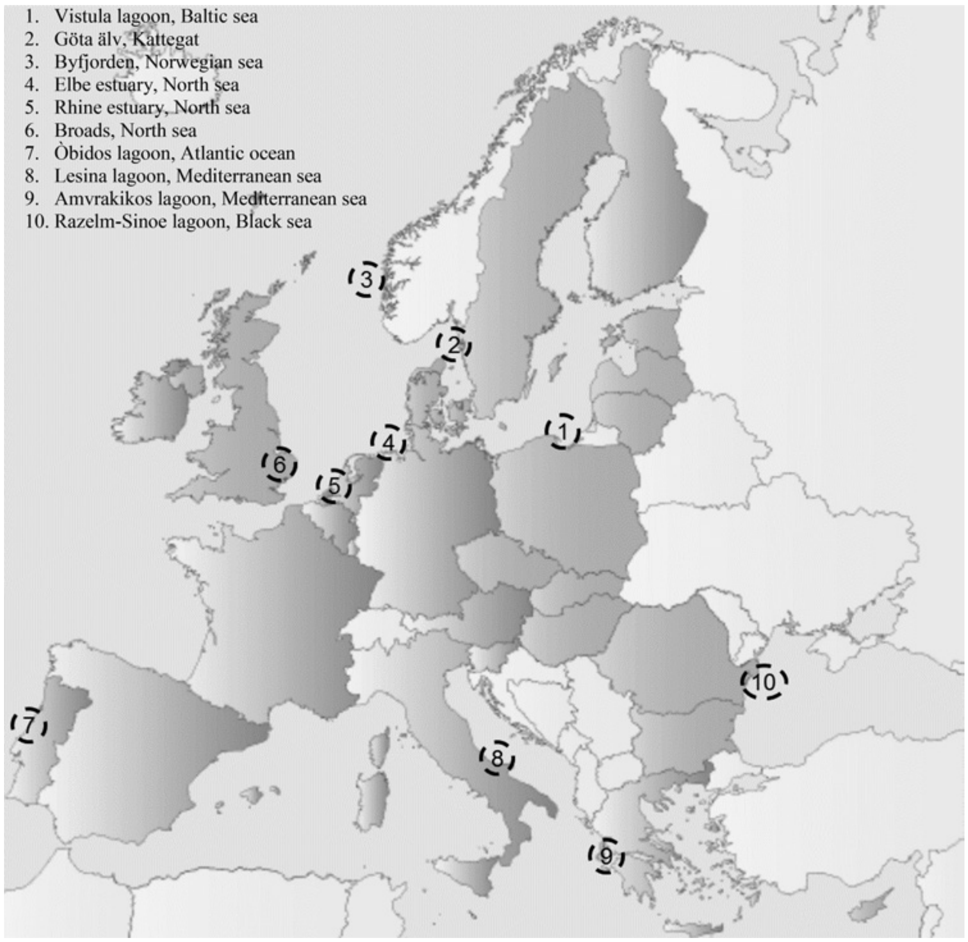

Figure 18.1 Location of case study sites in the ARCH project, Vistula lagoon (1) is also included in lagoons.

18.2 PROMOTION OF AN INTEGRATED RESEARCH APPROACH

The ARCH project itself is organized in order to facilitate knowledge transfer among the partners, representing the environmental, economic and social-sciences. Consortium meetings with all project partners provide a platform for integrating multiple disciplines. Furthermore, the multidisciplinary approach is used to analyse each of the case study sites addressing central elements, as indicated in Table 18.1, to produce a 'State-of-the-lagoon' report.

Since the ARCH ambition has been cross-disciplinary integration, the process of establishing the 'State-of-the-lagoon' framework is an exercise in integrating different disciplines and different fields of expertise. This means a transition:

- From segregated disciplinary scientific results to well-integrated and usable scientific knowledge;
- From 'government' to 'governance';
- From sectorial policies towards sustainable management;
- From an unaware and uninformed 'lagoon community' towards an involved and well-informed community.

The 'State-of-the-lagoon' report proved that such integration, even at the preliminary stage, is not an easy task. This can be observed in the reports, which appear to be biased by the particular disciplinary knowledge and expertise of their authors. Only a few reports provide a balanced description of the natural and human systems, including the socio-economic and governance systems, as well as the interplay between the natural and human systems. This should be treated as strong evidence of the underlying need for changing the nature of EU research and education towards a more interdisciplinary and cohesive approach. In terms of integration, the best results were achieved by the teams which either had some experience of joint working initiatives in ecological and socio-economic fields (e.g., through preparing maritime spatial plans, management plans of ecologically valuable areas) or are working in disciplines that, by their nature, demand a good understanding of both natural and socio-economic processes.

Table 18.1 Structure of the 'State-of-the-lagoon' report (ARCH, 2012).

Main elements to be described	**The natural system** its environmental status, its resilience and main direction of change	**The human system** and its ability to maintain and develop evolutionary resilience	**The human-nature relationship** and relations between the lagoon system and the outside world
Key points for description	• hydromorphological status (separately for rivers and lagoons) • biological status • physico-chemical status • harm by specific pollutants • dynamics and the vulnerability of the natural system	• the place and its history • developmental drivers within human system • the social structure • governance and the institutional structure • vulnerabilities • resources • adaptive capacities	• main pressures and drivers affecting the natural system, exposure of the natural system • forms of nature protection • ecosystem services provided for the benefit of the 'human system' • relations between the lagoon region and the outer world

Overall, we can conclude that the ARCH-project has already achieved a high degree of interdisciplinarity in producing the 'State-of-the-lagoon' reports. With regard to the degree of interdisciplinarity the following observations have been made (ARCH, 2013):

- The scope of the ARCH project has a high level of interdisciplinarity: there are eleven different research institutes involved, covering at least eight different disciplines and crossing social and natural sciences.
- When it comes to the degree of interactive research, the level of interdisciplinarity differs. Some research components have been accomplished in a quite interactive way, leading to interdisciplinary results, while other components have been produced in a less interactive manner, leading to less interdisciplinary results.
- The level of interdisciplinary understanding of the empirical phenomena is relatively high, although this counts more for the overall project level than for the individual case study analyses.
- The ARCH project achieved a relatively high level of interdisciplinary learning. All respondents note that they learned a lot about the project so far, and note that they now more appreciate the relevance and the value of other disciplinary knowledge.

An important function of 'State-of-the-lagoon' reports is to direct the case study teams towards integrated, problem-oriented analysis. The reports have provided a framework for an integrated methodology for assessing the lagoon and estuary regions.

18.2.1 Case study sites and their key issues as identified in an integrated and multidisciplinary process

A summary of the content and issues at each case study site, the policy process, and the local situation indicate that all case studies are in need of complex management plans. This need for management plans is either due to anthropogenic pressures from different sources or due to extraordinary natural or symbolic (cultural, historical) values that require preservation (Table 18.2). The need for complex management plans reflects the trade-offs between current and long-term benefit s, which are present at all case study sites. This is a striking conclusion since the lagoons and estuaries assessed by ARCH differ considerably in terms of characteristics, developmental factors, and endowments. Some case study sites are urban (e.g., Rhine, Elbe, Byfjorden), whereas some are rural in their nature (e.g., Óbidos, Razelm-Sinoe, Lesina). Some lagoons are situated in the most prosperous regions of the EU. On the other hand, others are typical peripheral regions lagging behind in terms of prosperity and well-being of their citizens. However, all case study sites are faced with the same challenge of identifying wise, future-oriented management.

Table 18.2 Key issues at stake at the various case study sites (ARCH, 2013).

Case study site	Engineered lagoons	Urban development, quality of life	Lack of social capital	Lack of management	Nature protection and development	Institutional borders	Fisheries	Harbour development	Climate change and sea level rise	Sediments and eutrophication	Pressures of tourism	Fresh water flows
Vistula lagoon, Baltic Sea			X	X	X	X	X	X	X	X	X	X
Göta älv, Kattegat		X			X	X			X	X	X	X
Byfjorden, Norwegian Sea		X						X	X	X	X	
Elbe estuary, North Sea	X	X			X	X		X	X	X		X
Rhine estuary, North Sea	X	X			X	X		X	X	X		X
Broads, North Sea	X				X	X			X	X	X	
Òbidos lagoon, Atlantic Ocean	X		X	X			X		X	X	X	
Lesina lagoon, Mediteranean Sea			X	X	X	X	X		X	X		
Amvrakikos lagoon, Mediteranean Sea			X	X	X	X	X		X	X		X
Razelm-Sinoe lagoon, Black Sea	X		X		X	X	X		X	X	X	X

Among the specific issues identified in the 'State-of-the-lagoon' reports, the most relevant or the most frequent issues are related to natural capital and its wise exploitation and preservation. Main issues include eutrophication, quality of sediments, and nature protection. This is evidence that the slightly neglected or underestimated issue of supporting and regulating ecosystem services has nowadays become much better recognized, not only in the environmental field, but also in terms of socio-economic development. There is an urgent need for translation of this concept into management routines and procedures.

Another key issue focuses on institutional borders. Even in the case where appropriate management structures have been established, cross-sectorial management is a challenge. The problem is that the processes that should be managed in a coherent way are manifested at a different geographical scale, one that is not closely related to administrative mandates and borders. For example, eutrophication usually occurs at the scale of the lagoon or river catchment, and management measures should therefore be taken accordingly. Tourism pressures, on the other hand, require coordination at local level. On top of that, in many cases there is a sharp distinction between the management of the water body and the surrounding terrestrial areas.

Climate change has been identified as a management challenge in almost all cases regardless of the nature of the lagoon or estuary region. In highly industrialized regions, climate change can jeopardize shipping and port activities, as well as housing. In more rural regions, climate change can be detrimental for fishing and tourism. In all cases, climate change will require financial efforts in order to implement adaptation measures in the future. Although adaptation measures will probably vary between the different regions analysed, they form important challenges in relation to the regional financial base in all types of regions.

18.3 EMPLOYMENT OF A TRUE PARTICIPATORY PROCESS

18.3.1 The process in ARCH

The main objective of the participatory process is to compile 'collaborative roadmaps for local lagoon management' in close interaction with local lagoon managers, policy makers, stakeholders, and scientists.

The participatory methodology, which is employed to achieve this, includes a series of workshops, which are ideally linked to an ongoing policy process in the area.

The scientific 'State-of-the-lagoon' report for each case is the starting point for a joint process that is directed towards (i) problem identification, (ii) sharing knowledge, and (iii) identification of desired solutions. During this whole process, policy makers, stakeholders, scientists, local users, and managers are involved to identify realistic measures at the local scale.

This is accomplished through a sequence of three local workshops (at each case study site):

- *Workshop 1:* 'State-of-the-lagoon' (WS1)
- *Workshop 2:* Future challenges to the lagoon considering climate change (WS2)
- *Workshop 3:* Roadmaps for local lagoon management (WS3)

The discussion in the first workshop focused on the current status of the lagoon, which is based on the 'State-of-the-lagoon' report. The goal of the first workshop was to gain a joint understanding of the present situation and existing problems in the lagoon, especially the linkages between the existing problems. Furthermore, the workshop was aiming at sharing knowledge with all stakeholders involved to enrich the 'State-of-the-lagoon' report with local knowledge.

The aim of the second case study workshop was to look at future developments in the lagoon, based on scenarios as visions for the future (including social, economic and climate change projections), in collaboration with all involved local actors. The discussion focused on the future development of the pressures on the lagoons, as first presented in the 'State-of-the-lagoon' reports.

Finally, the third case study workshop utilized the outcomes from the first two workshops, and, together with the local lagoon actors, participants were involved in a 'back casting' exercise, where they were invited to think of measures that should be undertaken (by them, by authorities, etc.) to reach the desired state of the lagoon in the future. These measures will be discussed and prioritised. Based on the results from this workshop, a roadmap for local lagoon management will be prepared that describes the timeline, the instruments, the measures to implement and the tasks by all involved actors, based on spatial planning methodology.

18.3.2 A true participatory process

To identify the stakeholders at the case study sites, a stakeholder analysis was completed. In this stakeholder analysis, people and organizations were identified that have influence on the issues in the lagoon area, on the policy process and implementation of its outcomes. After identifying the most important stakeholders, some of them were interviewed to discuss the following topics:

- What can the stakeholders contribute to the process?
- What kind of knowledge do they possess?
- What are the relevant interests and goals of the stakeholders?
- How do the stakeholders interpret the issues at hand?
- How well informed are the stakeholders about the issues?
- What are the (possible) motives for stakeholders to participate, or not to participate?

The process itself is designed to best fit the local situation, which means that deviations of the workshop methodology (the follow-up from the present situation to the future, and to the actions) are accepted if this better fits to the actual state of the local discussion or would lead to better outcomes. The process design should facilitate a local discussion and not hamper it. For example, The ARCH project, as well as the LAGOONS project, are both involved at Vistula Lagoon. This required modification of the ARCH workshop methodology in order to provide a more suitable process, and to ensure close collaboration at the case study site level. More details illustrating the need for flexibility in the workshop methodology are provided in section 18.4.

Within the frame of the project, a tailored training was given to the researchers, who wanted to act as facilitator before the stakeholder processes started. In some cases, the researchers themselves acted as the facilitator(s) of the process. In other cases, an independent and experienced facilitator was hired to facilitate the stakeholder sessions. During the training, discussion also touched on 'The five golden rules for stakeholder involvement', which are essential for ensuring a true participatory process:

- Know your stakeholders (e.g., stakeholder analysis as mentioned above)
- Design a process that is transparent and fair
- Respect and appreciate different points of view
- Ensure frequent and open communication and a variety of knowledge input
- Be clear about how decisions will be made and the type of influence stakeholders can have on the decision

In some of the stakeholder processes 'rules of the game' were formulated to enhance transparency as well as to ensure that different points of view were respected and appreciated. These rules of the game could contain process rules for entering and leaving the process, how decisions are made, how information is brought into the process, and how the outcomes will be used in the policy process.

An important aspect of a true participatory process is to define the mandate of the stakeholders and to be clear about how decisions will be made. Input from stakeholders can be ranked to the extent of participation in the policy process. Do we only want to inform the stakeholders or do we want to engage them in the policy making process? The ladder of participation (Arnstein, 1969; Gerrits & Edelenbos, 2004) shows different categories of stakeholder involvement, from only informing them to making joint decisions:

- *Information:* providing information to the stakeholders
- *Consultation:* consult stakeholders to hear what they think that must be done
- *Advising:* stakeholders give advice about the policy or measures that should be taken. Their recommendations should be taken into account by the policy organisation
- *Co-producing:* stakeholders are regarded as equal policy makers but decision-making remains in the political domain
- *Co-deciding:* decision-making power is handed over to stakeholders.

Despite the implementation of the workshop methodology, the actual participation in the ARCH case studies can be characterised as the 'consultation' or 'advising' type of involvement.

18.3.3 Stakeholder knowledge

Different types of knowledge are valuable for complex policy processes. A distinction can be made between the use of procedural knowledge, scientific knowledge, and local knowledge. Procedural knowledge is knowledge about the laws and regulations that are applicable, the procedural stages of these laws or regulations, and the timing of them. Scientific knowledge is the formal knowledge, most of the time encoded in reports or models that can be used to understand the problem or to find solutions. Local knowledge is tacit knowledge of the people living in the area that resembles specific knowledge about the history or other aspects of the area. Stakeholders can bring in all three types of knowledge to the process, but especially the local knowledge is of great importance. In the ARCH workshops, the scientific knowledge was brought in (in a unified way) through the 'State-of-the-lagoon' reports, while stakeholders could bring in their knowledge of the lagoon area.

18.3.4 First conclusions concerning the workshop process

Based on the results of the first and second workshops performed at all case study sites, some first conclusions can be drawn, as at the moment of writing this chapter, the evaluation of the whole workshop process was still in execution. All workshops were successful in reaching their aim of promoting a better understanding of the current environmental state of the case study sites, their key problems, and management challenges. Stakeholders provided valuable information, for instance on the environmental conditions of the sites and on the threats to their natural assets. Stakeholders had the opportunity to share their thoughts on the issues they face and the concerns they have, working and living in the case study sites. This helped the broader group of stakeholders to gain a 'bigger picture', a vision and a better understanding of other stakeholders' point of view, while the organizers were able to identify management problems such as a lack of plans, poor integration and, in some instances, stakeholder conflicts. The constructed futures scenarios can take a number of forms, and the case studies have implemented a number of innovative approaches including narrative construction, interactive games, and editorial cover story writing. Stakeholders gained a better understanding of the management processes during the workshops. While at some case study sites stakeholder involvement processes are standard practice through public consultations (e.g., Göta älv, Byfjorden, Broads), at other sites, these kind of processes have seldom or never been developed (e.g., Amvrakikos lagoon, Razelm-Sinoe lagoon).

Discussions during the workshops were generally constructive. This applies to both those, which were deviating from the ARCH workshop methodology (e.g., Vistula Lagoon) and those, which followed the ARCH methodology (e.g., Göta älv, Byfjorden). The success of both approaches may reflect the fact that the choice of approach was based on what was most suitable to the case study site policy process and the country specific cultural context of the participants. In the workshops where smaller group discussions were held (e.g., Göta älv, Broads), they were deemed useful in ensuring the participation of all attendees. The same consideration applies to the round table discussion format adopted in two workshops (i.e., Amvrakikos lagoon, Razelm-Sinoe lagoon), and to the discussion sessions built around presentations delivered by the participants themselves (i.e., Lesina lagoon). Therefore, the form and content of the deliberation process needs to be carefully tailored to suit the national/regional/local culture, socio-economic circumstances, and governance regime. A 'one size fits all' approach will not succeed.

18.4 FORMULATING REALISTIC STRATEGIES

ARCH is a research project with focus on its practical application in policy. Therefore, emphasis is placed on attaching to an existing policy process at the respective case study sites, which worked out differently at each site. As described above, the case study sites are different in many aspects (see Table 18.2). Additionally, the different case study sites and their respective policy processes are progressing according to different timelines, and, thus, are starting at different phases with regard to stakeholder involvement. These differences, together with the opportunity to connect to an existing policy process, influence the process as well as the outcomes from the process at each case study site. With respect to this distinction, roughly three different types of case studies exist.

One type included the case studies that could make a good connection to an ongoing policy process, and could roll out the three staged stakeholder process as was intended in the ARCH-project. For instance, the Byfjorden case study in Norway was linked to the process of finalizing the local River Basin Management Plan (Sub-district West) that is to be produced in the context of the Water Framework Directive. The three ARCH workshops were executed in a very tight time schedule as to deliver outcomes to be used in the program of measures for the River Basin Management Plan. There were also case studies that followed the ARCH-methodology but failed to make a connection to a policy process, for several reasons. The Elbe estuary case study, for instance, had initially established a link to a process that the Hamburg Port Authority would start to develop an integrated estuary management plan. Although there were several attempts to formally connect to this process, they were unable to do so. In some of the other cases (for instance the Amvrakikos case), a policy process was simply lacking, so there was nothing to attach to. Finally, there were some case studies that made a connection to a policy process, but at the end couldn't follow the complete ARCH-methodology for different reasons. In the Dutch case study, the connection to the policy process that was established in an early stage of the ARCH-project (the Rotterdam area) was lost, due to the fact that the contact point at the policy side accepted a new job. In this case study, new contact points with a policy process at a new site had to be established, which led to adaptation of the workshop methodology. A new topic of the case study was found in the policy process for coastal adaptation and safety. The ARCH-process focused therefore on the options and implementation of the adaptation policies. In another example, the Broads, the case study was linked to a regional process to develop a climate adaptation plan, and the ARCH methodology was therefore adapted. In general, in these case studies, one or two workshops could be organised with ARCH elements in it but, in order to keep a good connection to the policy process, the ARCH workshop methodology had to be modified.

18.4.1 ARCH roadmaps

The ARCH workshop methodology is designed in such a way that the third workshop focuses on interventions and measures that are needed to reach the common vision, and to counterbalance the future risks from pressures on the lagoon. The participants are invited to develop interventions and measures, as well as methods to monitor the development and progress of the lagoon in the future. From these actions a roadmap will be developed. The roadmap is a one to two page visualization of realistic strategies suggested for a case study site including a timeline, connecting actions to the timeline and, if possible, it will present the actions spatially (i.e., on a geographical map).

18.4.2 Evaluating the connection

One of the hypotheses in ARCH is that a better connection to the policy process will generate a better (local) impact, and will generate traceable results in the policy plans or roadmaps. We will test this hypothesis in the final evaluation of the workshop methodology. In all workshops, participants were asked to fill in questionnaires at the end of the workshop as to get their feedback on: what they learned, what elements they appreciate the most, and how the methodology can be improved. Furthermore, the contact points in the policy organisations will be interviewed to find out how results from the ARCH-workshops and the roadmap that has been produced, are taken up in policies. The case study organisers (from the ARCH project team) were asked to fill in a questionnaire about the design of the workshop before its start, and were also asked to fill in a questionnaire after the three workshops to reflect on the methodology. These different types of evaluation instruments make a thorough evaluation of the workshop methodology possible, in many aspects, and will generate insights in the impact of the ARCH methodology. This will deliver valuable results and material for the guide and handbook that will be produced in the last year of the project

18.5 OUTLOOK

ARCH will continue to September 2015, and the last year of the project will focus on synthesizing all documentation from the case study sites. Outputs will include the European Lagoon Management Handbook and Guide for the coastal lagoon manager. The Handbook will contain the workshop methodology, the way to produce the background materials, relevant examples from the 'collected case study histories', experiences with the implementation of the roadmaps, an instruction guide, and relevant training materials. The Handbook is intended as a 'reference book' for lagoon managers, scientists, and facilitators. The Guide will be a short, practical and easy to read document for lagoon managers that will present the specific and generic conclusions from the ARCH-project, including:

- Lagoon/coastal zone management and the challenges (dealing with dynamics, multi disciplines, multi visions (from stakeholders), multi policies, and multi scales)
- Summary of the methodology (referencing the Handbook)
- How to fit the participatory methodology to the policy processes?
- Examples from the case studies
- Conditions for a successful management (conclusions from cases)

Observations during the process include evaluating the integrated research approach as well as drawing on comparisons between the different case study sites to explore how the context of their issues influences identifying opportunities and enabling stakeholders. The ARCH research project builds on these experiences in order to raise awareness and enhance system understanding. Involvement in the selection of management strategies enhances commitment towards implementing feasible solutions at the local scale.

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Chapter 19

European coastal lagoons: an integrated vision for ecosystem services, environmental SWOT analysis and human well-being

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Summary: A SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis was applied to four selected European lagoons, with the main objective to identify common factors that represent an advantage versus disadvantage for the provisioning of ecosystem services. Our approach aimed at transforming the threats in opportunities, by maximizing the strengths and minimizing the weaknesses, all under the context of human well-being. The analysis was applied by compiling existing knowledge combined with the joint expert knowledge from different scientific disciplines, and the view of stakeholders including local citizens from the Ria de Aveiro Lagoon (Portugal), Mar Menor (Spain), Vistula Lagoon (Poland and Russia) and the Tyligulskyi Liman Lagoon (Ukraine). Afterwards, the SWOT analysis was supplemented with data from a ecosystem-based questionnaire collected at a stakeholder workshop organized by the project team in each case study lagoon. The questionnaires helped the project team to better understand the stakeholders' perception of the benefits provided by each lagoon, the main beneficiaries, and how the key benefits should be managed in the near future (2030). Overall, the application of the ecosystem services concept and the SWOT analysis, combined with participatory stakeholder processes, (workshops and/or questionnaires) seems to be a useful tool, which can present an integrated vision for the management of coastal lagoons at the European level.

Keywords: Stakeholders, natural capital, coastal management, participatory process.

19.1 THE CONCEPTS OF NATURAL CAPITAL, ECOSYSTEM SERVICES AND SWOT

Coastal lagoons have a strong connectivity to the adjacent ecosystems (freshwater, terrestrial and ocean), and represent valuable features in coastal areas in terms of their natural capital and importance for human well-being. Following the 'Natural Capital Forum' definition (http://www.naturalcapitalforum.com/), the coastal lagoon natural capital can be defined as the lagoons' '*stocks of natural assets which include geology, soil, air, water and all living things*', from which '*humans derive a wide range of services*'. According to Haines-Young and Potschin (2013), the natural capital can be divided into: i) sub-soil assets; ii) abiotic flows; and iii) ecosystems capital. Sub-soil assets are non-renewable and depletable, corresponding to geological resources (e.g., minerals, fossil fuels, gravel, salts, etc.). Abiotic flows are renewable and non-depletable, being linked to geophysical cycles (e.g., solar, wind, hydro, geo-thermal, etc.). Ecosystem capital assets are renewable and depletable, being linked to ecological systems and processes, including the ecosystem assets (e.g., structure and condition) and ecosystem services (e.g., provisioning, regulation and maintenance, and cultural services). For the purpose of this chapter, we will only consider the ecosystem capital and will follow the definitions by the Common International Classification of Ecosystem Services (CICES), that is, '*final ecosystem services are the contributions that ecosystems make to human well-being*', whilst *'human well-being arises from adequate access to the basic materials for a good life needed to sustain freedom of choice and action, health, good social relations and security'* (Haines-Young & Potschin, 2013).

The identification of individual elements of a management system into a framework that recognises its various strengths (S), weaknesses (W), opportunities (O) and threats (T) is a widely used tool for organizing information, with respect to situation analysis. When presented as a SWOT matrix, it can be used for strategic planning including environmental planning and management (e.g., Zavadskas *et al.* 2011; Scolozzi *et al.* 2014). This approach can be combined with a participatory process, that is, it can take into account the opinion of the key-actors or stakeholders, and, therefore, incorporate their vision into the strategic planning and management process.

In this study we hypothesised that there are common strengths, weaknesses, opportunities and threats in the four case study lagoons that can be identified, and which can give an indication of management needs of coastal lagoons at a pan-European level.

19.2 ENVIRONMENTAL CHARACTERISTICS OF THE SELECTED EUROPEAN LAGOONS

To test our hypothesis, we selected four European coastal lagoons (Figure 19.1): Ria de Aveiro Lagoon in the Atlantic Ocean (Portugal); Mar Menor in the Mediterranean Sea (Spain); Vistula Lagoon in the Baltic Sea (Poland/Russia); and Tyligulskyi Liman Lagoon in the Black Sea (Ukraine).

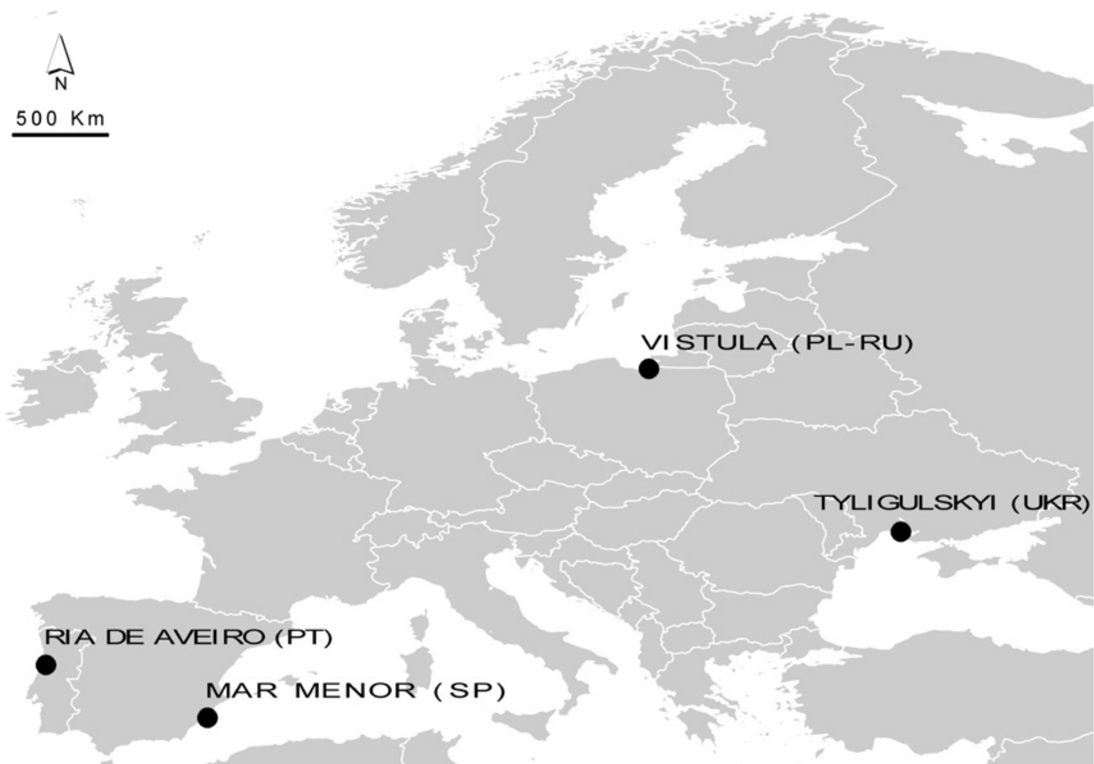

Figure 19.1 The geographic location of the four selected coastal lagoons.

These lagoons were selected in order to reflect the diversity of coastal lagoons in Europe. Their main environmental characteristics and usage of the natural capitals are summarized in Table 19.1 (detailed information regarding each lagoon can be found in Chapters 3–10).

19.3 THE CICES ECOSYSTEM SERVICES CLASSIFICATION METHOD

Within marine ecosystems, coastal lagoons belong to the marine inlets and transitional waters typology, being defined as '*ecosystems on the land-water interface under the influence of tides and with salinity higher than 0.5*' (Maes *et al.* 2014). For the classification of ecosystem services (ES) provided by coastal lagoons we used the CICES (Common International

Classification of Ecosystem Services), which, at its highest-level of hierarchical structure, includes three categories of ES following the nomenclature used by the Millennium Assessment (Provisioning; Regulating and maintenance and Cultural services). Within these three major categories, there is a further sub-division into 'divisions', 'groups' and 'classes' (Haines-Young & Potschin, 2013; Maes *et al*. 2014) as shown in Table 19.2

Table 19.1 Summary of the environmental characteristics of the selected European lagoons.

Ria de Aveiro	Vistula Lagoon
The Ria de Aveiro is a shallow mesotidal lagoon located on the north-west coast of Portugal, with a wetland area of 83 km^2 at high tide. The Ria is part of the Natura 2000 network (EU Habitats Directive); has the designation of Special Protection Area (SPA), includes several areas classified as Sites of Community Importance (SCI), and is protected by the EU Birds Directive (79/409/CEE). Since the 19th century, the settled population has shaped the ecosystem by creating salt pans and drainage marshes, opening small channels for navigation, and by creating farmlands such as the smallholdings named 'bocage', thus contributing to the increase of habitat diversity and associated biodiversity. The lagoon and the adjacent watershed areas comprise a whole variety of human uses including fishing, agriculture, recreation and tourism. The Ria's natural capital is an important factor for the development of the municipalities situated in the lagoon area.	The Vistula Lagoon is located in the South Baltic and is separated from the Gulf of Gdansk by the Vistula Spit and its extension on the Russian side called the Baltiyskaya Kosa. The lagoon covers an area of 838 km^2, and has one connection with the Gulf of Gdansk, which is located in the Russian part of the lagoon. This lagoon is part of one of the most important bird migration routes in Europe, and is protected by the EU Birds Directive (79/409/CEE). Two protected areas have been established in the region of the Polish part of Vistula Lagoon within the Natura 2000 network (EU Habitats Directive): A Special Protected Area (SPA) for birds and a Special Area of Conservation (SAC). There are also conservation areas established by the Polish and Russian national laws. The lagoon and the associated watershed areas comprise a whole variety of human uses including fishing, transport, agriculture, recreation and tourism.
Mar Menor	**Tyligulskyi Liman**
The Mar Menor, a hypersaline lagoon located in a semi-arid region of south-east Spain, is one of the largest coastal lagoons in the Mediterranean, covering an area of approximately 135 km^2. The importance of the lagoon and its salt marshes in terms of biodiversity has been recognised in numerous international protection schemes: it is a Ramsar International site since 1994; it is considered a Special Protected Area of Mediterranean Interest (SPAMI), established by the Barcelona Convention in 2001; and a Site of Community Importance (SCI) to be integrated in the Natura 2000 Network (EU Habitats Directive). This zone is also a Special Protection Area (SPA) for the nest building, migration and wintering of aquatic birds, and by the EU Birds Directive (79/409/CEE). The lagoon and the associated watershed areas comprise a whole variety of human uses including large tourist resorts and intensively irrigated agriculture.	The Tyligulskyi Liman is one of the largest, longest and deepest lagoons located between the Dnieper and Danube rivers in the Ukrainian part of the north-west coast of the Black Sea. The surroundings of the Tyligulskyi Liman consist of a unique coastal landscape, rich flora and fauna, and therapeutic mineral muds. The lagoon is a natural reserve in Ukraine and it has been a part of the Ramsar Wetlands of International Importance since 1995. Tyligulskyi is one of the most natural limans (brackish lagoons) on the northwest coast of the Black Sea. The importance of the Tyligulskyi Liman as a place for feeding, nesting and rest of migrant birds, is recognised by its inclusion as an Important Bird Area (IBA) and a waterfowl habitat of international value. It possesses numerous natural resources that can be used for the socio-economic development of adjacent territories, particularly for recreational purposes, eco-tourism, public health, aquaculture, and fishing.

19.4 THE SWOT ANALYSIS METHOD

Our starting point was the SWOT matrix as illustrated in Figure 19.2, which represents the perspective of the LAGOONS project proposal (for more details about the LAGOONS project see Chapter 2). Meaning that, at this point of the approach to test our hypothesis, the SWOT matrix does not contemplate the view of stakeholders or the complementary ecosystem-based approach questionnaire.

The SWOT analysis allows the identification of internal and external factors that impact on a lagoon's potential and actual development. '*Internal factors'* include: i) the strengths (S) – positive tangible and intangible attributes that can be internally controlled; and ii) the weaknesses (W) – negative internal attributes that represent barriers to improvement and need to be addressed. '*External factors'* include: i) the opportunities (O) – positive/attractive factors beyond internal control representing potential goals for development; and ii) the threats (T) – negative/harmful factors beyond internal control representing risks for development.

Table 19.2 Representation of the CICES hierarchical structure for the classification of ES following Maes *et al.* 2014. Column in the right: dark grey = non-pertinent service for marine inlets and transitional waters; Light grey = emerging or relevant at local scale, can become preeminent in the future; white = applicable.

Section	Division	Group	Class	
Provisioning	Nutrition	Biomass	Cultivated crops	
			Reared animals and their outputs	
			Wild plants, algae and their outputs	
			Wild animals and their outputs	
			Plants and algae from *in-situ* aquaculture	
			Animals from *in-situ* aquaculture	
		Water	Surface water for drinking	
			Ground water for drinking	
	Materials	Biomass	Fibres and other materials from plants, algae & animals for direct use or processing	
			Materials from plants, algae & animals for agricultural use	
			Genetic materials from all biota	
		Water	Surface water for non-drinking purposes	
			Ground water for non-drinking purposes	
	Energy	Biomass-based energy sources	Plant-based resources	
			Animal-based resources	
		Mechanical energy	Animal-based energy	
Regulation & Maintenance	Mediation of waste, toxics and other nuisances	Mediation by biota	Bio-remediation by micro-organisms, algae, plants, and animals	
			Filtration/sequestration/storage/ accumulation by micro-organisms, algae, plants, and animals	
		Mediation by ecosystems	Filtration/sequestration/storage/ accumulation by ecosystems	
			Dilution by atmosphere, freshwater and marine ecosystems	
			Mediation of smell/noise/visual impacts	
	Mediation of flows	Mass flows	Mass stabilisation and control of erosion rates	
			Buffering and attenuation of mass flows	
		Liquid flows	Hydrological cycle and water flow maintenance	
			Flood protection	
		Gaseous / air flows	Storm protection	
			Ventilation and transpiration	
	Maintenance of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Pollination and seed dispersal	
			Maintaining nursery populations and habitats	
		Pest and disease control	Pest control	
			Disease control	

Table 19.2 Representation of the CICES hierarchical structure for the classification of ES following Maes *et al.* 2014. Column in the right: dark grey = non-pertinent service for marine inlets and transitional waters; Light grey = emerging or relevant at local scale, can become preeminent in the future; white = applicable (*Continued*).

Section	Division	Group	Class	
		Soil formation and composition	Weathering processes	
			Decomposition and fixing processes	
		Water conditions	Chemical condition of freshwaters	
			Chemical condition of salt waters	
		Atmospheric composition and climate regulation	Global climate regulation by reduction of greenhouse gas concentrations	
Cultural	Physical and intellectual interactions with biota, ecosystems, and land-/seascapes	Physical and experiential interactions	Experiential use of plants, animals and land-/seascapes in different environmental settings	
			Physical use of land-/seascapes in different environmental settings	
		Intellectual and representative interactions	Scientific	
			Educational	
			Heritage, cultural	
			Entertainment	
			Aesthetic	
	Spiritual, symbolic and other interactions with biota, ecosystems, and land-/seascapes	Spiritual and/or emblematic	Symbolic	
			Sacred and/or religious	
		Other cultural outputs	Existence	
			Bequest	

Strengths Ecosystem services Science-policy-stakeholder interface and networks	**Weaknesses** Economics' resilience Ecological resilience
Opportunities Eco-innovation Ecoefficiency Ecosystem services trade-offs Capacity building EU Directives context	**Threats** Climate change Global crisis

Figure 19.2 Starting point SWOT analysis for European coastal lagoons in the perspective of LAGOONS project proposal (for more details about the LAGOONS project see Chapter 2).

In terms of coastal lagoon management, the object of applying this analysis was to identify and capitalize the strengths; minimize or overcome the weaknesses; follow the opportunities and adapt and/or mitigate the threats (e.g., Wheelen & Hunger, 2012). In this study, the information used for the SWOT analysis in each case study lagoon combined existing knowledge on the lagoon's physical, chemical and biological characteristics, with expert knowledge and the stakeholders' perception (which included the local population). This was achieved through a sequence of participatory methods, which included focus groups, citizen juries, and workshops (for a detailed description of the participatory methods please see Chapter 14).

19.5 THE ECOSYSTEM BASED APPROACH QUESTIONNAIRE

A set of questions, framed around ecosystem services, was translated into the respective local languages, and was distributed and completed by stakeholders at the final workshops that took place in each case study lagoon. The questionnaire included a set of multiple-choice options related to how stakeholders would like the key benefits to be managed in the near future (2030).

The stakeholders were invited to score their response to each question, described as follows:

(a) How important is the lagoon to you in terms of the following kinds of benefits?

Score options: very important; moderately important, not important or don't know.

List of benefits: Recreational fishing; Commercial fishing; Agriculture; Raw materials; Salt production; Port and harbour facilities; Industries; Other economic activities; Employment; Reducing the incidence and severity of flooding; Reducing the patterns of erosion; Maintaining good water supply; Source of bio-chemicals and medicines.

(b) Thinking about the way in which the lagoon supports plant and animal life, how important are the following types of benefits?

Score options: very important; moderately important, not important or don't know.

List of benefits: Habitats and Wildlife; Nesting areas for birds; Nursery and migration habitats for fish; Primary production; Nutrient cycling; Water cycling; Supporting populations of pollinating insects.

(c) How important is the lagoon to you in other kinds of ways?

Score options: very important; moderately important, not important or don't know.

List of benefits: Education and knowledge; Sense of place; History and archaeological heritage; Spiritual and religious values; Recreation & leisure; Bird watching; Hunting; Boating; Swimming; Walking; Tourism; Health; Landscape and scenic qualities; Local culture and customs; Traditional products; Genetic resources; Research.

(d) Some things are more important to local communities, others are enjoyed by those living elsewhere. Which groups benefit most from the lagoon?

Score options: Local lagoon community; Regional community; National community; Global community.

List of benefits: Commercial fishing; Recreational fishing; Agriculture; Timber and forestry; Raw materials; Salt production; Port and harbour facilities; Employment; Reducing the incidence and severity of flooding; Maintaining the water quality; Helping carbon storage in vegetation and soils; Influencing the local climate; Source of biochemicals and medicines; Health; Habitats and wildlife; Nursery areas for fish; Primary production; Water cycling; Nutrient cycling; Supporting populations of pollinating insects; Tourism; Education; Research; Traditional products; Recreation and leisure; Sense of place; Landscape and scenic qualities; History and archaeological heritage; Spiritual and religious values.

(e) How would you like to see the various benefits provided by the lagoon managed in the future?

Score options: Increased; Maintain the current levels; Accept some reductions to meet other objectives (specify which alternative objectives).

List of benefits: Agriculture; Catches of wild species; Port and harbour activities; Commercial industry; Salt production; Employment; Flood and erosion management; Water quality controls; Recreational activities; Tourism; Education and knowledge; Wildlife and habitats; Landscape and scenery; History and archaeology; Research; Other benefits.

19.6 RESULTS

19.6.1 Ecosystem services in the four case study lagoons

The information used in the ecosystem services analysis for each case study lagoon combined existing knowledge on the lagoons' physical, chemical and biological characteristics with expert knowledge. In this study, we considered all the three main categories and respective classes that were identified in at least one of the selected coastal lagoons, as summarized in Table 19.3 (for a detailed description of the ES provided by each case study lagoon please see Chapters 3, 5, 7 and 9).

The provisioning services in coastal lagoons consist of all their nutritional, material and energetic outputs. In all four case study lagoons, we found that the common provisioning services were the existence of wild animals and their human usage (e.g., fish and/or shellfish), and the harvesting of fibres and other materials from plants, algae and animals for direct use or processing (e.g., common reeds). Regulation and maintenance services, which consist of the ways in which living organisms can mediate or moderate the lagoon's environment, and, thus, inherently affect human activities and well-being, are provided in all case study lagoons (e.g., mediation of waste, toxics and other nuisances by biota and by ecosystems; mediation of mass, liquid and gaseous/air flows; maintenance of physical, chemical, biological conditions). The only exception could be the presence of invasive non-native species, which, to the best of our knowledge, is not experienced by the Tyligulskyi Liman (see Chapter 7). The presence of invasive species is an indicator for pest control (Maes *et al.* 2014). Cultural services, which include non-material and/or non-consumptive ecosystem outputs that affect human physical and mental states, are represented among all the case study lagoons. Each lagoon provides experiential interactions (e.g., bird watching) and physical interactions (e.g., diving, sailing and angling), as well as intellectual and representative interactions (e.g., research, educational, entertainment, heritage, inspiration for painters, writers). Similarly, none of the selected lagoons provided spiritual and/or emblematic services (i.e., authors could not identify emblematic plants or animals) or a spiritual, ritual identity. Furthermore, all lagoons provide other cultural interactions with environmental settings, namely the sense of place and the willingness to preserve the ecological capital of these coastal ecosystems.

Table 19.3 Summary of ecosystem services identified by the authors in each one of the four case study lagoons, following the CICES hierarchical structure for the classification (Maes *et al.* 2014).

	Class	**Ria de Aveiro**	**Mar Menor**	**Vistula Lagoon**	**Tyligulskyi Liman**
Provisioning	Wild plants and their outputs	✓			
	Wild animals and their outputs	✓	✓	✓	✓
	Plants and algae from *in situ* aquaculture	✓		✓	
	Animals from *in situ* aquaculture	✓		✓	
	Fibres and other materials from plants, algae and animals for direct use or processing	✓	✓	✓	✓
	Materials from plants, algae and animals for agricultural use	✓			
	Genetic materials from all biota		✓		
	Surface water for non-drinking purposes	✓	✓		
	Ground water for non-drinking purposes	✓	✓		✓
Regulation and maintenance	Bio-remediation & Filtration/ sequestration/ storage/ by micro-organisms, algae, plants, animals	✓	✓	✓	✓
	Filtration/ sequestration/ storage/ accumulation by ecosystems	✓	✓	✓	✓
	Dilution by atmosphere, freshwater and marine ecosystems	✓	✓	✓	✓
	Mass stabilisation & control of erosion rates	✓	✓	✓	✓
	Buffering & attenuation of mass flows	✓	✓	✓	✓
	Flood protection	✓	✓	✓	✓
	Maintaining nursery populations and habitats	✓	✓	✓	✓
	Pest control (presence of alien species)	✓	✓	✓	
	Decomposition and fixing processes	✓	✓	✓	✓
	Chemical condition of salt waters	✓	✓	✓	✓
	Global climate regulation by reduction of greenhouse gas concentrations	✓	✓	✓	✓
Cultural	Experiential use of plants, animals and land-/seascapes in different environmental settings	✓	✓	✓	✓
	Physical use of land-/seascapes in different environmental settings	✓	✓	✓	✓
	Scientific	✓	✓	✓	✓
	Educational	✓	✓	✓	✓
	Heritage, cultural	✓	✓	✓	✓
	Entertainment	✓	✓	✓	✓
	Aesthetic	✓	✓	✓	✓
	Existence	✓	✓	✓	✓
	Bequest	✓	✓	✓	✓

Note: grey cells stand for not applicable.

19.6.2 Coastal lagoons SWOT analysis in four coastal lagoons

Table 19.4 summarizes the strengths, weaknesses, opportunities and threats identified in each case study lagoon under current conditions. It can be seen that all of the coastal lagoons have common features; (i) strengths: natural capital, biodiversity and tourism potential; (ii) weaknesses: the untreated waste water inputs and/or potential for eutrophication and uncoordinated management; (iii) opportunities: EU Directives; RTD (Research and technological development) activities and tourism; and (iv) threats: climate change, environmental pressures and conflicting activities. The common factors, giving a pan-European perspective, are highlighted in Figure 19.3.

19.6.3 Stakeholders vision

We obtained 24 answered questionnaires for Ria de Aveiro, Vistula and Tyligulskyi, and 16 for Mar Menor (N = 88), and the results are summarized in Tables 19.5–19.9.

(a) Most relevant benefits: It can be seen from a pan-European view that employment is a relevant and commonly recognized provisioning service benefit, together with the regulation and maintenance of ecosystem services (more than 50% of the respondents) (Table 19.5). Fisheries or aquaculture and agriculture are, to some extent, also recognised as important benefits.

(b) Most possible relevant regulating and maintenance ecosystem services: In all case studies, it can be seen that habitats and wildlife, nesting areas for birds and habitats for migratory fish, primary production, and water and nutrients cycling are common denominators that are recognized by more than 50% of the respondents (Table 19.6).

(c) Other ways in which coastal lagoons are important: From the choices of more than 50% of the respondents, we can highlight the importance of coastal lagoons for education and knowledge, research, landscape and scenic qualities, health, 'the sense of place' and the importance for tourism, including some recreation and leisure activities (e.g., boating, walking and bird watching) (Table 19.7).

(d) Which groups, from local to global level, benefit most from the lagoon ecosystem: The results summarized in Table 19.8 show that the major benefits for the local community, acknowledged by more than 50% of the inquired stakeholders, come from fisheries and from the local regulation of the hydrological cycle, namely floods. To some extent, these benefits are also acknowledged at the regional community level. As we move towards the national level, the diversity in the answers increases. The common vision gets weaker. From the local level to the national level a bigger diversity of cultural services are recognized as being important (e.g., education, tourism and research), and habitats and wildlife are highlighted. At the global European level, the answers tend to acknowledge global biogeochemical cycles (like carbon and nutrient cycles), habitats and wildlife, and, to some extent, also research.

(e) The stakeholder views on the various benefits the lagoon can provide in the near future are summarized in Table 19.9. The common denominator, taking into account the choices of more than 75% of the respondents, is the need to increase education and knowledge levels. Additional future benefits mentioned were water management (regarding water quality control), wildlife and habitats, research and tourism and/or recreational activities. To some, but lesser extent, increase of employment was also mentioned.

Interestingly, the consensus among the respondents on the benefits they would like to see in the near future is striking (the highlighted choices correspond to more than 75% of the respondents). Regarding the benefits that European stakeholders could accept to maintain in the current levels or even accept to reduce, most options were chosen by 25% to 50% of the respondents, meaning that there could be more resistance towards its implementation. Results show that 25 to 50% of the respondents could, to some extent, accept to maintain the current levels of port and harbour activities and/or commercial industry, and to keep the current catches of wild species for food or agriculture. On the other hand, 25 to 50% of the respondents could accept a decrease in the catches of wild species for human consumption as food resource in future.

19.7 INTEGRATED VISION FOR THE MANAGEMENT OF COASTAL LAGOONS AT THE EUROPEAN LEVEL

The identified strengths, weaknesses, opportunities and threats under present conditions, our reference conditions, were combined with the stakeholders' visions regarding how they would like the key benefits to be managed in the near future (2030). The list of benefits (set as options in the ecosystems based approach questionnaire) did not always correspond exactly with the benefits, in the sense of well-being, driven by marine ecosystem services (as defined by CICES), since the questionnaire also included relevant services driven by sub-soil assets such as abiotic provisioning (e.g., sand and gravel, marine salt) (Haines-Young & Potschin, 2013). Furthermore, the list of benefits also included general human activities (e.g.,

Table 19.4 Summary of the strengths, weaknesses, opportunities and threats identified in each one of the four case study lagoons.

Strengths	Weaknesses
Ria de Aveiro – One of the largest contiguous salt marsh in Europe; Central geographic location; Natural Capital richness; High number of species; Rich social-cultural heritage; Diversity of activities developed in the Ria; Scientific and technological research; Tourism and leisure potential; Dynamics of the industrial sector; Ria de Aveiro with the status of legal and juridical protection. **Mar Menor** – High biodiversity; Singular and attractive landscape; Therapeutic values; Educational value; Fishing value; Tourist value; Research facilities in the study area; Environmental Educational facilities in the study area; Sport facilities; Infrastructures and transportation network; Protection areas of international interest in the study area; Network of Protection areas of regional interest in the study area. **Vistula Lagoon** – Long history of scientific research; Potentially well established monitoring system; Developed environmental legislation; Great 'natural' potential of the region (Polish and Russian parts); Vistula Lagoon is an important ecosystem; Landscape values; Relatively clean environment; Touristic potential. **Tyligulskyi Liman** – Nature reserve; Biodiversity; Tourist potential; Small farming; Convenient geographical location; Ecological management.	**Ria de Aveiro** – Complex policy and legislative context; Direct discharge of untreated domestic sewage; Abandonment of agricultural activities; Abandonment of salt pans; Abandonment of 'moliço' harvesting; Degradation and lack of maintenance of saltpans; Lack of dredging in navigation secondary channels; Increased velocity of water; Presence of invasive species; Salinization of agricultural land; Lack of monitoring data; Lack of active participation of the general population. **Mar Menor** – Loss of biodiversity; Exotic species; Jellyfish proliferations; 'Mediterraneanisation' process; Silting; High population density on littoral areas in summer; Agricultural and urban waste water inputs; Increase of urban and artificial landscapes; High number of recreational vessels; Degradation and lack of maintenance of salt pans. **Vistula Lagoon** – High potential for eutrophication; Limited monitoring data exchange and access; Unbalanced distribution of tourism infrastructures; Low environmental education of most population; Escape of young generation to more prosperous regions; Limited communication between Polish and Russian parts, Decrease of commercial fishing; Difficulties caused by the need of transboundary negotiations; Administrative division of the Polish part. **Tyligulskyi Liman** – High potential for eutrophication and increasing salinity; High potential for fish mortality; Uncoordinated policy and legislation; Monitoring system and data access; Lack of complex management
Opportunities	**Threats**
Ria de Aveiro – Tourism; RTD activities; Environmental and civic awareness; Improved knowledge and regular collection of information; Increasing socio-economic valuation of biodiversity; Investment in international communication routes; Existence of tools to support the development of conservation actions, namely EU Directives and EC funds; Recreational nautical activities; Gastronomic tourism. **Mar Menor** – Long history of RTD; Regional Research Centres; Local and regional naturalistic associations; Monitoring programs of endangered species populations; Regional volunteer programs in Protected Areas; Network of control and monitoring of coastal water quality in the Region of Murcia; Oceanographic Information System of the Region of Murcia (SIOM), EU Directives (e.g., WFD, Nitrate, UWWTD); **Vistula Lagoon** – EC funding; Helsinki Convention strong and proactive; Baltic Sea Action Plan (BSAP); Natura 2000 classification and WFD; permanent process of harmonisation of EU and Russian environmental legislation. **Tyligulskyi Liman** – Tourism; RTD activities; WFD.	**Ria de Aveiro** – Environmental degradation; Climate change; Damage of infrastructures; Risk of pollutants caused by accidents due to maritime traffic; Presence of invasive species; Law infringement on the capture of species; Silting; Reflection of the economic crisis in some sectors; Use of chemicals and pesticides in agriculture; Risk of technological accidents; Illegal practices related to fishing and shell fishing activities; Natural hazards; Bathymetry changes; Parallel economy. **Mar Menor** – Climate change; Tourist development in littoral areas and in the Campo de Cartagena; Irrigation agriculture expansion; Competition among economic activities; Current economic crisis; Construction project of a submarine tunnel to connect La Manga north with San Pedro del Pinatar and San Javier; Soil Law adopted by the Regional Government in April 2001; Complex policy and legislative context. **Vistula Lagoon** – Climate change; Unemployment; Outflow of young people; aging of the population; EU/Non-EU states borders, conflicting interests in Natura 2000 area, Different goals, approach and deadlines for Baltic Sea Action Plan (BSAP) and WFD and large catchment area; variations of EU-Russia political relations. **Tyligulskyi Liman** – Climate change; Environmental degradation; Damage of natural integrity.

port and harbour facilities, tourism), in addition to other benefits underpinned by ecosystem services and human related activities (e.g., employment). Having in mind these stakeholder benefits, we identify the ones that could capitalize the strengths; convert weaknesses to strengths; overcome the weaknesses; and those that represent opportunities to be followed, as shown in Figure 19.4.

Strengths **(Capitalize)** Natural capital Biodiversity Tourism potential	**Weaknesses** **(Minimize and/or convert to Strengths)** Untreated waste water inputs and/or potential for eutrophication Uncoordinated management
Opportunities **(Follow)** EU Directives RTD activities Tourism	**Threats** **(Minimize and/or convert to Opportunities)** Climate change Environmental pressures Conflicting activities

Figure 19.3 Summary of the Pan-European coastal lagoons SWOT analysis resulting from this study. This analysis took into account the existing scientific knowledge on the lagoons' physical, chemical and biological characteristics, with expert knowledge and the stakeholders' perception obtained though focus groups and citizen juries (for a detailed description of the participatory methods please see Chapter 14).

Table 19.5 Summary of the most relevant benefits chosen in question a) How important to you is the lagoon in terms of the following kinds of benefit?

Stakeholders' answers	Ria de Aveiro	Mar Menor	Vistula Lagoon	Tyligulskyi Liman
More than 75% considered the benefit very important	Employment; reducing the incidence and severity of flooding; reducing the patterns of erosion and maintaining good water quality	Employment maintaining good water quality; shaping the local climate	Port and harbour facilities; reducing the incidence and severity of flooding; shaping the local climate	Maintaining good water quality
Between 50% and 75% considered the benefit very important	Commercial Fishing; agriculture; salt production; port and harbour facilities; shaping the local climate and Source of water supply	Agriculture; reducing the patterns of erosion; helping store carbon in vegetation and soils; source of water supply; Source of bio-chemicals and medicines	Commercial and recreational fishing; employment	Aquaculture; employment; reducing the incidence and severity of flooding; reducing the patterns of erosion
More than 75% considered the benefit moderately important		Commercial fishing		

Note: grey cells stand for not applicable.

Our results highlight the fact that stakeholders acknowledged many provisioning, regulation and maintenance, and cultural marine ecosystem services provided by coastal lagoons. However, the wording used in each case does not necessarily match that of the ecosystem service paradigm, but expresses these in more tangible terms. Relevant examples include regulation and maintenance services that might be capitalized to convert weaknesses to strengths, thus, leading to benefits to the system and, ultimately, contributing to the human well-being such as:

- the *mediation of liquid flows* (group), and *flood protection* (class) category (benefit: regulation of floods);
- the *maintenance of physical, chemical and biological conditions* (division), more specifically the lagoons *sediment bed formation and composition* (group), that is, *decomposition and fixing processes* (class) category (benefit: nutrient cycling); and
- the *water conditions* (group), that is, the *chemical condition of salt waters* (class) category (benefit: water quality control).

Table 19.6 Summary of the most relevant regulating and maintenance ecosystem services, chosen in question b) Thinking about the way in which the lagoon supports plant and animal life, how important are the following types of benefit?

Stakeholders' answers	**Ria de Aveiro**	**Mar Menor**	**Vistula Lagoon**	**Tyligulskyi Liman**
More than 75% considered the benefit very important	Habitats and wildlife; nesting areas for birds; nursery and migration habitats for fish;	Habitats and wildlife; nesting areas for birds; nursery and migration habitats for fish; primary production; nutrient cycling; water cycling	Habitats and wildlife; nesting areas for birds; nursery and migration habitats for fish; primary production; water cycling	Nesting areas for birds; nursery and migration habitats for fish; primary production;
Between 50% and 75% considered the benefit very important	Primary production; nutrient cycling; water cycling; supporting populations of pollinating insects		Nutrient cycling	Habitats and wildlife; nutrient cycling; water cycling; supporting populations of pollinating insects

Table 19.7 Summary of other ways in which coastal lagoons are important to stakeholders, chosen in question c) How important is the lagoon to you in other kinds of ways?

Stakeholders' answers	**Ria de Aveiro**	**Mar Menor**	**Vistula Lagoon**	**Tyligulskyi Liman**
More than 75% considered the benefit very important	Education and knowledge; birdwatching; landscape and scenic qualities; research	Education and knowledge; sense of place; walking; tourism; research	Walking, tourism, landscape and scenic qualities	Education and knowledge; landscape and scenic qualities; research
Between 50% and 75% considered the benefit very important	Sense of Place; boating; walking; tourism; health	History and archaeological heritage; boating; health; landscape and scenic qualities; local cultural customs; genetic resources	Education and knowledge; sense of place; birdwatching, boating; research	Sense of place; History and archaeological heritage; swimming; walking; tourism; health

In addition, provisioning and cultural ecosystem services were identified as benefits; through these services, opportunities are likely to emerge from the threats. The relevant provisioning marine services were included in the *nutrition* (division) and *biomass* (groups) categories, including the following classes:

- *wild animals and their outputs* that will support commercial and recreational fisheries;
- *animals from in situ aquaculture* that underpins aquaculture activity

Table 19.8 Summary of the groups that benefit most from the lagoon, chosen in question d) Some things are more important to local communities, others are enjoyed by those living elsewhere. Which groups benefit most from the lagoon?

Stakeholders' answers	Ria de Aveiro	Mar Menor	Vistula Lagoon	Tyligulskyi Liman
More than 75% considered the benefit important for the local lagoon community	Commercial fishing	Commercial fishing; timber and forestry; raw materials		Employment; reducing the incidence and severity of flooding; helping store carbon in vegetation and soils; traditional products
Between 50% and 75% considered the benefit important for the local lagoon community	Aquaculture; salt production; reducing the incidence and severity of flooding; sense of place	Recreational fishing; reducing the incidence and severity of flooding; influencing the local climate; nursery areas for fish; nutrient cycling; spiritual and religious values	Commercial fishing; aquaculture; employment; sense of place	Commercial fishing; recreational fishing; aquaculture; raw materials; maintaining the water quality; influencing the local climate; nursery areas for fish; primary production; local traditions and culture
Between 50% and 75% considered the benefit important for the regional community	Recreational fishing, employment; water cycling; nutrient cycling; supporting populations of pollinating insects	Employment	Timber and forestry; raw materials; reducing the incidence and severity of flooding; tourism, influencing the local climate; nutrient cycling; education; traditional products	Recreational fishing
Between 50% and 75% considered the benefit important at the national level		Recreation and leisure	Source of biochemicals and medicines	
Between 25% and 50% considered the benefit important at the national level	Timber and forestry, raw materials; health; habitats and wild life; tourism, education, research; landscape and scenic qualities	Maintaining the water quality; source of biochemicals and medicines; health; habitats and wild life; tourism; education; landscape and scenic qualities; history and archaeological heritage	Port and harbour facilities; maintaining the water quality; health; habitats and wild life; tourism; education, research; recreation and leisure; landscape and scenic qualities; history and archaeological heritage	Port and harbour facilities; maintaining the water quality; Source of biochemicals and medicines; health; tourism, education, research; recreation and leisure; landscape and scenic qualities; history and archaeological; Spiritual and religious values
Between 50% and 75% considered the benefit important the global level		Research		
Between 25% and 50% considered the benefit important at the global level	Port and harbour facilities; helping store carbon in vegetation and soils; source of biochemicals and medicines; health; habitats and wild life; tourism; research	Agriculture; helping store carbon in vegetation and soils; source of biochemicals and medicines; habitats and wild life; nutrient cycling; supporting populations of pollinating insects; tourism; spiritual and religious values	Habitats and wildlife; nutrient cycling	

Note: As can be seen in table 19.2, cultivated crops, underpinning agriculture, is not a marine ecosystem service (Maes *et al*. 2014). Regarding these provisioning services, the stakeholders were, to some extent, able to accept to maintain or even decrease the current catches of wild species for human consumption. Interestingly, wild animals and their outputs were acknowledged as a relevant provisioning service provided by coastal lagoons. In addition, more than 50% of the respondents also highlighted that fisheries and aquaculture represent major benefits for the local community, meaning that their willingness to maintain or reduce these benefits implies that the concept of trade-off is present in stakeholders' choices.

Table 19.9 Summary of the way how stakeholders would you like to see the various benefits provided by the lagoon managed in the future chosen in question e) How would you like to see the various benefits provided by the lagoon managed in the future? (*50% or more; **75% or more).

Stakeholders' answers	**Ria de Aveiro**	**Mar Menor**	**Vistula Lagoon**	**Tyligulskyi Liman**
More than 75% would like to see the increase of	Employment; floods and erosion management; water quality control; research, tourism, education and knowledge; aquaculture; recreational activities; wildlife and habitats;	Water quality control; education and knowledge; research; wildlife and habitats; landscape and scenery; other benefits	Port and harbour activities; employment; recreational activities; tourism, education and knowledge; other benefits	Aquaculture; employment; water quality control; recreational activities; tourism, education and knowledge; wildlife and habitats; landscape and scenery; research
Between 25% and at least 50% could accept to maintain the current levels of	Port and harbour activities; commercial industry; catches of wild species for food	Agriculture**; catches of wild species for food*, salt production*;	Agriculture; commercial industry; water quality control; wildlife and habitats*; landscape and scenery**; history and archaeology*	Port and harbour activities*; commercial industry; salt production**; history and archaeology
Between 25% and at least 50% could accept reductions of	Catches of wild species for food	Port and harbour activities*; commercial industry*; Catches of wild species for food; flood and erosion management	Catches of wild species for food	Agriculture; catches of wild species for food*; commercial industry

The relevant cultural marine services that, when properly managed to overcome possible conflicting services, could be converted to opportunities, were included in the *physical and experiential interactions with lagoons environmental settings* (group) category, including the following classes:

- *experiential use of biota and coastal lagoons environment* (benefit: bird watching);
- *physical use of coastal lagoons* (benefit: boating, walking).

The benefit 'education and knowledge' was included in the cultural services within the *intellectual and representative interactions* (group) category. This service can be seen as an opportunity supporting the management of European coastal lagoons. Other regulating and maintenance marine ecosystem services, namely *lifecycle maintenance, habitat and gene pool protection* (group) category within *maintaining nursery populations and habitats* (class) category, could capitalize some of the benefits (e.g., habitat and wildlife, nesting areas for birds, habitats for migratory fish, primary production) that represent strengths for European coastal lagoons.

To the best of our knowledge, only a few recent papers apply a SWOT analysis approach to achieve conservation objectives and ecosystem services delivery (e.g., Scolozzi *et al*. 2014). Although Scolozzi *et al*. (2014) include the environmental and social perspectives in their analyses, the process does not involve a stakeholder participatory process, but a trans-disciplinary interpretation combined with expert consultation (Delphi method). In fact, at the European and global levels, other studies have highlighted the need to increase our understanding of stakeholders' socio-cultural values and perceptions of ecosystem services, since this can serve as a tool to identify relevant services for people (e.g., Fanning *et al.* 2007; Carpenter *et al.* 2009; Martín-López *et al.* 2012; Fletchera *et al.* 2014). Other relevant examples can also be found in Martín-López *et al.* (2012, Table 1). Thus, our study contributes with a novel methodology to this discussion.

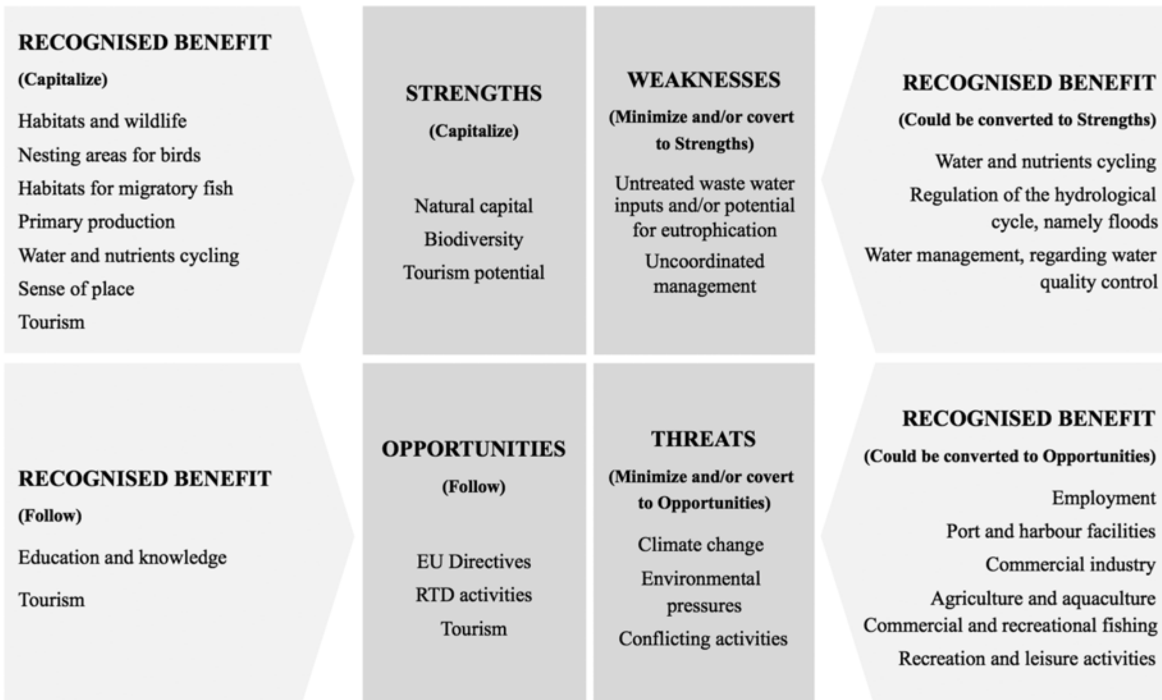

Figure 19.4 Summary of the Pan-European coastal lagoons SWOT analysis combined with the stakeholder's vision regarding how they would like the key benefits to be managed in the future (2030).

19.8 FINAL REMARKS

The present study reinforces that there are common strengths, weaknesses, opportunities and threats that can be highlighted for a strategic management of coastal lagoons at the pan-European level. Furthermore, despite the relatively low number of questionnaires, combining a SWOT analysis with the stakeholders' perception of lagoon ecosystem benefits proves to be a very useful tool for an integrated vision for the management of coastal lagoons at the European level. This study also reinforced that the concept of ecosystem services can be very useful for establishing a link between scientists (academic knowledge), stakeholders (values, perceptions and local knowledge), and managers (to support environmental management policies).

Finally, it can be seen that tourism represents a present strength as well as an opportunity for the future, being also recognized as a benefit that can be capitalized and followed. In addition, taking into account the minimization of conflicting activities within the European lagoon areas, many recognized benefits driven from cultural ecosystem services, including recreation and leisure activities (e.g., boating, walking, bird watching), could be converted into opportunities. In fact, tourism is seen as a priority sector for the EU sustainable economic development (COM(2014) 85 final, 2014/0044), and, in this sense, tourism can also be seen as an important driver for coastal lagoons (Newton *et al.* 2014). The identification of possible management recommendations for tourism in European coastal lagoons will be further discussed in the following chapter.

19.9 ACKNOWLEDGEMENTS

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Chapter 20

The DPSIR framework applied to the society vision for tourism in 2030 in European coastal lagoons

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Summary: We applied the DPSIR (Drivers-Pressures-State-Impacts-Response) framework to four European lagoons, covering a wide geographical distribution. We took their present/reference condition as well as a desirable scenario/vision for 2030 for each lagoon into account, with regard to the Driver 'Population, Tourism and Related Activities'. Our goal was to identify possible management recommendations for the selected Driver for all lagoons, taking into account the views of end-users. As such, the present and future DPSIR's were applied by combining different scientific disciplines in a multidisciplinary approach. The lagoons' present condition was defined through quantitative-qualitative information from current scientific knowledge and from knowledge collected from the local population. The considered possible vision for 2030 for each lagoon was underpinned by mathematical modelling, from the catchment to the coast, Eurostat data and expert knowledge, and defined by the lagoon's end-users through a participatory approach. We proposed a 'backwards' DPSIR framework to identify the State change to be achieved by 2030, taking into account both the desirable and undesirable Impacts and potential Pressures. We also evaluated if the Responses proposed in the present/reference conditions will enable achieving the desirable scenario. Overall, the application of the DPSIR framework seems to be a very useful tool to propose recommendations for the management of coastal lagoons at the European level, with sustainable tourism considered as a major goal to achieve.

Keywords: Coastal management, Participatory scenarios, Human well-being, Population growth, Sustainable tourism.

20.1 INTRODUCTION

Coastal lagoons are highly productive and provide several ecosystem services essential to human well-being. As such, the management of lagoons and consequent conservation and exploitation of their services is highly influenced by societal needs and the current state of knowledge (Chapman, 2012; Newton, 2014). Describing future desirable and undesirable changes provides a way to decide on management priorities for coastal lagoons. Scenarios reflecting plausible future environmental and socio-economic developments are useful tools for estimating possible future states and conditions, and for supporting locally effective management measures (Gooch *et al.,* 2010). Still, the effective implementation of management proposals necessarily implies the involvement of different end-users in the formulation of possible future changes to accommodate the locally specific needs and values of the lagoon (Elliott, 2013).

The DPSIR framework (Drivers-Pressures-State-Impacts-Response) results from the development of the PSR framework (Pressure-State-Response), and is recognized as an important environmental assessment tool to support appropriate management options (e.g., European Environmental Agency, EEA). In this chapter, we applied the DPSIR framework to a desirable environmental and socio-economic development scenario, underpinning human well-being, in four European coastal lagoons.

The information used here for the DPSIR framework application combined existing knowledge on the lagoons' physical, chemical and biological characteristics, demographic growth forecasts, data modelling on the lagoon and its catchment basin and the end-users views. With the DPSIR framework, the complex relationship between the Drivers of change and their Impacts on human well-being and environmental sustainability were streamlined. Our main objective was to identify possible management recommendations for the Driver 'Population, Tourism and Related Activities' for European coastal lagoons, taking into account the views of their end-users. The framework was applied to the Driver because tourism is the only activity with continuous growth in Europe, and is therefore considered a priority sector for the EU sustainable economic development (COM(2014) 85 final, 2014/0044).

20.2 METHODS

20.2.1 The four European lagoons and the desirable 2030 scenario for each lagoon

The DPSIR framework was applied to the following European lagoons: Ria de Aveiro, a shallow mesotidal lagoon, (45 km-long; 10 km-wide) located along the Atlantic Ocean on the northwest coast of Portugal and characterized by a temperate maritime climate; Mar Menor – a microtidal lagoon (22 km-long; 9 km-wide), located along the Mediterranean sea on the south coast of Spain, and characterized by a warm-temperate dry climate; Tyligulskyi Liman, a tideless lagoon (52 km long; 0.3 to 4.5 km wide) located in Ukraine on the southeast coast of the Black Sea and characterized by a temperate continental climate; and the Vistula Lagoon, a non-tidal lagoon (91 km-long; 13 km-wide) located along the Baltic sea, partially on the coast of Poland and partially on the coast of Russia, and characterized by a maritime climate and continental climate. For a more detailed description of each lagoon we refer the reader to Chapters 3, 5, 7 and 9.

The supporting information/knowledge for each lagoon's end-users to formulate the desirable environmental and socio-economic scenario for 2030, resulted from a multidisciplinary approach that combined mathematical modelling (e.g., water management and land use from catchment to coast), Eurostat data (e.g., population growth and human activities) and expert knowledge (the team included natural and social scientists) combined with local knowledge, as a result of a sequence of participatory methods that involved the local populations and managers (for a detailed description of the scenario building and the participatory method please see Chapters 14–16). The detailed description of the desirable 2030 scenario for each lagoon can be found in Chapter 14.

20.2.2 The DPSIR framework

For the DPSIR framework application we considered the environmental and socio-economic aspects following the definitions by Atkins *et al.* (2011), where: Drivers (D) are the anthropogenic activities that may generate environmental effects; Pressures (P) are any direct and quantifiable effects of a Driver in the system; State (S) is the condition of the lagoon area resulting from both natural and anthropogenic factors including physical, chemical and biological characteristics; Impact (I) is defined as the impact of the activities on human well-being, welfare and sustainability; and Responses (R) are the interventions by governmental or institutional bodies to minimise or mitigate negative effects of an impact. The framework was applied as illustrated in Figure 20.1. First we applied the framework to each lagoon's present conditions for the considered Driver following the original DPSIR structure; then, we used a 'backwards' DPSIR framework in order to evaluate the possible consequences of the chosen environmental and socio-economic scenario for 2030. In the 'backwards' DPSIR, we considered that the Responses at the present conditions represent the starting point to achieve the desirable Impacts and State, and to avoid the undesirable Impacts in 2030. From the 2030 state, we identified potential Pressures and, finally, we analysed if additional Responses are needed to achieve the desirable scenario in each lagoon (Figure 20.1). Then, we combined all the results for an overview of recommendations for the management of European lagoons.

20.3 THE DRIVER: POPULATION GROWTH AND TOURISM

In the selected coastal lagoons, several inter-related Drivers have been identified, for example, population growth, tourism, agriculture, fishing, uncoordinated management, economic crisis (Dolbeth *et al.,* submitted); as well as several exogenic unmanaged Pressures as defined by Atkins *et al.* (2011), for example, climate, ecohydrological characteristics and invasive species (Dolbeth *et al.*, submitted). For the purpose of the application of the proposed 'backwards' DPSIR to the chosen scenario for the year 2030, we selected the combined Driver of 'Population, Tourism and Related Activities'. Population growth and tourism are highly associated: as population density increases during high season tourism, the pressures related to the needs of increased urbanisation (e.g., urban expansion, water needs and water management, and conflicting recreational coastal activities) increase as well. Special attention was given to tourism because the activity has registered continuous growth in Europe, and has great potential to contribute to '*Europe 2020, the EU's growth strategy for a smart, sustainable and inclusive EU economy*' (COM(2014) 85 final, 2014/0044). In addition, the importance of this Driver is recognized for coastal areas worldwide (Newton *et al.* 2014). The detailed DPSIR cycles regarding the present conditions and the proposed 'backwards' framework applied to the chosen desirable scenarios for 2030 for each lagoon are presented in Figures 20.2–20.5.

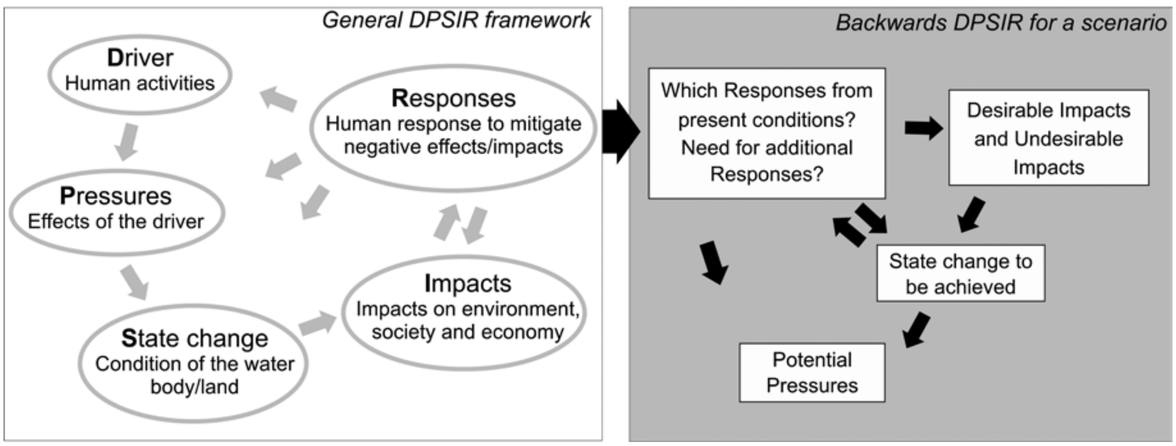

Figure 20.1 Conceptual design of the original DPSIR framework and the proposed 'backwards' framework for the 2030 scenario analysis.

20.3.1 Present conditions (Pressures, State change and Impacts)

The four lagoons have increased seasonal human population densities due to tourism. Still, the lagoons have different degrees of Pressures, in part due to the economic development and investment in the region, and specifically in the tourism sector itself. Relevant examples are: tourism over-exploitation in Mar Menor; unregulated human activities in Ria de Aveiro and Vistula; and less developed tourism and unregulated human activities in Tyligulskyi (Figures 20.2–20.5). For all lagoons, the high urban and touristic growth has threatened the natural habitats and biodiversity, and, in an extreme case, it resulted in the occupation of the maritime public domain (Figure 20.3). Pressures from the Driver are also related to the households' effluents following the seasonal variability of population. These Pressures have resulted in wastewater and waste disposal problems, and this, together with the Pressures from other Drivers such as agriculture, have contributed to enhance eutrophication in Mar Menor and Vistula, and in specific areas of the Tyligulskyi Lagoon. Overall, these Pressures and consequent State have contributed to the seasonal degradation of the water quality and the ecological status of those lagoons (Figures 20.3–20.5). Comparatively, the Ria de Aveiro lagoon's susceptibility to eutrophication is much lower due to the hydrodynamic characteristics of the system.

In Ria, there has been a progressive abandonment of traditional activities (e.g., salt-works, '*moliço*' collection) resulting in the degradation of the salt pans and salt marshes (Figure 20.2), which are important habitats for several species and important components of the cultural identity of the region. The lack of efficient communication within the lagoon, by ferry or other regular boats and/or by road, which results in the isolation of some communities, has also been pointed out, especially for Ria de Aveiro and Vistula (Figures 20.2, 20.4).

For all lagoons, tourism and related activities were considered extremely important for the local economy and employment, and have long traditions in some of the lagoons (Ria de Aveiro and Mar Menor). The lagoons have recognized natural capital that, when preserved, is attractive for a variety of visitors. This includes natural high-value habitats and species (e.g., Ria de Aveiro and Vistula lagoons have several protected habitats integrated in the Natura 2000 network and Mar Menor and Tyligulskyi are Ramsar sites), natural resources for recreational activities (e.g., fishing, hunting) and therapeutic uses, as well as aquatic sports (e.g., kite-surf, sailing, diving) (Figures 20.2–20.5). Cultural activities related to the lagoon are also present and appealing for the local population and tourists (e.g., traditional activities, local festivals and local products, gastronomy), especially in Ria de Aveiro and Mar Menor. However, it was highlighted that these are not conveniently promoted (Figures 20.2–20.3).

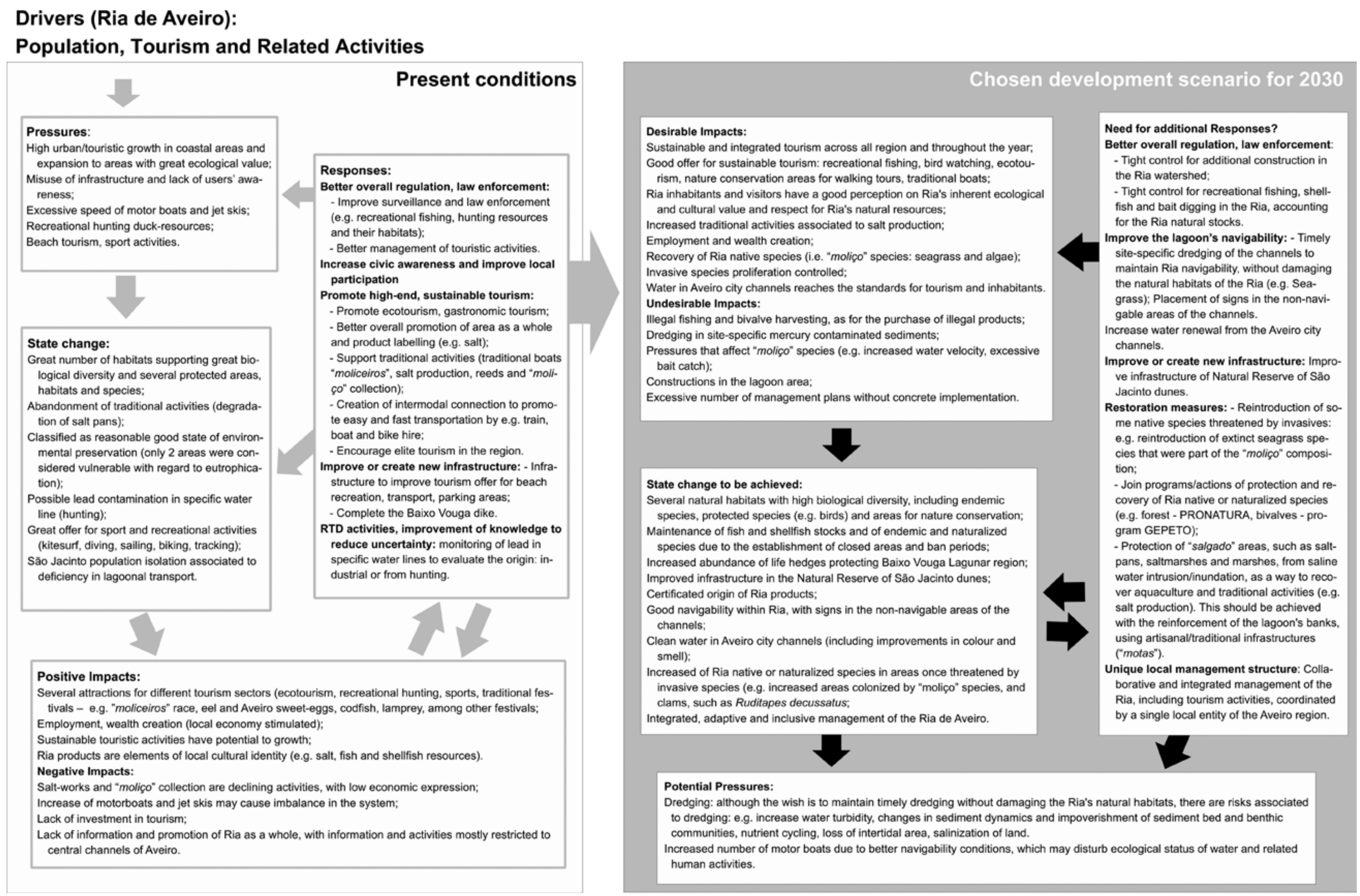

Figure 20.2 DPSIR framework of the Driver 'Population, Tourism and Related Activities' applied to the present conditions and the 'backwards' DPSIR applied to the desirable environmental socio-economic development scenario for 2030, for Ria de Aveiro (Portugal).

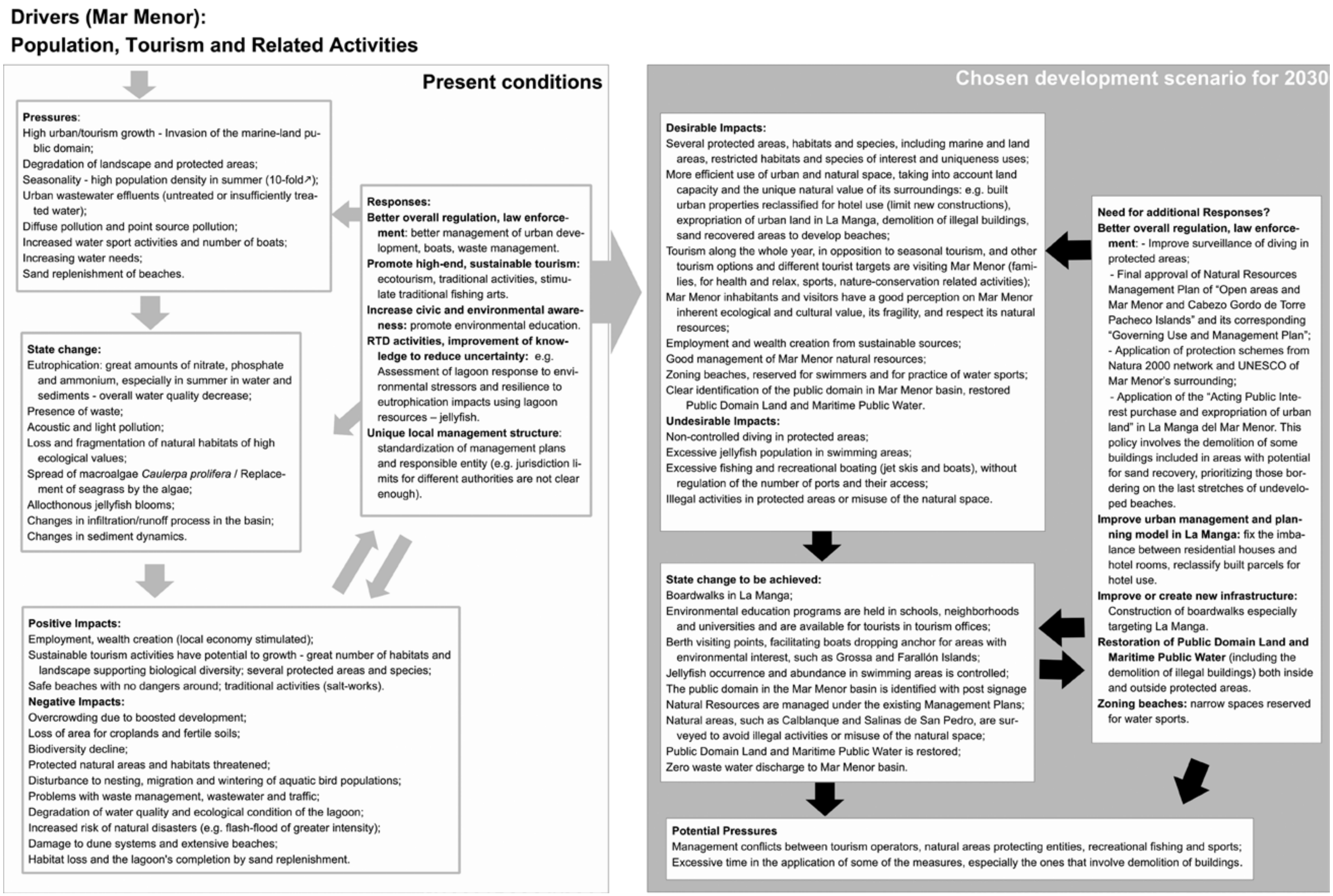

Figure 20.3 DPSIR framework of the Driver 'Population, Tourism and Related Activities' applied to the present conditions and the 'backwards' DPSIR applied to the desirable environmental socio-economic development scenario for 2030, for Mar Menor (Spain).

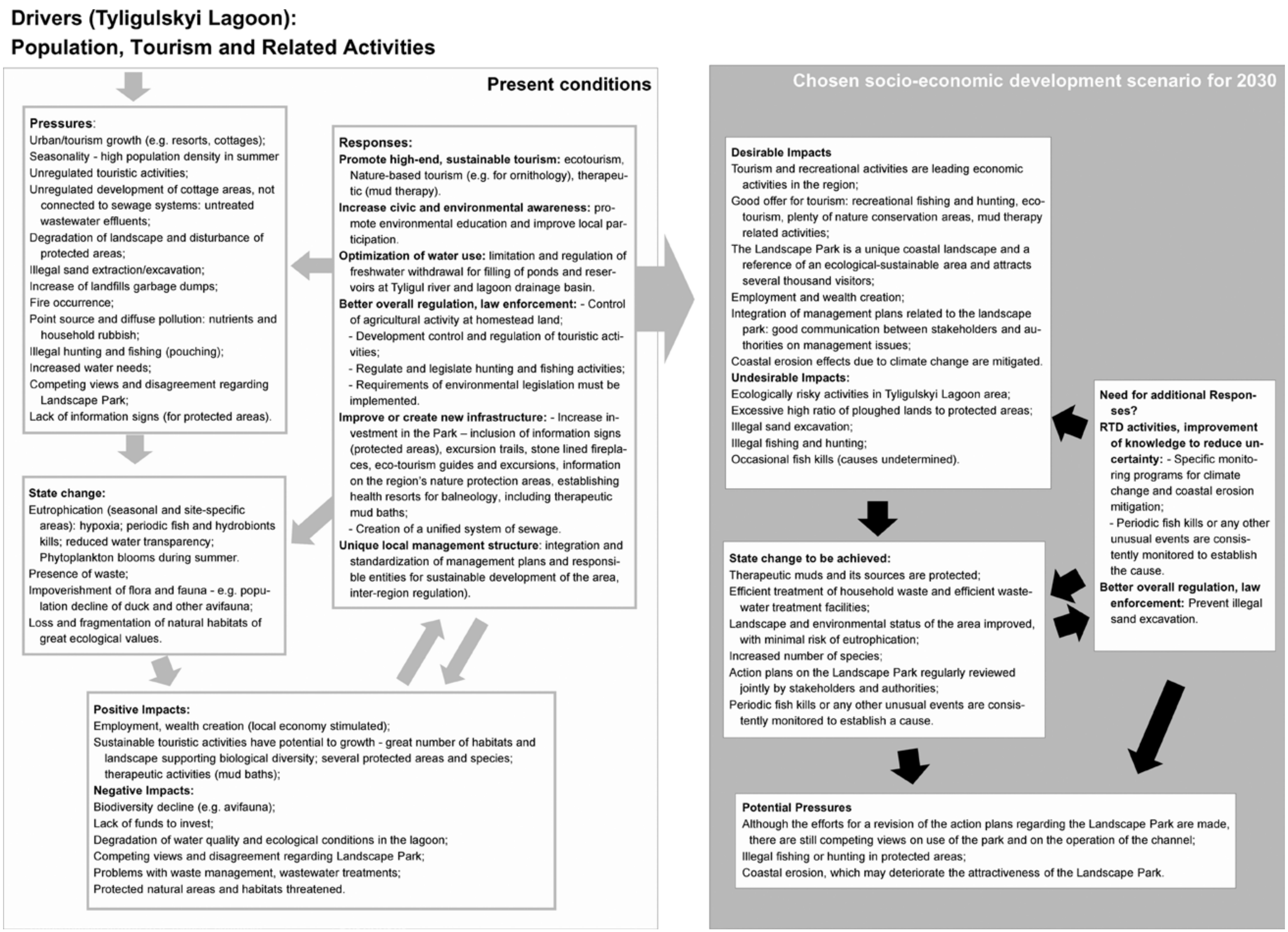

Figure 20.4 DPSIR framework of the Driver 'Population, Tourism and Related Activities' applied to the present conditions and the 'backwards' DPSIR applied to the desirable environmental socio-economic development scenario for 2030, for the Tyligulskyi lagoon (Ukraine).

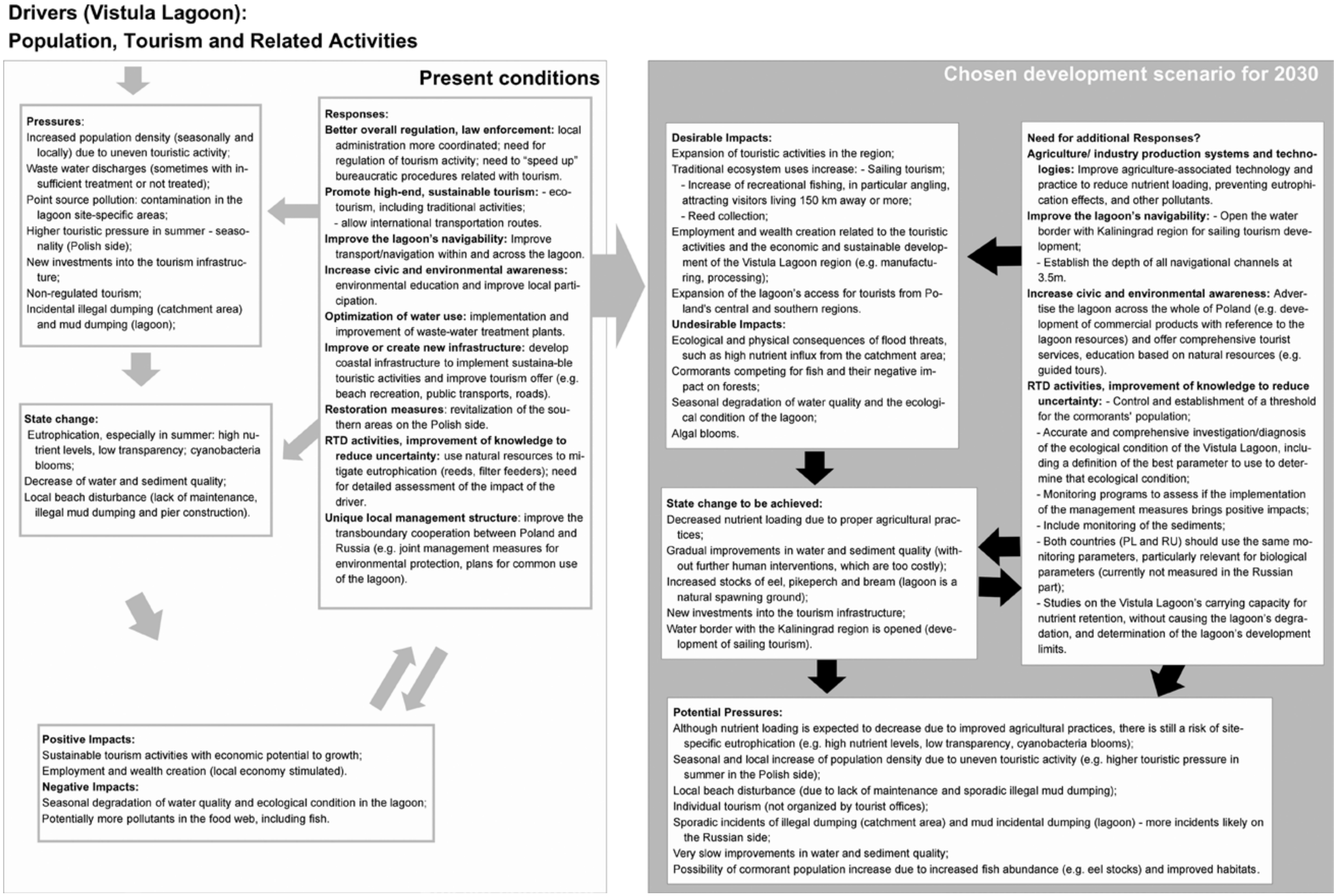

Figure 20.5 DPSIR framework of the Driver 'Population, Tourism and Related Activities' applied to the present conditions and the 'backwards' DPSIR applied to the desirable environmental socio-economic development scenario for 2030, for the Vistula lagoon (Poland and Russia).

20.3.2 Desired vision for the 2030 and link to EU policy instruments

The seasonality and the unregulated tourism practices are some of the concerns of the end-users from all lagoons, which recognized the importance to turn touristic activities sustainable more evenly spaced throughout the year (Figures 20.2–20.5). This goal is part of the desired vision that considers the State change to be achieved by 2030 by the end-users, and is complemented by us with the relevant policy instruments. In general, tourism is seen as a major and leading economic activity, potentially generating employment and wealth. However, '*good business relies on good ecology/biology/husbandry*' (Elliott, 2013), and a conversion of today's tourism into a sustainable practice would imply changes at several levels of organization. Indeed, to facilitate the practice of more desirable kinds of touristic activities such as ecotourism, bird-watching, nature-conservation related activities, sailing and recreational fishing, it is necessary to have:

1) lagoons with preserved habitats, with biodiversity protection and conservation measures, including efforts to recover the endemic and naturalized species and control the invasive ones. Relevant EU-policies for this goal are the Habitats Directive (92/43/EEC) and the Biodiversity strategy for 2020 (COM(2011) 244 final, 3.5.2011);
2) improved or new infrastructure such as boardwalks, information signs in protected areas, among others;
3) good navigability and improved access to the lagoon and its watershed area. Relevant EU-policy for this goal is the Integrated Coastal Zone Management – ICZM recommendation (COM(2007) 308 final, 7.6.2007);
4) informed visitors and local population; and
5) overall improved water quality, in line with the goals of the Water Framework Directive – WFD (2000/60/EC), the Marine Strategy Framework Directive – MSFD (2008/56/EC) and the proposal for the Tourism Council Recommendation on European Tourism Quality Principles (COM(2014) 85 final, 2014/0044).

In some lagoons, these goals imply drastic changes such as a reconsideration of how urban and natural spaces are used, including the demolition of illegal constructions (Mar Menor, Figure 20.3).

20.4 MANAGEMENT RECOMENDATIONS

20.4.1 Overview for all lagoons

In general, the end-users of all lagoons recognized the importance of a healthy ecosystem for the maintenance of human activities and well-being. In general, this translated into several common recommendations for all lagoons:

1) a promotion of sustainable touristic activities and other sorts of high quality tourism (i.e., in opposition to mass and unregulated tourism);
2) a need for better governance of touristic activities themselves, coordinated by a unique local management structure; in the case of Vistula, the need for improvement of trans-boundary cooperation. For all lagoons this includes regulations for currently non-regulated activities (e.g., diving, hunting) and surveillance of the regulated ones (e.g., illegal recreational fishing);
3) a need to improve the environmental awareness of the population, through environmental educational activities and stimulate the local community engagement in the management of the lagoon;
4) research and technology development (RTD) activities to improve knowledge on the lagoon's responses to environmental or anthropogenic impacts (e.g., long term data sets);
5) a need to improve existing infrastructure or creation of new infrastructure to support tourism.

For some lagoons, the need was also recognised for: (i) environmental restoration measures (e.g., Ria and Vistula); (ii) optimization of water use and management, including a sustainable use of water resources and waste water treatment (Tyligulskyi and Vistula); (iii) improvement of the lagoon's navigability within and across the lagoon, also to boost sailing and other water sports (e.g., Ria and Vistula); and (iv) an improvement in agricultural technology to reduce nutrient loading (Vistula) (Figures 20.2–20.5). Most of these Responses were identified in the DPSIR of the present conditions. Still, additional Responses were needed for all lagoons, although most of them were specifications of already existing management recommendations (e.g., better overall regulation and law enforcement, improvement of knowledge to reduce uncertainty, Figures 20.2–20.5).

20.4.2 Specific recommendations and potential Pressures

The majority of the Responses were common to the four hotspot lagoons. Still, several site-specific and detailed recommendations were developed taking into account ecological and socio-economic aspects of each lagoon. For instance, RTD activities regarding tourism and related activities recommended for each lagoon were adjusted to their present State. For Mar Menor and Vistula, this included measures to mitigate eutrophication (Figures 20.3, 20.5); for Vistula it included a standardization of monitoring networks and parameters between the two countries, Poland and Russia (Figure 20.5). For Ria, research should clarify whether the presence of lead in some water courses is related to recreational hunting activities; in addition, research regarding the lagoon's hydrology should be strengthened (Figure 20.2). Finally, in Tyligulskyi, research activities are needed to understand the causes of occasional fish kills and how to mitigate coastal erosion and eventual impacts from climatic changes (Figure 20.4). There were also other specific Responses that did not fit into a general common recommendation such as the need to decrease the water residence time in Aveiro city channels (Figure 20.2) or the need to improve urban management and planning in Mar Menor (Figure 20.3). Other specifications can be found in Figures 20.2–20.5.

The desirable scenario of each lagoon synthetises what the end-users have considered to be the best compromise between their environmental, social and economic needs. However, potential Pressures arise from the desirable and undesirable Impacts and needed Responses. For instance, a goal for a better navigability, obtained through timely and site-specific dredging as recommended for Ria de Aveiro (Figure 20.2), needs to consider the dredging history in Ria, and especially the impact on the seagrass community (Azevedo *et al.,* 2013). In Vistula, the improved fish stocks and habitats as desirables could lead to an unbalanced cormorant population, if no control measures are taken (Figure 20.5). More potential Pressures can be found in Figures 20.2–20.5.

20.5 FINAL REMARKS

20.5.1 Sustainable tourism as a goal for European coastal lagoons

The management of the marine ecosystem is extremely complex, as it needs to accommodate several users, entities and disciplines. Socio-economic and political matters largely influence water management. To turn water management objective and cost-effective, the views and needs from end-users need to be taken into account. In this chapter, we used the DPSIR framework to identify management recommendations from the end-users of the lagoons. For the four lagoons, sustainable tourism was considered to be a priority goal with potential growth in the future that would help boost local economy and generate employment, and, at the same time, preserve the environment. In this way, all three pillars of a sustainable development – environment, society and economy – can be addressed. In addition, a goal for sustainable tourism implies several other Responses identified in both present conditions and in the desirable scenario for 2030 such as the regulation for non-regulated activities and law enforcement and an increase of civic and environmental awareness to ensure that inhabitants and visitors respect the lagoons' natural capital.

The applied DPSIR framework allowed for a better comprehension of the complex relationships between the driving forces and their impacts on coastal lagoons regarding the 'Population, Tourism and Related Activities'. This work highlights the importance of multidisciplinary knowledge combined with participatory methods for coastal management, foreseeing sustainable growth of human activities and human well-being.

20.6 ACKNOWLEDGEMENTS

This study was supported by the European Commission, under the 7th Framework Programme, through the collaborative research project LAGOONS (contract n° 283157); by European funds through COMPETE and by Portuguese funds through the national Foundation for Science and Technology – FCT (PEst-C/MAR/LA0017/2013). The PhD grant SFRH/BD/79170/2011 (LP Sousa) supported by FCT is also acknowledged. Authors also acknowledge LAGOONS partners involved in building the scenarios presented to the stakeholders, namely partners involved in WP4, WP5 and WP6. Finally, we gratefully acknowledge all stakeholders that actively contributed to the participatory processes.

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Chapter 21

Management of coastal lagoons – lessons learnt and recommendations

P. Stålnacke, A. I. Lillebø and G. D. Gooch

Summary: This final chapter summarizes and discusses the major findings from the studies of the four case study lagoons: the Ria de Aveiro Lagoon in the Atlantic Ocean (Portugal), the Mar Menor in the Mediterranean Sea (Spain), the Vistula Lagoon in the Baltic Sea (Poland/Russia) and the Tyligulskyi Liman Lagoon in the Black Sea (Ukraine). Particular emphasis is placed in this chapter on presenting the results and challenges concerning environmental issues (water quantity and quality), ecosystem services, water governance, and scientific scenario impact modelling. We also include the main results of the interactions between LAGOONS scientists and local/regional stakeholders and citizens. The lessons learnt in the project and the recommendations deriving from the work conducted in the project are also provided in a pan-European perspective. It is shown that effective coastal lagoon management is hampered by several short-comings, particularly those related to suboptimal coordination between different sectors involved in their management, and a lack of easy access to basic knowledge and data. It is recommended that an integrated vision and strategy for all European coastal areas, including drainage areas, should be initiated; this strategy should go beyond present policies such as various EC Directives. More specifically, there is a need for a better coordination of surface and lagoon waters (including the specific problems around transboundary waters) and for a single coordinating unit for coastal zone management, including lagoons. Easier access to data and information sharing is also needed in order to better include citizens and stakeholders in the management of the lagoons. Moreover, the science-policy interface should be improved, and it is also necessary for better recognition of the connectivity of land, streams, rivers, lagoons and coastal zones. Integrated scenarios developed jointly with stakeholders coupled with nested hydro-chemical impact modelling, as demonstrated in LAGOONS, seems to be a promising tool that could be further developed in order to achieve these aims.

Keywords: Coastal lagoons, climate change, ecosystem services, governance, management, modelling, stakeholders.

21.1 INTRODUCTION

Coastal zones, due to their natural capital and related ecosystem services, are crucial geographical domains for our economy. According to EEA (2013), approximately 40% of the EU's population live within 50 km of the sea; almost 40% of the EU's GDP is generated in these maritime regions, and a staggering 75% of the volume of the EU's foreign trade is conducted by sea. At the same time, many coastal areas are under heavy pressure from a number of sources, and significant environmental degradation is present. Eutrophication resulting from nutrient enrichment, primarily from drainage basin inputs and direct discharges along the coasts, has been recognised for many years as one of the main pressures on the marine environment, and pollution remains a threat for marine biodiversity in European coastal waters (EEA, 2013). As a policy response to this, eutrophication has been identified as a major target issue in a number of EC Directives such as the Nitrates Directive, Urban

Waste Water Directive, Water Framework Directive, and Marine Strategy Framework Directive, as well as in marine related international conventions such as OSPAR and HELCOM.

Coastal lagoons are a specific spatio-geographic feature of coastal zones. Coastal lagoons represent nearly 13% of the shoreline globally, and around 5% in Europe. Many of these European lagoons are experiencing particularly strong anthropogenic pressures due to nutrient pollution inflows from point and diffuse sources. These originate from rivers and streams from upstream catchments and from direct discharges from urban and/or industrial effluents along the shorelines of the lagoons. In addition to nutrients, these inflows to the lagoons may also contain hazardous substances specifically identified under the WFD and prioritised as representing a significant risk to the aquatic environment. In addition, port infrastructure development and related activities, and other human activities such as boating, fishing, shell-fishing and aquaculture, may also represent additional pressures, as they may affect eco-hydrological and geomorphological conditions through lagoon bed disturbance, the results of sediment dredging, and changes in lagoon hydrodynamics. These may, in turn, induce changes to water quality and result in the loss of endemic species. They may also cause changes in the food chain structure. Activities related to coastal tourism may, if not developed in a sustainable way, also produce strong pressures through land reclamation for infrastructures and increased water demand, which may in turn overstretch the drinking water supply and wastewater treatment plant capacity, particularly during the summer season.

In this chapter we summarize the main findings from this book and the LAGOONS project. The following sections focus on addressing the challenges facing integrated management strategies, seen in a land-sea and science-stakeholder-policy perspective. Pan-European management challenges are examined in the context of the perspectives of environmental (section 21.2), modelling (section 21.3), and governance (section 21.4) issues. The four case studies in the LAGOONS project provide examples of some of the practical experiences and results around these challenges. The possible future impacts of socio-economic and environmental change in drainage basins and lagoons are introduced through integrated scenarios for the year 2030. These were developed through a multi-science and land-lagoon science perspective combined with interactions and contributions from stakeholders and citizens, and in the context of climate change (see chapters 14 for scenarios building; chapter 15 for impacts on lagoon drainage basins; and chapter 16 for impacts on lagoons).

21.2 ENVIRONMENTAL MANAGEMENT OF COASTAL LAGOONS

The Water Framework Directive (WFD) aims to achieve '*good ecological and chemical status*' in all European waters by 2015. This includes surface, groundwater and coastal transitional waters. Regarding the marine environment, which is the sea boundary of coastal lagoons, the Marine Strategy Framework Directive (MSFD) aims to achieve or maintain a good environmental status by 2020 at the latest. Note that, in coastal waters, where both the directives overlap, the MSFD is only intended to apply to those aspects of '*good environmental status*', which are not already covered by the WFD (e.g., noise, litter, aspects of biodiversity) (Maes *et al*. 2014). When looking at the environmental management of the lagoons in the framework of catchment to coast processes and under the context of climate change, other policies also need to be taken into account, namely:

– Floods Directive (aims to reduce and manage the risks that floods pose to human health, the environment, cultural heritage and economic activity);
– Nitrates Directive (aims to protect water quality across Europe by preventing nitrates from agricultural sources polluting ground and surface waters, and by promoting the use of good farming practices) and the Common Agricultural Policy (in terms of environment, aims relating to resource efficiency, soil and water quality and threats to habitats and biodiversity);
– Habitats Directive (on the conservation of natural habitats and of wild fauna and flora) and Biodiversity strategy for 2020 (aiming to halt the loss of biodiversity and ecosystem services in the EU by 2020);
– EU strategy on adaptation to climate change (aiming to make Europe more climate-resilient).

These policies and strategies are heavily interconnected since biodiversity underpins the delivery of ecosystem services, and healthy ecosystems are likely to be more resilient and therefore better able to recover after disturbance (Maes *et al*. 2014). Results of the LAGOONS project show that the natural capital (e.g., ecosystems capital assets) was considered by the stakeholders in all four case lagoons as a '*Strength*' (Chapter 19). It has recently been shown that one way to protect the natural capital is by conserving biodiversity using a network of nature reserves, such as the EU's Natura 2000 network (Maes *et al*. 2014). Significantly, coastal lagoons are classified within '*coastal and halophytic habitats*' under the Habitats Directive as a priority habitat type, with the Natura 2000 code 1150. Regarding the management of coastal lagoons, there are links between the WFD aims of '*good ecological and chemical status*' and the Nature Directives aims '*to promote the maintenance of biodiversity, taking account of economic, social, cultural and regional requirements*'. In addition, human well-being and ecological status are regarded as linked (UNEP, 2011; Maes *et al.* 2014). These examples clearly show that coastal lagoons are a melting pot of various environmental and nature-related policies (a further discussion about this is performed in section 21.4)

One of the '*Opportunities*', identified by the stakeholders in the four case lagoons, were the EU Directives (see Chapter 19). It was mentioned that the effective articulation, coordination and implementation of these Directives would help to overcome the defined '*Weaknesses*' such as untreated wastewater inputs and/or the potential for eutrophication. This opinion is in line with the blueprint to Safeguard Europe's Water resources (Communication from the Commission (COM(2012)673). This '*blueprint outlines actions that concentrate on better implementation of current water legislation, integration of water policy objectives into other policies, and filling the gaps in particular as regards water quantity and efficiency. The objective is to ensure that a sufficient quantity of good quality water is available for people's needs, the economy and the environment throughout the EU'*. All these interconnections are also underpinned by the concept of ecosystem services and human well-being, as described in Chapter 1.

Moreover, the potential management strategy of coastal lagoons, following the results of the LAGOONS project (see Chapters 19 and 20), clearly falls into the concept of an ecosystem-based management (UNEP, 2011). This acknowledges the '*complexity of marine and coastal ecosystems, the connections among them, their links with land and freshwater, and how people interact with them*'. As highlighted in Chapter 1, challenges to this approach lie in identifying environmental management priorities (e.g., Granek, 2010).

In the context of ecological quality status (WFD), ecosystem services and human well-being, our results have identified some specificities among the studied coastal lagoons, which, in turn, led to management recommendations at the European level (Table 21.1). In the first column to the left, we refer to the common recommendations provided by stakeholders at the final workshops that took place at each case study lagoon; in the second one, we refer to the recommendations from the project itself at a pan-European scale; in the third column, we identify the main target policies at local, regional and European levels.

Table 21.1 Summary of the main recommendations for the environmental management of costal lagoons.

Main environmental recommendations from stakeholders	**Main recommendations of the project**	**Main target policy (regional, national or European level)**
Sustainable use of water resources; Agriculture based on modern technologies and practices; Diversified agriculture with crops adapted to the local conditions.	Sustainable use of water resources; best agricultural practices;	Regional – River basin management plans; National – water law (water uses regulation and surveillance) EU level – WFD (chemical and biological indicators); Nitrates Directive; CAP (2014); Habitats Directive; Biodiversity 2020
Maintenance of natural habitats and endemic species and establishment of means and ways of nature conservation to sustain traditional and other uses of lagoons ecosystem.	Assessment of ecosystem services and their beneficiaries; Spatial planning of activities taking into account natural habitats and enabling the local traditional activities and livelihood's; Elaboration of a best practices guide for the natural and human capital balance.	Regional – improvement of ecological attractiveness National – water law (water uses regulation and surveillance); national nature strategies EU level – WFD; MSFD; EIA; Habitats Directive (Natura, 2000); Biodiversity 2020
Increase RTD, namely related to flood threats, nutrient inputs from the catchment, hydrology, impact of climate change on water resources and ecological conditions	RTD on flood risk; adaptation to climate change; eco-hydrology	Regional – River basin management plans; National – water law (water uses regulation and surveillance); national nature strategies EU level – Floods Directive; EU strategy on adaptation to climate change

Results from the previous chapters also show that the four coastal lagoons share common external '*Threats*', for example, climate change, environmental pressures and conflicting activities, and '*Opportunities*' such as research and technological development (RTD) activities and tourism, besides the potentially positive effects of EU Directives. The lagoons also share internal '*Weaknesses*' such as the untreated waste water inputs and/or potential for eutrophication, and uncoordinated management, as well as '*Strengths*' such as the natural capital, biodiversity and tourism potential (Chapter 19). In addition, we identified several inter-related drivers in the coastal lagoons (Chapter 20). These drivers are population growth, tourism, agriculture, fishing, uncoordinated management, and economic crisis, which act in combination with other exogenic unmanaged pressures such as climate, eco-hydrological characteristics, and invasive species (Dolbeth *et al. submitted*). Together, these constitute major challenges for the management of coastal lagoons, which include the following:

- Coping with increasing water stress (quantity & quality)
- Reducing the impact of extreme events (droughts & floods)
- Managing infrastructures vulnerable to climate risks
- Developing science-based innovative methodologies for enhanced lagoon resource management
- Developing and ranking eco-innovative (engineering) technologies
- Promoting ecosystem services trade-offs
- Managing the economical sector in spatial planning
- Promoting trans-boundary management options
- Promoting the eco-efficiency of new economic opportunities
- Promoting coastal lagoon economies' resilience to climate risks
- Promoting ecological resilience to climate risks in coastal lagoons

21.3 LESSONS LEARNT ON THE CHALLENGES OF USING NUMERICAL MODELS

Lagoon ecosystems are subject to significant spatial and temporal variations due to their dependency on inputs from upstream drainage areas, and on the interplay of seawater and sea-lagoon connections. Besides being influenced by the intensity of and rapid changes in hydro-meteorological factors at the catchment level (e.g., precipitation and run off), coastal lagoons are also exposed to marine-meteorological impacts (e.g., wind speed and direction, and storm surge events) in addition to climate change impacts (e.g., sea-level rise and meteorological extreme events). Such complexity and interaction can be studied by the use of biophysical models.

LAGOONS brought together end-users and stakeholders (e.g., national, regional and local authorities, managers, and civil society) to work in partnership with the projects' scientists. The socio-economic scenario building, conducted jointly with the stakeholders (see Chapter 14), served as an excellent basis for cooperation, and increased the end-user relevance of the scientific environmental impact modelling. More precisely, throughout the numerous interactions with the stakeholders, it became clear that they perceived that research and technological development represent an 'Opportunity' for lagoon development. They pointed out the specific need for increased knowledge related to flood threats, nutrient inputs from the catchment, hydrology, and impact of climate change. Thus, after the identification of these issues together with the stakeholders, we focused our environmental scenario impact modelling on those issues. A general scheme of the work with the models and scenarios is presented in Figure 21.1

The eco-hydrological model SWIM (Soil and Water Integrated Model) (Krysanova & Wechsung, 2000) was used in the LAGOONS project in all four case study lagoons to assess the catchment influences on the lagoons in terms of freshwater quantity and nutrient pollution inputs via streams, rivers and direct discharges (see Chapters 11 and 15). More specifically, the model was used to quantify the possible environmental impacts of socio-economic and environmental changes in drainage basins through integrated scenarios for the year 2030 (Chapter 14), and to model the possible impacts of climate change on water quantity and quality for waters that reach the lagoon area.

The scenarios adopted for the drainage basins were also applied on the lagoon environments, where various models were applied to study the possible impacts on the lagoons water quantity and quality. More precisely, in each of the four case study lagoons, different numerical models were set up and calibrated: Delft3D-Flow (Deltares, 2014a) for hydrodynamics and Delft3D-WAQ (Deltares, 2014b) for water quality both in Ria de Aveiro and in Vistula lagoon; MOHID (Braunschweig *et al*. 2004) for hydrodynamics and water quality in Mar Menor; and OSENU-MECCA-EUTRO (Ivanov & Tuchkovenko, 2008) for hydrodynamics and water quality in Tyligulskyi Liman. Further details about the models are presented in Chapter 13. The watershed modelling outputs from SWIM (i.e., water flows, nitrogen and phosphorus inputs) were, besides the ocean boundary and atmospheric conditions, treated as input (i.e., forcing functions) to the lagoons models.

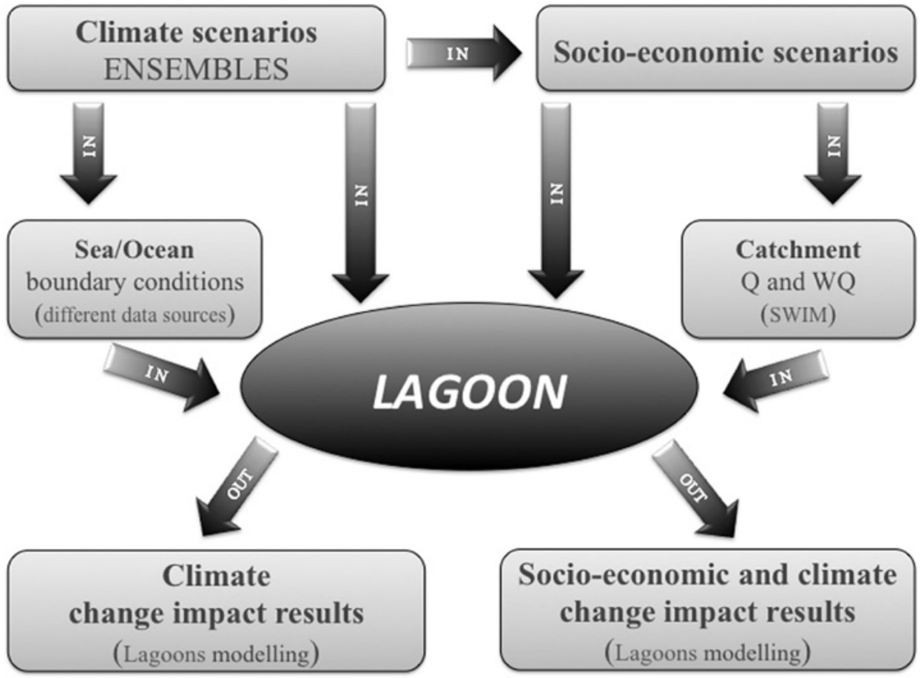

Figure 21.1 General scheme of coupling models and scenarios. Source: Chapter 12.

The models use spatial data, time series and management data as inputs (see chapter 11 and 13 for more details). As already pointed out in Chapter 1, there are several challenges facing modelling; besides the selection of the most appropriate and suitable model, there are also challenges related to issues around input data availability and the uncertainty of the models' outputs. In our project we also faced the same challenges. In all four case study areas, some data was missing or incomplete in time and/or space. Some examples of this are:

– there was only one water level station in the Ria de Aveiro drainage area (see Stefanova et al. 2014);
– there were no gauging stations in the Mar Menor drainage area, and only estimated seasonal dynamics of water flow existed;
– there were no climate stations in the drainage area of the Tyligulsky Liman, where re-analysed data from the WATCH project (Weedon et al. 2010, 2011) was used instead;
– there were no water quality measurements available for the Pregolya river, which is the largest river in the drainage area of the Vistula lagoon.

Source: Chapter 11

Further data weaknesses are described in Chapter 11, whilst other challenges concerning the selection of appropriate models, coupling them, setting them up, calibrating and validating them, are presented in Chapter 12. These gaps in data were solved through various interpolation and extrapolation methods and/or qualified estimates and assumptions by the experts or through the utilisation of local knowledge. Despite all these uncertainties, it was, with a sufficient degree of accuracy and precision, possible to show that the lagoons respond differently to the proposed scenario change in climate, environmental and socio-economic conditions (Chapters 13, 15 and 16). The reasons for the differences in responses between the lagoons seem to be related to the hydrologic characteristics of each lagoon, namely the water residence time (due to tidal exchange or artificially opening to the sea), the fresh water flow (climate driven changes in water quantity and quality from the catchment), and the ocean boundary related events (e.g., upwelling water). The model analysis of 15 climate change scenarios (van der Linden & Mitchell, 2009) showed that the surface water temperatures will, on average, increase by one to around three degrees in all four lagoon regions by the end of this century (Chapter 13). At the same time, the models showed that the precipitation and water discharge will increase in the Vistula Lagoon catchment, while they will decrease in the Ria de Aveiro and Mar Menor catchments (Chapter 13). For Tyligulskyi Liman, the 15 climate projections were not conclusive on future precipitation changes, while water discharge is likely to increase slightly due to increased groundwater recharge (Chapter 13). The corresponding change in nutrient loads via the streams and rivers as well as in nutrient concentrations in the lagoons show a more diverse pattern. Overall, results of the impacts of potential climate change for the middle and end of this century show that the lagoons will be affected by changes in both upstream catchment(s) and downstream ocean borders (Chapter 13).

In addition to climate change scenarios, four future socio-economic scenarios were constructed per case study lagoon, all with a time span up to the year 2030 (Chapter 14). Results showed that environmental response in water quantity and quality, as a result of socio-economic changes, for all four scenarios, were only minor for the Ria de Aveiro case study, moderate for the Vistula. However, changes were quite significant for some scenarios in the Mar Menor and Tyligulskyi Lagoon catchments (Chapter 15). The latter two lagoons are strongly influenced by human activities such as an all-year-round cultivation of irrigated horticulture in the Mar Menor catchment and the operation of numerous irrigation ponds in the catchment of the Tyligulskyi Liman Lagoon.

Another striking result in the scenario exercise was that the scenarios that were initially expected to be more environmentally friendly did not always lead to an improvement in water quality (Chapter 15). For example, in the cases of Mar Menor and Vistula, one of the scenarios (entitled 'Managed Horizon'; see Chapter 14) assumed a significant level of environmental concern and quite hard environmental legislation, but, at the same time, assumed a growth in the economy and an associated increase in population, number of tourists, and amounts of applied fertilizers. The modelling results showed that these changes will lead to a decrease in water availability and the deterioration of water quality (Chapter 15). Furthermore, and as shown in Chapter 15, some changes, which were evaluated as positive for the catchment, may have negative effects on the lagoon. Overall, it was found that the case lagoons' environmental responses to socio-economic scenarios (up to the year 2030) were small to moderate. For example, changes in nutrient concentrations and chlorophyll *a* did not exceed a 25%-change in any of the lagoons. This might be regarded as somewhat surprising since in some scenarios we postulated quite large changes in some of the factors, for example, decreases of agricultural land up to 50% or changes in the use of mineral fertilizers up to 100% (Chapters 14 and 15).

The expected impacts on the lagoons due to the combined climate and socio-economic changes in the catchments for the year 2030 were analysed (Chapter 16). The results showed that changes in the lagoons' water quality was small to moderate. The reason for this is related to the combined effect of freshwater flow (climate driven changes and/or water use management), land use, and management.

As pointed out in Chapter 13, climate change will have an impact on water resources (both quantitatively and qualitatively), but future socio-economic change (economical conditions, human and societal actions, land use change etc.) will have an additional and, in some cases, multiplicative effect, which may be crucial for the future environmental condition of these vulnerable coastal areas. Such conclusions with supportive quantitative evidence would not have been possible without advanced mathematical modelling of the environmental impacts. Moreover, the scenarios and their modelled environmental impacts were presented to the stakeholders at a final workshop (Chapter 14), which led to the production of a comprehensive list of recommendations (see section 21.2 above). Our opinion is that such new sets of ideas and recommendations would not have happened without the results of the impact modelling. The modelling results have enabled the stakeholders to better grasp and understand the factors that determine the future of their lagoon. Overall, we have demonstrated that a combination of focus groups, citizen juries, and stakeholder workshops, together with scientific scenario impact modelling, can be used to provide quantitative inputs into discussions on the desirable or undesirable future of a lagoon. These governance issues are discussed in the next section.

21.4 LESSONS LEARNT ON THE CHALLENGES FACING THE GOVERNANCE OF COASTAL LAGOONS

Coastal lagoons are complex systems from a governance perspective, not only do they involve the need for cooperation between a number of agencies, but the legal and administrative systems determining their management are also multidimensional. The needs of agriculture, tourism, industry, nature protection, fisheries and so on, must all be recognised, and the legal structures within which they operate must be managed in order to cover land, freshwater, coastal zones and the sea. The pressures on coastal lagoons have been shown to be considerable, and besides the need for more data in many of them, it has also been recognized that improvements in governance systems are a vital aspect. In the first chapter, three main aspects of the governance of coastal lagoons were introduced:

a) Governance systems
b) The interplay of laws, policies, institutions and actors
c) Administrative capacity

21.4.1 Governance systems

The previous chapters of this book have shown that there is a wide variety of governance systems in place for coastal lagoons in Europe, with varying combinations of participation from formal actors such as authorities, civil society and NGO's, the public, and the business community. The work presented in the different chapters of this book has also clearly shown that a combination of actors can be brought together to cooperate in the planning the management of lagoons. The informed input of stakeholders and the public has been shown to be feasible and effective, as long as the planning for such participation is clear and the potential for influence made clear. In the work described in the book, the three stage approach to participation was shown to be a clear improvement over approaches where only one or a limited number of participatory methods are used. The focus groups conducted in all case lagoons helped identify the main challenges, and to engage stakeholders and the public in the following processes. The focus groups also brought together groups of people with similar interests, who could then continue discussions outside of the process organised by the Lagoons project. The second stage, where citizen juries were used, allowed participants to collectively form a number of future visions for their lagoon. During the final stage of the process, these visions were further discussed, using the results of the modelling exercises.

The success of this participatory process was notable to both the participants and to the natural scientists working in the project. A significant result and recommendation is that scientists with little or no experience of participatory methods can be both trained and inspired through the cooperation with social scientists, and not least, the stakeholders and public themselves. In order to achieve this, however, a well-planned series of training sessions needs to be implemented, in which the scientists working in the case areas can be introduced to the participatory methods, and in which they can practice different roles in these processes in order to gain confidence. Another important experience from the project is that there is a widespread understanding that there are major challenges to improving the cooperation between the different authorities engaged in managing the lagoons, and between these and the local population. However, while there is acceptance of these challenges, ways to overcome them are still lacking, partly because the authorities are bound by their own mandates, and partly because inter-organisational rivalries inhibit such cooperation. In the cases where different stakeholders have participated in the focus groups, citizen juries and stakeholders workshops, there has been a better understanding of the different roles that different authorities and that local population can play in the management of lagoons, but this has been on a personal, not organisational level.

Moreover, common recommendations given by stakeholders at the final workshops were:

– To promote collaborative, integrated and coordinated management of the lagoons;
– To promote public awareness and involvement of the local population

21.4.2 Interplay – laws, policies, institutions and actors

A central aspect of governance is the role that law, policies and institutions play in influencing the affairs of society (and actors), as these provide the playing field on which actors can interact. In the first chapter it was pointed out that while these factors are often considered synonymously, more work is needed to ascertain the role and function of each, in order to better understand, firstly, their individual contribution; and secondly, the interplay between different instruments. The mapping of the overlapping systems of laws and regulations conducted in the project show how complicated these systems are (see Figure 21.2). From regulations covering marine transport and fishing, over laws on construction of dwellings on beaches, through directives on water quality to the regulation of agriculture, the complexity of the legal and poly systems governing coastal lagoons is apparent. While regulations and directives at the European level were easily available for study, and in many cases also at the national levels, there were difficulties in achieving the same levels of analyses at the regional and local levels due to language constraints. Despite all these constraints, an attempt on describing the management system for each case study lagoon was made (Chapters 4, 6, 8, and 10).

Here, it is important to point out once again that European regulations such as the Water Framework Directive must be implemented at the national, regional and local levels, and that the form of this implementation differs according to the administrative and political landscape of the country (or countries) in questions. In one of the case studies included in this book, the Vistula Lagoon, there was also the added complexity of a transboundary context, with Poland and Russia only having responsibility for the management of their own parts of the lagoon. Understandings of territorial sovereignty may in such conditions constitute a barrier for the successful joint management of the lagoon, and special initiatives such as a joint commission for the lagoon need to be substantially supported. The results of this project have also shown how diverse the groups of actors that interact with law, policies and institutions are.

The variety of actors involved in the different lagoons is striking. However, while there is a wide variety, it is also possible to identify some common traits. In each case area, there were authorities tasked with managing water for agricultural production (water quantity), ensuring satisfactory water quality, regulating the construction of housing and infrastructure, managing fishing and ensuring nature protection. In some of the lagoons, maritime transport was also an important sector, especially in the Ria de

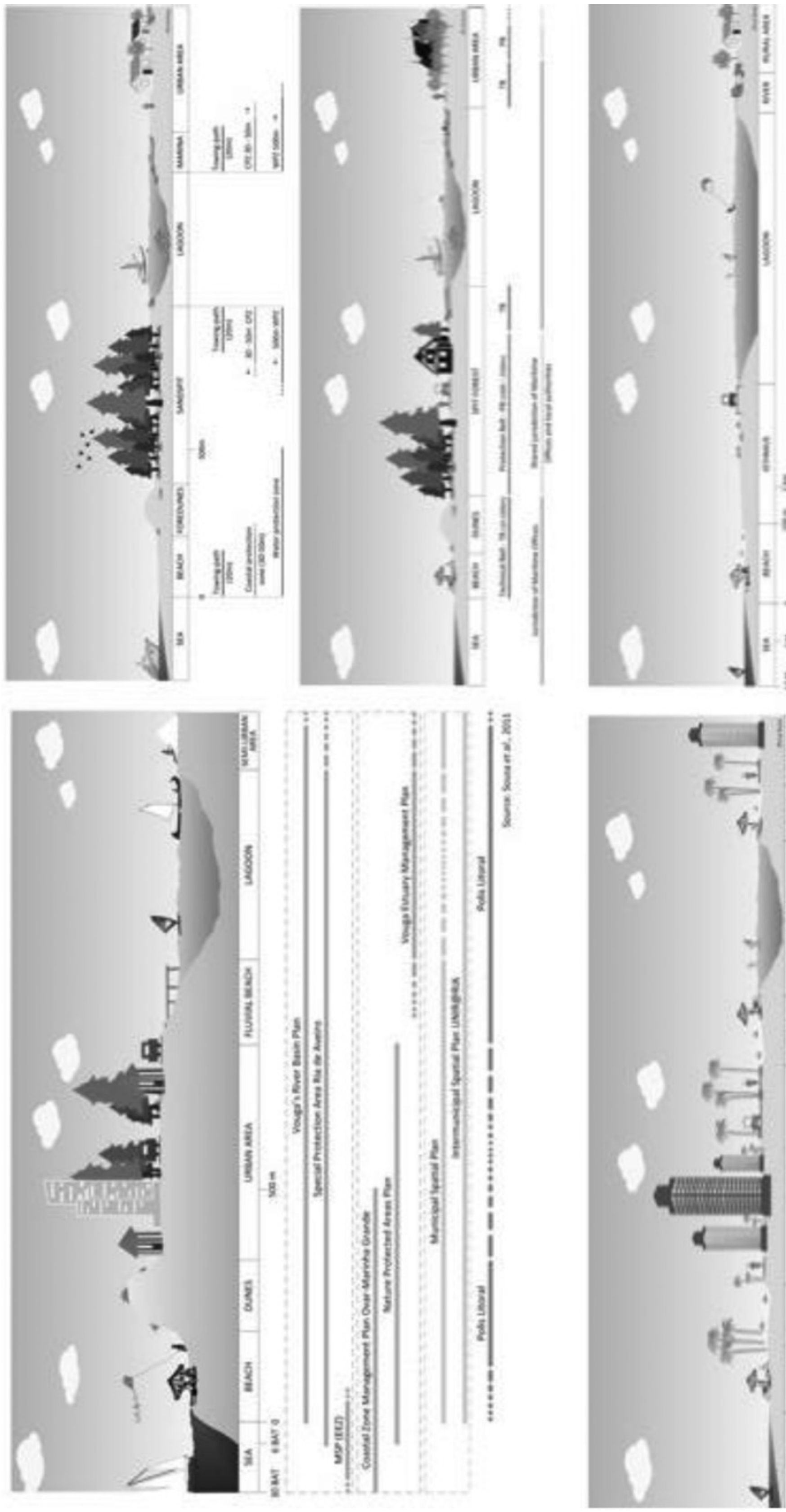

Figure 21.2 Schematic sketch of the various geographical features in Ria de Aveiro (top left); Vistula lagoon Russian and polish parts (top right); Mar Menor (bottom left) and Tyligulskiy Liman (bottom right) in relation to some of the most important policies and management plans (© Lisa Sousa, CESAM/DAO, UAVR).

Aveiro and Vistula lagoons. There were also similarities in the types of water users in the lagoons. Fishing and shellfish collection were important economic and/or social activities in all the lagoons. Farming was also a significant activity, although its significance differed between the lagoons. Tourism was seen as an important existing or potential economic activity, and the tourist sector was an important actor. The variety of actors and interests demonstrates that it is necessary to take all sectors into account and to create a mix of policy instruments to manage and coordinate these interests.

The work conducted in this project showed that the use of scenarios could be a way to stimulate discussions as to the most suitable policy mixes, as during scenario exercises the different groups must come to an understanding of the pay-offs between different development strategies.

21.4.3 Administrative capacity

Improvements in governance systems and in the interplay of legal and policy instruments, as well as in the engagement of stakeholders and the public, are all dependent, however, on the economic and technical capacities of those responsible for the implementation of law and policy commitments. In the present economic climate in Europe, economic conditions limit the approaches that can be taken, and may lead to a wariness of testing innovative methods such as those used in this project. However, the recommendations suggested here need not necessarily lead to increased costs. A better coordination of the work of the authorities involved in the management of the lagoons may instead lead to financial savings, as it could also lead to improved efficiency, minimise repetition, and produce better results. This project has shown that it is therefore important to ascertain whether there is sufficient capacity to fulfil the substantive and procedural commitments necessary for improved lagoon management and governance. What seems today to be an output based management system needs to be changed to an outcome based system, in which scenario exercises such as those described in this book are used as a base for identifying which future conditions are desirable and feasible, and then analysing which changes in policy and administrative organisation are needed to achieve these outcomes.

21.5 FINAL REMARKS

The approach taken by the LAGOONS project was to connect the stakeholders' views and knowledge, obtained through a three stage participatory process, with multi-discplinary scientific analyses, using scenario environmental impact modelling. This strategy of integrating stakeholder and scientific views was a deliberate choice taken at the onset of the project, and was implemented throughout the project in order to increase the likelihood that the project results were relevant for (and used by) the case study lagoons. Another key ambition was to target the pan-European management level by specifically contributing to the connectivity between research and policy-making in support of the common implementation strategy of the Water Framework Directive and other water and environmental related EU policies.

In LAGOONS, we have identified several short-comings and challenges that the management communities need to address in a better way. Our recommendations are as follows:

These recommendations are also, to a large extent, in line with those recently recognised by the EEA on data and information issues (EEA, 2013).

- There is a need for better knowledge around the linkage between environmental conditions and impacts, and socio-economic development and climate change;
- There is a need to better address the coupling of the land to sea continuum;
- Effective lagoons management critically depends on high-quality data, particularly comparable water quality data, uniform pressure data and harmonised data in geospatial format;
- There is a lack of clear administrative responsibility for the implementation of coastal lagoon management and an absence of commonly agreed objectives and timeframes in which these objectives should be achieved. A better coordination of the work of the authorities involved in the management of the lagoons is recommended.

The work in LAGOONS has highlighted that multidisciplinary scientific knowledge combined with participatory methods can contribute to better management of coastal lagoons in terms of environmental concern and growth of human activities and wellbeing. This study also reinforces the position that the concept of ecosystem services is a very useful one that enables the sharing of knowledge amongst scientists (academic knowledge), stakeholders (values, perceptions and local knowledge), and managers (to support environmental management policies). All four lagoons that were part of this study are managed within a complex legislative and policy context, with a wide variety of institutions and actors involved in the use and management of the lagoons. It is therefore necessary to develop a framework of common objectives and management guidelines for lagoons. This will enhance a more sustainable development in the areas, and protect its natural resources and biodiversity, especially facing the expected impacts of future global climate change.

To conclude:

- Lagoons represent a complex and, at the same time, unique coastal environment, which requires special attention. There is a need to create an integrated vision for all European coastal areas and its drainage areas. More specifically, there is a need for better sectorial coordination of all waters related to a lagoon and for a single coordinating unit for coastal zones management. Openness around data and information sharing is also needed in order to include citizens and stakeholders into the management of the lagoons. The science-policy interface should be improved and it is also necessary for a better recognition of the connectivity of land, streams, rivers, lagoons and coastal zones. Integrated scenarios developed jointly with stakeholders coupled with nested hydro-chemical impact modelling as demonstrated in LAGOONS seem to be a promising tool.

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Glossary

Term	Meaning	Reference when available
Anthropogenic pressures or endogenic managed pressures	'Pressures whose causes of potential adverse effects come from within a system and require local, regional, and/or international management. Both the causes and consequences of change can be managed'	Atkins *et al.* 2011
Better overall regulation, law enforcement	This includes adequation of legislations and regulations, the simplification of legal and juridical processes, and the improvement of supervision to apply the legislation in vigour	Adapted from http://glossary.eea.europa.eu
Civic awareness	Increased perception of general public, ends users and stakeholders in their community or environment. State of citizens of being aware of their civic obligations	Adapted from Oxford advanced learner's dictionary, http://glossary.eea.europa.eu
Improve or create new infrastructure	For the context of lagoons, it refers to the creation of new infrastructure (grey or green), and/or improvement and the maintenance of the existing ones	LAGOONS project context
Cultural Services	'All the non-material, and normally non-consumptive, outputs of ecosystems that affect physical and mental states of people. All services, whether they be provisioning or regulating can have a cultural dimension. However, it is valuable to retain the section for Cultural, and to make the category distinct.' See also provisioning and regulating services.	Haines-Young and Potschin 2013
DPSIR framework	Causal framework for describing the interactions between society and the environment adopted by the European Environment Agency: driving forces, pressures, states, impacts, responses (extension of the PSR model developed by OECD - Organisation for Economic Cooperation and Development). It is regarded as a philosophy for structuring and communicating policy-relevant research about the environment'	Atkins *et al.* 2011, http://glossary.eea.europa.eu
DPSIR sub-cycle	For the context of lagoons, we define DPSIR sub-cycle as the application of the DPSIR framework for a single driver	LAGOONS project context
Drivers	In the DPSIR context, drivers are 'changes in social, economic and cultural settings that generate pressures'	Atkins *et al.* 2011, Barnard and Payn 2012
Ecological potential	Expression to designate the 'quality of the structure and functioning of a heavily modified or an artificial body of water'	WFD 2000
Ecological status	Expression to designate the 'quality of the structure and functioning of aquatic ecosystems associated with surface waters. For transitional waters the quality elements for the classification of ecological status are: biological elements (phytoplankton, other aquatic flora, benthic invertebrate fauna and fish fauna), hydro-morphological elements supporting the biological elements (Morphological conditions and tidal regime), chemical and physico-chemical elements supporting the biological elements (general, including nutrient concentrations, and specific pollutants).' For more details see Annex W from WFD	WFD 2000
End-users	A person or organisation that uses the outcome of a program/plan/project applied to a system or product	Adapted from Oxford advanced learner's dictionary

Environmental awareness	Perception of local environmental needs by their users (e.g., general public, end users, stakeholders). Understanding and consciousness toward the biophysical environment and its problems, including human interactions and effects. See also civic awareness.	Adapted from Oxford advanced learner's dictionary, http://glossary.eea.europa.eu
Exogenic unmanaged pressures	'Pressures for which our local management cannot address the causes of change, only the consequences. There is no sufficient knowledge of how and why change occurs in such systems, or simply nothing can be done, and so our Response is not management of the Pressure but of the consequences of that Pressure.'	Atkins *et al.* 2011, Elliott 2011
Extreme weather events	For the context of lagoons, extreme weather events are defined as unusual, severe or unseasonal weather events occurring nowadays. According to the IPPC 2013 definition, 'an extreme weather event is an event that is rare at a particular place and time of year. Definitions of rare vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile of a probability density function estimated from observations.'	IPCC 2013 glossary
Global climate change	For the context of lagoons, global climate change is defined as future change trends in weather patterns that last over a significant period of time and occur globally, as the ones predicted by IPPC reports.	Adapted from IPCC 2013 glossary
Governance	In the SWOT context, the exercise of economic, political, and administrative authority to manage a country's affairs at all levels. It comprises mechanisms, processes, and institutions through which citizens and groups articulate their interests, exercise their legal rights, meet their obligations, and mediate their differences.	UNDP
High end tourism	High quality tourism (appealing to sophisticated and discerning tourists)	Adapted from Oxford advanced learner's dictionary
Impact	In the DPSIR context, impact is defined as the effect of the anthropogenic activities for human well-being (economic – welfare, social – wellbeing, ecological - sustainability). It considers the impacts on society, in association with ecosystem services.	Atkins *et al.* 2011
Improvement of the lagoon navigability	Improve the transport or navigation conditions within and across the lagoon	LAGOONS project context
Natural capital richness	Refers the presence of natural areas of regional, national or/and international significance in the lagoon or catchment area	LAGOONS project context
Natural resources demands for consumption	For the context of lagoons, this refers to natural resources catches/extraction in the lagoon, such as fish, shellfish and bait. It does not involve farming new resources for harvesting	LAGOONS project context
Nested DPSIR	For the context of lagoons, we define nested DPSIR as a set of sub-cycles, encompassing different drivers/sectors, which may have multiple interactions among each other and need an integrated management plan/recommendations (response)	Atkins *et al.* 2011

(*Continued*)

Term	Meaning	Reference when available
Opportunities	Challenges that could exploit to its advantage	LAGOONS project context
Optimization of water use	For the context of lagoons, we define optimization of water use as better use of water resources, including sustainable use of water resources and waste water treatment plants	LAGOONS project context
Pressure	In the DPSIR context, a pressure is a direct and quantifiable effect of a driver in the system	Atkins *et al.* 2011
Harvesting activities	For the context of lagoons, this refers to the activities that involved collection of farming products, such as agriculture, aquaculture, livestock	Adapted from FAO
Provisioning services	'All nutritional, material and energetic outputs from living systems. In the proposed structure a distinction is made between provisioning outputs arising from biological materials (biomass) and water'. See also regulating and maintenance services and cultural services	Haines-Young and Potschin 2013
Regulating and maintenance services	'All the ways in which living organisms can mediate or moderate the ambient environment that affects human performance. It therefore covers the degradation of wastes and toxic substances by exploiting living processes; by reconnecting waste streams to living processes it is in this sense the opposite of provision. Regulation and maintenance also covers the mediation of flows in solids, liquids and gases that affect people's performance as well as the ways living organisms can regulate the physico-chemical and biological environment of people.'	Haines-Young and Potschin 2013
Response	In the DPSIR context, response refers to 'design interventions by governmental or institutional bodies to minimise or mitigate negative effects of an impact.'	Atkins *et al.* 2011, Barnard and Payn 2012
RTD activities, improve knowledge to reduce uncertainty	Research and technological development (RTD) to improve knowledge on the lagoon' responses to environmental or anthropogenic impacts	LAGOONS project context
Stakeholders	A person or organisation with a legitimate interest (or 'stake') in what may affect the economy or environment. See also end-users	Adapted from Oxford advanced learner's dictionary
State change	In the DPSIR context, state change refers to the condition of the water body resulting from both natural and anthropogenic factors (i.e., physical, chemical and biological characteristics).	Atkins *et al.* 2011
Strengths	Characteristics related to competitive advantages; good or beneficial quality	LAGOONS project context
Sustainable tourism	Sustainable tourism is defined as 'tourism that respects both local people and the traveller, cultural heritage and the environment'	UNESCO
Threats	Components that could cause problems, stresses and pressures	LAGOONS project context
Weakness	Limitations which hinder the progress in a certain direction; disadvantage	LAGOONS project context

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WATER RESEARCH SERIES

COASTAL LAGOONS IN EUROPE

Integrated Water Resource Strategies

Lagoons represent nearly 13% of the shoreline globally and around 5% in Europe. Coastal lagoons are shallow water bodies separated from the ocean by a barrier (e.g., narrow spit), connected at least intermittently to the ocean by one or more restricted inlets, and usually geographically oriented parallel to the shore-line. Coastal lagoons are flexible and usually able to cope with environmental change, yet nowadays they are under threat. This is partly due to climate change impacts (for example, sea-level rise and hydro-meteorological extreme events) but also due to more direct human activities and pressures.

The book focuses on addressing these challenges through integrated management strategies seen in a land-sea and science-stakeholder-policy perspective. Pan-European management challenges are seen from the context of the perspectives of Policy, Environment and Modelling. Four case study lagoons in different geographical locations in Europe provide examples of some of the practical experiences and results around these challenges. Possible impacts on drainage basins and lagoons are introduced through integrated scenarios which were developed through a multi-science and land-lagoon science perspective combined with interactions and contributions from stakeholders and citizens.

Issues around climate change impacts on environmental conditions in both drainage basins and lagoons are also included.

The book derives from a collaborative EC-funded project entitled *Integrated Water Resources and Coastal Zone Management in European Lagoons in the Context of Climate Change* comprising nine partner institutes with a wide diversity in the scientific disciplines covered.

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