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).

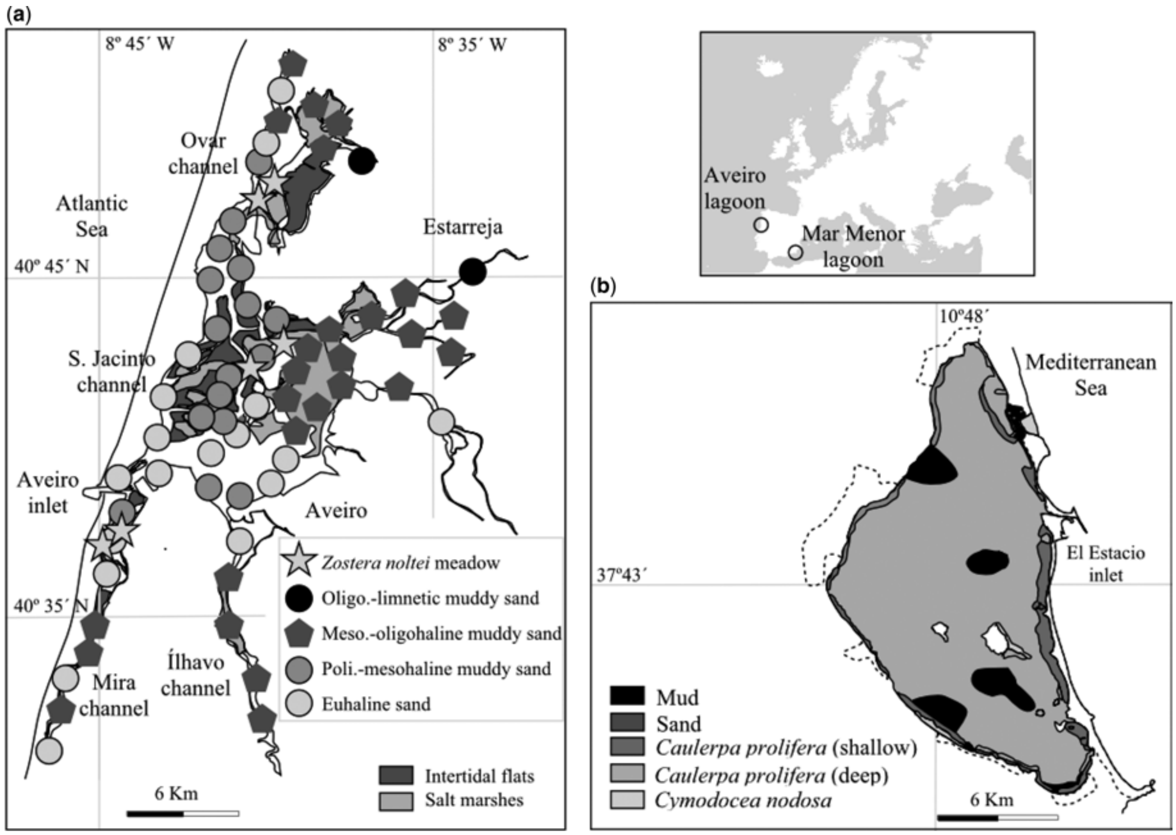

Figure 17.1 Ria de Aveiro and Mar Menor lagoons. Classification of major benthic habitats based on the sediment granulometry and the presence of benthic macrophytes. (A) Ria de Aveiro lagoon, main habitats (modified from Rodrigues *et al.* 2011; Nunes *et al.* 2008); (B) Mar Menor lagoon, main benthic 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.

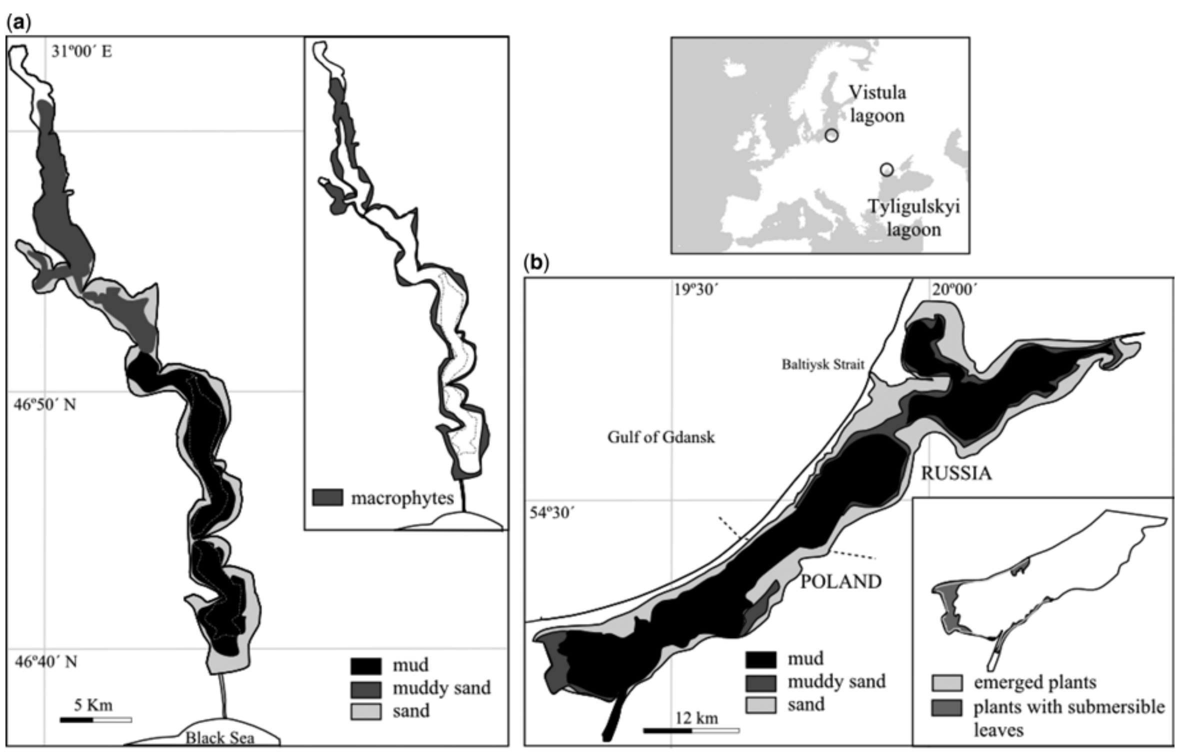

Figure 17.2 Tyligulskyi Liman and Vistula lagoon. Classification of major benthic habitats based on the sediment granulometry and the presence of benthic macrophytes. (A) Tyligulskyi Liman lagoon; (B) Vistula lagoon (the map of the macrophytes covers the Polish part of the lagoon only). Vistula lagoon 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.

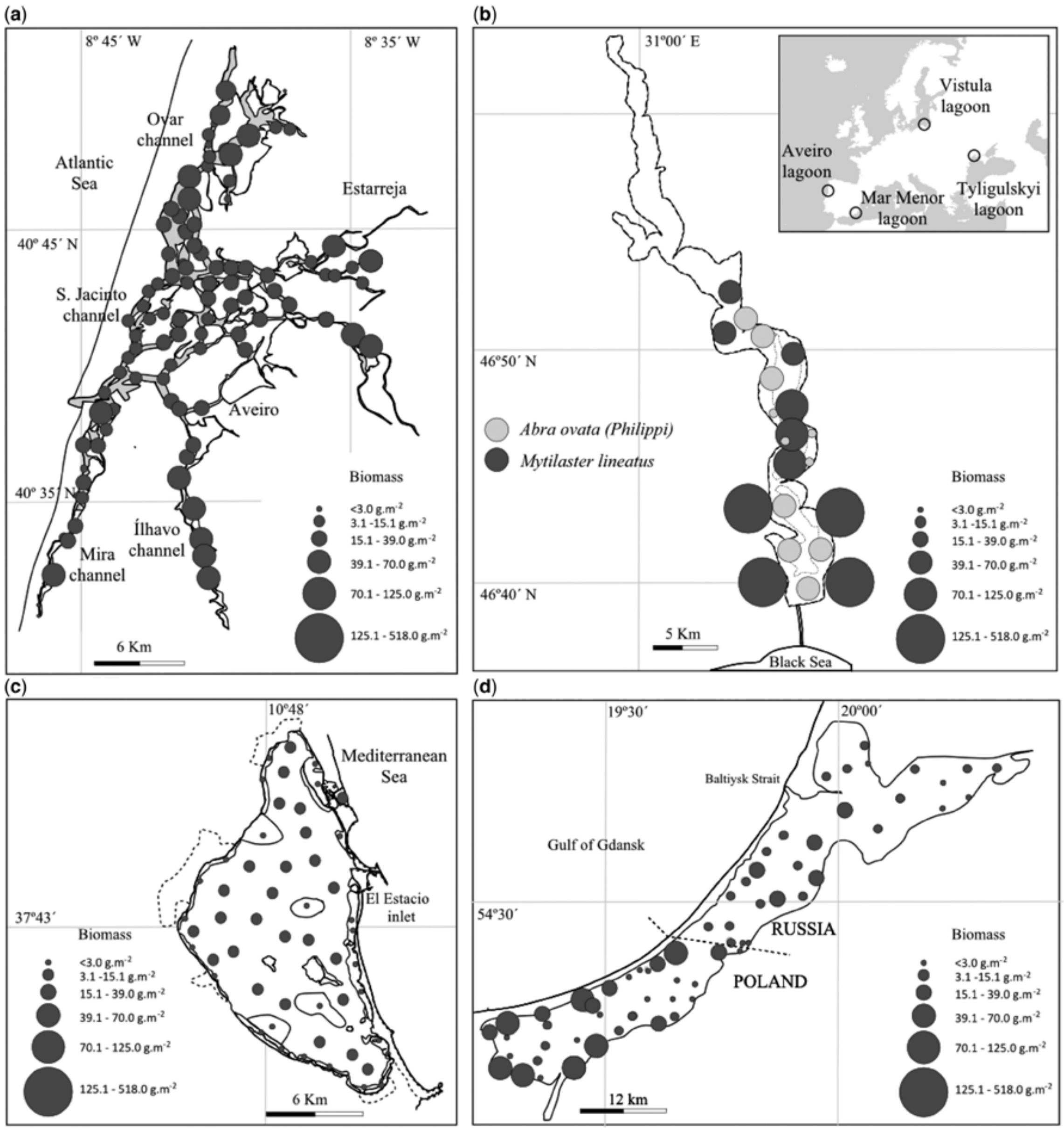

Figure 17.3 Macroinvertebrate biomass distribution in Ria de Aveiro (A) Tyligulskyi Liman (B), Mar Menor (C) and Vistula lagoon (D). In Ria de Aveiro and Mar Menor lagoons, the biomass is referred to the total invertebrate biomass. In Tyligulskyi Liman lagoon is represented the biomass of the bivalves *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.

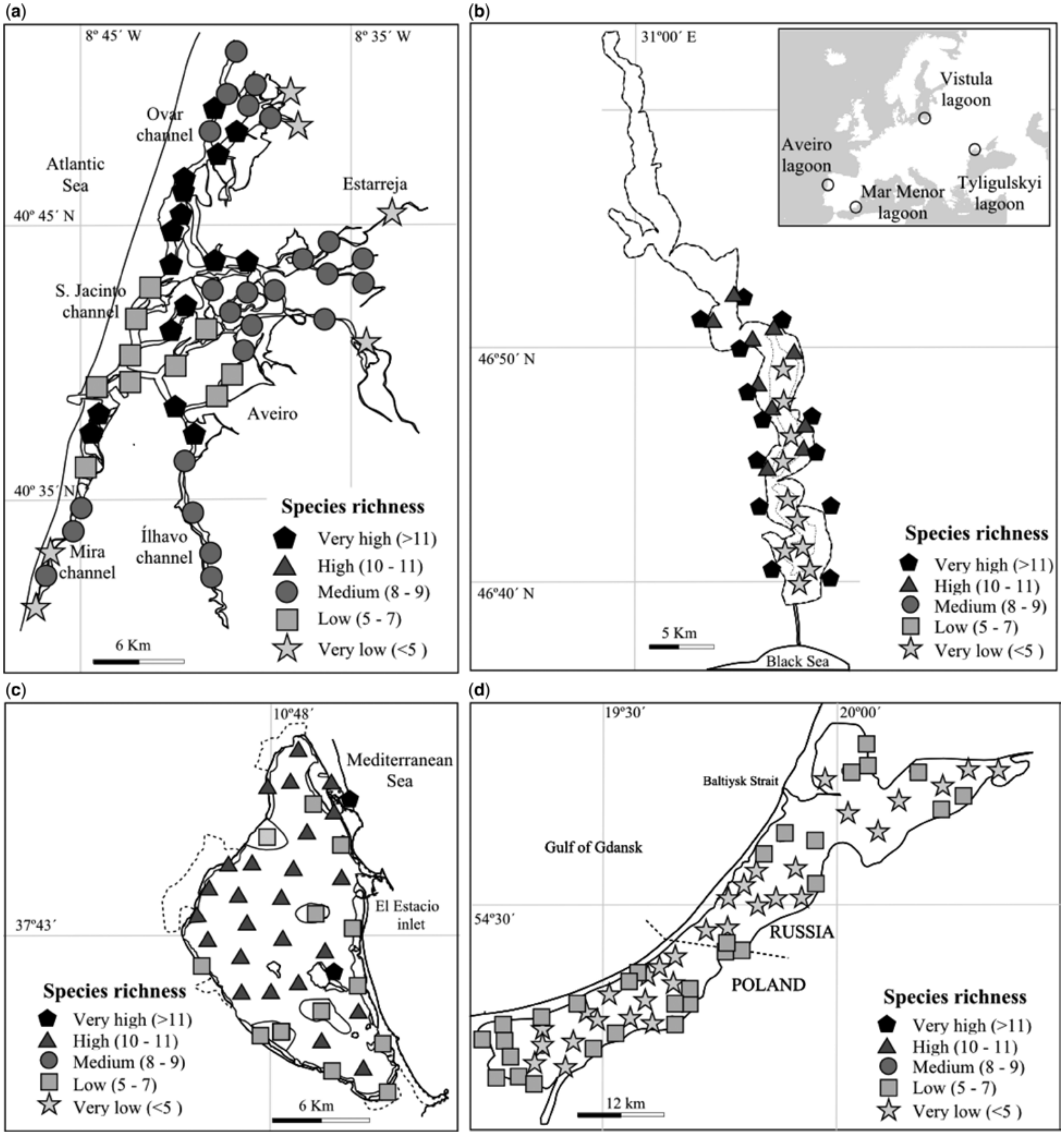

Figure 17.4 Species richness distribution in Ria de Aveiro (A) Tyligulskyi Liman (B), Mar Menor (C) and Vistula lagoon (D). Species richness was calculated as the medium number of invertebrate species per m^2. Note: The positions of the represented symbols are only an indication, they do not intend to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

$$AMBI = [(0 \times \%EGI) + (1{,}5 \times \%EGII) + (3 \times \%EGIII) + (4{,}5 \times \%EGIV) + (6 \times \%EGV)] /100$$

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).

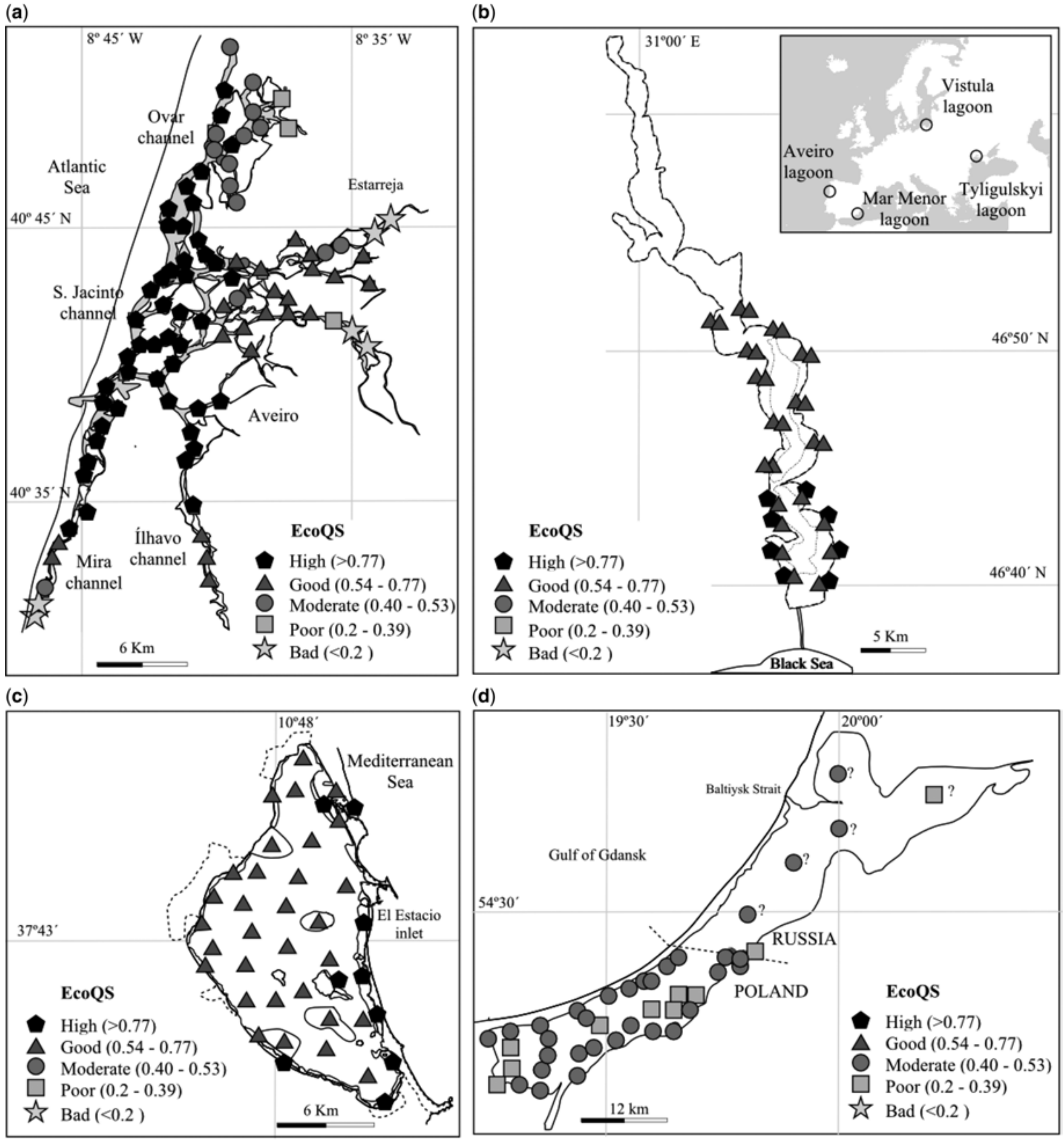

Figure 17.5 The ecological status (EcoQS), calculated with M-AMBI index, in Ria de Aveiro (A) Tyligulskyi Liman (B), Mar Menor (C) and Vistula lagoon (D). In the Ria de Aveiro lagoon EcoQS was recalculated from Rodrigues *et al.* (2011). M-AMBI index of Vistula lagoon was calculated with the invasive 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.

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