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Black Sea Network of Marine Protected Areas: European Approaches and Adaptation to Expansion and Monitoring in Ukraine

Boris Alexandrov, Galina Minicheva and Yuvenaliy Zaitsev

Institute of Marine Biology, National Academy of Sciences of Ukraine, Odessa, Ukraine

Introduction

This chapter brings together several strands of current research concerning Marine Protected Areas (MPAs) in the Black Sea in general, and in Ukraine in particular. First, it provides a more accurate assessment of the total area of MPAs of different status within six Black Sea countries. Second, the impact of eutrophication on the features and the development of MPAs in Ukraine is considered. This is followed, thirdly, by a brief overview of the method used for identifying and justifying the designation of new MPAs (or expanding existing MPAs) in Ukraine, based on integrated evaluation of anthropogenic impact, aquatic plant morphological indicators, and determining the ecological value of marine areas. Finally, the opportunity of developing public ecological monitoring for the Black Sea is explored.

Overview of MPAs in the Black Sea

It is well known that the reproduction of most living marine natural resources takes place in the coastal zones (Zaitsev, 2006) because of the edge effect in which physicochemical and biological interactions are most intense at the interface between land and water. It is no coincidence that most protected areas are located near coasts. At the same time, this zone suffers the highest human pressure because of urban expansion, transport and other infrastructure development, exploitation of living and non-living resources and steady extension of recreation areas. Around 15 million people live in the 2 km wide coastal zone of the Black Sea, 6 million of them in Ukraine alone (Panchenko, 2009).

Conflict between economic activities and the need to maintain living resources has led to the establishment of MPAs. One of the first Black Sea MPAs, the Black Sea Biosphere Reserve, was established in Ukraine as early as 14 July 1927 to protect coastal and marine communities near the Dnieper River delta.

It is difficult to determine the precise extent of the existing Black Sea MPA network. First, almost all the MPAs comprise not only marine waters but also terrestrial areas, which are generally larger. Second, parts of the aquatic area are lagoons or closed limans, isolated from the sea, which

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cannot be included with the Black Sea by definition. Third, the definition and classification of protected areas in the Black Sea countries differ to a greater or lesser degree from the IUCN classification (Lausche, 2011). For example, where the IUCN has seven categories of protected area, Bulgaria has five, Romania has 10 (Begun *et al.*, 2012), and Ukraine has 11; moreover their classification criteria are different.

Another difficulty in determining the total area of MPAs in different countries is that their areas often include sites with multiple designations. For example, the transnational Danube Delta Biosphere Reserve in Romania and the Danube Biosphere Reserve in Ukraine also include wetlands in the Ramsar list. The Natura 2000 protected area 'Ropotamo' (Ropotamo wetland complex) in Bulgaria contains four natural reserves (Begun *et al.*, 2012), several Ramsar wetlands (Marushevsky, 2003) and the Blato Alepu nature monument. A recent publication on Black Sea MPAs says that there are no protected areas in Turkey apart from Ramsar wetlands in the Kizilirmak River delta (Begun *et al.*, 2012). However, we know about two nature reserves (Igneada Flooded Forest and Sarikum Lake) and a permanent wildlife reserve in Yesilirmak Delta (Marushevsky, 2003; Öztürk *et al.*, this volume).

To consolidate the existing data about the actual area of the existing Black Sea MPAs, they were divided into three groups: (i) protected areas (reserves) of international significance (importance); (ii) Ramsar wetlands; and (iii) areas of national significance. Protected areas of local importance were not taken into account. Map measurement was used to determine the areas of the MPAs connected with the Black Sea in cases where the figures were absent from the available literature (Marushevsky, 2003).

Analysis of the information collected enabled us not only to map the current distribution of MPAs in the Black Sea (Figure 12.1), but also to establish some important quantitative characteristics about them. Thus, the area of water-bodies in the MPAs connected with the Black Sea amounts to a total of 755 840 ha. The Black Sea countries can be ranked by their MPA extent as follows: Ukraine – 82.0%; Romania – 14.7%; Georgia – 2.2%; Turkey – 0.7%; Bulgaria – 0.4%; and Russia – 0.1%.

Ecological Characteristics of the Ukrainian Part of the Black Sea

Geographic Features

The Ukrainian part of the Black Sea coast has a length of some 1829 km. It has special geographical conditions and associated ecosystems that have to be taken into account when planning a network of MPAs. The vast, shallow (15 to 55 m depth) shelf platform in the north-western Black Sea (Öztürk *et al.*, this volume), from the Danube River to Cape Tarchankut, extends over more than 55 000 km^2. It receives the waters from three large nutrient-rich European rivers: the Danube, Dniester and Dnieper. These conditions result in the shelf being the most biologically productive area of the Black Sea (Zaitsev, 2006), contrasting with the Crimean Peninsula coast (acknowledged by IUCN as one of nine centres of European biological diversity) which is less productive but has the highest national level of landscape and biological diversity (Yena *et al.*, 2004).

Biodiversity

According to the Black Sea Transboundary Diagnostic Analysis, Annex 4 (Commission on the Protection of the Black Sea Against Pollution, 2007), the Black Sea hosts 44 distinct habitat types. Of these, 42 are present in the Ukrainian part of the Black Sea,

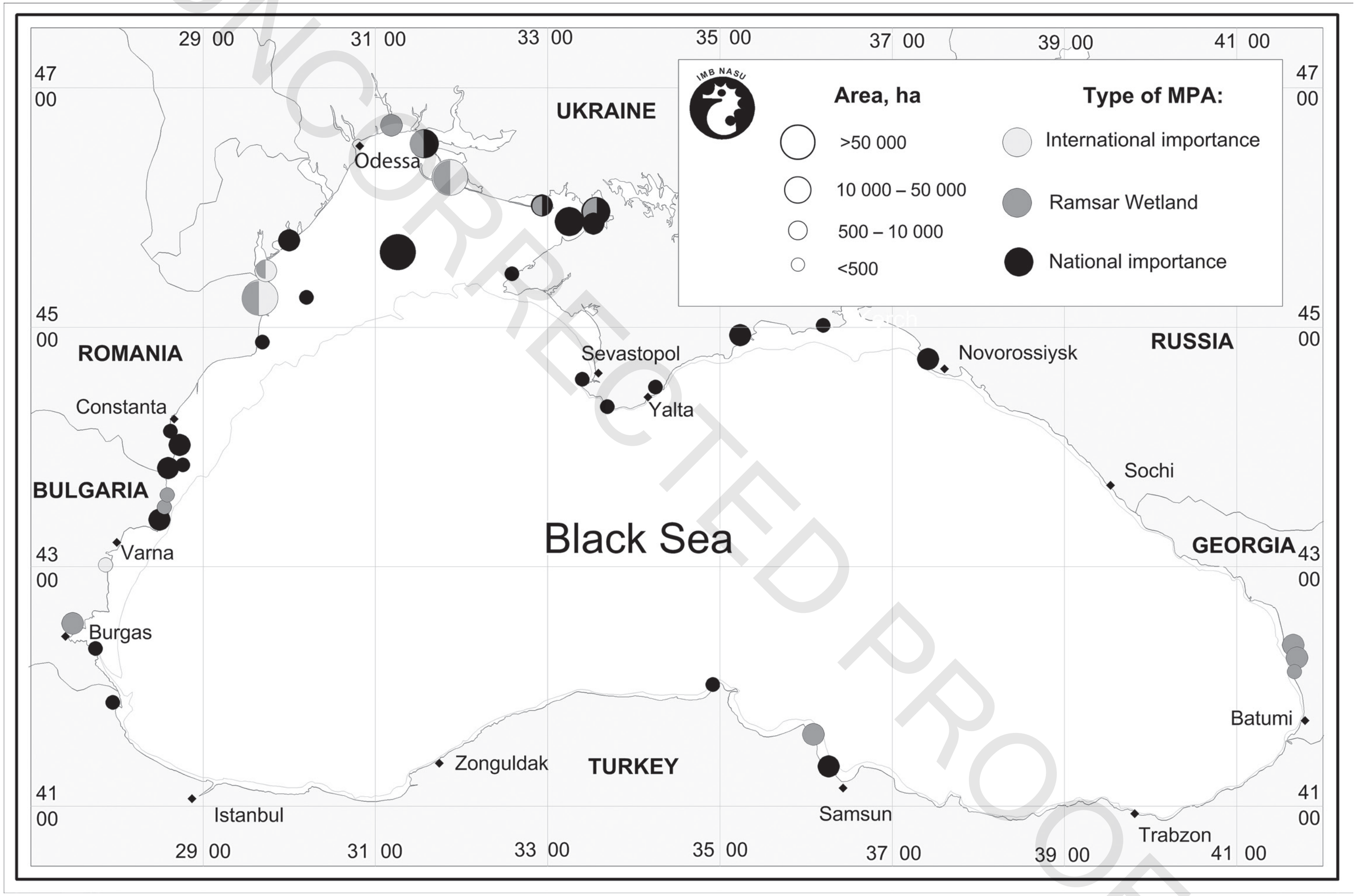

Figure 12.1 The Black Sea MPAs of international and national importance.

with 40 in Bulgaria, 35 in Romania, 28 in Turkey, 25 in Russia and 18 in Georgia. The Red Data Book of Ukraine includes 1368 species. Of these, 10.5% or 88 plant and 57 animal species are Black Sea inhabitants (Black Sea Environment Programme, 2009). This confirms the importance, and responsibility, of Ukraine for conserving marine biodiversity in the Black Sea.

At the same time, the very diversity of the Ukrainian Black Sea area, lying on the intersection of many wildlife migratory paths and human transportation routes, explains why it also has more non-indigenous species than any other Black Sea country. Out of the 261 non-indigenous marine species registered in the database of the Permanent Secretariat of the Black Sea Commission by 2013, some 148 were recorded in Ukraine, with 94 in Turkey, 82 in Romania, 80 in Bulgaria, 51 in Russia and 34 in Georgia. More than 80% of the species originated from the Atlantic Ocean and the Mediterranean Sea (Alexandrov *et al.*, 2013; data available at http://www.corpi.ku.lt/databases/index.php/aquanis). The spread of non-indigenous species common to neighbouring countries follows the counter-clockwise Black Sea coastal cyclonic current. Thus, the highest percentage of common non-indigenous species between neighbouring countries is between Ukraine and Russia (64.0%) and Ukraine and Romania (61.2%), while the lowest percentage is between Bulgaria and Turkey (32%).

Eutrophication of the Black Sea Shelf Area

As mentioned above, the Ukrainian Black Sea shelf is the most biologically productive area of the Black Sea and therefore has the highest level of eutrophication risk connected with nutrient pollution, phytoplankton blooms and hypoxia (Zaitsev, 1992). Analysis of long-term biological changes in response to eutrophication since the 1970s has shown increases in production of dominant phytoplankton species (by 150%), zooplankton species (by 280%), macrophytes (by 54%) and zoobenthos (by 112%). Among the dominant species, non-indigenous ones generally had the highest levels of production (Alexandrov and Zaitsev, 1998).

Four distinct periods of Black Sea shelf eutrophication have been distinguished using indices derived from morphological parameters of aquatic vegetation associated with the ecosystem's trophic status (Minicheva *et al.*, 2008; see below): *natural state* (before the 1970s), *intensive eutrophication* (early 1980s), *immobility* (mid-1990s) and a *steady trend of de-eutrophication* since the turn of the millennium (Figure 12.2).

However, the recent steady trend of de-eutrophication has sometimes been interrupted by abnormal climatic conditions. In 2010, for example, the Danube River discharge was 45% below its average multi-annual level which, combined with unusually high summer temperatures, created conditions that stimulated primary production processes. As a result, the Ecological Status Class (ESC) of the Ukrainian Black Sea shelf, which had been recorded as 'Good' during the previous decade, had to be revised to 'Poor' (Minicheva, 2013).

The MPA Network of Ukraine

The formation of an ecological network in Ukraine is regulated by national legislation (Verkhovna Rada Ukrainy, 2000, 2004). The main aims of the National Program of Forming a National Ecological Network of Ukraine in 2000–2015 were to determine the network's spatial structure in order to unite natural habitats, and to increase the protected area territory from 4% to 10.4% of the country's total area within 15 years.

There are two marine elements within the structure of the Ukrainian National Ecological Network – the Black Sea natural region (north-west shelf of the Black Sea),

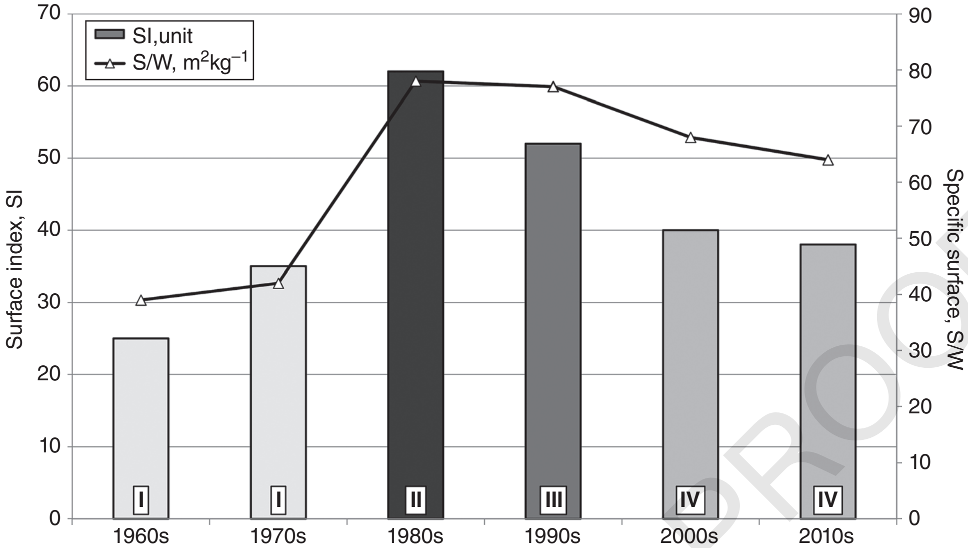

Figure 12.2 Historical stages of eutrophic status in the north-west Black Sea shelf: I – *natural state*; II – *intensive eutrophication*; III – *immobility*; IV – *steady trend of de-eutrophication* (SI reflects the intensity of primary production processes in marine coastal ecosystem; S/W reflects the ecological activity of bottom vegetation: see text for details).

and the natural coastal corridor along the Sea of Azov and the Black Sea. Ukrainian MPAs of international, national and local levels, as well as marine wetlands of international importance, are located within the boundaries of these two elements of the ecological network, totalling an area of just over 6090 km^2 (Table 12.1, Figure 12.3). Most of the MPAs are represented by coastal complexes attached to terrestrial protected areas of different categories and different levels of protection. There are just two MPAs not connected to the coast: Zernov's Phyllophora Field, which is well known and the largest protected area on the north-west shelf, and the Small Phyllophora Field located in the central part of Karkinitskyi Gulf. Thus, practically all the existing accumulations of *Phyllophora* red algae on the north-west shelf, together with their associated communities of invertebrates and fish, are protected by the State.

At present, the Ukrainian Black Sea MPAs (excluding unprotected Ramsar-listed wetlands) cover almost 11% of the national marine area (55 750 km^2), which is much more than in the other Black Sea countries. In this respect, it is fair to say that Ukraine has fulfilled its commitments under the Convention on Biological Diversity Aichi Targets (CBD, 2008), namely to establish MPAs over at least 10% of the ocean by 2020 (in 2010, approximately 6000 MPAs had been declared worldwide, but they covered only 1.17% of the total marine area; Toropova *et al*., 2010).

A distinctive feature of Ukraine's marine ecological network is the very uneven distribution of sites between the two Black Sea ecoregions, which differ markedly in their biological structures and ecological processes. About 99.8% of the Ukrainian MPA area is situated in the north-west shelf, above the line connecting the Ukrainian part of the Danube Delta and Cape Tarchankut. Accordingly, the coastal ecosystems of the Crimean Peninsula, which are valued for their underwater habitats and

Table 12.1 Black Sea MPAs of international and national level in Ukraine.

No.[a)]	MPA	Protected status	General area (ha)	Marine area (ha)
1	Danube	Biosphere Reserve	50 253	6 686
10	Chornomorskyi	Biosphere Reserve	109 255	93 960
25	Karadag	Natural Reserve	2 874	809
14	Lebiazhi Islands	Natural Reserve	9 612	9 612
23	Cape Martian	Natural Reserve	240	120
27	Cape Opuk	Natural Reserve	1 592	62
3	Tuzla liman complex	National Natural Park	27 865	883
16	Tarchankut Cape	National Natural Park	10 900	360
9	Biloberezhia Sviatoslava	National Natural Park	35 223	25 000
11	Dzharylgachskyi	National Natural Park	10 000	2 469
5	Zernov's Phyllophora Field	State Significance Preserve (botanical)	402 500	402 500
12	Small Phyllophora Field	Nationally Important Reserve (botanical)	38 500	38 500
2	Zmiyiny Island	Nationally Important Reserve (zoological)	640	232
13	Karkinitskyi Gulf	Nationally Important Reserve (zoological)	27 646	27 646
19	Kozachia Bay	Nationally Important Reserve (zoological)	23	23
21	Cape Aiya	Nationally Important Reserve (landscape)	1 132	208
Total areas			728 256	609 070

a) Numbers refer to sites shown in Figure 12.3.

high level of marine biodiversity, include only 0.2% of all Ukrainian MPAs of international and national importance.

Approaches to Management and Monitoring of MPAs in Ukraine

Taking Account of Anthropogenic Influence in the Justification of an MPA

As mentioned above, the coastal zone supports high biological diversity and concentration of life due to edge effects. This zone also experiences significant conflicts between different human economic activities (such as construction, agriculture, industry and recreation). These conflicts adversely affect the state of marine ecosystems to a greater or lesser degree. A matrix comprising 27 human-caused stress factors and 15 types of biota response (Zaitsev, 2006) was proposed for integrated assessment of the anthropogenic impact (AI).

If the intensity of anthropogenic impacts is assessed on a seven-point scale from 'very negative' (1) to 'very positive' (7), it is possible to estimate an overall AI score for a given area. For this purpose, a matrix of expert

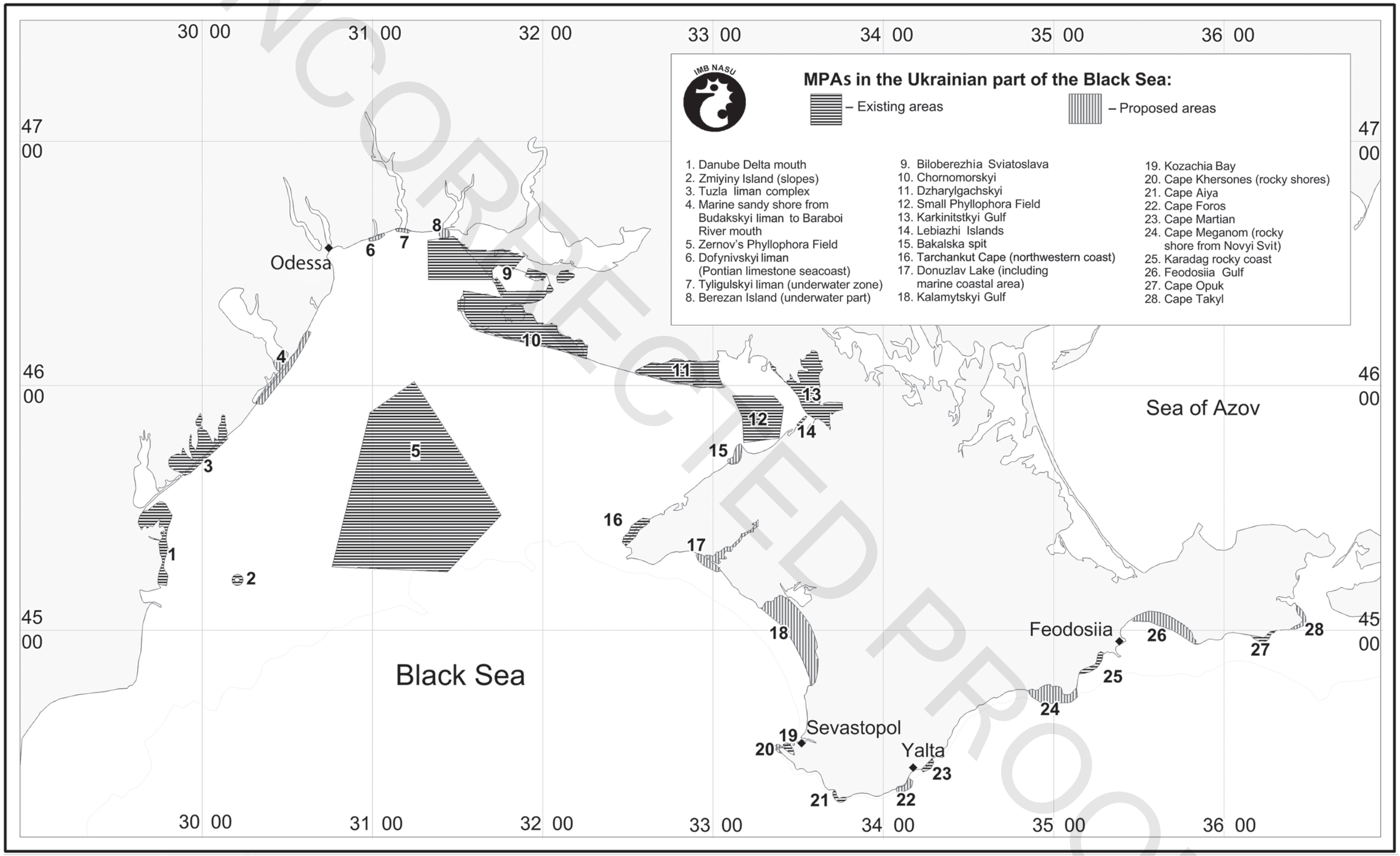

Figure 12.3 Current Ukrainian MPA network and proposed new MPAs.

assessment of stress factors and biota responses can be used (see Table 12.2). For example, the average AI scores for 26 areas of the Black Sea in Ukraine, from the Danube Delta to the Kerch Strait, are given in Table 12.3. The AI scores correspond well with protected areas and can be used as an additional indicator in support of the MPA.

The least number of stress factors (3) influenced the Zernov's Phyllophora Field MPA, while the most (24) affected the Odessa Gulf ecosystem. The AI scores show that Sukhoy liman, which hosts a commercial seaport, had the highest level of anthropogenic impact. In contrast, the marine areas having protected status and situated at some distance from the coastline (Zernov's Phyllophora Field and Zmiyiny Island) had the lowest level of anthropogenic impact.

Plant Morphological Indicators for Rapid Monitoring of MPAs

In 2015, the Commission on the Protection of the Black Sea Against Pollution approved the use of plant morphological indicators (Minicheva *et al*., 2014) as part of the Black Sea Integrated Monitoring and Assessment Programme standards. These indicators directly reflect the ecological function of the bottom vegetation and therefore have advantages over other structural phytoindicators such as floristic composition, biomass and cover. The simple morphological methods involved allow rapid and accurate assessment of the intensity of autotrophic processes and thus the ESC of the marine ecosystem.

The main aim of the Marine Strategy Framework Directive (MSFD, 2008/56/EC) is to achieve Good Environmental Status (GES) of marine waters, such that they provide ecologically diverse and dynamic oceans and seas which are clean, healthy and productive. Reaching GES is not only the main aim of joint efforts by European states in marine protection and management, but also an important aspect of MPA monitoring and assessment. To interpret what GES means in practice, the MSFD sets out 11 descriptors, which describe what the environment will look like when GES has been achieved. Each descriptor reflects different aspects of the marine environment's resilience to the most widespread and intensive human impacts on it. Quantitative evaluation of the descriptors requires a measuring tool, and different indicators of the ecosystem's state could be used as such a tool. The selection of the most suitable indicators for GES assessment out of the huge number of available hydro-ecological parameters is a vital task. If the indicators selected for monitoring MPA condition only reflect the dynamics of biological features, then the functional state of biological elements and the real ecological status of the protected ecosystem could be obscured. Thus, the GES indicators should reflect the functional properties of biological elements (intensity of production and destruction processes on which high biological diversity depends, branching of food chains, good quality of biological resources and aquatic environment) and at the same time applicable to several descriptors at once.

Indicators based on morphological features of aquatic vegetation, in particular the active surface area to weight ratio, could be a sensitive means for rapid assessment of the ESC as part of MPA monitoring (Minicheva, 1998). The main advantage of such an indicator is that it is based on simple measurement methods of macrophytes (which are permanent and functionally important components of coastal ecosystems). In addition to the assessment of ESC, indicators based on macrophyte morphology can be used for quantitative evaluation of four GES descriptors, namely:

- Descriptor 1: Biodiversity is maintained
- Descriptor 4: Elements of food webs ensure long-term abundance and reproduction
- Descriptor 5: Eutrophication is minimised
- Descriptor 6: The sea floor integrity ensures functioning of the ecosystem.

Table 12.2 Generalized matrix of expert assessments of ecological processes in the Black Sea coastal zone.

Stress \ Response		Salinity	Currents	Transparency	Pollution	Trophicity	Bottom sediments	Oxygen content	Disturbance	Concentration	Biological diversity	Bottom hypoxia	Stocks	Health risks	Marine food quality	Aesthetic qualities
		Changes of life conditions									**Biological and general changes**					
I	Fishing	4	4	3	3	4	1	2	1	4	2	3	1	3	4	3
	Mining	4	3	2	2	3	1	2	1	4	2	3	1	3	4	3
	Industrial wastes	1	4	2	1	3	3	2	1	1	1	1	1	1	1	1
II	Pesticides	4	4	2	2	3	2	2	2	1	1	1	1	1	1	1
	Soil erosion	4	4	1	2	3	1	2	3	3	2	3	1	2	2	2
	Agricultural runoff	3	4	1	1	3	1	1	2	1	2	1	1	1	1	1
III	Residual foods	4	4	2	1	5	3	2	3	4	4	3	4	3	3	2
	Genetic degeneration	4	4	4	4	4	4	4	4	4	2	4	5	4	4	4
IV	Ports development	4	2	2	1	3	1	1	1	1	3	3	3	2	3	3
	Deepening, dumping	4	2	2	2	2	1	2	1	4	2	3	3	3	4	3
	Ballast waters and exotic species	4	4	4	3	4	4	4	4	4	3	4	2	4	4	4
	Shipwrecks	4	4	3	2	3	4	4	3	1	1	4	4	3	3	3
V	Urban sewage	3	4	2	1	3	2	2	3	1	1	1	1	1	1	2
	Rain waters	3	3	2	2	3	3	3	3	1	2	3	3	2	2	2
VI	Addition of sand	4	4	3	4	4	1	4	3	4	1	4	2	2	4	4
	Coast protection constructions	4	2	3	2	3	2	2	2	4	6	4	4	3	4	3
VII	Dams	3	3	4	4	4	4	4	2	4	4	4	1	4	4	4
	Reservoirs	3	3	4	4	4	4	4	2	4	4	4	1	4	4	4
VIII	Resort development	4	3	3	2	3	3	3	2	3	3	4	4	3	3	4
	Resort sewage	4	3	2	2	3	3	2	2	2	2	3	3	2	2	2
	Recreational activities	4	3	4	3	4	4	3	1	4	4	4	4	4	4	4
IX	Nature conservation	4	5	5	7	6	6	6	7	4	7	6	7	7	7	7
	Environmental control	4	5	5	6	6	6	6	7	6	6	6	7	7	7	7
	Artificial reefs	4	3	6	6	6	6	7	7	4	7	6	6	6	6	7
X	Environmental education	6	6	6	6	6	6	6	6	6	6	6	6	6	6	7
	Field trips	6	6	6	6	6	6	6	6	6	6	6	6	6	6	7
	Books, posters, films	6	6	6	6	6	6	6	6	6	6	6	6	6	6	7
Integrated coastal zone management		7	7	7	7	7	7	7	7	7	7	7	7	7	7	7

Source: After Zaitsev (2006).
Key: *Consequences*: 1, very negative; 2, negative; 3, more negative than positive; 4, uncertain; 5, more positive than negative; 6, positive; 7, very positive. *Uses*: I, industry; II, agriculture; III, pisciculture; IV, sea transport; V, municipal economy; VI, coastal protection; VII, hydro-power engineering; VIII, tourism, resorts; IX, nature conservation; X, environmental education and environmental ethics.

Table 12.3 Average score of anthropogenic impact (AI) on selected marine and coastal sites in Ukraine.[a]

Site name[b]	AI score
Sukhoy liman	3.08
Budakskyi liman	3.10
Kalamytskyi Gulf	3.35
Feodosiia Gulf	3.41
Dniester liman	3.44
Kerch Strait	3.45
Khadjibeyskyi liman	3.45
Sasyk reservoir	3.46
Tuzla liman complex*	3.51
Kuyalnytskyi liman	3.56
Odessa Gulf	3.56
Karkinitskyi Gulf*	3.59
Dnipro and Bug liman*	3.60
Donuzlav Lake	3.66
Dofinovskyi liman	3.68
Sevastopol Bays	3.74
Grigorivskyi liman	3.81
Tyligulskyi liman*	3.82
Danube Delta mouth*	3.87
Berezanskyi liman	3.93
Karadag coast*	4.14
Zhebrianskyi Bay	4.18
Tendrivskyi Bay*	5.52
Yagorlytskyi Bay*	5.52
Zmiyiny Island (slopes)*	5.57
Zernov's Phyllophora Field*	6.07

a) The higher the score, the lower the level of impact (based on expert evaluation of anthropogenic impacts on the sites using the stress factors in Table 12.2).
b) Asterisk (*) indicates Marine Protected Area.

Macroalgae and angiosperms are Biological Quality Elements in the EU Water Framework Directive (WFD, 2000/60/EC), and their exchange processes with water go via the external contour of the thallus. The specific surface (thallus surface/weight ratio – S/W) is the basic parameter reflecting the intensity of water vegetation function, from which a set of indicators can be derived. Depending on the morphological structure and size of the thallus of a particular species, the S/W ratio can vary between several and several hundred square metres of photosynthetic surface area per kilogram of the plant's weight. Thus, the S/W ratio can be used to characterize the ecological function of the species concerned. Under conditions of high rates of biological production–destruction processes, species with high S/W ratios (small filamentary forms with short life cycle and high growth rates) tend to proliferate. Conversely, where production–destruction processes are relatively slow, populations of plants with low S/W ratios (big, perennial, slow-growing, habitat-forming species) tend to increase. The degradation of coastal ecosystems associated with a decline of biological diversity, simplification of food chains, increase of eutrophication level and decrease of benthic communities is accompanied by replacement of species having low S/W ratios (about 8–25 $m^2\,kg^{-1}$) with macroalgae having S/W ratios from 100 to more than 1000 $m^2\,kg^{-1}$). Accordingly, the morphological portrait of coastal and shelf bottom vegetation contains information about the intensity of ecological processes, and hence about the ecological status of protected ecosystems.

The S/W ratios of the most abundant macrophyte species growing in Ukrainian MPAs are available (Minicheva *et al.*, 2003). To use information about the ecological properties of different macrophytes (*r*- and *k*-selected species) for assessment of the ESC of marine ecosystems, ecological evaluation indices (EEI) have been proposed (Orfanidis *et al.*, 2011). As indicators derived from the S/W ratios enable us to go from qualitative to quantitative assessment of marine plants' ecological properties, they also appear to be effective to express the EEI determining the ESC of marine coastal ecosystems. For rapid assessment and monitoring of MPAs, the two simplest indicators are proposed (Minicheva, 2013): Three Dominants Ecological Activity (S/W_{3Dp}) and Phytocoenosis Surface Index (SI_{ph}).

Rapid ESC assessment of a number of existing or proposed protected areas in the Ukrainian part of the Black Sea using the S/W_{3Dp} indicator showed that most of them are in the categories 'High' and 'Good' (Minicheva, 2014). Good Environmental Status corresponding to high ESC is characteristic of Ukrainian MPAs having international and national levels of protection. There are marine areas in Ukraine with high ESC, but which have no conservation status at present, and so are promising for further expansion of the ecological network; these include Donuzlav Lake, Kalamytskyi Gulf and Feodosiia Gulf. At the same time, there are protected areas in the categories 'Moderate' and 'Poor' (Zhebriyanskyi Bay, Danube Delta mouth). This can be largely explained by the fact that these water areas are situated near, and suffer the influence of, big rivers.

Thus, the method of bottom vegetation morphological indicator assessment, which is simple to use, can be very helpful for determining the ecological status of a marine area and determining the need for its protection; it can also be used for routine monitoring of existing MPAs.

Method for Determining the Ecological Value of MPAs

Marine Protected Areas are not only intended to protect and restore endangered flora and fauna; they also serve as reference sites for assessment of GES according to the MSFD descriptors. The main ecological criteria for identifying potential MPAs are: uniqueness, rarity, representativeness, diversity, naturalness, dependency, critical habitats, vulnerability, and connectivity (Begun *et al*., 2012). The expansion of MPA coverage should also take into account the creation of ecological corridors, or networks, which should ensure adequate reproduction of wide-ranging species (see Beal *et al*., this volume).

To justify designating new MPAs and to expand existing ones in Ukraine, a novel integrated indicator of the biological value of a marine water area was developed (Alexandrov *et al*., 2010; Alexandrov, 2012). This indicator is derived from both the biological diversity of bottom and pelagic communities as well as their productivity. To calculate the integrated indicator of biological value (K_f) of marine water areas, the following formula is used:

$$K_f = (K_i^{a_i})^{0.5} \cdot \left(K_1^{a_1} \cdot K_2^{a_2} \cdot \ldots K_n^{a_n}\right)^{1/2n}$$

where K_1, K_2, … K_n are the values of seven distinct characteristics reflecting the state of the ecosystem in the area concerned (the so-called metrics; see below); a_1, a_2, … a_n are weight coefficients of the characteristics reflecting their level of significance; $K_i^{a_i}$ is the minimum value of all metrics (with their weight coefficients) that characterize the area concerned; and n is the total number of characteristics taken into account in accordance with the number of criteria selected. The K_f value thus unites heterogeneous characteristics taking into consideration the level of their significance. Since the parameters considered are not independent, the resulting value of K_f represents the general status of the characteristics it comprises. The selection of the metrics (K_i) and determination of the weights (a_i) of characteristics were done taking into account the following conditions:

$$0 < K_i \leq 1, \quad \text{and} \quad 0 < a_i \leq 1.$$

All the characteristics selected can be divided into two categories: (i) indirect indices of biodiversity such as: primary production of phytoplankton (K_{PP}); ecological activity of macrophytes (see previous section) as an index of primary production of phytobenthos (K_{EAM}); ratio of biomass of plankton to benthos ($K_{P/B}$); and (ii) direct indices of biodiversity such as: number of macrozoobenthic species (K_{MZB}); total number of benthic biocoenoses (K_{BB}); and number of Red Data Book species (K_{RDB}). The numbers of direct and indirect biodiversity indicators in K_f are equal. However, there is a feedback between these indicators: high primary production reduces the species diversity of ecosystems. It was shown above that the value of anthropogenic impact (K_{AI}) is highly correlated with the state of ecosystems in protected areas. Thus K_{AI} can also be treated as an indirect indicator of biological value and included in K_f calculations. All of these metrics reflect the indicative lists of characteristics, pressures and impacts (MSFD Annex III, Table 1; 2008/56/EC): physical and chemical features, habitat types (structure and substrata composition of the seabed), biological features (phytoplankton and zooplankton communities; macroalgae and invertebrate bottom fauna; status of species), and other features (chemicals, sediments contamination, hotspots, health issues).

The weight coefficients of characteristics (a_i) were determined from paired correlation coefficients of the selected metrics value with two of them, K_{RDB} and K_{EAM}, as these were the most important direct and indirect metrics respectively for assessing the biological significance of a marine area (Table 12.4).

The approach was applied to 26 brackish or marine areas in the Ukrainian part of the Black Sea coast from the Danube Delta to the Kerch Strait: 11 limans, eight bays and gulfs, one island, one delta, one open shelf area, one reservoir, one lake, one coastal cliff and one strait (Table 12.5). The characteristics required for calculating K_f values were taken from Alexandrov *et al.* (2010). Special attention was paid to the fact that values of K_f have to be determined not for the whole area, but for each component ecosystem present (Alexandrov, 2012). To determine the boundary values of K_f for the five classes envisaged by the MSFD (High, Good, Moderate, Poor, Bad), the percentile rule was used (Ohio Environmental Protection Agency, 1987). When a metric tends to decrease with the increase of human pressure, a deviation of more than 25% from the norm is evidence of an aggravated ecological situation.

Applying the method described here (which now incorporates K_{AI} in the K_f calculation originally used by Alexandrov, 2012; values of AI metric normalized similar to direct indices of biodiversity) shows that those marine ecosystems having the highest biological significance (and thus protected

Table 12.4 Matrix of cross-correlation between seven selected biological characteristics of marine ecosystems for determination of their weight coefficients (a_i).

Characteristics (metrics)	RDB	EAM	BB	MZB	P/B	PP	AI
RDB	—	0.24	**0.51**[a)]	**0.48**	–0.09	–0.03	0.31
EAM	0.24	—	**0.43**	**0.37**	–0.22	–0.18	**0.40**
Weight coefficients of characteristics (a_i)	0.6	0.6	0.9	0.9	0.5	0.1	0.8

a) Bold values indicate significant coefficients of cross-correlation at <5% confidence level ($k = 32$).
Key: RDB, number of Red Data Book species; EAM, ecological activity of macrophytes; BB, number of benthic biocoenoses; MZB, total number of macrozoobenthic species; P/B, ratio of total plankton to benthos biomass; PP, gross primary production of phytoplankton; AI, integrated anthropogenic impact.

Table 12.5 Status of protection of Black Sea coastal and marine areas in Ukraine and associated integrated index of biological value (K_f).

No.[a)]	Assessed area	Protected area		Ramsar Site	K_f	K_f normalized[b)]	Biological value
		Status	Aquatic area (%)				
Sediments (sand, mud, clay)							
13	Karkinitskyi Gulf	1, 2	15.17	+	0.68	1.00	H
17	Donuzlav Lake	NP	0		0.50	0.49	G
–	Zhebriyansky Bay	NP	0		0.38	0.14	M
5	Zernov's Phyllophora Field	2	100.00		0.33	0.00	P
–	Odessa Gulf	NP	0		0.33	0.00	P
Rocky coast							
19	Sevastopol Bays (Kozachia)	2, 3	49.02		0.67	1.00	H
2	Zmiyiny Island (slopes)	2	0.50		0.65	0.95	G
25	Karadag coast	1, 2	4.92	+	0.57	0.77	M
18	Kalamytskyi Gulf	3	0.35		0.51	0.64	M
26	Feodosiia Gulf	NP	0		0.46	0.52	P
–	Kerch Strait	1, 2, 3	1.82		0.23	0.00	B
Saline lagoons (inlets)							
10	Tendrivsky Bay (Chornomorskyi)	1	59.84	+	0.72	1.00	G
9	Yagorlytsky Bay (Biloberezhia Sviatoslava)	1, 2	96.46	+	0.71	0.98	M
3	Tuzla liman complex	1, 2	8.90	+	0.20	0.00	P

Table 12.5 (Continued)

No.[a)]	Assessed area	Protected area		Ramsar Site	K_f	K_f normalized[b)]	Biological value
		Status	Aquatic area (%)				
Limans and deltas							
–	Dnipro and Bug liman	1	24.85	+	0.53	1.00	H
–	Berezansky liman	NP	0		0.48	0.89	H
4	Dniester liman	1, 2	30.55	+	0.47	0.87	G
1	Danube Delta mouth	1	95.50	+	0.44	0.80	G
–	Khadzhibeisky liman	NP	0		0.20	0.28	M
–	Grigorivsky liman	NP	0		0.17	0.22	M
–	Tyligulsky liman	1, 3	100.00	+	0.14	0.15	P
–	Sukhyi liman	NP	0		0.11	0.09	P
–	Budaksky liman	NP	0		0.10	0.07	B
–	Dofinovsky liman	NP	0		0.07	0.00	B
Wetlands and salt marshes							
–	Sasyk reservoir	1	16.19	+	0.42	1.00	G
–	Kuyalnytsky liman	NP	0		0.06	0.00	P

a) Numbers refer to sites shown in Figure 12.3.
b) Normalization of K_f values within each habitat carried out using the formula: $(x - \min)/(\max - \min)$.
Key: *Protection level of areas*: 1, international; 2, national; 3, local; NP, not protected. *Biological value*: H, high; G, good; M, moderate; P, poor; B, bad.

status) also typically have high values of K_f. It allows a more accurate ranking of the biological value of 26 coastal and marine areas of Ukraine and thus potential expansion of the number of MPAs, or a change of the protection status of some existing MPAs. The method will also help to work out a better quantitative framework for establishing the boundaries of MPAs and their connections through ecological corridors (see Table 12.5, Figure 12.3).

Using Environmental Sentinels for Public Monitoring of MPAs

The work of Vernadsky (1968) and its further development by Zaitsev (1986, 2015) shows that marine life has a non-uniform (or 'contoured') distribution: the main concentrations of organisms are located on the outer boundary of the pelagic zone while life in the water column is sparse (Vernadsky called it 'dispersed life'). Yet, traditional sampling methods regarding the biology and ecology of the sea largely overlook this phenomenon. This is not to suggest that further study of the water column and great depths is not required, but that more attention should be paid to peripheral biotopes and communities that have been neglected in marine biology and ecology to date.

The external boundaries of the water column, which are in contact and interact with the atmosphere, sandy and rocky coasts or silty bottoms are especially rich in life. Here are found the greatest concentrations of living matter, the effects of external influences are powerful, and the most significant 'hotspots' are located. On the other hand, the ecological conditions in the water column and at lower depths are much more stable.

Peripheral biotopes are inhabited by a large number of diverse organisms adapted to these specific conditions, from bacteria (Tsyban, 1971), unicellular and multicellular algae, protozoans, fungi, molluscs, crustaceans, worms and other invertebrates to the eggs, larvae, fry and adults of fish such as Gobiidae, Mugilidae and Pleuronectidae (Zaitsev, 2006, 2015). As the result of natural processes, many toxic substances accumulate in the same biotopes causing serious consequences for the communities, especially at the early stages of invertebrate and fish development. Some of these plants and animals are sensitive indicator species, whose presence, abundance or absence is indicative of changes in the biotope. They are the first to signal a change and could be termed 'environmental sentinels' (ES) (Zaitsev, 2015).

The ES from peripheral biotopes provide the clearest evidence of the consequences of anthropogenic eutrophication of the northwest Black Sea shelf, whose waters are strongly affected by discharges from three big rivers: the Danube, Dniester and Dnieper. For example, a particularly sensitive ES is the perennial brown alga *Cystoseira barbata*. Between 1979 and 1981, *C. barbata* that once occurred in dense beds on hard substrates at 1–3 m depth disappeared from the rocky coasts of Odessa Gulf and Zmiyiny Island. Organisms closely associated with *C. barbata*, including the polychaetes *Janua pagenstecheri* and *Spirobranchus triqueter*, which are usually attached to *C. barbata* thalli and surfaces of molluscs and crabs, also disappeared. At present, mussels and crabs are free from these polychaetes, showing that immediate contact with *C. barbata* is essential for maintaining the polychaetes' populations.

During the same period, populations of the polychaete *Ophelia bicornis* and bivalve mollusc *Donacilla cornea* disappeared from sandy coasts. In the 1960s, the abundance of *D. cornea* in the mediolittoral zone of the shelf reached dozens of thousands per square metre (Zakutsky and Vinogradov, 1967) and it was even used as a raw material for local handicrafts. Similarly, in the neustonic biotope, the abundance of the neustonic copepods *Pontella mediterranea* and *Anomalocera patersoni*, decapod larvae, flathead grey mullet *Mugil cephalus* larvae, and fry belonging to the genera *Mugil*, *Liza*, *Belone*, *Solea* and *Callionymus* and other fish developing in the neuston layer also shrank by several orders of magnitude.

The number of grey mullet fry coming to the Black Sea coast in summer is a particularly important indicator of the ecological state of the neuston. This fish hatches from eggs laid on the water surface in the open sea, tens of kilometres away from the coastline. Reaching a body length of 4–5 mm, the fry remain in the neuston while migrating towards the coast to feeding grounds in shallow bays and limans. The quantity of fry reaching the coast between July and September could be used to assess the ecological condition of the sea surface for the period from their hatching until arrival at the coast (Alexandrov and Zaitsev, 1989).

Phytoplankton blooms are easily recognized. On sandy beaches they can clog the interstices between sediment particles with detritus, which decreases the rinsing and drainage of the sand by seawater and reduces its aeration. On rocky coasts a phytoplankton bloom could impede filter feeding by sedentary organisms such as sponges and polychaetes. Furthermore, the production of toxic substances by algal metabolites can occur.

Thus, the most dramatic ecological changes, when entire populations of marine organisms practically disappear, take place only in peripheral biotopes. By contrast, in the water column of the pelagic zone and at great depths, the chemical composition and other properties of the water mass are more stable. This explains why stocks of the commercial pelagic fish species sprat *Sprattus phalericus* and whiting *Merlangus euxinus* hardly changed during the major eutrophication episode from the 1980s to 1990s and retained their socioeconomic value.

Using ES to assess the ecological status of peripheral marine biotopes has a number of advantages compared to traditional methods: it requires no research vessels; it clearly reveals sharp changes in the marine environment; it shows precisely the location of ecological 'hotspots' and time of their emergence; and it encourages the involvement of amateur naturalists (especially young ones), under the leadership of experienced specialists, in ecological monitoring of the coastal zone.

A preliminary list of ES genera comprises: attached brown algae of *Cystoseira* and *Sargassum*; gastropod molluscs of *Littorina* and *Melaraphe*; bivalve molluscs of *Patella*, *Fissurella* and *Diodora*; polychaetes of *Ophelia*, *Janua*, *Spirobranchus* and *Serpula*; mullet fry of *Mugil* and *Liza*; and piscivorous birds hunting for mullet fry: little egret *Egretta garzetta* and grey heron *Ardea cinerea*.

Expansion of the Ukrainian MPA Network

The Ukrainian ecological network to date has been formed based on the principles of nature protection and conservation of areas having high ecological value. The functionally integrated network is aimed at maintaining high biological diversity (Verkhovna Rada Ukrainy, 2000). Future expansion of the Ukrainian ecological network implies taking account of innovative European concepts and approaches demonstrating importance not only for nature conservation, but also for socioeconomic aspects. Further development of a European MPA network and its Ukrainian component should therefore consider the specific natural features of marine ecosystems resulting from the interactions between coastal and offshore, pelagic and bottom ecosystems (which have a three-dimensional structure and function), together with physical, chemical, biological and ecological processes that underlie cells of ecosystem functioning (Boero, this volume). Socioeconomic issues are also important as a basis for regulatory mechanisms (Ojea *et al*., this volume), and for forming and managing the objectives of ecological networks, which can have different purposes: connectivity, conservation, socioeconomic, geographic, collaborative, cultural and transnational (Beal *et al*., this volume). Out of the various types of ecological networks, the Ukrainian MPA network could be classified chiefly as the conservation type. More attention should be paid in future to a more multi-faceted development of the national ecological network, strengthening socioeconomic, geographical, cultural and other aspects. Already, Ukrainian experts taking nature conservation principles as the basis are starting to pay more attention to the socioeconomic features of ecological networks, which can provide a strong foundation for 'blue' and 'green' economic growth in the country and regions (Harichkov and Nezdoyminov, 2013). Ukraine still has important marine and coastal areas not yet included in its ecological network, which together with their natural value, have high recreation and resource potential, including the possibility for setting up offshore wind-farms.

One of the legislative measures ensuring further development of the Ukrainian national MPA network is the listing of new areas and objects (Verkhovna Rada Ukrainy, 2004). The selection of promising new MPAs was based on criteria in the regulations (Verkhovna Rada Ukrainy, 1992) as well as approaches to ecological value assessment in line with the WFD and MSFD (EC, 2008) (Alexandrov *et al*., 2010; Minicheva, 2013).

As the result of expert work, taking into account the new national and European principles of forming ecological networks, as well as new approaches in the determination of the ecological value of marine areas, it is presently proposed to include 12 new nationally protected areas in the existing Ukrainian MPA network. These sites have a combined area of 104 300 ha, which represents 17% of the current total area of Ukrainian MPAs (Figure 12.3).

Most of the MPAs in the north-west shelf are connected with the Crimean coast by the main cyclonic (counter-clockwise) Black Sea rim current (Öztürk *et al*., this volume), which ensures population stability of many flora and fauna species by carrying their larvae and mature individuals downstream. To correct the misbalance of area coverage, 8 out of 12 of the new MPAs will be established on the Crimean Peninsula. These sites have high environmental status, socioeconomic potential and support reproduction of key plant and animal species both for Ukrainian MPAs and for the Black Sea in general. Implementation of plans for extending the Ukrainian MPA network and its integration within the European Coastal and Marine Ecological Network will unite the efforts of researchers and state officials responsible for ecological integration across Europe.

Conclusion

The total area of MPAs of international and national significance in the Ukrainian ecological network is over 6000 km^2. As a result, Ukraine ranks highest among the Black Sea countries for the overall extent of MPAs, and more than 82% of the area of all Black Sea MPAs are in Ukraine. The highest percentage cover of MPAs, 10.9%, occurs in the north-west shelf area of the Black Sea. However, in Ukraine the distribution of MPAs is very uneven: 99.8% of them are in the shelf area and only 0.2% around the Crimean Peninsula.

It is proposed to expand the Ukrainian MPA network to include 12 new sites covering more than 1040 km^2 (about 17% of the existing area). To help correct the misbalance of distribution between the MPAs in the shelf area and the Crimean Peninsula, eight of the proposed new MPAs lie in the coastal part of Crimea. The expansion of the Ukrainian MPA network takes account of such important natural characteristics as the main cyclonic Black Sea current and the influence of river discharges (as a main factor of eutrophication).

In order to integrate the Ukrainian MPA network into the European Coastal and Marine Ecological Network, a number of new methods of identifying MPAs were elaborated based on the requirements and standards of the WFD and MSFD. These methods and indicators should be incorporated into the Black Sea Integrated Monitoring and Assessment Programme (2015–2020) of Ukraine.

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References

Alexandrov, B. (2012) Black Sea marine protected areas and an approach to the creation of ecocorridors, in *Marine Nature Conservation and Management at the Borders of the European Union* (ed. D. Czybulka). Beitraege zum Landwirtschaftsrecht und zur Biodiversitaet 7. Nomos Verlag, Baden-Baden. pp. 121–135.

Alexandrov, B. and Zaitsev, Y. (1989) Man-made impact on the neuston of marine coastal waters and modes of its assessment. *Biologya Moria*, **2**, 56–60. (In Russian)

Alexandrov, B. and Zaitsev, Y. (1998) Black Sea biodiversity in eutrophication conditions, in *Conservation of the Biological Diversity as a Prerequisite for Sustainable Development in the Black Sea Region* (eds V. Kotlyakov, M. Uppenbrink and V. Metreveli). Kluwer, Dordrecht. pp. 221–234.

Alexandrov, B., Galperina, L., Groza, V. *et al.* (2010) *Strategy and Methodological Approaches to Building a Network of Marine Protected Areas in the Coastal Waters of the Ukrainian Part of the Black and Azov Seas.* Report on the project JWP-Ukr-2009–14 Living Black Sea: Strategy for expansion of marine protected areas in the Black Sea coastal waters of Ukraine funded by the Royal Embassy of the Netherlands. Odessa. (In Ukrainian)

Alexandrov, B., Gomoiu, M., Mikashavidze, E. *et al.* (2013) *Non-Native Species of the Black Sea*. Abstracts book of 4th Black Sea Scientific Conference 'Challenges towards good environmental status' (28–31 October 2013, Constanta). Editura Boldaş, Constanta. pp. 62–63.

Begun, T., Velikova, V., Muresan, M. *et al.* (2012) *Conservation and Protection of the Black Sea Biodiversity: Review of the existing and planned protected areas in the Black Sea (Bulgaria, Romania and Turkey) with a* *special focus on possible deficiencies regarding law enforcement and implementation of management plans*. Report for Marine Strategy Framework Directive (MSFD) Guiding Improvements in the Black Sea Integrated Monitoring System (MISIS). http://www.misisproject.eu/

Black Sea Environment Programme (2009) *Black Sea Red Data Book*. http://www.grid.unep.ch/bsein/redbook/index.htm

Commission on the Protection of the Black Sea Against Pollution (2007) *Black Sea Transboundary Diagnostic Analysis and Strategic Action Plan* (TDA). Istanbul. 269 pp. http://www.blacksea-commission.org/_tda2008.asp

Convention on Biological Diversity (2008) *COP Decision IX/20 Marine and Coastal Biodiversity*. https://www.cbd.int/decision/cop/default.shtml?id=11663

Harichkov, S. and Nezdoyminov, S. (2013) Ecological networks as a 'green' growth factor of the region's economy. *Economy: Realities Time*, **4** (9), 174–182. (In Ukrainian)

Lausche, B. (2011) *Guidelines for Protected Areas Legislation*. IUCN, Gland, Switzerland. xxvi + 370 pp.

Marushevsky, G. (ed.) (2003) *Directory of Azov–-Black Sea Coastal Wetlands: Revised and Updated*. Wetlands International, Kyiv.

Minicheva, G. (1998) *The foundations of morphofunctional forming of the marine phytobenthos*. PhD thesis, Institute of Biology of the Southern Seas, NAS Ukraine, Sevastopol. (In Russian)

Minicheva, G. (2013) Use of the macrophytes morphofunctional parameters to assess ecological status class in accordance with the EU WFD. *Marine Ecological Journal*, **12** (3), 5–21.

Minicheva, G. (2014) Monitoring of wetlands ecological status on the basis of morphofunctional estimation of the bottom vegetation, in *Monitoring of Wetlands of International Significance* (ed. O. Petrovich). DIA, Kyiv. pp. 19–23.

Minicheva, G., Zotov, A. and Kosenko, M. (2003) *Methodical recommendations for determining the complex of morpho-functional parameters of unicellular and multicellular forms of aquatic vegetation*. GEF Project for Renewal of the Black Sea Ecosystem. Odessa.

Minicheva, G., Maximova, O., Morushkova, N. *et al*. (2008) State of the environment of the Black Sea (2001–2006/7), in *State of the Environment of the Black Sea (2001–2006/7)* (ed. Temel Oguz). Commission on the Protection of the Black Sea Against Pollution, Istanbul, Turkey. pp. 247–272.

Minicheva, G., Afanasyev, D. and Kurakin, A. (2014) *Black Sea Monitoring Guidelines: Macrophytobenthos*. http://emblasproject.org/wp-content/uploads/2013/12/Manual_macrophytes_EMBLAS_ann.pdf

Ohio Environmental Protection Agency (1987) *Biological criteria for the protection of aquatic life: User manual for biological field assessment of Ohio surface water*. Ohio Environmental Protection Agency 2. Columbus, Ohio.

Orfanidis, S., Panayotidis, P. and Ugland, K. (2011) Evaluation index continuous formula (EEI-c) application: a step forward for functional groups, the formable and reference condition values. *Mediterranean Marine Science*, **12**, 199–231.

Panchenko, T. (2009) *Guidelines on Territorial Planning in Coastal Zone. Version 2*. Environmental Collaboration for the Black Sea Project (ECBSea). EuropeAid/120117/C/SV/Multi.

Toropova, C., Meliane, I., Laffoley, D. *et al.* (eds) (2010) *Global Ocean Protection: Present Status and Future Possibilities*. Agence des aires marines protégées, Brest, France; IUCN WCPA, Cambridge, UK; TNC, Arlington, USA; UNU, Tokyo, Japan.

Tsyban, A. (1971) Marine bacterioneuston. *Journal of the Oceanographical Society of Japan*, **27** (2), 56–66.

Verkhovna Rada Ukrainy (1992) *On the nature reserve fund of Ukraine*. Law 2456-XII, 16 June 1992. (In Ukrainian)

Verkhovna Rada Ukrainy (2000) *On national program of formation of the national ecological network of Ukraine for 2000–2015*. Law 1989-III, 21 September 2000. (In Ukrainian)

Verkhovna Rada Ukrainy (2004) *On the ecological network of Ukraine*. Law 1864-IV, 24 June 2004. (In Ukrainian)

Vernadsky, V. (1968) *The Biosphere*. Mysl, Moscow. (In Russian)

Yena, V., Yena, A. and Yena, A. (2004) *Tavridas' Protected Landscapes*. Business-Inform, Simferopol. (In Russian)

Zaitsev, Y. (1986) Contourobionts in ocean monitoring. *Environmental Monitoring and Assessment*, **7**, 31–38.

Zaitsev, Y. (1992) Ecological state of the Black Sea shelf zone near the Ukrainian coast (a review). *Hydrobiology Journal*, **28** (4), 3–18. (In Russian)

Zaitsev, Y. (2006) Littoral concentration of life in the Black Sea area. *Journal of the Black Sea/Mediterranean Environment*, **12**, 113–128.

Zaitsev, Y. (2015) On contour structure of the hydrosphere. *Hydrobiology Journal*, **51** (1), 3–27. (In Russian)

Zakutsky, V. and Vinogradov, K. (1967) *Macrozoobenthos*. Naukova dumka, Kiev. (In Russian)