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und zur Biodiversität

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# Marine Nature Conservation and Management at the borders of the European Union

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# Black Sea marine protected areas and an approach to the creation of ecocorridors

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The creation of protected areas has a long history. The first government reserves were founded more than 300 years ago. In 1872 Yellowstone National Park was established by the US Congress, in an attempt to save endangered plant and animal species.

Today, with increasing anthropogenic pressure upon the natural world, the variety of nature conservation measures being taken is increasing. In 1979 the member states of the European Community adopted the Birds Directive and in 1992 the Habitats Directive to protect species and habitats. The provisions of the EU Birds and Habitats Directives call for the member states to maintain a favourable conservation status with respect to species and habitats of European importance, including those present in the marine and coastal zones. The sites established for protecting these species and habitats form a network known as Natura 2000. In 2007, the EU published guidelines on establishing marine Natura 2000 sites in order to facilitate their designation and future management (European Commission, 2007).

As a result of the progress made in the field of ecology, the efficiency of nature conservation measures has improved substantially. Approaches to the organisation of protected areas have been greatly enhanced. A network of connections between the separate protected areas has also been established.

Different geographic zones of the Earth differ not only in terms of their biological diversity, but each has its own special adaptations and responses to anthropogenic influences. The conservation of biodiversity requires the maintenance of a range of landscapes and biotopes as habitats, also within the context of their specific location. To this end, 238 ecoregions have been distinguished, made up of 142 terrestrial, 53 freshwater, and 43 marine ecoregions. The Black Sea is part of Mediterranean ecoregion (Olson & Dinerstein, 2002). A series of technical guidance manuals for protected area systems in general has been produced through the Convention on Biological Diversity and the World Commission on Protected Areas, for example, a review of ecological networks and corridors (Bennet & Mulongoy, 2006). These contain a direct connection to the aim of this publication.

An additional target in this respect is the effective conservation of at least 10 % of each of the world's ecological regions. At present only about 3 % is protected.

Many vertebrates (mammals, birds, reptiles, amphibians and fish) engage in seasonal migrations across hundreds and thousands of kilometres between overwintering and reproduction areas. In addition to protecting such sites, these animals also require the possibility for unimpeded movement between them. Ecological corridors represent one reasonable approach to facilitating this unimpeded movement. The integration of ecological corridors in ecological networks increases the possibilities for the preservation of greater numbers of plant and animal species.

A wildlife corridor, or green corridor, is an area of habitat connecting wildlife populations separated by human structures and activities (such as roads, development, logging, etc.). Corridors may also help facilitate the re-establishment of populations that have been reduced or eliminated due to random events (such as fires or disease). This may potentially moderate some of the worst effects of habitat fragmentation (Bond, 2003). The conservation of biodiversity is particularly important along ecotones. These are the borders where different ecosystems and biocoenoses meet. Due to the 'edge effect' there is an increase in the number of species found along ecotones, as well as increases in terms of abundance, biomass and production.

There are a number of characteristic differences between aquatic and terrestrial ecosystems. The most fundamental is the presence of a water mass, in which practically the entire population of the ecosystem spends a part or all of its life. This includes the bottom fish and invertebrates. The spatial distribution of the water mass is extraordinarily dynamic and determined by the influence of wind, especially in the upper 10 m, where the greatest concentration of aquatic life occurs. Some distinctive features of aquatic ecosystems are:

- a concentration of life in the off-shore and shelf areas to the depth to which sunlight penetrates;
- there is a definite advantage in terms of the selection of protected areas according to benthic biocoenoses, as most are connected with the landscape (unlike the pelagic biocoenoses);
- there is a low probability of anthropogenic limitations being placed on ecological corridors allowing the movement of species between separate protected areas.

Marine protected areas (MPAs) are being considered at the national, regional and global levels as a mechanism for the protection of marine biodiversity, the conservation of ecologically sensitive areas and endangered species and the sustainable management of all human activities including fisheries, research, education and recreation.[1]

The Black Sea is included in the Mediterranean ecoregion and the European ecological network. The surface area of totally protected areas in the Black Sea amounts to 68.263 km$^2$, but the distribution varies considerably between the different countries (Goriup, 2009). The highest number of MPAs of varying statuses is concentrated in the Ukraine (35), which has the longest coastline, at 1.628 km or 37 %. The total Black Sea shelf area belonging to the Ukraine is 55.750 km$^2$, corresponding to 57 % of the total shelf area (Zaitsev, 1992). All five marine coastal ecotones registered in Europe are present in the Black Sea. There are also 37 benthic biocoenoses, distinguished here on the basis of the dominant plant and animal species (indicator species). Of these, 37 are found in the Ukraine. Many of these benthic biocoenoses are unique, and are found only in the Black Sea (Commission on the Protection of the Black Sea Against Pollution, 2007).

The development of networks of marine protected areas first requires the science-based identification of ecologically or biologically significant areas. This identification should focus on developing an initial set of sites already recognised for their ecological values, with the understanding that other sites can be added as more information becomes available (Goriup, 2009).

The aim behind the research presented in this paper was to develop a method for the quantitative determination of the biological value of marine aquatic objects (lagoons, bays, etc.) for the formation of ecological corridors and the determination of the sequence of creation of new MPAs, or of the expansion of existing MPAs.

The approach developed will be illustrated using the example of aquatic objects situated within the Ukraine.

A total of 34 different aquatic objects were singled in the Ukrainian part of the Black Sea coast, from the Danube Delta (Black Sea) to Taganrogskiy Bay (Sea of Azov): three bays; nine inlets; 13 limans (estuaries); two lagoons; two lakes; one delta (Danube); one island (Zmeiny); one open shelf area; one strait (Kerch); and one marine coastal zone (Karadag shore).

In order to describe the ecological state of the Ukraine's aquatic objects, all of the accessible data contained in the literature from the last decade (more than 100 references) describing the aquatic objects investigated were used. The aspects incorporated were:

1 http://www.esf.org/research-areas/marine-sciences/marine-board-working-groups.html.

- primary production of phytoplankton;
- specific surface area of macrophytes, as an index of the primary production of phytobenthos;
- biomass of plankton and benthos;
- number of macrozoobenthos species;
- total number of benthic biocoenoses; and
- number of red data book species.

Associated with each of the six chosen ecological characteristics of water bodies are specific methods of determination and units of measurement. The method developed by M.D. Burnstein (Babenko et al., 1988) was applied in the calculation of the integral indicator of the biological value ($\mathbf{K}_f$) of water bodies in the ecological corridor. This method is used in geology, in the search for minerals, and allows for the comparison of any amount of descriptions with differing dimensions. The calculation of $K_f$ was made according to the formula:

$$\mathbf{K}_f = (K_{i\,min}^{\;a_i})^{0.5} \cdot (K_1^{\;a_1} \cdot K_2^{\;a_2} \cdot \ldots \cdot K_n^{\;a_n})^{1/2n}$$

- where $K_1$, $K_2$, $K_n$ are the values (measures) of different characteristics describing the water bodies studied, in particular their conservation value in terms of the preservation of the biological diversity of water and land ecosystems;
- $K_{i\,min}$ is the minimum value of those characteristics used to define the state of a water body;
- $a_1$, $a_2$, $a_n$ are weighting coefficients of the individual characteristics;
- $n$ is the total number of characteristics taken into consideration in accordance with the number of criteria selected (in this case 6).

All of the analysable characteristics interact and the value of $K_f$ represents a combination (integration) of all of these characteristics for each particular aquatic object. The selection of the methods for the determining of the characteristics ($K_i$), and their weightings ($a_i$), was based on the following pre-requisite:

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

All of the chosen characteristics can be divided into two categories: 1) indirect indices of biodiversity (primary production of plankton, primary production of benthos, ratio of plankton to benthos biomass); and 2) direct indices of biodiversity (number of macrozoobenthos species, number of benthic biocoenoses, number of red data book species). The number of direct and indirect indices of biodiversity incorporated into $K_f$ is identical.

The next step was to determine numeric values of the chosen characteristics.

## I. Indirect indices of biodiversity

As all indirect indices of biodiversity are related to primary production, and as they determine the trophic status of an aquatic object, they are bound by an inverse dependence upon species richness. According to the general ecological rule, the higher the level of primary products, the higher the correlation between plankton and benthos biomass, the lower the species number in an ecosystem (Odum & Barrett, 2005). The characteristics primary production of phytoplankton and phytobenthos were determined as inverse values.

All values of the gross primary production of phytoplankton (**$K_{PP}$**) found in the literature, which was determined either by means of oxygen and radiocarbon methods or on the basis of chlorophyll a content, were counted in the same units ($mg\ O_2 \cdot l^{-1} \cdot d^{-1}$). $K_{PP}$ was calculated using the following formula:

$$K_{PP} = 1 - \lg[8.5 / (8.5 - K_{average})]$$

where $K_{average}$ is the value of a characteristic in an investigated water body.

The three most dominant species of macrophytobenthos (potential ecological activity of associations of the bottom vegetation, $K_{PM}$) were identified for the investigated water bodies for the purposes of indexing the average primary benthos production for a specific area. For more detail regarding the determination of the specific area of aquatic plants and their connection to primary production refer to the work of Minicheva (Minicheva, 1998; Minicheva et al., 2003). The numeric value of the characteristic $K_{PM}$ was calculated using the following formula:

$$K_{PM} = 10\ S/W_{average}$$

where $S/W_{average}$ is the arithmetic mean of the specific status ($S$ is the surface area and W the biomass of aquatic plants) of three dominant macrophytobenthos species in each water body.

For more information on the significance of $S/W_{average}$ in relation to the 34 water bodies investigated refer to the report prepared by the project 'Living Black Sea: strategy for expansion of marine protected areas in the Black Sea coastal waters of the Ukraine' entitled 'Strategy and methodology for the development of marine protected areas network in the coastal waters of the Ukrainian part of the Azov and Black Seas.'

The ratio of total plankton (phyto- and zoo-) to macrozoobenthos biomass ($K_{P/B}$) was determined on a sample basis. Taking into account the fact that the quantitative development of plankton is usually determined in relation to the volume of water, whereas that of benthos is determined according to surface area, a numeric value $K_{P/B}$ was determined for the water column 1 $m^2$ above the bottom surface, and taking into account the middle depth of the water body, using the formula:

$$K_{P/B} = 1 - \lg(1000 \cdot K_{average}) / 5$$

where $K_{average}$ is an average value for the particular characteristic in the aquatic object investigated.

## II. Direct indices of biodiversity

All of the characteristics directly reflecting the biological diversity of the water bodies investigated ($K_{MZB}$ is the number of macrozoobenthos species, $K_{BB}$ the number of benthic biocoenoses, $K_{RDB}$ the number of red data book species) were determined using the formula:

$$\mathbf{K_i} = K_{average} / K_{max}$$

- where $K_{average}$ is the value of each characteristic in the water body investigated, and
- $K_{max}$ is the maximum possible (limit) value in the ecotone investigated.

The weighting coefficients associated with the aforementioned characteristics should not be identical. For their calculation, a paired correlation of all six characteristics with the two deemed most important for MPA identification ($K_{PM}$ and $K_{RDB}$) was carried out. $K_{RDB}$ is a direct index of biodiversity and $K_{PM}$ is major indirect characteristic of the biological significance of aquatic areas (table 1). The weighting coefficients were calculated on the basis of the data presented in table 2.

On the basis of the calculation method used, an ideal aquatic object must be characterised by a high value in terms of the integral index of biological value, or $K_f$ value.

However, the $K_f$ calculation method used is not applicable to all of the objects investigated without due consideration of their belonging to one ecotone or other. As areas on the border of different ecosystems and biocoenoses, ecotones are of considerable importance in terms of the maintenance of biodiversity. Due to a 'marginal (edge) effect', ecotones exhibit greater species numbers, species abundances, and higher levels of biomass and production.

The analysis of data concerning a specific species or the quantitative distribution of benthic biocoenoses in different ecotones revealed large differences (even for the same species; for example, *Mytilus galloprovincialis*). In spite of a high habitat quality and the quantitative predominance of organisms in the rocky coast ecotone (table 3), as a result of an 'edge effect' at the interface of three physical environments (namely air, water and solid substrate) some species found in other habitats in this biotope are not present at this ecotone, and vice versa (biocoenoses). The approach presented is applicable for the maintenance of specific and unique communities within the limits of each ecotone (habitat). To this end, all of the water bodies investigated were distributed between six ecotones. As the biodiversity of water bodies belonging to various ecotones differs considerably, the $K_{max}$ direct indices of biodiversity ($K_{MZB}$, $K_{BB}$, $K_{RDB}$) were determined for each ecotone at the level of 120 % of the maximum value from the list of those registered in water bodies of the particular ecotone (table 4).

Table 1: A cross-correlation matrix of the chosen biological parameters (characteristics) of aquatic ecosystems for the determination of their weighting coefficients ($a_i$)

| Characteristics | RDB | PM | BB | MZB | P/B | PP |
|---|---|---|---|---|---|---|
| RDB |  | 0.24 | 0.51 | 0.48 | -0.09 | -0.03 |
| PM | 0.24 |  | 0.43 | 0.37 | -0.22 | -0.18 |
| Weighting coefficients of the characteristics ($a_i$) | a=0.9 | a=0.7 | a=0.9 | a=0.9 | a=0.6 | a=0.5 |

Significant coefficients of the cross-correlation at a 5 % confidence level (k = 32) are presented in bold font.

- ***RDB*** is the number of red data book species;
- ***PM*** is the index of primary production of bottom vegetation;
- ***BB*** is the number of benthic biocoenoses;
- ***MZB*** is the total number of macrozoobenthos species;
- ***P/B*** is the ratio of total plankton to benthos biomass;
- ***PP*** denotes the gross primary products of phytoplankton.

Table 2: Values of the selected characteristics and the integral index of the biological value ($K_f$) of water bodies of the Ukraine

| № | Water body | Biological parameters (characteristics) | | | | | | Components of the $\mathbf{K_f}$ calculation | | | | | | $K_f$ | MPA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | PP | PM | P/B | MZB | BB | RDB | a=0.5 | a=0.6 | a=0.9 | a=0.9 | a=0.9 | a=0.7 | | |
| | | | | | | | | $K_{PP}$ | $K_{PM}$ | $K_{P/B}$ | $K_{MZB}$ | $K_{BB}$ | $K_{RDB}$ | | |
| 1 | Danube Delta mouth | 1.04 | 0.018 | 0.278 | 39 | 8 | 30 | 0.943 | 0.511 | 0.182 | 0.333 | 0.909 | 0.18 | 0.385 | 95.5 |
| 2 | Zhebrianskaya Bay | 2.82 | 0.028 | 1.119 | 28 | 5 | 19 | 0.825 | 0.390 | 0.131 | 0.208 | 0.576 | 0.28 | 0.258 | 0 |
| 3 | Zmiinyi Island (slopes) | 0.19 | 0.039 | 0.012 | 95 | 5 | 24 | 0.990 | 0.784 | 0.444 | 0.208 | 0.727 | 0.39 | 0.377 | 50.0 |
| 4 | Lake Sasyk | 1.96 | 0.016 | 0.053 | 74 | 1 | 1 | 0.886 | 0.655 | 0.346 | 0.042 | 0.030 | 0.16 | 0.101 | 0 |
| 5 | Tuzla liman group | 0.39 | 0.030 | 0.017 | 53 | 3 | 1 | 0.980 | 0.754 | 0.248 | 0.125 | 0.030 | 0.30 | 0.112 | 8.9 |
| 6 | Shabolatskiy Liman | 7.31 | 0.022 | 1.064 | 23 | 3 | 1 | 0.146 | 0.395 | 0.107 | 0.125 | 0.030 | 0.22 | 0.093 | 0 |
| 7 | Dniester Liman | 6.45 | 0.042 | 16.157 | 82 | 11 | 17 | 0.382 | 0.158 | 0.383 | 0.458 | 0.515 | 0.42 | 0.400 | 30.5 |
| 8 | Zernov's phyllophora field | 0.26 | 0.042 | 0.278 | 27 | 4 | 8 | 0.987 | 0.511 | 0.126 | 0.167 | 0.242 | 0.42 | 0.243 | 100.0 |
| 9 | Sukhoy Liman | 2.20 | 0.021 | 0.756 | 36 | 2 | 1 | 0.870 | 0.424 | 0.168 | 0.083 | 0.030 | 0.21 | 0.100 | 0 |
| 10 | Odessa Bay | 1.13 | 0.027 | 0.388 | 43 | 4 | 9 | 0.938 | 0.482 | 0.201 | 0.167 | 0.273 | 0.27 | 0.280 | 0 |
| 11 | Khadjibeiskiy Liman | 1.17 | 0.005 | 14.300 | 10 | 2 | 3 | 0.936 | 0.169 | 0.047 | 0.083 | 0.091 | 0.05 | 0.107 | 0 |
| 12 | Kuyalnitskiy Liman | 1.29 | 0.008 | 60.000* | 1 | 1 | 0.5 | 0.929 | 0.044 | 0.005 | 0.042 | 0.015 | 0.08 | 0.026 | 0 |
| 13 | Dofinovskiy Liman | 5.09 | 0.031 | 0.049 | 21 | 1 | 0.5 | 0.603 | 0.662 | 0.098 | 0.042 | 0.015 | 0.31 | 0.065 | 0 |
| 14 | Grigorevskiy Liman | 0.37 | 0.027 | 0.289 | 67 | 4 | 2 | 0.981 | 0.508 | 0.313 | 0.167 | 0.061 | 0.27 | 0.165 | 0 |
| 15 | Tiligulskiy Liman | 1.33 | 0.064 | 0.017 | 43 | 2 | 0.5 | 0.926 | 0.754 | 0.201 | 0.083 | 0.015 | 0.64 | 0.078 | 38.4 |
| 16 | Berezanskiy Liman | 1.33 | 0.022 | 0.201 | 48 | 8 | 4 | 0.926 | 0.539 | 0.224 | 0.333 | 0.121 | 0.22 | 0.240 | 0 |
| 17 | Dnieper and Bug Liman | 7.04 | 0.023 | 0.254 | 158 | 16 | 21 | 0.235 | 0.519 | 0.738 | 0.667 | 0.636 | 0.23 | 0.458 | 1.9 |
| 18 | Yegorlykskiy Inlet | 0.27 | 0.080 | 0.008 | 62 | 8 | 12 | 0.986 | 0.819 | 0.290 | 0.333 | 0.364 | 0.80 | 0.435 | 0.3 |
| 19 | Tendrovskiy Inlet | 0.45 | 0.097 | 0.017 | 63 | 9 | 11 | 0.976 | 0.754 | 0.294 | 0.375 | 0.333 | 0.97 | 0.442 | 99.8 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20 | Karkinitskiy Inlet | 0.06 | 0.097 | 0.115 | 80 | 18 | 14 | 0.997 | 0.588 | 0.374 | 0.750 | 0.424 | 0.97 | 0.532 | 15.2 |
| 21 | Lake Donuzlav | 3.36 | 0.084 | 0.018 | 67 | 8 | 8 | 0.782 | 0.749 | 0.313 | 0.333 | 0.242 | 0.84 | 0.387 | 0 |
| 22 | Kalamytskiy Inlet | 0.19 | 0.024 | 0.003 | 59 | 10 | 11 | 0.990 | 0.905 | 0.276 | 0.417 | 0.333 | 0.24 | 0.435 | 56.5 |
| 23 | Sevastopol Bay | 0.09 | 0.045 | 0.025 | 86 | 9 | 18 | 0.995 | 0.720 | 0.402 | 0.375 | 0.545 | 0.45 | 0.501 | 9.8 |
| 24 | Karadag coast | 0.03 | 0075 | 0.188 | 116 | 5 | 18 | 0.998 | 0.545 | 0.542 | 0.208 | 0.545 | 0.75 | 0.382 | 4.9 |
| 25 | Feodosiya Inlet | 071 | 0.051 | 0.180 | 55 | 4 | 13 | 0.962 | 0.549 | 0.257 | 0.167 | 0.394 | 0.51 | 0.306 | 0 |
| 26 | Kerch Strait | 0.18 | 0.041 | 0.191 | 12 | 5 | 13 | 0.991 | 0.544 | 0.056 | 0.208 | 0.394 | 0.41 | 0.168 | 1.7 |
| 27 | Central Sivash | 0.96 | 0.018 | 57.605 | 2 | 1 | 4 | 0.948 | 0.048 | 0.009 | 0.042 | 0.121 | 0.18 | 0.044 | 35.8 |
| 28 | Eastern Sivash | 0.96 | 0.018 | 0.110 | 62 | 2 | 4 | 0.948 | 0.592 | 0.290 | 0.083 | 0.121 | 0.18 | 0.185 | 35.8 |
| 29 | Utlyukskiy Liman | 1.36 | 0.035 | 0.016 | 43 | 8 | 4 | 0.924 | 0.759 | 0.201 | 0.333 | 0.121 | 0.35 | 0.249 | 4.6 |
| 30 | Molochniy Liman | 1.36 | 0.048 | 0.033 | 88 | 4 | 3 | 0.924 | 0.696 | 0.411 | 0.167 | 0.091 | 0.48 | 0.218 | 84.8 |
| 31 | Obitochnaya Inlet | 1.36 | 0.039 | 0.158 | 30 | 8 | 4 | 0.924 | 0.560 | 0.140 | 0.333 | 0.121 | 0.39 | 0.240 | 5.1 |
| 32 | Berdianskiy Inlet | 1.36 | 0.026 | 0.098 | 30 | 8 | 4 | 0.924 | 0.602 | 0.140 | 0.333 | 0.121 | 0.26 | 0.235 | 8 |
| 33 | Belosarayskiy Inlet | 0.28 | 0.026 | 0.098 | 30 | 8 | 4 | 0.985 | 0.602 | 0.140 | 0.333 | 0.121 | 0.26 | 0.236 | 100.0 |
| 34 | Taganrogskiy Inlet | 3.86 | 0.048 | 0.512 | 53 | 10 | 6 | 0.737 | 0.458 | 0.248 | 0.417 | 0.182 | 0.48 | 0.314 | 0 |

* As macrozoobenthos are practically absent in the Kuyalnitskiy Liman, the value of the ratio of plankton biomass to benthos biomass approaches an infinitely large value. Therefore, for this particular water body, the value was assumed to be the maximum amongst those determined.

- PP is the gross primary product of phytoplankton (mg O·l-1·d-1);
- PM is the potential ecological activity of the bottom vegetation communities;
- P/B is the ratio of plankton biomass to benthos;
- MZB is the number of macrozoobenthos species;
- BB is the number of bottom biocoenoses;
- RDB is the number of red book species;
- ai is the weighting coefficients of the selected characteristics;
- Ki is the values of the selected characteristics;
- MPA is marine protected area (%).

The biological parameters were taken from the 'Strategy and methodology for the development of marine protected areas network in the coastal waters of the Ukrainian part of the Azov and Black Seas' report (2011) prepared by the project 'Living Black Sea: strategy for expansion of marine protected areas in the Black Sea coastal waters of the Ukraine.'

Table 3: Features of the benthic biocoenoses in the Black Sea and the Sea of Azov.

| Biocoenosis | Depth (m) | | Number of macrozoobenthos species | Average number. (ind.·m$^{-2}$) | Average biomass. (g·m$^{-2}$) |
|---|---|---|---|---|---|
| | Range | Average | | | |
| Hard substrates (stones, rocks, piers, etc.) | | | | | |
| Mytilus galloprovincialis [2] | 0-4 | 2 | 104 | 11510 | 8541 |
| M. galloprovincialis [1] | 0-7 | 3.5 | 20 | 247782 | 35600 |
| M. galloprovincialis [6] | 0-7 | 3.5 | 70 | 31716 | 14327 |
| M. galloprovincialis – Balanus improvisus [5] | 0-5 | 2.5 | 62 | ? | 7600 |
| Average* | 0-7 | 3 | 55 | 44889 | 13489 |
| Sandy sediments (sand, mud, clay) | | | | | |
| Donacilla cornea – Ophelia bicornis [3] | 0-2 | 0.5 | 13 | 970 | 87 |
| Nana neritea – Diogenes pugilator [3] | 2-5 | 3.5 | 49 | 370 | 6 |
| Lentidium mediterraneum [3] | 3-12 | 7.5 | 36 | 900 | 305 |
| Chamelea gallina [3] | 7-30 | 25 | 140 | 2185 | 150 |
| Average* | 0-30 | 9 | 42 | 917 | 70 |
| Sandy-mud sediments | | | | | |
| Mya arenaria [3] | 3-16 | 10 | 22 | 772 | 300 |
| Mytilaster lineatus [4] | 6-20 | 15 | 43 | 1202 | 136 |
| Neanthes succinea [4] | 10-25 | 20 | 19 | 1453 | 8 |
| Gouldia minima [3] | 20-50 | 40 | 106 | 930 | 30 |
| Upogebia pusilla – Pitar rudis [3] | 25-27 | 26 | 45 | 2065 | 33 |
| Pitar rudis [3] | 25-28 | 26 | 78 | 4000 | 47 |
| Average* | 3-50 | 23 | 43 | 1476 | 50 |
| Muddy sediments | | | | | |
| Melinna palmata [3] | 12-28 | 20 | 47 | 564 | 76 |
| Abra nitida [3] | 25 | 25 | 29 | 900 | 58 |
| Spisula subtruncata – Abra nitida [3] | 18-49 | 30 | 29 | 490 | 21 |
| Mytilus galloprovincialis [3] | 20-53 | 40 | 131 | 2050 | 640 |
| Nephtys hombergii [4] | 25-38 | 30 | 21 | 70 | 10 |
| Plagiocardium simile [3] | 40-52 | 45 | 50 | 1980 | 5 |
| Amphiura stepanovi [3] | 50-105 | 70 | 53 | 1350 | 14 |
| Sternaspis scutata [3] | 73 | 73 | 25 | 4000 | 58 |

| | | | | | |
|---|---|---|---|---|---|
| Modiolus phaseolinus [3] | 60-125 | 80 | 81 | 3700 | 59 |
| Average* | 12-125 | 46 | 44 | 1039 | 37 |

* Due to the great heterogeneity of benthic communities in terms of spatial distribution, the average species number, abundance and biomass of benthic biocoenoses were determined as geometric means.

The number presented in brackets in the left column indicates the source of the information:

- 1: Gomoiu, M.-T.; Tiganus, V.; Structure qualitative et quantitative des salissures formees dans les eaux du large de la Mer Noire. Rapp. Comm. Int. Mer Medit. Monaco. 1981. 27(2): 183-184.
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- 4: Losovskaja, G.V.; Macrozoobenthos bottom communities (1970-1983). In: North-western part of the Black Sea: biology and ecology. Kiev. Naukova dumka Publ. 2006. pp. 268-276 (in Russian).
- 5: Partaly, E.M. Fouling in the Sea of Azov. Mariupol. Renata Publ. 2002. 378 pp. (in Russian).
- 6: Zaitsev, Yu. P.; Aleksandrov, B.G.; Berlinskij, N.A.; Bogatova, Yu. I.; Bolshakov, V.N.; Bushuev, S.G.; Volia, E.G.; Garkavaja, G.P.; Gelmboldt, M.V.; Zolotarev, V.N.; Kopytina, N.I.; Kulakova, I.I.; Kurilov, A.V.; Losovskaja, G.V.; Minicheva, G.G.; Nesterova, D.A.; Polischuk, L.N.; Sinegub, I.A.; Terenko, L.M.; Shurova, N.M.; Base biological investigations of Odessa marine port (August-December 2001): Final report. Series of monographs of the Odessa demonstration site of the GloBallast Programme. Odessa, Ukraine. 2004. Vol. 7. 171 pp. (in Russian).

Table 4: Determination of the maximum values of the biologically important characteristics of the water bodies of the coastal ecotones of the Black Sea and the Sea of Azov within the boundaries of the Ukraine.

| № | Ecotone type and water body name | Measures of selected characteristics of the biological value of water bodies | | |
|---|---|---|---|---|
| | | MZB | BB | RDB |
| Sediments (sand, mud, clay) | | | | |
| 2 | Zhebrianskaya Bay | 28 | 5 | 19 |
| 8 | Zernov's phyllophora field | 27 | 4 | 8 |
| 10 | Odessa Bay | 43 | 4 | 9 |
| 20 | Karkinitskiy Inlet | 80 | 18 | 14 |
| 21 | Lake Donuzlav | 67 | 8 | 8 |
| 34 | Taganrogskiy Inlet | 53 | 10 | 6 |
| $K_{max}$ | | 96 | 22 | 23 |
| Rocky coast | | | | |
| 3 | Zmiinyi Island (slopes) | 95 | 5 | 24 |
| 22 | Kalamytskiy Inlet | 59 | 10 | 11 |
| 23 | Sevastopol Bay | 86 | 9 | 18 |
| 24 | Karadag coast | 116 | 5 | 18 |
| 25 | Feodosiya Inlet | 55 | 4 | 13 |

| | | | | |
|---|---|---|---|---|
| 26 | Kerch Strait | 12 | 5 | 13 |
| $K_{max}$ | | 139 | 12 | 29 |
| Salty lagoons* | | | | |
| 5 | Tuzla liman group | 53 | 3 | 1 |
| 15 | Tiligulskiy Liman | 43 | 2 | 0.5 |
| 16 | Berezanskiy Liman | 48 | 8 | 4 |
| 18 | Yegorlykskiy Inlet | 62 | 8 | 12 |
| 19 | Tendrovskiy Inlet | 63 | 9 | 11 |
| 29 | Utlyukskiy Liman | 43 | 8 | 4 |
| 30 | Molochniy Liman | 88 | 4 | 3 |
| 31 | Obitochnaya Inlet | 30 | 8 | 4 |
| 32 | Berdianskiy Inlet | 30 | 8 | 4 |
| 33 | Belosarayskiy Inlet | 30 | 8 | 4 |
| $K_{max}$ | | 106 | 11 | 14 |
| Limans and deltas | | | | |
| 1 | Danube Delta mouth | 39 | 8 | 30 |
| 6 | Shabolatskiy Liman | 23 | 3 | 1 |
| 7 | Dniester Liman | 82 | 11 | 17 |
| 9 | Sukhoy Liman | 36 | 2 | 1 |
| 11 | Khadjibeiskiy Liman | 10 | 2 | 3 |
| 13 | Dofinovskiy Liman | 21 | 1 | 0.5 |
| 14 | Grigorevskiy Liman | 67 | 4 | 2 |
| 17 | Dnieper-and-Bug Liman | 158 | 16 | 21 |
| $K_{max}$ | | 190 | 19 | 36 |
| Wetlands and salt marshes | | | | |
| 4 | Lake Sasyk | 74 | 1 | 1 |
| 12 | Kuyalnitskiy Liman | 1 | 1 | 0.5 |
| 27 | Central Sivash | 2 | 1 | 4 |
| 28 | Eastern Sivash | 62 | 2 | 4 |
| $K_{max}$ | | 89 | 2.4 | 5 |

* Salty lagoons differ from marshes in that they have direct (permanent or temporary) access to the sea.

- $K_{max}$ is a maximum possible (boundary) value of the measure of the selected characteristic.
- *MZB* is the number of macrozoobenthos species;
- *BB* is the number of bottom biocoenoses;
- *RDB* is the number of red book species.

The $K_f$ value for each of the 34 aquatic areas was calculated according to the method outlined and the data contained in table 2. On the basis of these values, recommendations for the establishment and the extension of existing MPAs was made for Ukrainian coastal waters of the Black and Azov Seas. The ranges of the aquatic areas were identified and a map of the distribution of the aquatic objects of biological value is presented in figure 1. The results achieved with the help of the $K_f$ value largely coincide with existing nature protection areas (see table 2).

The approach proposed will help in the development of a more suitable quantitative method upon which to base the designation of MPAs, their areas (borders) and their connection to other MPAs via ecological corridors.

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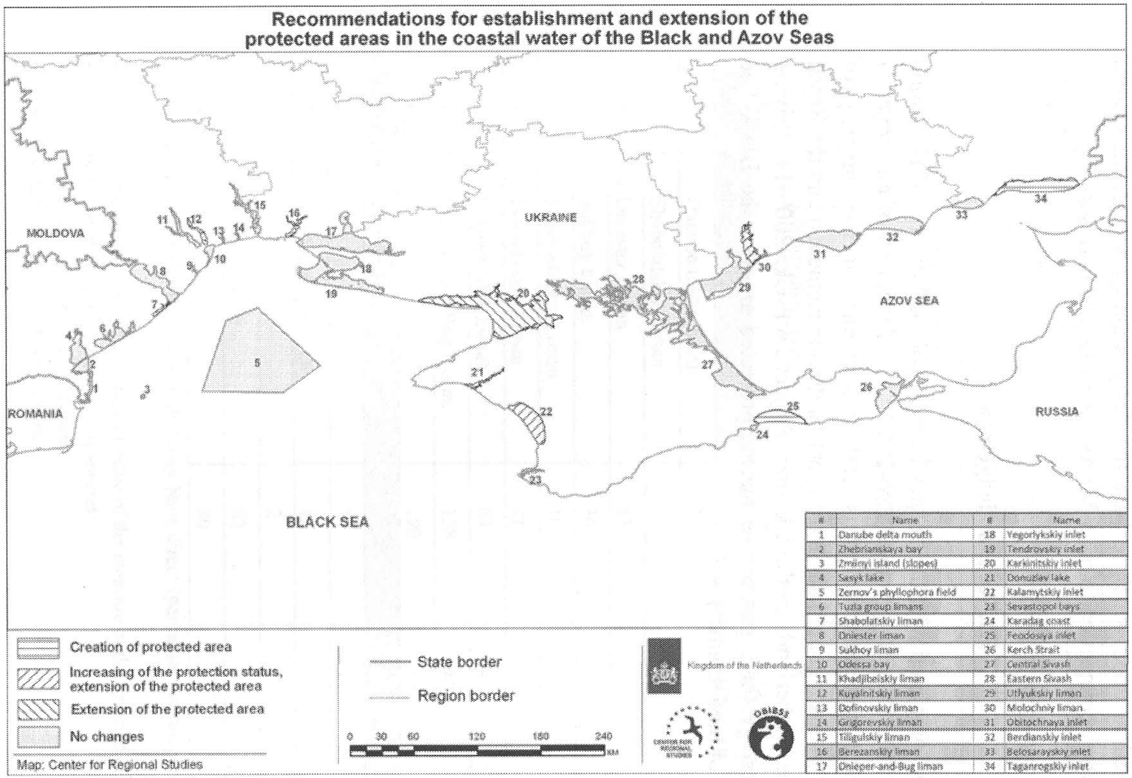


Figure: Recommendations for the establishment of new and the expansion of existing protected areas in the coastal waters of the Black and Azov Seas.
Note: The numbers of the water bodies correspond to those in tables 2 and 4.

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