Biological valorisation of the southern Baltic Sea (Polish Exclusive Economic Zone)*

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Abstract

A biological valuation system to assess the value associated with ecosystem stability and richness (and not that from the point of view of users) is proposed to provide

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scientific decision support for marine protected areas and marine spatial planning. The system is based on the assessment of individual species and habitat/species assemblages. An extensive set of recently collected (2007–08) and archival (1970 –2000) data on the occurrence of marine benthos was analysed for the Polish Marine Areas. Based on matching data sets of sediments, the euphotic zone, temperature and salinity, as well as fetch and sea current values, a GIS model was used to visualise the results; a map indicates the two areas which are considered to be biologically the most valuable (Puck Bay and the stony shallows of the central coast).

1. Introduction

The current scientific approach to the value of nature is based largely on two papers published in 'Nature' by Costanza et al. (1997) and Costanza (1999). These articles set forth the foundation for assessing the value of environmental goods and services, and the number of papers and books that followed them dealt with all major ecosystems (for the Baltic Sea, see Węsławski et al. 2006, Rönnbäck et al. 2007). Socio-economic valuation and the economics of natural resources have gained acceptance within scientific circles, and a methodology has been developed (Beaumont et al. 2007, Wallmo & Edwards 2008).

A more recent concept is biological valuation as proposed by Derous et al. (2007), which considers the value of an area in terms of its resilience and the stability of species and species assemblages, and not from the human (goods and services) point of view. This approach was developed for the conservation of nature, specifically for the establishment of the best criteria for delineating marine protected areas. Since biological valuation requires ranking selected living objects as more or less valuable, it raises ethical and philosophical questions, namely, whether all species are equal or not. Some recent studies discuss this dilemma, including Linder (1988), Singer (1989), Schmidtz (2002) and Jennings (2009). While we accept the view that living beings are equal in moral terms, their contributions to ecosystem structure and function differ, and this can be assessed in scientific terms.

'Biological value' is not a direct measure of ecosystem health. Often, areas regarded as being of high biological value are considered to be valuable providers of socio-economic goods and services and are of high quality in terms of environmental health. The main difference is, however, that biological valuation focuses on the features of species and communities themselves and not on the contamination or the extractable/usable part of the ecosystem. The present paper is based on the results of a major habitat-mapping project supported by the Norwegian Financial Mechanism in 2007–2008. Using archival and new data, our aim was to scientifically delineate the biologically most valuable areas of the seabed in the Polish Exclusive Economic Zone.

2. Methods

A modification of the Derous et al. (2007) methodology is presented here for the Polish Marine Areas (PMA) in the Baltic Sea (Figure 1). The main modification to this methodology was the introduction of the following two concepts:

1) individual species are not equal in terms of their contribution to the value of the area;

2) the biomass and completeness of the species list are measures of the fitness or value of the analysed area.

The importance of species that are, for example, habitat builders, keystone species, rare species, or difficult to restore, is emphasised by the introduction of various ranks (wages). It is widely accepted that species are organised in assemblages/communities in relation to specific environmental conditions. Although the stability and patterns of formation of benthic communities remain disputed issues, the concept is a useful one in management and

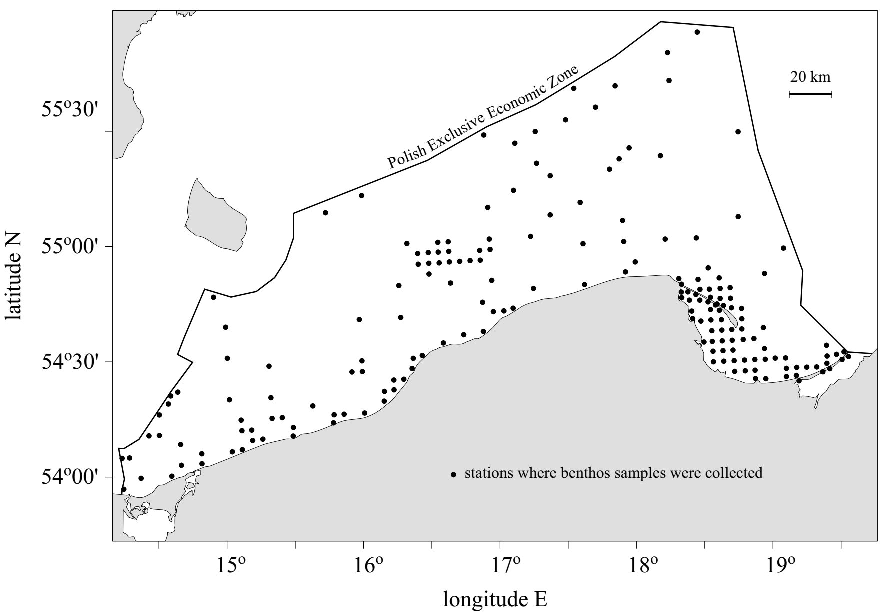

Figure 1. The Polish Marine Areas (PMA) and stations where benthos samples were collected by the Sea Fisheries Institute and during the present project (1995 –2008)

nature protection. Through the analysis of samples collected in one given community/assemblage, we can define the characteristic set of species, their density and biomass. The same assemblage of, for example, *Zostera marina* sea grass might be degraded in one sample with an impoverished list of associated species with low macrophyte density and biomass, while another spot of healthy *Z. marina* will have a species list and biomass close to the maximum values noted in the literature for this type of habitat in Poland. By analysing the range of data from the lowest to the highest, the results can be grouped into three fitness categories (low, medium, good) of the quality of the assemblage analysed in a given locality.

The valuation process was organised in three steps, as detailed below.

2.1. Step one (objective)

New georeferenced data on benthos occurrence in the Polish Marine Areas (PMA) was collected in summer 2007 and 2008, and archival material was provided by the Sea Fisheries Institute in Gdynia (www.mir.gdynia.pl). Quantitative seabed samples were analysed (Van Veen and Box Corer) with biomass data (wet weight) calculated per m^2 (Figure 1). The PRIMER package was used to calculate species assemblages (Bray Curtis similarity, double square root transformation); this generated a list of 72 species (Table 1), and ten benthic assemblages were identified (Table 2). The seabed habitat distribution and background physical data used in this study are available on the project web page: http://www.pom-habitaty.eu/index.php.

2.2. Step two (subjective)

2.2.1. Description of the value of individual species

Species were assessed on the basis of an author's responses to assessment questions (Table 3). The assessment questions were assigned three values. The most valuable features (3 points) were habitat building and longevity (perennial). These two features describe species that provide space for other species and for those whose regeneration takes a long time. The second category of questions (2 points) included features that describe the role of species in the food web (key species or not). Rare species (frequency $< 5\%$) ranked as such are those that occur in one specific habitat only. The third category (1 point) covers features such as bioturbation, filtration (valued as services to other species), susceptibility to mechanical disturbance, and sensitivity to oxygen depletion (valued as an indicator of species fragility).

Table 1. List of species and their valuation according to assessment questions. Species are sorted according to the value obtained (score of points) – see also Table 3

Taxon	Score	Habitat builder	Regeneration	Key spp.	Rare	Habitat specific	Bio turbation	Filter feeder	Native	Sensitive to mechanical disturbance	Sensitive to O_2 depletion
Fucus vesiculosus	15	3	3	2	2	2	0	0	1	1	1
Mytilus edulis trossulus	11	3	3	2	0	0	0	1	1	1	0
Chara sp.	11	3	3	0	0	2	0	0	1	1	1
Zostera marina	11	3	3	0	0	2	0	0	1	1	1
Talitrus saltator	10	0	0	2	2	2	1	0	1	1	1
Furcellaria fastigiata	10	3	3	0	0	2	0	0	1	1	0
Saduria entomon	10	0	3	2	0	2	1	0	1	1	0
Syngnathus typhle	10	0	3	0	2	2	0	0	1	1	1
Nerophis ophidion	10	0	3	0	2	2	0	0	1	1	1
Mya arenaria	10	0	3	2	0	0	1	1	1	1	1
Pomatoschistus minutus	9	0	3	2	2	0	0	0	1	0	1
Pomatoschistus microps	9	0	3	2	2	0	0	0	1	0	1
Astarte borealis	9	0	3	0	2	2	0	0	1	0	1
Macoma balthica	9	0	3	2	0	0	1	1	1	1	0
Ruppia maritima	8	3	3	0	0	0	0	0	1	1	0
Zanichella palustris	8	3	3	0	0	0	0	0	1	1	0
Sphaeroma hookeri	7	0	0	0	2	2	0	0	1	1	1
Cyathura carinata	7	0	0	0	2	2	0	0	1	1	1
Orchestia deshayeshi	7	0	0	0	2	2	1	0	0	1	1
Talorchestia sp.	7	0	0	0	2	2	1	0	0	1	1
Electra crustulenta	7	3	0	0	0	0	0	1	1	1	1

Table 1. (*continued*)

Taxon	Score	Habitat builder	Regeneration	Key spp.	Rare	Habitat specific	Bio turbation	Filter feeder	Native	Sensitive to mechanical disturbance	Sensitive to O_2 depletion
Palaemon adspersus	7	0	3	2	0	0	0	0	1	0	1
Liparis liparis	7	0	3	0	2	0	0	0	1	0	1
Crangon crangon	7	0	3	2	0	0	0	0	1	0	1
Eriocheir sinensis	7	0	3	0	2	0	1	0	0	0	1
Platichthys flesus	7	0	3	2	0	0	0	0	1	0	1
Scopothalmus maximus	7	0	3	2	0	0	0	0	1	0	1
Zoarces viviparius	7	0	3	2	0	0	0	0	1	0	1
Cerastoderma glaucum	7	0	3	0	0	0	0	1	1	1	1
Monoporeia affinis	6	0	0	0	2	2	0	0	1	0	1
Eurydyce pulchra	6	0	0	2	0	2	0	0	1	0	1
Bathyporeia pilosa	6	0	0	2	0	2	0	0	1	0	1
Mysis mixta	6	0	0	2	0	2	0	0	1	0	1
Balanus improvisus	6	3	0	0	0	0	0	1	0	1	1
Corophium volutator	6	0	0	2	0	0	0	1	1	1	1
Rhitropanopenus harrisi	6	0	3	0	2	0	0	0	0	0	1
Carcinus maenas	6	0	3	0	2	0	0	0	0	0	1
Neogobius melanostomus	6	0	3	2	0	0	0	0	0	0	1
Idotea granulosa	5	0	0	0	0	2	0	0	1	1	1
Heterotanais oerstedi	5	0	0	0	2	0	0	0	1	1	1
Idotea chelipes	5	0	0	2	0	0	0	0	1	1	1
Idotea balthica	5	0	0	2	0	0	0	0	1	1	1
Leptocheirus pilosus	5	0	0	0	2	0	0	0	1	1	1

Table 1. (*continued*)

Taxon	Score	Habitat builder	Regeneration	Key spp.	Rare	Habitat specific	Bio turbation	Filter feeder	Native	Sensitive to mechanical disturbance	Sensitive to O_2 depletion
Melita palamata	5	0	0	0	2	0	0	0	1	1	1
Gammarus oceanicus	5	0	0	2	0	0	0	0	1	1	1
Lymnea peregra	5	0	3	0	0	0	0	0	1	0	1
Myoxocephalus scorpius	5	0	3	0	0	0	0	0	1	0	1
Praunus inermis	4	0	0	0	2	0	0	0	1	0	1
Halicryptus spinulosus	4	0	0	2	0	0	1	0	1	0	0
Calliopius laeviusculus	4	0	0	0	2	0	0	0	1	0	1
Nemertea	4	0	0	0	2	0	1	0	1	0	0
Hediste diversicolor	4	0	0	2	0	0	1	0	1	0	0
Gammarus salinus	4	0	0	2	0	0	0	0	1	0	1
Gammarus zaddachi	4	0	0	2	0	0	0	0	1	0	1
Gammarus duebeni	4	0	0	0	2	0	0	0	1	0	1
Gammarus inaequicauda	4	0	0	0	2	0	0	0	1	0	1
Neomysis integer	4	0	0	2	0	0	0	0	1	0	1
Fabricia sabella	4	0	0	2	0	0	0	1	1	0	0
Palaemon elegans	4	0	3	0	0	0	0	0	0	0	1
Marenzellaria neglecta	3	0	0	2	0	0	1	0	0	0	0
Pygospio elegans	3	0	0	2	0	0	0	0	1	0	0
Gammarus tigrinus	3	0	0	2	0	0	0	0	0	0	1
Oligochaeta	3	0	0	2	0	0	0	0	1	0	0
Jaera sp.	3	0	0	0	0	0	0	0	1	1	1
Corophium curvispinum	3	0	0	0	0	0	0	1	0	1	1

Table 1. (*continued*)

Taxon	Score	Habitat builder	Regeneration	Key spp.	Rare	Habitat specific	Bio turbation	Filter feeder	Native	Sensitive to mechanical disturbance	Sensitive to O_2 depletion
Corophium multisetosum	3	0	0	0	0	0	0	1	0	1	1
Dendrocoelum lacteum	2	0	0	0	0	0	0	0	1	0	1
Planaria torva	2	0	0	0	0	0	0	0	1	0	1
Hydrobia ulvae	2	0	0	0	0	0	0	0	1	0	1
Theodoxus fluviatilis	2	0	0	0	0	0	0	0	1	0	1
Procerodes litoralis	1	0	0	0	0	0	0	0	1	0	0
Piscicola geometra	1	0	0	0	0	0	0	0	1	0	0
Chironomidae	1	0	0	0	0	0	0	0	1	0	0
Potamophyrgus antipodarum	1	0	0	0	0	0	0	0	0	0	1

Table 2. Benthic assemblages of PMA with their characteristics. The line marked 'total species value' summarises the individual species scores from Table 1

No.	1	2	3	4	5	6	7	8	9	10
Depth range in PMA [m]	0–50	0–20	0–20	0–5	0–5	infralittoral	2–100	20–100	0–80	2–20
Sediment	sandy-mud	sand	mixed	muddy sand	sand	mixed	mud-sand	mud-sand	mixed	stones
Feature	unvegetated	unvegetated	unvegetated	vegetated	vegetated	vegetated	below euph.	below euph.	below euph.	vegetated
community/ assemblage	*Hediste*	*Bathyporeia*	*Gammarus*	*Zanichella*	*Zostera*	*Cladophora*	*Macoma*	*Saduria*	*Mytilus*	*Furcellaria*
EUNIS habitat symbol	A52	A52	A51	A52	A52	A51	A54	A54	A54	A54
Total number of species	12	25	16	47	56	43	17	18	22	23
Total species value (from Table 1)	**47**	**128**	**72**	**223**	**302**	**181**	**100**	**102**	**125**	**123**
species										
Fucus vesiculosus										15
Mytilus edulis trossulus			11	11	11	11	11	11	11	11
Chara sp.					11					
Zostera marina					11					
Talitrus saltator		10								
Furcellaria fastigiata									10	10
Saduria entomon							10	10		
Syngnathus typhle					10					

Table 2. (*continued*)

No.	1	2	3	4	5	6	7	8	9	10
species										
Nerophis ophidion					10					
Mya arenaria	10	10		10	10					
Pomatoschistus minutus		9			9					
Pomatoschistus microps					9					
Astarte borealis							9		9	
Macoma balthica		9		9	9	9	9	9		
Ruppia maritima				8	8					
Zanichella palustris				8	8					
Sphaeroma hookeri				7	7					
Cyathura carinata				7	7					
Orchestia deshayeshi		7								
Electra crustulenta			7	7	7	7			7	7
Palaemon adspersus				7	7	7				
Liparis liparis								7	7	7
Crangon crangon		7			7					
Eriocheir siniensis	7						7			
Platichthys flesus		7	7	7	7				7	
Scopothalmus maximus		7			7				7	
Zoarces viviparius				7	7		7	7	7	7
Cerastoderma glaucum				7	7	7				
Monoporeia affinis							6	6	6	
Eurydyce pulchra		6								

Table 2. (*continued*)

No.	1	2	3	4	5	6	7	8	9	10
species										
Bathyporeia pilosa		6								
Mysis mixta				6	6	6	6	6	6	
Balanus improvisus		6	6		6	6		6	6	6
Corophium volutator	6			6						
Rhitropanopenus harrisi			6	6	6	6				
Carcinus maenas				6	6	6				
Neogobius melanostomus		6	6	6	6	6				
Idotea granulosa				5	5	5				
Heterotanais oerstedi						5		5	5	5
Idotea chelipes				5	5	5				
Idotea balthica				5	5	5				
Leptocheirus pilosus						5			5	5
Melita palamata							5	5	5	5
Gammarus oceanicus					5	5	5	5	5	5
Lymnea peregra				5	5	5				
Myoxocephalus scorpius				5	5	5	5	5	5	5
Praunus inermis				4	4	4				
Halicryptus spinulosus							4	4		
Calliopius laeviusculus				4	4	4				
Nemertea sp. non det.				4	4	4	4	4	4	4
Hediste diversicolor	4	4	4	4	4	4	4	4	4	4
Gammarus salinus		4	4	4	4	4				4

Table 2. (*continued*)

No.	1	2	3	4	5	6	7	8	9	10
species										
Gammarus zaddachi				4	4	4				4
Gammarus duebeni				4	4	4				4
Gammarus inaequicauda				4	4	4				4
Neomysis integer	4	4	4	4	4	4				
Fabricia sabella		4	4	4	4	4				
Palaemon elegans				4	4	4				
Marenzellaria neglecta		3	3	3	3	3	3	3		
Pygospio elegans		3		3	3					
Gammarus tigrinus	3	3	3	3	3	3				
Oligochaeta sp. non det.	3	3	3	3	3	3	3	3	3	3
Jaera sp. non det.									3	3
Corophium curvispinum	3	3		3	3	3				
Corophium multisetosum	3	3		3	3	3				
Dendrocoelum lacteum				2	2	2				
Planaria torva				2	2	2				2
Hydrobia ulvae	2	2		2	2	2	2	2	2	2
Theodoxus fluviatilis				2	2	2				
Procerodes litoralis				1	1	1			1	1
Piscicola geometra				1	1	1				
Chironomidae sp. non det.	1	1	1							
Potamophyrgus antipodarum	1	1	1	1	1	1				

Table 2. (*continued*)

No.	1	2	3	4	5	6	7	8	9	10
species										
spatial uniqueness	4	1	2	3	4	2	2	1	3	4
share of species pool	1	2	2	3	4	3	2	2	2	2
share of species value	1	3	2	4	4	3	2	2	3	3
biological value of PMA habitat	**6**	**6**	**6**	**10**	**12**	**8**	**6**	**5**	**8**	**9**

Table 3. Assessment questions for biological valuation of species (for results, see Table 1)

Question (answer 1 or 0)	Explanation	Weight
Is the species a habitat builder?	A perennial, encrusting, erect, large species that provides shelter for other species	3
Is the generation time over 2 years?	A long-lived species will regenerate slowly after disturbance	3
Is it a key species?	A species that is a major predator or an important food item, placed centrally in the food web or primary production	2
Is the species rare?	A species that is encountered in single locations and/or as single specimens only	2
Is the species specific to one habitat only?	A species that has a narrow niche and is strongly linked to specific physical conditions	2
Is the species a bioturbator?	A species that stirs up the sediment, enhancing oxygen exchange	1
Is the species a filter feeder?	A species that removes particles from the water, thereby enhancing transparency	1
Is the species native?	A native species is natural to the area, unlike a non-indigenous one	1
Is the species sensitive to mechanical disturbance?	A sessile, crustose species is vulnerable to siltation and rapid water dynamics	1
Is the species sensitive to oxygen depletion?	A species that is sensitive to oxygen depletion is most vulnerable to environmental stress	1

2.2.2. Species assemblage/habitat valuation

The value of each habitat was calculated as the sum of three elements (summary value of the species set, the spatial uniqueness value, the share of species pool value). The summary species value was calculated for each of the ten habitats based on the sum of individual species values (Table 2). The second element was the spatial uniqueness score; each habitat was valued from 1 to 4 – as a division on the quartiles (rare and small habitats received a score of 1 and the most extensive got a 4; Table 2). The third element of habitat valuation was to score the share of the benthic species pool associated with each of the ten habitats analysed. The share of the species pool was scored from 1 for habitats typically poor in species to 4 for the richest in species, such as the *Z. marina* assemblage (Table 2). In effect, each habitat received a 'fixed' value from 6 to 12 points.

2.2.3. Specific site valuation

The specific sampling point (site) was valued after its quality was ranked as poor, fair, good, or optimal (based on biomass and species list values). For example, the most valuable type of habitats, *Z. marina* assemblages that scored 12 points optimally, might be in poor condition with a low biomass and an incomplete species list and classified as poor (6 points, Table 4). The scores of poor *Z. marina* assemblage sites were of as good a quality as habitat sites that are not very valuable (e.g. mobile sands score only 6 points). Specific site valuation is concluded by calculating the mean value from the two characteristics mentioned above (e.g. the *Bathyporeia* habitat site with 13 to 24 species and a biomass between 1.1 to 5 g wet weight m^{-2} receives a score of 5 – this is 'good' for both categories and gives a mean of 5).

2.3. Step three (objective) – Conversion of the point layers of the evaluated sites to a continuous map layer

Global Ordinary Least Squares (OLS) multiple linear regression was used to generate a continuous prediction of dependent variables (valorisation value) for PMA using the set of potential explanatory variables available in continuous form. The Akaike Information Criterion (AIC) was used to choose a model from among several alternatives that performs best (Maindonald & Braun 2005). It was assumed that the following factors are good, possibly explanatory variables: depth or alternative wave exposure, sediments, and the amount of light that reaches the sea bottom.

The depth map for the PMA was generated using the Topo to Raster interpolation method. The input data used in the process were sounding points, contour lines, and the coastline as the boundary feature class. The wave exposure factor was represented by the layer of the maximum orbital velocity at the bottom. The raster layer of this parameter for the PMA was created by combining the maximum orbital velocity map for the Gulf of Gdańsk (Urbański et al. 2008) and the depth map. In the area outside the gulf, the regression relation was determined on the basis of maximum orbital velocity and depth using extracted points of both variables in the open part of the gulf. This regression formula was used to predict the maximum orbital velocity outside the Gulf of Gdańsk. The sediment map was produced by converting the vector map of surface sediments of the southern Baltic Sea to the raster layer and assigning quantitative values correlated with the seventeen sediment fractions, numbered from 1 for clay to 17 for boulders. The amount of light (photosynthetically active radiation – PAR) reaching the sea bottom was calculated as statistical seasonal

Table 4. Habitat valuation – scoring the condition of habitats. The optimal (maximum) value of each community (obtained from Table 2) is divided to represent the four states (from optimal to poor) of the condition (two categories: completeness of species list and biomass)

Community/ assemblage	Maximum biological value of community taken from Table 2	Optimal species	Good species	Fair speciess	Poor pecies	Optimal biomass	Good biomass	Fair biomass	Poor biomass
		[n m^{-2}]				[g ww m^{-2}]			
Hediste		12	7–11	3–6	< 3	> 50	11–50	0.2–10	< 0.2
points	6	**6**	**5**	**4**	**3**	**6**	**5**	**4**	**3**
Bathyporeia		25	13–24	6–12	< 6	> 5	1.1–5	0.2–1	< 0.2
points	6	**6**	**5**	**4**	**3**	**6**	**5**	**4**	**3**
Gammarus		16	9–15	4–8	< 4	> 35	6–35	0.2–5	< 0.2
points	6	**6**	**5**	**4**	**3**	**6**	**5**	**4**	**3**
Zanichella		47	21–46	10–20	< 10	> 200	21–200	0.2–20	< 0.2
points	10	**10**	**8**	**6**	**4**	**10**	**8**	**6**	**4**
Zostera		56	31–55	15–30	< 15	> 300	31–300	0.2–30	< 0.2
points	12	**12**	**10**	**8**	**6**	**12**	**10**	**8**	**6**
Cladophora		43	21–42	10–20	< 10	> 150	11–150	0.2–10	< 0.2
points	8	**8**	**6**	**4**	**2**	**8**	**6**	**4**	**2**
Macoma		17	9–16	4–8	< 4	> 300	31–300	0.2–30	< 0.2
points	6	**6**	**5**	**4**	**3**	**6**	**5**	**4**	**3**
Saduria		18	9–17	4–8	< 4	> 200	21–200	0.2–20	< 0.2
points	5	**5**	**4**	**3**	**2**	**5**	**4**	**3**	**2**
Mytilus		22	11–21	5–10	< 5	> 1000	51–1000	0.2–50	< 0.2
points	8	**8**	**6**	**4**	**2**	**8**	**6**	**4**	**2**
Furcellaria		23	11–22	5–10	< 5	> 1000	51–1000	0.2–50	< 0.2
points	9	**9**	**7**	**5**	**3**	**9**	**7**	**5**	**3**

maps according to Beer's law using the depth map described above. The diffuse light attenuation coefficients were derived from channels 1 & 2 of MODIS data from the period 2001–07. These were calibrated against Secchi disc depths averaged from long-term in situ observations (Aarup 2002). Non-linear regression models and maps of ice cover (as a light inhibitor) probability (Urbański & Kryla 2006) were used. Values of solar radiation flux at the sea surface were taken from simulations using a solar energy input model (Krężel 1997). All layers were created at a spatial resolution of 100 m.

3. Results

Using AIC for several models created by OLS, multiple linear regression enabled the best-performing model to be selected. The results of modelling are shown in Table 5. Redundancy among model explanatory variables was

Table 5. Results of OLS modelling of relation between valorisation and three variables: waves; sediments; radiation (confidence level of 95% in bold)

Summary of OLS Results

Variable	Coefficient	Std Error	t-Statistics	Probability	Robust-SE	Robust-t	Robust-Pr	VIF
Intercept	6.3615	0.7121	8.9335	**0.0000**	0.5871	10.8350	**0.0000**	
Waves	–2.9048	1.5609	–1.8610	0.0640	1.4494	–2.0040	**0.0466**	3.3738
Sediments	0.1196	0.0566	2.1119	**0.0360**	0.0418	2.8608	**0.0047**	1.7493
Log radiation	0.4218	0.0545	7.7377	**0.0000**	0.0508	8.3025	**0.0000**	3.4051

OLS Diagnostics

Number of observations	179	Number of variables	4
Degrees of Freedom	175	Akaike's Information Criterion (AIC)	733.846
Multiple R-Squared	0.50799	Adjusted R-squared	0.4996
Joint F-Statistic	60.2291	Prob(> F), (3,175) degrees of freedom	**0.0000**
Joint Wald Statistic	298.48	Prob(> chi-squared), (3) degrees of freedom	**0.0000**
Koenker (BP) Statistic	9.633	Prob(> chi-squared), (3) degrees of freedom	**0.2196**

tested using VIF (Variance Inflation Factor) statistics, and this indicated that multicolinearity was not a problem in the regression analyses. The scatterplot matrix graphic was used to elucidate the relationships among the variables. The curvilinearity of the radiation variable was remedied by logarithmic transformation. The final formula is:

$$\text{Valorisation} = 6.3614 - 2.9048\ \text{WAVES} + 0.1195\ \text{SEDIMENTS} + \\ + 0.4216\ \ln(\text{RADIATION})$$

Small p-values suggest that the coefficients determined are important for the model and that the model is statistically significant at a confidence level of 95%. Multiple R-Squared and adjusted R-Squared show that the model explained about 50% of dependent variable variation. The Koenker test also showed that explanatory variables are statistically significant. Figure 2 presents the result of the project, which is the biological valorisation of the benthic habitats. The sheltered, shallow waters of Puck Bay, and the stony outcrops on the open coast are biologically the most valuable areas in PMA. The lowest value was assigned to deeper, anoxic muddy sediments, devoid of macro-organisms.

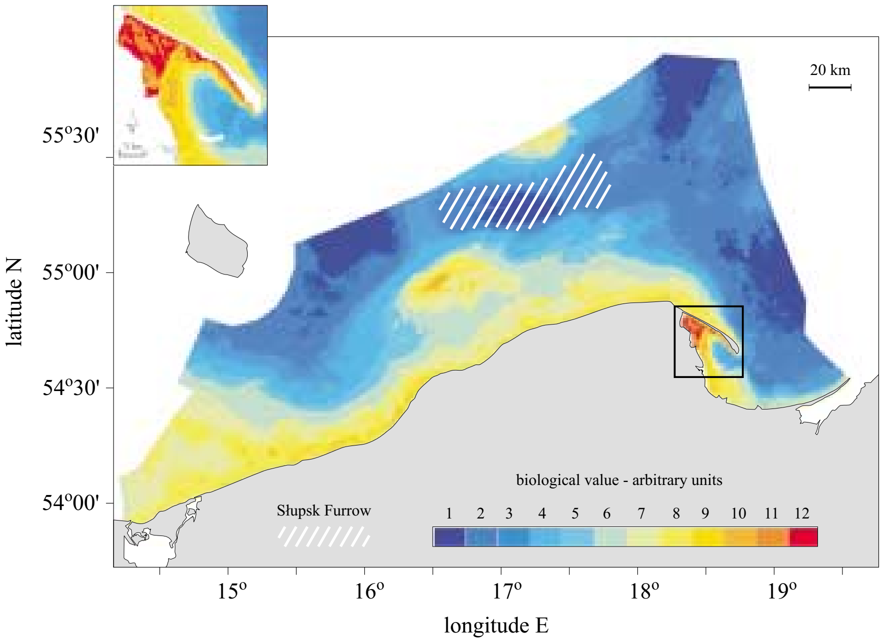

Figure 2. The biological valuation of the Polish Marine Areas (scale from low (blue) to high values (red). Shaded area indicates inadequate sampling for biological valuation

4. Discussion

This valuation map (Figure 2) does not simply mirror habitat distribution, and the value of the area cannot be assessed merely by analysing habitat occurrence (Warzocha 1995, Urbański & Szymelfenig 2003). The valuation map presented here does not indicate ecosystem health, since the most valuable area, Puck Bay, is also the most degraded (Pliński & Florczyk 1984), whereas some areas of intermediate value (e.g. coastal sands) are the cleanest and least disturbed habitats in Polish waters (Kotwicki et al. 2007). A socio-economic valuation of the area would show a different picture that would not correspond with the present biological valuation. The key goods of the PMA are the fishery, gas, extractable sands and recreational areas (Węsławski et al. 2006). The map undervalues the Słupsk Furrow area, which hosts relict assemblages of cold-water species with *Astare borealis* bivalves (Warzocha 1995); this undervaluation is due to the lack of samples collected. The values presented in Figure 2 are valid for the PMA only, as most of the characteristics are related to this delineated area (e.g. rarity, conservation status and spatial extension are related to the situation in the PMA). This is why it is impossible to compare the present map with similar ones produced for the Belgian shelf (Vincx & Degraer 2008, http://www.vliz.be/projects/bwzee/). The most valuable, rare species in PMA waters, *Fucus vesiculosus*, is very common in the north-eastern Baltic. The modest set of valuable habitat-forming species in the PMA would be overshadowed by the numerous habitat builders in the Kattegat area (Bonsdorff & Pearson 1999). The methodology proposed in this paper allows for relative precision in the valuation of seabed space, it demonstrates the patchiness of valuable habitats, and finally, it may help in spatial planning for sea beds. One of the key uses of biological valuation is scientific support for planning in Marine Protected Areas. This study supports the existing or planned protection of Puck Bay and the Słupsk shallows, as well as the marine part of the Słowinski National Park (the MPA in Poland are presented in Węsławski et al. 2006), and also demonstrates that the extensive Natura 2000 area (which covers almost the entire PMA coastal belt) extends well beyond the areas recognised here as biologically valuable sea beds (the designations of the Polish maritime Natura 2000 areas are available on http://natura2000.mos.gov.pl/natura2000/index.php). It should be borne in mind that important biological elements like plankton, birds and marine mammals were not considered here, as the emphasis was on benthic organisms only.

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