Preliminary assessment of the eutrophication status of selected areas in the Polish sector of the Baltic Sea according to the EU Water Framework Directive*

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Elżbieta Łysiak-Pastuszak[1]
Andrzej Osowiecki[2]
Magdalena Filipiak[1]
Anna Olszewska[1]
Grażyna Sapota[1]
Jerzy Woroń[1]
Włodzimierz Krzymiński[1]

[1] Institute of Meteorology and Water Management,
Maritime Branch,
Waszyngtona 42, PL–81–342 Gdynia, Poland;
e-mail: Elzbieta.Lysiak-Pastuszak@imgw.pl

[2] Maritime Institute in Gdańsk,
Abrahama 1, PL–80–307 Gdańsk, Poland

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Abstract

The implementation of the European Union Water Framework Directive required a number of tasks to be fulfilled: classifying the various water bodies into different types, defining reference conditions for each of the types and assessing their ecological quality status – this last is based on biological, hydromorphological and physicochemical quality elements of the ecosystem.

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The paper presents an attempt to estimate reference values in selected areas of Polish coastal and transitional waters as well as in an open sea area following WFD principles.

The preliminary eutrophication assessment showed all the assessed areas to be eutrophication problem areas.

1. Introduction

The ecological status of the Baltic Sea is affected by land- and sea-based human activities and in particular by nutrient inputs. Nutrient enrichment exerts an ecological impact on biological communities associated with the eutrophication process (Wasmund et al. 2001, HELCOM 2002, 2003). However, there is no single and commonly accepted definition of marine eutrophication. Nixon (1995), for example, defines it as 'an increase in the supply of organic matter'; Gray (1992) focuses on the direct effects of nutrient enrichment on productivity; according to the EU Urban Waste Water Directive (EU 1991) it is: 'The enrichment of water by nutrients, (...), causing an accelerated growth of algae and higher forms of plant life to produce an undesirable disturbance to the balance of organisms present in the water and to the quality of the water concerned'. Despite this disparity, the direct and indirect adverse effects of eutrophication in the Baltic Sea are well recognised and documented (Bonsdorff et al. 2002, HELCOM 2003). Eutrophication should be perceived both as a process and as a continuum, since the background values may vary naturally from one area to another (Ærtebjerg et al. 2003). For example, productivity in the open Baltic Sea is relatively low compared to that of the coastal regions.

To address these problems the European Union Water Framework Directive (WFD) (EU 2000) proposes an ambitious legal platform for protecting, enhancing and restoring good ecological conditions in all water bodies, including transitional and coastal waters. Various tasks need to be undertaken in relation to the implementation of the WFD (COAST 2003): classifying the different water bodies into different types, defining reference conditions for each type and assessing its ecological quality status, the last-mentioned being based on biological, hydromorphological and physico-chemical quality elements of the ecosystem.

When the WFD is implemented, the ecological status of the aquatic environment will be assessed on the basis of a unified typological classification and commonly accepted definitions of reference conditions (background values). The basis for assessing ecological status will therefore change from expert judgements to an operational and numerical quality evaluation harmonised throughout Europe.

This paper attempts to estimate reference values in the Polish marine areas of the southern Baltic Sea with respect to water transparency, winter concentrations of the main nutrients (inorganic nitrogen salts and phosphate), summer concentrations of total nitrogen and total phosphorus, the summer oxygen minimum in near-bottom water, and the summer chlorophyll-*a* concentration. An attempt was also made to estimate reference conditions for phytoplankton, zooplankton and zoobenthos indicators, e.g. biomass, abundance and species richness, in selected water bodies.

A preliminary eutrophication assessment using WFD principles was also conducted for an offshore area.

2. Material and methods

2.1. Assessment areas

The first step in the implementation of the Water Framework Directive (WFD) was to carry out a typological classification of the Polish coastal areas of the Baltic Sea (Krzymiński et al. 2004). Unit water bodies were determined in transitional and coastal waters according to the WFD guidance documents (COAST 2003).

During the process of revising the Baltic Sea monitoring programme and its harmonisation with pan-European procedures, the Helsinki Commission (HELCOM) initiated in 2005 the HELCOM EUTRO project – 'Development of tools for a thematic eutrophication assessment' for developing the tools and assessing the eutrophication status in selected areas of the Baltic Sea *sensu* Water Framework Directive.

Five areas were chosen for the HELCOM EUTRO assessment of eutrophication: a transitional water body (according to the WFD classification) – the outer Puck Bay[1], two coastal water bodies with different nutrient loading pressure – Rowy-Jarosławiec and Dziwna-Świna, and two areas located in the open Baltic Proper – the Gdańsk Deep and the south-eastern Gotland Basin.

This article discusses three of the assessed areas (Fig. 1) for which the biological data set was available from the monitoring activities in the period assessed. In addition, it was attempted, from pre-existing data, to set down reference conditions for biological quality elements. Altogether, one transitional water body, one coastal water body and one offshore area were assessed.

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[1] On 7 December 2005, the Polish Parliament in amendments to the 'Water Law', classified the entire area of the Gulf of Gdańsk (including 'outer Puck Bay') as coastal waters.

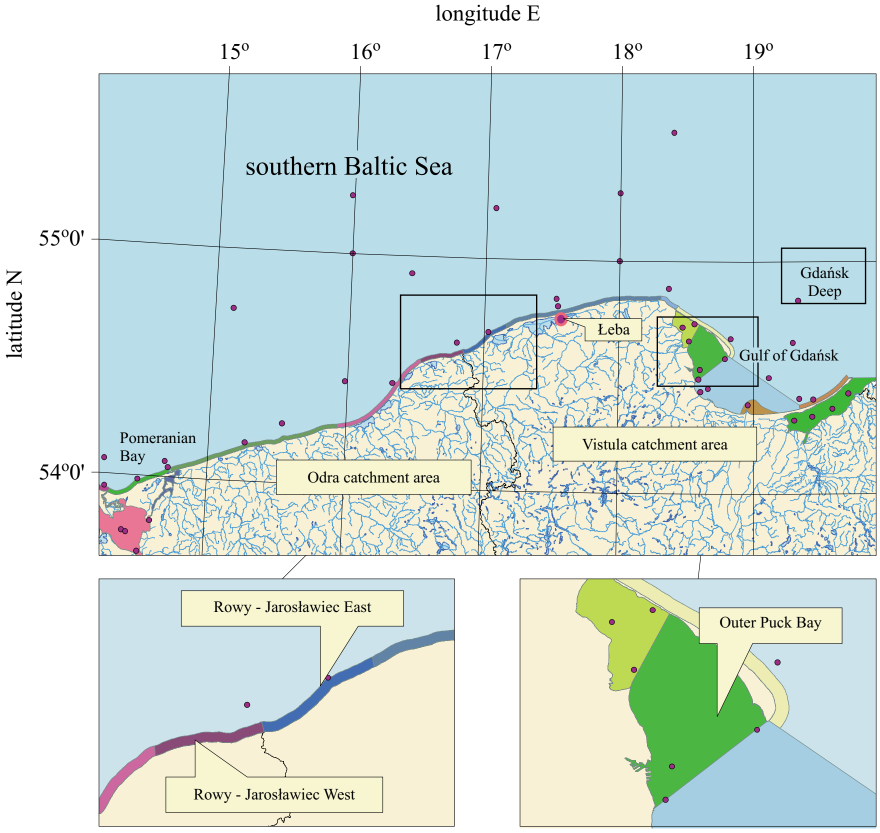

Fig. 1. Location of assessment areas in the Polish sector of the southern Baltic Sea; location of the atmospheric deposition measurement station at Łeba

Outer Puck Bay – transitional water body

The transitional water body 'Outer Puck Bay' ($\phi = 54°36'$N, $\lambda = 19°33'$E) is part of the Gulf of Gdańsk and belongs to the River Vistula catchment area (Mikulski 1987). Its main features: salinity in the range 5.0–9.0, an exchange rate of c. 14 days, a substratum of marine medium-grained sand and marine clayey silt; the water may be temporarily stratified (Krzymiński et al. 2004).

Gdańsk Deep – open sea

The Gdańsk Deep is an area in the Gdańsk Basin, a region of the southern Baltic Proper (Majewski 1990). In the shape of an elongated bowl, the Gdańsk Deep merges with the SE Gotland Basin in the north and spreads into the Gulf of Gdańsk in the south. It functions as a sedimentation sink primarily for the material carried in by the River Vistula (Wisła), but the Rivers Nemunas (Niemen) and Pregel (Pregola) should also be regarded as important pollution sources in this region (Andrulewicz 1996). The main morphometric features of the area: maximum depth 113–118 m, salinity between 7.00 (surface) to 11.50 (max 13.00) (bottom), a permanent density stratification with a consequent oxygen deficit and anoxia in the near-bottom water, and a marine clayey silt substratum (Krzymiński et al. 2004).

Rowy-Jarosławiec – coastal water body

Rowy-Jarosławiec is a coastal water body located along the central Polish coast. It consists of two parts: 'Rowy-Jarosławiec east' ($\phi = 54°39'$N, $\lambda = 17°00'$E), belonging to the Vistula catchment area, and 'Rowy-Jarosławiec west' ($\phi = 54°57'$N, $\lambda = 16°69'$E), which belongs to the River Oder (Odra) catchment area. Because the main morphological features and environmental conditions are very similar in both parts, the assessment was conducted as for a single water body. The main morphological features of the area: an open shore with cliffs, water salinity between 7.0–8.0 with a residence time $<$ 7 days, a substratum in the form of marine vari-grained sand, marine gravelly sand and sandy gravel (Krzymiński et al. 2004).

2.2. Quality elements and indicators

The following indicators were considered for the assessment of the eutrophication status.

Biological quality elements – direct and indirect effects

- Chl-*a* summer – mean summer (August) concentration of chlorophyll-*a* [mg m^{-3}];
- Chl-*a* year – mean annual (measurements carried out from March to November) concentration of chlorophyll-*a* [mg m^{-3}].

Phytoplankton:

- DSP – list of dominant taxa in seasons;
- AB – mean annual abundance integrated over a 0–20 m water layer [million cells m^{-3}];
- BI – mean annual biomass integrated over a 0–20 m water layer [mgC m^{-3}].

Zooplankton:

- DSZ – list of dominant species in seasons;
- AB – mean annual abundance [indiv. m^{-3}];
- BI – mean annual biomass [mg m^{-3}].

Benthic macro-invertebrates:

- LT – list of taxa: names of species found below 100 m in the Gdańsk Deep area;
- TR – taxonomic richness = number of taxa (phylum in the case of NEMERTINEA);
- AB – abundance: number of specimens per 1 m^2 [N m^{-2}];
- BI – macrozoobenthos biomass [g m^{-2}], on a wet weight basis.

Physico-chemical quality elements – causative factors and direct effects:

- DIP – winter concentration (mean) of dissolved phosphate [mmol m^{-3}] in the 0–10 m water layer; winter season: January, February and March;
- TOxN – winter concentration (mean) of the sum of nitrate + nitrite [mmol m^{-3}] in 0–10 m water layer;
- DIN – winter concentration (mean) of inorganic nitrogen salts – sum of nitrate + nitrite + ammonia [mmol m^{-3}] in the 0–10 m water layer;
- N:P = DIP:DIN – ratio of winter concentrations;
- Secchi sp. – mean Secchi depth [m] determined in spring (April, May and June);
- Secchi summer – mean Secchi depth [m] determined in summer (August);
- Secchi year – mean annual Secchi depth [m];
- Oxygen conditions summer – mean oxygen concentration [cm^3 dm^{-3}] in the near-bottom water in summer (August);
- O_2 min – minimum oxygen concentration [cm^3 dm^{-3}] in the near-bottom water in summer (August);
- H_2S summer – hydrogen sulphide concentration [mmol m^{-3}] in the near-bottom water in summer (August);
- P-tot. – total phosphorus concentration [mmol m^{-3}]; mean in the 0–10 m water layer in summer (August);
- N-tot. – total nitrogen concentration [mmol m^3]; mean in the 0–10 m water layer in summer (August).

Hydromorphological quality elements – causative factors:

Riverine nutrient concentrations:

- P-tot-P - mean annual concentration of total phosphorus [mmol P m^{-3}];

- N-in – mean annual concentration of nitrogen salts – nitrate + ammonia [mmol N m^{-3}].

N-air – atmospheric deposition of nitrogen; annual mean [mg N m^{-2}].

2.3. Assessment data

The assessment of the eutrophication level in the selected Baltic Sea areas within the framework of the HELCOM EUTRO project addressed the period 1999–2004.

Riverine nutrients

The data on riverine nutrient loads were collected as part of the Polish national monitoring programme of surface waters carried out by the relevant voivodship (district) Inspectorates for Environmental Protection. Monthly mean riverine flows and nutrient concentrations in 1990–2004 were supplied for the present assessment by Ośrodek Monitoringu Jakości Wód in Katowice (the Katowice Branch of the Institute of Meteorology and Water Management). The analyses were done according to Polish standard methods for surface water analyses.

Atmospheric deposition

Atmospheric deposition of nitrogen was assessed on the basis of data collected between 1999 and 2004 at the Polish coastal station in Łeba, one of the Polish EMEP (Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe) stations. Nitrate and ammonia determinations were conducted using the Polish standard methods.

Marine data

The data for the assessment period 1999–2004 were collected within the national monitoring programme of the Baltic Sea, conducted by the Maritime Branch of the Institute of Meteorology and Water Management in Gdynia, co-ordinated by the Chief Inspectorate for Environmental Protection and financed by the National Fund for Environmental Protection. In general, 6 monitoring cruises per year were organised to survey the environmental conditions: in February – to map the winter distribution of nutrients, in March or April – to assess the extent of the spring phytoplankton bloom, in June – primarily to sample the zoobenthos, in August – to monitor the high-summer conditions, in September or October and in November – to assess the progress of organic matter remineralisation.

Phytoplankton and zooplankton data were available only for the years 1999–2001. Macrozoobenthos data were analysed for the period 1999–2003.

All measurements, chemical analyses and determinations of biological parameters were performed according to the COMBINE Manual (HELCOM 1997).

2.4. Reference conditions

The reference conditions for the physico-chemical eutrophication indicators/metrics in the marine environment were determined for the time point of the early 1950s (HELCOM 2000). The sources of the reference values were scarce historical data (Kijowski 1938, Piątek 1962, Wiktor & Wiktor 1962, Głowińska 1963, Trzosińska 1978) and the oceanographic data base of the Institute of Meteorology and Water Management in Gdynia relating to the period 1959–2004. Regular HELCOM BMP/HELCOM COMBINE monitoring in the Polish sector of the southern Baltic Sea started in 1979. Prior to that time, data were collected on random occasions during the course of various oceanographic projects. The reference values were determined by extrapolating temporal trends (Łysiak-Pastuszak et al. 2004), mainly for the pre-1985 data. Steep positive trends (statistically significant according to Student's *t*-test) in the winter concentrations of oxidised nitrogen forms (TOxN) and dissolved phosphate (DIP) were discerned in the surface water layer (0–10 m) in the Polish bays between the late 1960s and the late 1980s. Although winter nutrient concentrations in the coastal (central Polish coast) and offshore waters had also increased, the detected trends were not statistically significant (Łysiak-Pastuszak et al. 2004).

The reference conditions for the macrozoobenthos were determined from historical data (Demel & Mańkowski 1951, Demel & Mulicki 1954, Mulicki & Żmudziński 1969).

Riverine reference concentrations of nitrogen (nitrate + ammonia) and total dissolved phosphorus were taken from Schernewski & Neumann (2005); these authors took the year 1900 as their reference point.

Atmospheric deposition of nitrogen was assessed on the basis of data collected at the Polish coastal station in Łeba (IMGW 1987–99, 2000–2001). For determining the reference values of atmospheric deposition of nitrogen the general rule of a 10% input was assumed after Schernewski & Neumann (2005), but applied to a different period. Schernewski & Neumann selected data from 1980–90 for determining their reference values, but the measurements at the Łeba station started only in 1987. The mean concentration of nitrogen compounds in atmospheric precipitation between 1987 and 1990 reached 1.37 mg dm^{-3}, but was only 1.03 mg dm^{-3} if the entire measurement series (1987–2004) was considered; this difference was due to the considerable decline in nitrogen deposition after 1990. The calculated reference deposition of nitrogen was therefore determined as 10% of the mean from the entire 1987–2004 data series.

2.5. Assessment metrics

To establish metrics for assessing eutrophication or ecological status, the question 'What is an acceptable deviation from reference conditions?' has to be answered. The normative definition in WFD Annex V (EU 2000) puts the acceptable deviation as the borderline between good and moderate ecological status. Following the recommendations of the EUTRO 1/2005 Workshop (HELCOM 2005) and for practical reasons, an acceptable deviation from reference conditions was here assumed to be 50%. The assessment metrics were calculated in relation to two reference values. One is denoted by 'PL' (determined from the Polish data for the reference year of 1950), the other by 'Lit.' (taken from the literature: * – from Schernewski & Neumann (2005), where the authors determined reference conditions by modelling in relation to the year 1900, and ** – from SEPA (2000), where the reference conditions were determined from measured historical values or by statistical methods from the data collected between 1950 and 1991).

The preliminary assessment was carried out by applying the ecological quality ratio (EQR) (COAST 2003)

$$EQR = \frac{\text{present value}}{\text{reference value}},$$

where EQR $>$ 1 indicates negative and undesirable changes due to eutrophication, and EQR $<$ 1 is assumed to indicate no variation from the pristine conditions.

3. Results

The assessment results are presented in Tables 1.1–3.3: a '+' indicates negative/undesirable changes in relation to the reference conditions, and a '–' indicates no variation from the reference value. The data from the assessment period (1999–2004) were evaluated mainly in relation to the Polish (PL) reference values; where these were lacking, literature reference values (SEPA 2000, Schernewski & Neumann 2005) were applied. The indices in brackets were not taken into account in the final assessment. A question mark '?' in the assessment tables indicates that the reference value could not be determined or reflects the doubts concerning the applicability of a given parameter as an indicator of changes caused by eutrophication, hence the presented assessment result is doubtful.

Table 1. Preliminary assessment of eutrophication status of the transitional water body 'Outer Puck Bay'

1.1. Biological quality elements

Quality element	Reference value		Unit	Metrics		Mean	EQR'50%		Assessment	
	PL	Lit.		PL 50%	Lit. 50%	1999–2004	PL	Lit.	PL	Lit.
chlorophyll-*a* su.	2.10	2.70**	mg m^{-3}	3.15	4.05**	7.01	2.23	1.73**	+	+
chlorophyll-*a* year	?	2.20*	mg m^{-3}		3.30*	5.57		1.69*		+
phytoplankton:										
– DSP	DSP***					DSP'99–01			?	
– AB	?		mio. cells m^{-3}			492.35			?	
– BI	?		mgC m^{-3}			11.13			?	
zooplankton:										
– DSZ	?					DSZ'99–01			?	
– AB	?		indiv. m^{-3}			37.275			?	
– BI	?		mg m^{-3}			180.6			?	
macro-invertebrates:										
– LT	LT'1950					LT'99–03			+?	
– TR	4–6 (4.7)		N of sp.	5.7		6–12 (9.6)	1.7		+?	
– AB	203–973		N m^{-2}	723		1 946.0–4 746.0				
	(482)					(3123)	4.3		+	
– BI	35.8–193.3		g m^{-2}	133.8		130.5–435.9				
	(89.2) (mean)					(245.0)	1.8		+	
sum assessment									**+?**	**+**

PL – refcond (reference conditions) based on Polish data; Lit. – refcond from * Schernewski & Neumann 2005, ** SEPA 2000; AB – abundance; BI – biomass; TR – taxonomic richness; '+' – negative changes in relation to refcond; '–' – no variation from refcond; '?' – refcond could not be determined, or assessment results are doubtful; *(continued, p. 223)*.

Table 1.1. description:

DSP*** (list of dominant, abundant and frequent species found in the Gulf of Gdańsk and Gdańsk Deep in 1946–47 (Heiskanen et al. (2005) after Rumek (1948))):

spring

- **dominant species:** *Bacillaria paxilifera, Chaetoceos pseudocrinitus, Chaetoceros eibenii, Diatoma tenuis, Dinobryon balticum, Dinobryon sertularia; Fragilaria islandica, Melosira lineata, Melosira moniliformis, Melosira nummuloides, Melosira varians, Skeletonema costatum, Tabellaria fenetrata, Tabellaria flocculosa;*
- **abundant and frequent species:** *Actinocyclus octonarius, Aphanizomenon flos-aquae, Asterionella formosa, Chaetoceros danicus, Chaetoceros holsaticus, Cheatoceros wighamii, Coscinodidcus radiatus, Dinophysis acuminata, Dinophysis rotundata, Fragilaria crotonensis, Gomphosphaeria aponina, Kolkwitziella acuta, Oocystis pelagica, Pediastrum kawrayski, Peridiniella catenata, Peridinium grenlandicum, Protoperidinium bipes, Protoperidinium granii, Protoperidinium pellucidum, Protoperidinium steinii, Synedra ulna, Thalassiosira baltica, Trochiscia clevei;*

summer

- **dominant species:** *Aphanizomenon flos-aquae, Botryococcus braunii, Chaetoceros eibeni, Coscinodidcus oculus-iridis, Diatoma tenuis, Nodularia spumigena;*
- **abundant and frequent species:** *Anabaena baltica, Anabaena flos-aquae, Anabaena spiroides, Aphanothaece microscopica, Chaetoceros danicus, Chaetoceros wighamii, Chlamydocapsa planctonica, Chlorangiella pygmae, Coscinodiscus radiatus, Dinophysis acuminata, Dinophysis norvegica, Dinophysis rotundata, Diploneis didyma, Dissodinium pseudolunnula, Ebria tripartita, Fragilaria crotonensis, Melosira moniliformis, Nodularia litorea, Oocystis pelagica, Oocystis submarina, Pediastrum boryanum v. longicorne, Pediastrum boryanum, Pediastrum duplex, Pediastrum kawrayski, Protoceratium reticulatum, Protoperidinium deficiens, Sorastrum americanum, Sorastrum spinulosum, Thalassiosira baltica, Trochiscia clevei;*

autumn

- **dominant species:** *Bacillaria paxillifera, Chaetoceros eibenii, Coscinodidcus oculus-iridis, Dinophysis acuminata, Melosira moniliformis, Skeletonema costatum;*
- **abundant and frequent species:** *Aphanizomenon flos-aquae, Chaetoceros danicus, Coscinodiscus radiatus, Dinophysis rotundata, Dissodinium pseudolunnula, Fragilaria crotonensis, Nodularia spumigena, Protoceratium reticulatum, Protoperidinium steinii, Thalassiosira baltica;*

DSP'99–01 (1999–2001):

spring – *Amylax triacantha, Chaetoceros wighami, Diatoma elongatum, Gymnodinium* indiv. 10, *Gymnodnium* sp./*Gyrodinium* sp., *Heterocapsa triquetra, Myrionecta rubra, Peridiniella catenata, Protoperidinium bipes, Skeletonema costatum;*

summer – *Anabena lemmermannii, Aphanizomenon* sp., Flagellata, *Heterocapsa triquetra, Merismopedia warmingiana, Plagioselmis prolonga, Thalassiosira* sp.;

autumn – *Aphanizomenon* sp., *Coscinodiscus granii, Cryptomonas* sp., *Eutreptiella* sp., *Heterocapsa triquetra, Myrionecta rubra, Rhodomonas marina;*

DSZ'99–01 (1999–2001):

spring – *Acartia* spp., *Synchaeta* sp., *Temora longicornis*;
summer – *Acartia* spp., *Bosmina cor. maritima Keratella* sp., *Synchaeta* sp.;
autumn – *Acartia* spp., *Synchaeta* sp., *Temora longicornis;*

LT'1950 (1950): *Halicryptus spinulosus, Harmothoe sarsi, Macoma balthica, Mytilus edulis, Pontoporeia femorata, Saduria entomon*;

LT'99–03 (1999–2003): *Balanus improvisus, Bylgides (Harmothoe) sarsi, Corophium volutator, Diastylis rathkei, Electra crustulenta, Gammarus salinus, Halicryptus spinulosus, Hydrobia* sp., *Jaera albifrons, Macoma balthica, Marenzelleria viridis, Monoporeia affinis, Mya arenaria, Mysis mixta, Mytilus edulis trosusulus, Nereis (Hedside) diversicolor, Oligochaeta* nd., *Pontoporeia femorata, Pygospio elegans, Saduria entomon.*

1.2. Physicochemical quality elements

Quality element	Reference value		Unit	Metrics		Mean	EQR'50%		Assessment	
	PL	Lit.		PL 50%	Lit. 50%	1999–2004	PL	Lit.	PL	Lit.
Secchi spring$^{\blacktriangledown}$	6.50		m	4.88$^{\blacktriangledown}$		4.73	1.03$^{\blacktriangledown}$		+	
Secchi summer$^{\blacktriangledown}$	6.00	5.1**	m	4.50$^{\blacktriangledown}$	2.55**	3.49	1.29$^{\blacktriangledown}$	0.73**	+	–
Secchi year$^{\blacktriangledown}$	7.70		m	5.78$^{\blacktriangledown}$		4.69	1.23$^{\blacktriangledown}$		+	
oxygen cond. summer	> 6.0	4.0–6.0**	$cm^3\ dm^{-3}$	3.0	3.0**	5.57	0.53	0.53**	–	–
[O_2 min]			$cm^3\ dm^{-3}$			[1.77]				
DIP	0.40	0.23*	mmol m^{-3}	0.60	0.35*	0.46	0.77	1.31*	–	+
TOxN	5.50	6.90**	mmol m^{-3}	8.25	10.35**	5.08	0.62	0.49**	–	–
DIN	6.50	10.00*	mmol m^{-3}	9.75	15.00*	6.18	0.63	0.43*	–	–
N:P	16.3	43.5*		24.4	64.3*	16.9	0.69	0.26*	–	–
P-tot.	0.70	0.28**	mmol m^{-3}	1.05	0.42**	1.04	0.99	2.48**	–	+
N-tot.	18.0	17.0**	mmol m^{-3}	27.00	25.5**	25.80	0.96	1.01**	–	+
sum assessment									+	+

PL – refcond (reference conditions) based on Polish data; Lit. – refcond from * Schernewski & Neumann 2005; ** SEPA 2000; $^{\blacktriangledown}$ HELCOM EUTRO defined acceptable deviation for Secchi depth at 25%; DIP – dissolved inorganic phosphate; TOxN = $NO_3 + NO_2$; DIN = $NO_3 + NO_2 + NH_4$; N:P = DIN:DIP; N-tot. – total nitrogen; P-tot. – total phosphorus; '+' – negative changes in relation to refcond; '–' – no variation from refcond; '?' – refcond could not be determined, or assessment results are doubtful.

1.3. Hydromorphological quality elements

Quality element	Reference value		Unit	Metrics		Mean	EQR'50%		Assessment	
	PL	Lit.		PL 50%	Lit. 50%	1999–2004	PL	Lit.	PL	Lit.
P-tot-P Vistula		0.6*	mmol m^{-3}		0.9*	9.0		10.0*		+
N-in Vistula		71.5*	mmol m^{-3}		107.3*	122.9		1.15*		+
sum assessment										+

PL – refcond (reference conditions) based on Polish data; Lit. – refcond from * Schernewski & Neumann 2005; ** SEPA 2000;
P-tot-P – total phosphorus; N-in – total nitrogen; '+' – negative changes in relation to refcond.

Table 2. Preliminary assessment of eutrophication status in the off-shore area of the Gdańsk Deep

2.1. Biological quality elements

Quality element	Reference value		Unit	Metrics		Mean	EQR'50%		Assessment	
	PL	Lit.		PL 50%	Lit. 50%	1999–2004	PL	Lit.	PL	Lit.
chlorophyll-*a* su.	?	1.00^{**}	mg m^{-3}		1.50^{**}	1.51		1.01^{**}		–
chlorophyll-*a* year	?	1.80^{*}	mg m^{-3}		2.70^{*}	3.34		1.24^{*}		+
phytoplankton:										
– DSP	DSP^{***}					DSP'99–01	?		?	
– AB	?		mio. cells m^{-3}			63.3	?		?	
– BI	?		mgC m^{-3}			6.18	?		?	
zooplankton:										
– DSZ	?					DSZ'99–01	?		?	
– AB	?		indiv. m^{-3}			13 789.0	?		?	
– BI	?		mg m^{-3}			115.3	?		?	
macro-invertebrates:										
– LT	LT'1950					LT'99–02; LT'2003			+?; +?	
– TR	0–5 (1.9)		N of sp.			0; 1			+?; +?	
– AB	0–208 (42.9)		N m^{-2}			0; 4			+?; +?	
– BI	0–60 (19.14) (mean)		g m^{-2}			0; 0.05			+?; +?	
sum assessment									+?	+

PL – refcond (reference conditions) based on Polish data; Lit. – refcond from *Schernewski & Neumann 2005; **SEPA 2000; AB – abundance; BI – biomass; TR – taxonomic richness; '+' – negative changes in relation to refcond; '–' – no variation from refcond; '?' – refcond could not be determined, or assessment results are doubtful; *(continued, p. 226).*

Table 2.1. description:

DSP*** (list of dominant and abundant and frequent species found in the Gulf of Gdańsk and Gdańsk Deep in 1946–47 (Heiskanen et al. (2005) after Rumek (1948))) – see Table 1.1:

DSP'99–01 (1999–2001): spring – *Gymnodinium* sp., *Gyrodinium* sp., *Myrionecta rubra, Peridiniella catenata, Skeletonema costatum*; **summer** – *Aphanizomenon* sp., *Dinophysis norvegica,* Flagellata, *Gymnodinium simplex, Gyrodinium* sp., *Myrionecta rubra*; **autumn** – *Chaetoceros* sp., *Coscinodiscus granii, Skeletonema costatum*;

DSZ'99–01 (1999-2001): spring – *Acartia longiremis, Fritillaria borealis, Pseudocalanus elongatus* ; **summer** – *Acartia longiremis, Bosmina cor. maritima, Pseudocalanus elongatus, Synchaeta* sp., *Temora longicornis*; **autumn** – *Acartia* spp., *Pseudocalanus elongatus, Temora longicornis*;

LT'1950 (1950): *Halicryptus spinulosus, Harmothoe sarsi, Macoma balthica, Monoporeia affinis, Mysis mixta, Mytilus edulis, Neomysis integer, Pontoporeia femorata, Priapulus caudatus, Scoloplos armiger*;

LT'99–02 (1999–2002): azoic bottom;

LT'2003 (2003): *Bylgides (Harmothoe) sarsi.*

2.2. Physicochemical quality elements

Quality element	Reference value		Unit	Metrics		Mean	EQR'50%		Assessment	
	PL	Lit.		PL 50%	Lit. 50%	1999–2004	PL	Lit.	PL	Lit.
Secchi spring▼	9.20		m	6.90▼		6.03	1.14▼		+	
Secchi summer▼	7.50	10.0**	m	5.63▼	5.00**	5.90	0.95▼	0.85**	–	–
Secchi year▼	10.0		m	7.50▼		7.73	0.97▼		–	
Oxygen cond. summer	1.22[a]		$cm^3\ dm^{-3}$	0.60		–0.67			+?	
[H_2S summer]	[12.0]		$mmol\ m^{-3}$			[27.50]				
DIP	0.25	0.22*	$mmol\ m^{-3}$	0.38	0.33*	0.46	1.21	1.39*	+	+
TOxN	3.00	2.0**	$mmol\ m^{-3}$	4.50	3.00**	4.05	0.90	1.35**	–	–
DIN	4.25	5.50*	$mmol\ m^{-3}$	6.38	8.25*	4.51	0.71	0.55*	–	–
N:P	17.0	25.0*		25.5	37.5*	13.80	0.54	0.37*	–	–
P-tot.	0.60	0.20**	$mmol\ m^{-3}$	0.90	0.30**	0.57	0.63	1.90**	–	+
N-tot.	14.0	12.0**	$mmol\ m^{-3}$	21.0	18.0**	20.60	0.98	1.14**	–	+
sum assessment									+	+

a – mean summer (August) concentration between 1959–1974; PL – refcond (reference conditions) based on Polish data; Lit. – refcond from * Schernewski & Neumann 2005; ** SEPA 2000; ▼ HELCOM EUTRO defined acceptable deviation for Secchi depth at 25%; DIP – dissolved inorganic phosphate; TOxN = $NO_3 + NO_2$; DIN = $NO_3 + NO_2 + NH_4$; N:P = DIN:DIP; N-tot. – total nitrogen; P-tot. – total phosphorus; '+' – negative changes in relation to refcond; '–' – no variation from refcond; '?' – refcond could not be determined, or assessment results are doubtful.

Table 3. Preliminary assessment of eutrophication status in the coastal water body ‘Rowy-Jarosławiec’

3.1. Biological quality elements

Quality element	Reference value		Unit	Metrics		Mean	EQR’50%		Assessment	
	PL	Lit.		PL 50%	Lit. 50%	1999–2004	PL	Lit.	PL	Lit.
chlorophyll-a summer	2.10	1.00**	mg m^{-3}	3.15	1.50**	2.22	0.70	1.48**	–	+
chlorophyll-a year	?	2.30*	mg m^{-3}		3.45*	2.51		0.73*		–
phytoplankton:										
– DSP	?					DSP’99–01	?		?	
– AB	?		mio. cells m^{-3}			106.1	?		?	
– BI	?		mgC m^{-3}			49.1	?		?	
zooplankton:										
– DSZ	?					DSZ’99–01	?		?	
– AB	?		indiv. m^{-3}			13 461.0	?		?	
– BI	?		mg m^{-3}			93.2	?		?	
macro-invertebrates:										
– LT	LT’1950					LT’99–03			+?	
– TR	2–6 (3.7)		N of sp.	5.6		9–15 (11.8)	2.1		+?	
– AB	47–373 (187)		N m^{-2}	280		659–5 236.0 (2 109)	7.5		+?	
– BI	12.68–29.54 (18.54) (mean)		g m^{-2}	27.8		11.60–234.2 (79.8)	2.9		+?	
sum assessment									**+?**	+

PL – refcond (reference conditions) based on Polish data; Lit. – refcond from * Schernewski & Neumann 2005; ** SEPA 2000;
AB – abundance; BI – biomass; TR – taxonomic richness; ‘+’ – negative changes in relation to refcond; ‘–’ – no variation from refcond; ‘?’ – refcond could not be determined, or assessment results are doubtful; *(continued, p. 228)*.

Table 3.1. description:

DSP'99–01 (1999–2001): spring – *Chaetoceros wighami, Gymnodinium* sp., *Myrionecta rubra, Peridiniella catenata, Skeletonema costatum*; **summer** – *Amylax triacantha, Coscinodiscus granii, Myrinecta rubra*; **autumn** – *Coscinodiscus grani, Eutreptiella* sp., *Heterocapsa rotundata, Heterocapsa triquetra*;

DSZ'99–01 (1999–2001): spring – *Acartia* spp., *Fritillaria borealis*; **summer** – *Acartia* spp., *Keratella quadrata*; **autumn** – *Acartia* spp., *Temora longicornis*;

LT'1950 (1950): *Balanus improvisus, Bathyporeia pilosa, Cardium glaucum, Hediste diversicolor, Macoma balthica, Monoporeia affinis, Pygospio elegans, Saduria entomon*;

LT'99–03 (1999–2003): *Cardium glaucum, Corophium volutator, Crangon crangon, Diastylis rathkei, Electra crustulenta,* Hydrobiidae nd., *Macoma balthica, Marenzelleria viridis, Mya arenaria, Mytilus edulis trossulus, Nereis (Hediste) diversicolor, Oligochaeta, Pygospio elegans, Saduria entomon, Streblospio shrubsoli.*

3.2. Physico-chemical quality elements

Quality element	Reference value		Unit	Metrics		Mean	EQR'50%		Assessment	
	PL	Lit.		PL 50%	Lit. 50%	1999–2004	PL	Lit.	PL	Lit.
Secchi spring$^{\blacktriangledown}$	10.0		m	7.50$^{\blacktriangledown}$		6.98	1.07$^{\blacktriangledown}$		+	
Secchi summer$^{\blacktriangledown}$	7.5	10.0**	m	5.63$^{\blacktriangledown}$	5.0**	6.34	0.89$^{\blacktriangledown}$	0.79**	–	–
Secchi year$^{\blacktriangledown}$	8.7		m	6.53$^{\blacktriangledown}$		6.93	0.94$^{\blacktriangledown}$		–	
Oxygen cond. summer	>6.0	4.0–6.0**	cm^3 dm^{-3}	3.00	3.00	6.10	0.71	0.71	–	–
[O_2 min]			cm^3 dm^{-3}			[4.90]				
DIP	0.35	0.25*	mmol m^{-3}	0.53	0.38*	0.50	0.94	1.32*	–	+
TOxN	3.50	2.00**	mmol m^{-3}	5.25	3.00**	4.64	0.88	1.55**	–	+
DIN	4.00	3.50*	mmol m^{-3}	6.00	5.25*	5.10	0.85	0.97*	–	–
N:P	11.40	14.0*		17.1	21.0*	9.94	0.58	0.47*	–	–
P-tot.	0.60	0.20**	mmol m^{-3}	0.90	0.30**	0.89	0.99	2.97**	–	+
N-tot.	13.00	13.00**	mmol m^{-3}	19.50	19.50**	20.32	1.04	1.04**	+	+
sum assessment									+	+

PL – refcond (reference conditions) based on Polish data; Lit. – refcond from *Schernewski & Neumann 2005; **SEPA 2000; $^{\blacktriangledown}$HELCOM EUTRO defined acceptable deviation for Secchi depth at 25%; DIP – dissolved inorganic phosphate; TOxN = NO_3+NO_2; DIN = NO_3+NO_2+NH_4; N:P = DIN:DIP; N-tot. – total nitrogen; P-tot. – total phosphorus; '+' – negative changes in relation to refcond; '–' – no variation from refcond.

3.3. Hydromorphological quality elements

Quality element	Reference value		Unit	Metrics		Mean	EQR'50%		Assessment	
	PL	Lit.		PL 50%	Lit. 50%	1999–2004	PL	Lit.	PL	Lit.
N-air	68.0	80.0*	mg N m^{-2}	102.0	120.0*	644.0	6.3	5.4*	+	+
TDP Pomeranian rivers	0.5^{b}		mmol m^{-3}	0.75		50.2	66.9		+	
N-in Pomeranian rivers	70.8^{b}		mmol m^{-3}	106.2		777.1	7.3		+	
sum assessment									+	+

PL – refcond (reference conditions) based on Polish data; Lit. – refcond from * Schernewski & Neumann 2005; b – calculated on the basis of *principles; P-tot-P – total phosphorus; N-in – total nitrogen; '+' – negative changes in relation to refcond.

On a precautionary note we should emphasise that the reference conditions presented here are tentative or preliminary. The majority need further elaboration and verification by, for example, a model simulation for the relevant time frame.

The final assessment (Table 4), based on the 'one out, all out' principle (COAST 2003), indicates that all the examined areas in the Polish sector of the Baltic Sea show signs of considerable eutrophication.

Table 4. Summary assessment

Assessment area	Quality elements			Final assessment
	Biological	Physico-chemical	Hydro-morphological	
Outer Puck Bay – transitional water body	+?	+	+	+
Gdańsk Deep – open sea area	+?	+	n.a.	+
Rowy–Jarosławiec – coastal water body	+?	+	+	+

'+' – negative changes in relation to refcond; '?' – refcond could not be determined, or assessment results are doubtful; n.a. – not assessed.

4. Discussion

Biological quality elements

The list of dominant (or frequent and abundant) phytoplankton species observed in the Gulf of Gdańsk and Gdańsk Deep areas in the assessment period (1999–2001) differs considerably from that found in 1946 –47 (Heiskanen et al. 2005). The reasons could be various, e.g. some of the flagellate species may not have been identified properly with the low-power microscopes used in the 1950s, or developments in taxonomy have led to changes in classification. Also, considerable salinity changes have to be taken into account: during the 1940s and 1950s Baltic waters were more saline, hence more 'oceanic' phytoplankton species predominated; they subsequently disappeared following the decline in salinity. The available historical data and the literature data did not allow reference conditions for phytoplankton abundance and/or biomass to be determined.

Similar problems were encountered while attempting to establish reference conditions for species structure, abundance and biomass of the zooplankton population. The literature data from the 1950s, although quite plentiful for the Gulf of Gdańsk and Gdańsk Deep area, reflect the results of studies conducted mainly for the benefit of the fisheries; hence, they are a source of reasonably good descriptions of fish larvae and macroplankton, but not of the mesozooplankton population.

Evaluation of eutrophication metrics relating to benthic macroinvertebrates in the coastal zone (the 'Rowy-Jarosławiec' coastal water body and the 'Outer Puck Bay' transitional water body) indicated that the species richness (TR) and biomass (BI) had roughly doubled in both areas, and that there were respective c. four- and seven-fold increases in abundance (AB) between 1950s and the assessment period (1999–2003). These changes were probably brought about by eutrophication, but it is questionable whether they should be interpreted as negative or undesirable, especially the increase in biodiversity. The analysis of a suitable indicator should probably probe more deeply into the changes in the contribution of functional groups of the zoobenthos.

Evaluation of the zoobenthos data in the Gdańsk Deep region revealed two distinct sub-periods: 1999–2002 and 2003. As a result of the considerable change in oxygen conditions in this area, changes were observed in the macrozoobenthos population. Between 1999 and 2002, azoic conditions (H_2S was ubiquitous) prevailed at the bottom of the Gdańsk Deep, with only very short spells when trace amounts of oxygen were detected (IMGW 2000–01). The improvement in oxygen conditions in the Gdańsk Deep between autumn 2002 and spring 2004 (Feistel et al. 2003) facilitated the reappearance of a few specimens of *Bylgides (Harmothoe) sarsi* in 2003. The observed changes are therefore related mostly to the natural hydromorphological conditions and not to anthropogenic pressure.

Physico-chemical quality elements

Most of the physico-chemical indicators tested were found suitable for assessing eutrophication, fulfilling such criteria as unambiguous interpretation, regional responsiveness and data availability.

Spring, summer (August) and annual mean Secchi depths (water transparency) were analysed. For both the open sea areas and the coastal waters along the central Polish coast, the spring measurement of transparency was considered to be the best indicator of the changes caused by eutrophication, whereas in transitional waters – the Gulf of Gdańsk – the summer (August) value was best suited for the analysis.

The minimal oxygen concentration in summer was put up for discussion: what should be regarded as a signal of oxygen deficit due to eutrophication: a single occurrence of an oxygen concentration < 4.0 cm^3 dm^{-3} or the mean concentration over a number of years falling below that level? Decidedly, even a single occurrence of oxygen concentration < 2.0 cm^3 dm^{-3} should give cause for serious concern, as it supplies evidence of a tendency towards an oxygen deficit; the monitoring frequency in the endangered waters should be increased in order to keep a better check on the process.

Neither the near-bottom oxygen conditions, nor hydrogen sulphide, nor the zoobenthos indicators examined seem to be appropriate for assessing eutrophication in deep basins, because natural factors more so than anthropogenic effects play an important role there. However, they are very important quality elements regarding the ecological status of these basins and should be included in the evaluation.

Hydromorphological quality elements

In the assessment of the riverine nutrient discharges, concentrations were evaluated separately from the flow, because the nutrient load is directly proportional to the flow, and load changes follow closely upon flow fluctuations, whereas the concentration variability can change significantly irrespective of the flow (Figs 2 and 3).

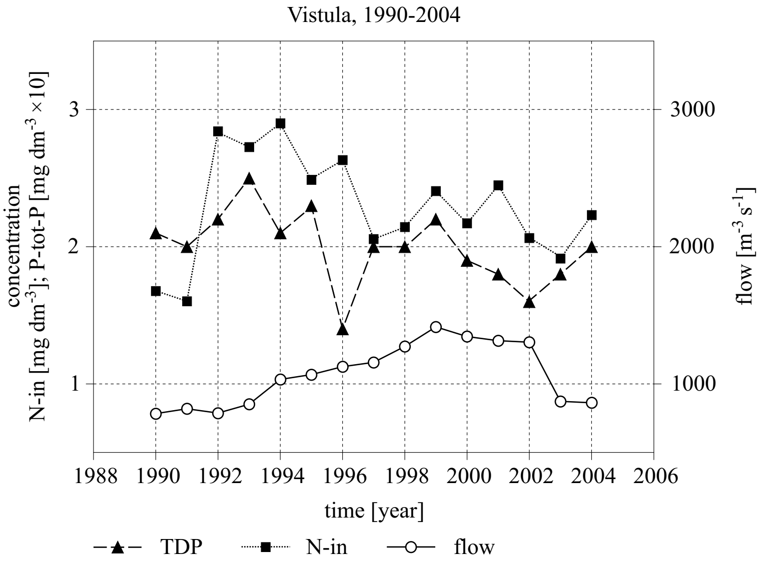

Fig. 2. Variability in the River Vistula flow and nutrient concentrations between 1990 and 2004

Both the mean annual inorganic nitrogen (nitrate + ammonia) and total dissolved phosphorus showed declining trends (1999–2004) in the Vistula and the Pomeranian rivers (taken as a sum). The declining trends in riverine nutrient concentrations started in the mid-1990s (Figs 2 and 3) despite the fact that highly significant positive trends were found in the flows then: Vistula – $R_{flow}(1990–1999) = +0.96$, $p < 0.05$; Pomeranian rivers – $R_{flow}(1990–1995) = +0.88$, $p < 0.05$.

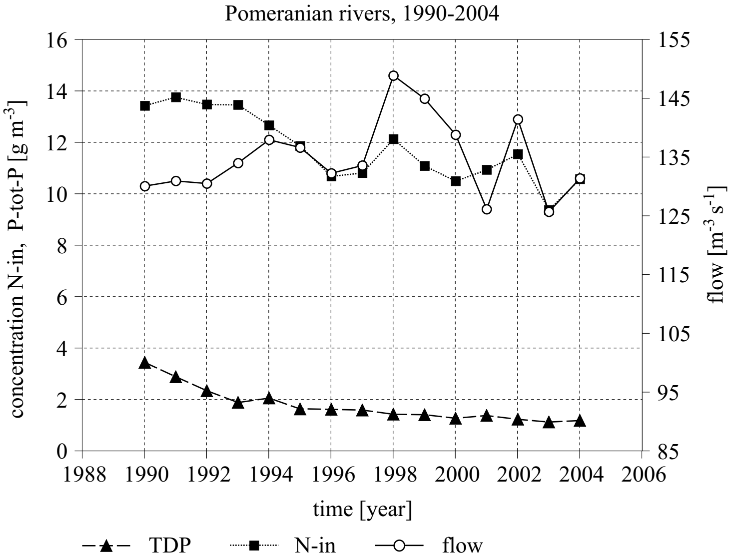

Fig. 3. Variability in the sum of the flow and nutrient concentrations of the Pomeranian rivers Ina, Rega, Parsęta, Grabowa, Wieprza, Słupia, Łupawa and Łeba between 1990 and 2004

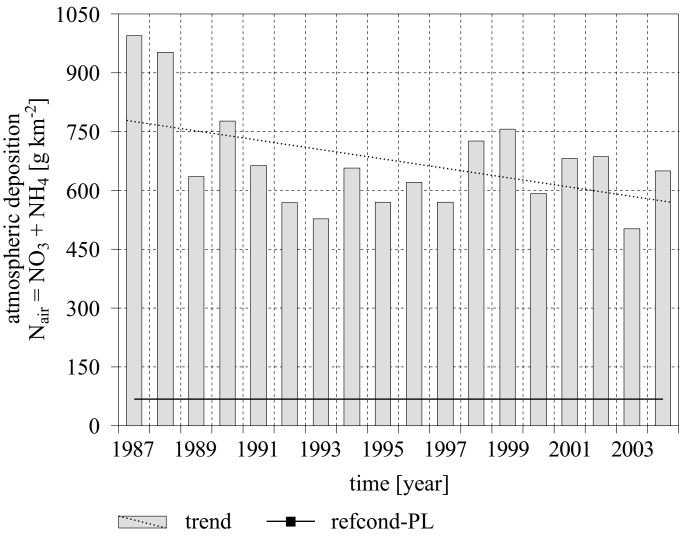

Fig. 4. Variability in the annual atmospheric deposition of nitrogen (nitrate+ammonia) over the southern Baltic Sea between 1987 and 2004, measured at the Łeba station; refcond-PL – reference value derived from the Polish data: 10% nitrogen deposition between 1987–2004

The application of 10% of the atmospheric nitrogen input from 1980–90 for the reference situation by Schernewski & Neumann (2005) has raised some doubts because nitrogen deposition reached very high levels during that period. Although the measurements at the Łeba station started in 1987, 10% of the 1987–90 bulk deposition was as high as 116.0 mg N m^{-2}. After 1990, atmospheric deposition of nitrogen declined significantly (Fig. 4); the decreasing trend marked in the figure is statistically significant ($R = -0.18$, $p = 0.0001$ by Student's t-test). The 10% of the bulk deposition was only 68.0 mg N m^{-2} if calculated from the entire Polish data series (1987–2004). It therefore seems more reasonable to base the reference value calculation on the longest data series, including the lower, present-day, values.

General conclusions

The assessment shows that there are key differences among the indicators owing to their different ecological weights. Hence, the generally assumed 50% deviation defining the borderline between good and moderate ecological status seems to be too high for certain indicators, e.g. transparency in the bays, winter nutrient concentrations in the offshore zone and along the central coast. The application of a 25% acceptable deviation from reference conditions is therefore to be recommended (Ærtebjerg et al. 2003).

There are differences between the assessment results of particular indicators based on the application of reference values determined by modelling the trophic conditions prevailing 100 years ago (Schernewski & Neumann 2005) and the ones determined by temporal trend extrapolation to the 1950s (PL), but the overall assessment provides evidence of enhanced eutrophication in the Polish sector of the southern Baltic Sea. This is in full agreement with the preceding periodic assessments of the state of the Baltic Sea environment carried out by HELCOM (HELCOM 1987–2002).

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