Oceanologia (2017) 59, 1—17

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.journals.elsevier.com/oceanologia/

ORIGINAL RESEARCH ARTICLE

Tracking trends in eutrophication based on pigments in recent coastal sediments

Małgorzata Szymczak-Żyła [a], **Magdalena Krajewska** [a], **Aleksandra Winogradow** [a], **Agata Zaborska** [a], **Gijs D. Breedveld** [b], **Grażyna Kowalewska** [a,*]

[a] *Institute of Oceanology, Polish Academy of Sciences, Sopot, Poland*
[b] *Norwegian Geotechnical Institute, Oslo, Norway*

Received 15 June 2016; accepted 22 August 2016
Available online 29 September 2016

KEYWORDS
Eutrophication;
Pigments;
Markers;
Sediments;
Baltic Sea;
Norwegian fjords

Summary Eutrophication in two different coastal areas — the Gulf of Gdańsk (southern Baltic) and the Oslofjord/Drammensfjord (Norway) — both subject to human pressure and with restricted water exchange with adjacent seas, was investigated and compared. Sediment cores (up to 20 cm long) were collected at 12 stations using a core sampler, 6 in each of the two areas, and divided into sub-samples. The physicochemical parameters characterizing the adjacent water column and near-bottom water, i.e. salinity, oxygen concentration and temperature, were measured during sample collection. Chlorophylls-a, -b and -c, their derivatives and selected carotenoids were determined for all the samples, as were additional parameters characterizing the sediments, i.e. C_{org}, N_{tot}, $\delta^{13}C$ and $\delta^{15}N$, grain size. ^{210}Pb activity was also determined and on that basis sediment mixing and accumulation rates were estimated. The distribution of pigments in sediments was related to environmental conditions, the sampling site location and sediment characteristics. The results are in agreement with other observations that eutrophication in the Gulf of Gdańsk has increased, especially since the 1970s, whereas in the Oslofjord it decreased during the same period. The pigments are better preserved in inner Oslofjord sediments than in those from the Gulf of Gdańsk. The results demonstrate that the sum of chloropigments-a in

---

* Corresponding author at: Institute of Oceanology, Polish Academy of Sciences, ul. Powstańców Warszawy 55, 81-712 Sopot, Poland. Tel.: +48 587311615.

E-mail addresses: szymczak@iopan.gda.pl (M. Szymczak-Żyła), mlawrec@iopan.gda.pl (M. Krajewska), olcia@iopan.gda.pl (A. Winogradow), agata@iopan.gda.pl (A. Zaborska), Gijs.Breedveld@ngi.no (G.D. Breedveld), Kowalewska@iopan.gda.pl (G. Kowalewska).

Peer review under the responsibility of Institute of Oceanology of the Polish Academy of Sciences.

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.oceano.2016.08.003

sediments calculated per dry weight of sediments is a valuable measure of eutrophication, providing that the monitoring site is selected properly, i.e. sediments are hypoxic/anoxic and non-mixed. Besides, the results confirm previous observations that the percentages of particular chlorophyll-a derivatives in the sum of chloropigments-a are universal markers of environmental conditions in a basin. The ratios of chloropigments-b and chlorophylls-c to the sum of chloropigments-a (ΣChlns-b/ΣChlns-a; Chls-c/ΣChlns-a) may by applied as complementary markers of freshwater and marine organic matter input, respectively.

1. Introduction

Eutrophication is one of the most important problems affecting many coastal areas worldwide (e.g. Bianchi et al., 2010; Chen et al., 2001; Fleming-Lehtinen et al., 2015; HELCOM, 2007; Li et al., 2013; Orive et al., 2002). It occurs in aquatic basins of high primary production caused by elevated nutrient concentrations (Edlund et al., 2009; Harmon et al., 2014). The intensive blooms of algae and cyanobacteria (including toxin-producing phytoplankton species), followed by high rates of sedimentation and accumulation, in conjunction with restricted water exchange result in eutrophication, which is manifested by hypoxia/anoxia in the sediments and near-bottom water (Conley et al., 2011; HYPOX, 2016). Oxygen depletion inhibits the growth of benthic organisms — this is reflected in the formation of laminar sediments (Reuss et al., 2005; Zhao et al., 2012). Like darkness and low temperatures, anoxia prevents the remineralization of organic matter in sediments (Hedges and Keil, 1995).

Despite the large body of knowledge relating to eutrophication and its imprint on bottom sediments, it is still not easy to evaluate it quantitatively, analyze its trends in a basin and compare it in different locations. Numerous proxies have been applied to this phenomenon, including organic compounds — principally pigments. These are chlorophyll-a, carotenoids and their derivatives. Chlorophyll-a in water is well known as a marker of primary production and has been used for this purpose in oceanography for over 50 years (e.g. Bianchi and Canuel, 2011; Jeffrey and Mantoura, 1997); the same applies to its derivatives (Bianchi et al., 1997, 2002a,b; Carpenter et al., 1988). However, chlorophyll-a concentrations in water change frequently in time and space, whereas chloropigments-a (chlorophyll-a and its derivatives) in sediments have been shown to be good indicators of the average primary production in a basin (Bianchi et al., 2002a,b; Harris et al., 1996; Stephens et al., 1997; Szymczak-Żyła et al., 2011). Particular sedimentary chlorophyll-a derivatives may be taken as markers of syn- and post-depositional environmental conditions (Szymczak-Żyła et al., 2011). Not only chloropigments but also carotenoids are monitored in sediments as chemotaxonomic and biomass markers; indeed, β-carotene is considered an even better proxy for total algal biomass than chlorophyll-a (Dixit et al., 2000; Leavitt, 1993; Schüller et al., 2013). Numerous papers have focused on chloropigments and carotenoids in recent and old sediments, mainly in lakes (e.g. Hodgson et al., 2004; Leavitt et al., 1997; McGowan et al., 2012; Moorhouse et al., 2014; Pienitz et al., 1992). Pigments have also been tracked in shelf areas (Chen et al., 2001; Li et al., 2012, 2013; Louda et al., 2000; Shankle et al., 2002; Sampere et al., 2008), in large river estuaries in America (Canuel et al., 2009; Chen et al., 2005; Edlund et al., 2009; Wysocki et al., 2006) and Asia (Li et al., 2011; Zhao et al., 2012), in New Zealand fjords (Schüller and Savage, 2011) and off the coast of Antarctica (Sañé et al., 2013). In contrast, not many papers have been written on pigments in European coastal zone sediments (Bianchi et al., 1996; Bourgeois et al., 2011; Reuss et al., 2005; Tselepides et al., 2000) and even fewer on Baltic sediments (Bianchi et al., 2002a,b; Kowalewska, 1997; Kowalewska et al., 2004; Reuss et al., 2005; Savage et al., 2010; Szymczak-Żyła and Kowalewska, 2007), despite the fact that eutrophication and hypoxia were identified as problems in this sea already many years ago (Conley et al., 2009; HELCOM, 2007).

Pigment concentrations in sediments depend on different factors, associated with (1) primary production and sedimentation, (2) pigment stability and (3) post-depositional conditions in sediments. Pigment degrade already in the water column and after deposition in the sediments as a result of senescence, oxidation, herbivore grazing or bacterial degradation (e.g. Bianchi et al., 1988; Louda et al., 1998, 2002; Spooner et al., 1994a,b; Szymczak-Żyła et al., 2006; Welschmeyer and Lorenzen, 1985). The influence of particular factors on pigment content may be different at different sites, so it is not an easy task to compare the extent of eutrophication in different areas based on pigment proxies in sediments, or to make judgements about eutrophication trends (Leavitt, 1993; Reuss et al., 2005).

The aim of this work was to compare eutrophication in different water basins, exemplified by the Gulf of Gdańsk (southern Baltic) and the Oslofjord/Drammensfjord (Norway), and its trends in each one. These two water bodies differ in salinity, geomorphology and the extent of water mixing, but both experience limited exchange of water with the adjacent sea and both are subject to human pressure. The aim was realized by analysing the pigment content in recent sediments in relation to environmental conditions in the near-bottom water as well as sediment characteristics, including accumulation rate, sediment mixing, grain size distribution, carbon and nitrogen content, i.e. parameters and factors associated with eutrophication.

2. Material and methods

2.1. Study areas

2.1.1. Gulf of Gdańsk

The Gulf of Gdańsk (Fig. 1, area 4940 km^2) is part of the southern Baltic Sea (Majewski, 1990). The adjacent