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Diatom-based estimation of sea surface salinity in the south Baltic Sea and Kattegat

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Abstract The new diatom-based sea-surface salinity (SSS) estimation has been applied to a collection of 27 taxa in 48 present-day sediment and surface water samples recovered in the Baltic Sea and Kattegat. The sediment core 303610-12 (2005) from the Eastern Gotland was chosen for the study of the Holocene sequence spanning the past 8160 yrs BP. The Artificial Neuronal Network (ANN) method provided an estimation of spring (March-April) SSS values ranging between 7.04-8.25 ‰. The low amplitude of salinity change might be caused by mixing of fresh water with upper surface layer of the Baltic Sea due to high precipitation and riverine input. These findings were compared with independent geochemical proxies for salinity (K, Ti and S) derived from XRF Core Scanner record. Significant correlation between salinity and sulphur records and an inverse correlation between K and Ti demonstrate that the ANN method, when combined with quantitative and qualitative analyses of diatoms, provides a useful tool for palaeo-salinity reconstructions from the Holocene sediments of the Baltic Sea.

Keywords *• diatoms (Bacillariophyta) • artificial neuronal network • salinity reconstruction • reference data set*

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INTRODUCTION

The Holocene Baltic Sea history is bound to sea level changes and isostatic rebound of the Fennoskandia affecting water mass exchange with the Atlantic Ocean that influence environmental conditions in the Baltic Sea basin (Svenson 1991; Bjorck 1995; Harff *et al.* 2001). The Littorina Sea transgression ca. 8500 cal. yrs BP was the most drastic environmental change expressed in terms of salinity increase (Jensen *et al.* 1999; Emeis *et al.* 2003). Inflow of saline waters resulted in a change of a freshwater Ancylus Lake into a brackish-marine water of the Littorina Sea. This caused drastic increase in the sea surface salinity since the last deglaciation (15–17 psu after Willumsen *et al.* 2012). Since the Littorina Sea transgression the Baltic Sea basin has been permanently connected with the Atlantic Ocean through the Danish straits. The intensity and frequency of saline, dense and rich in nutrients water inflows are coupled with the positive index of North Atlantic Oscillation which strength eastward direction of humid air masses. This, in consequence enhance marine inflows into the Baltic Sea (Alheit, Hagen 1997; Harff *et al.* 2011). One of the well proven proxies used to track changes in salinity and to reconstruct them through the Baltic Sea evolution stages is analysis of diatomaceous microfossils preserved in the well dated sediments of the sedimentary basins.

Diatoms are valuable bioindicators due to the abundant occurrence, short life cycle and high vulnerability to environmental parameters. They are sensitive tool often applied for short-term environmental reconstructions (Witkowski 1994; Snoeijs *et al.* 1999; Gersonde, Zielinski 2000; Emeis *et al.* 2003; Gersonde *et al.* 2003). Quantitative and qualitative analysis of diatom assemblages can be used as a proxy of water salinity or temperature in which they dwell. Moreover, based on diatomological analysis trophic status, oxygen saturation, water depth or water circulation pattern, including climate changes and anthropogenic impact can be estimated (Van Dam *et al.* 1994).

Qualitative diatom evaluation has been applied as primary mode of salinity reconstructions in the Baltic Sea Holocene history (Abelmann 1985; Gustafsson, Westman 2002). Chemical methods based on $\delta\ ^{13}C$ / $\delta\ ^{12}C$ ratio in organic matter from surface sediments or on chemical measurements of sediments have been important in previous studies on salinity reconstructions from the Baltic Sea. Isotopic studies took into account deeper water masses, below the halocline indicating higher salinity and greater salinity amplitudes during the Holocene (Emeis *et al.* 2003; Leipe *et al.* 2008). The chemical measurements have been performed on concentration of Boron (Sohlenius *et al.* 1996) and Bromine (Grigoriev *et al.* 2011). It resulted in correlation with water salinity and allowed quantitative reconstruction of palaeosalinity changes particularly during the Littorina Sea and Post-Littorina Sea periods.

Assumptions of this study include water stratification triggered by the inflow of dense saline bottom waters and large freshwater discharge due to riverine waters enhanced by precipitation which affect upper part of the water column (Voipio 1981; HELCOM 2010; Harff *et al.* 2011). Thus, the sea water surface seems to be sensitive to salinity changes.

The goal of this paper is to develop a diatom-based reference data set that in combination with a sophisticated statistical method of ANN can be useful for sea surface salinity reconstructions. Potentially high sensitivity of the surface water in the Baltic Sea to salinity changes provides an opportunity to reconstruct SSS fluctuations with high resolution during the Holocene. For this purpose the paper here presents correlations between observed and estimated salinities in selected areas of the Baltic Sea. Furthermore, assess applicability of the new diatom reference data set based on test SSS reconstructions in the sediment core 303610-12 encompassing sediments from an early-mid Holocene is shown here.

MATERIAL AND METHODS

A total of forty-eight samples were retrieved with the purpose of diatomological analysis based on forty-four present-day surface sediment samples made accessible by the Polish Geological Institute-Polish Research Institute (Marine Geology Branch in Gdańsk-Oliwa) and four surface water samples from PANGEA (Data Publisher for Earth & Environmental Science). Samples were collected from the Kattegat, Pomeranian Bay, Hell Peninsula offshore, Gdańsk Bay, and East Gotland Basin with use of box corer and plankton net (Fig. 1; Table 1).

The 114 Holocene sediment samples (spanning the last 8160 yrs BP) used for testing an applicability of diatom-based reference data set have been recovered from core 303610-12 at location of 57.28°N, 20.11°E (Eastern Gotland Basin; Harff *et al.* 2011). The diatomaceous composition of the core 303610-12 has been studied in the Palaeooceanology Unit at the Faculty of Geosciences, University of Szczecin. The 3.9 m postglacial sediment core have been subdivided into six zones (B1-B6) based on the con-

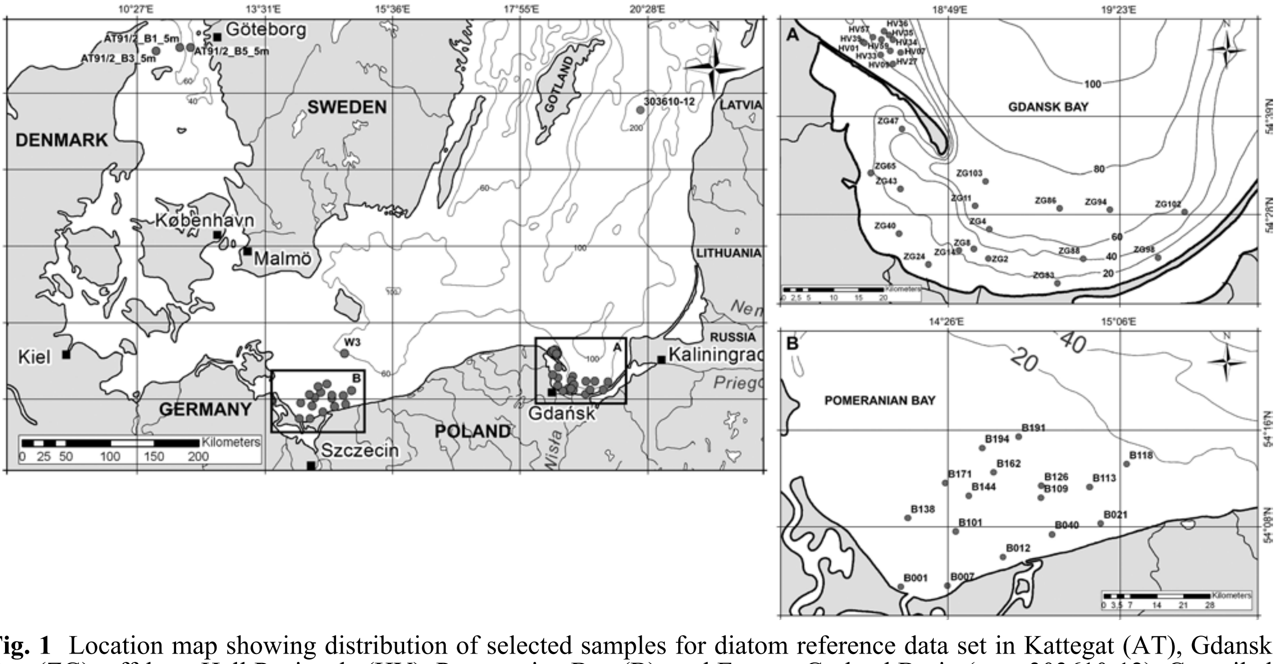

Fig. 1 Location map showing distribution of selected samples for diatom reference data set in Kattegat (AT), Gdansk Bay (ZG), offshore Hell Peninsula (HV), Pomeranian Bay (B), and Eastern Gotland Basin (core 303610-12). Compiled by B. Kotrys, 2014 (after W. Jeglinski, 2014, unpubl.).

Table 1 Codes of samples used for diatom reference data set, their coordinates (decimal latitude and longitude) and depths below sea level (m, b. s. l.)

Sample	Latitude	Longitude	Sample depth (m, b. s. l.)	Studied area
AT91/2_B1_5m	57.55000	11.52500	5	Kattegat
AT91/2_B3_5m	57.53330	11.32500	5	
AT91/2_B5_5m	57.46500	10.90000	5	
B001	53.93537	14.25665	6,9	Pommeranian Bay
B007	53.94830	14.44157	11,2	
B012	54.02777	14.65353	10,8	
B021	54.12632	15.03191	16,4	
B040	54.09136	14.84109	14,1	
B101	54.07751	14.45408	12,8	
B109	54.17494	14.78398	16	
B113	54.21012	14.97507	11,8	
B118	54.27174	15.11528	15,5	
B126	54.20338	14.78116	16	
B138	54.09835	14.25774	13,9	
B144	54.16440	14.49345	13,5	
B162	54.22488	14.58457	15,1	
B171	54.18922	14.39377	13,1	
B191	54.31368	14.67254	10	
B194	54.27992	14.52950	13,6	
W-3	54.63799	14.93805	60,0	Bornholm Basin
HV01	54.78573	18.55843	16,4	Hell Peninsula
HV07	54.76185	18.62259	19,9	
HV09	54.74779	18.65478	21,8	
HV27	54.79113	18.61618	23,1	
HV33	54.76863	18.67789	29,7	
HV34	54.79141	18.65263	28,8	
HV35	54.79971	18.63995	29,0	
HV36	54.80634	18.62357	27,1	
HV39	54.78361	18.56451	16,3	
HV57	54.79457	18.58986	21,1	
HV59	54.76557	18.65084	23,6	
ZG102	54.49540	19.57158	47,2	Gdansk Bay
ZG103	54.54187	18.95361	67,6	
ZG11	54.49690	18.92278	64,3	
ZG14	54.41596	18.87669	20,2	
ZG2	54.40229	18.96934	24,5	
ZG24	54.38886	18.78434	12,7	
ZG4	54.45547	18.96930	61,9	
ZG40	54.44259	18.69151	12,2	
ZG43	54.52350	18.69090	28,1	
ZG47	54.63138	18.69009	43,9	
ZG65	54.55018	18.59794	14,2	
ZG8	54.41599	18.92293	30,1	
ZG83	54.36194	19.18473	9,2	
ZG86	54.49679	19.18534	71,4	
ZG88	54.40674	19.26198	38,6	
ZG94	54.49644	19.34004	70,4	
ZG98	54.41205	19.49252	7,9	

tinuously measured physico-lithological properties. Zonation from B1 to B6 represents Littorina Sea to recent Baltic Sea stages which are dominated mainly by laminated sediments (Harff *et al.* 2011).

To process of cleaning the surface sediment began with application of hydrogen peroxide and hydrochloric acid (HCl) heated to 170°C and were then decanted ten times. For the preparation of microscopic slides with randomly dispersed diatom valves sediment residuals were diluted with demineralized water to an amount of 300 ml. Defined amount of suspension was carefully dispersed on the cover glass with an automatic pipette. The water was slowly removed from the cover glass dish by evaporation. After complete removal of the water the cover glass was mounted with Naphrax.

Light microscopic analyses were conducted with a Nikon Optiphot-2 microscope with at a magnification of 1000x. Generally ca. 300 diatom valves were identified and counted per sample. Based on the qualitative counting results and ecological characteristics particular diatom taxa diatoms were analysed in terms of habitat and salinity.

For the purpose of salinity estimations it was decided to use the Artificial Neuronal Network technique (ANN; Malmgren, Nordlund 1997). In spite of rare usage of ANN in micropalaeontological studies, however, it provides good results considered to be better estimate than statistical methods as for example Imbrie and Kipp Method (IKM) or Modern Analogue Technique (MAT; Chen *et al.* 2005). Particularly when the limited reference data set restricted mainly to the southern Baltic Sea is considered this method seems to be suitable for palaeosalinity estimations (Kotrys 2012).

The first description of principles for training the ANN was established in 1940 (Wasserman 1989). The ANN was found to be applicable for gas and oil exploration, in military techniques, in medicine or economy. For palaeoceanographic purposes the ANN was initially tested and applied by Malmgren and Nordlund (1997).

The learning sequence known as back propagation or propagation of error of ANN, which was applied to these studies, is processed by an algorithm that works by what is known as supervised training (Malmgren, Nordlund 1997). Firstly an input is transferred for a forward pass through the network. The network output is compared to the assumed output, which is specified by the computer simulation (as supervisor), and the error for all the neurons in the output layer is calculated. The essential mechanism behind back propagation is that the error is propagated backward to earlier layers so that a gradient descent algorithm can be applied (Malmgren, Nordlund 1997; Malmgren *et al.* 2001; Cortese *et al.* 2005; Kucera *et al.* 2005).

To perform the ANN salinity estimations on the basis of changes in diatom assemblages NeuroGenetic Optimizer (NGO, version 2.6.130, ©BioComp Systems, Inc.) software developed by Malmgren, Nordlund (1997) was applied. This software provided the best results from ANN tests conducted in a study by Cortese *et al.* (2005). They tested by means of a radiolarian reference data set and summer sea surface temperature the two different ANN programs: the NeuroGenetic Optimizer (NGO; ©BioComp Systems, Inc.) and the iModel (©BioComp Systems, Inc.). The most accurate data were produced by the NGO. Cortese *et al.* (2005) found, based on three test runs, that the NGO generated slightly lower error rates than the iModel.

REFERENCE DATA SET

A basic assumption to develop a reliable reference data set and perform sea surface salinity (SSS) reconstructions was that the composition of microfossil assemblages (e.g. diatoms) preserved in the surface sediment record corresponds with the present-day oceanographic parameters (e.g. salinity) and that this relation remained unchanged during the studied geological time period. The main principles of constructing of a microfossil-based reference data set for palaeoreconstructions are (1) the proper selection of surface water environmental parameters (e.g. salinity), and (2) the proper selection of microfossil species used as proxies for palaeoreconstructions (e.g. Cortese, Abelmann 2002). Following these principals salinity data from hydrographic data bank of Pan-European infrastructure for Ocean, Marine Data management (SeaDataNet) and European Marine Observation and Data Network (EMODNET Chemistry) have been used. Surface salinity data was extracted with application of the online OceanBrowser (access date 05. 2013).

The application of present day hydrographic data and surface sediment samples guarantees that the palaeosalinity estimations are based on reliable reference data set representing the modem environment condition. Palaeosalinity estimations were restricted to spring conditions when diatoms peak production occurs (Wasmund *et al.* 1998). The applied hydrographic data represent salinity values averaged over a time period spanning April-May. Salinity data were taken from two meters water depth. Values from this depth reflect surface water conditions that are sensible to short-term salinity changes that can occur in the marine water.

On the basis of the OMNIDIA ver. 3 software, which has a database (Omnis7) with information on more than 11 000 species, we selected surface and bottom water dwelling taxa that representing fresh,

fresh brackish, brackish fresh, brackish and brackish marine water environmental conditions. From the total of 265 taxa recorded in the analysed sample set, 27 planktonic taxa were chosen to be included in the reference data set (Table 2).

The selection of taxa was carried out as follows: surface water dwelling taxa were selected that demonstrate a clear geographic relationship with the surface water salinity pattern in the study area; only taxa that can be doubtless identified on the basis of unequivocal taxonomic description and documentation to guarantee that the species abundance pattern revealed from the analysed reference data set and down-core assemblages that can be related to each other in terms of ecology were selected; included were only diatoms from sediment samples containing well preserved and silicified specimens; to balance the weight between fresh, brackish, brackish fresh, brackish and brackish marine diatoms a comparable number of taxa representing each above mentioned group was included in the data set used herein; taxa inhabiting deeper waters have been eliminated from the data set; taxa representing no-analog species in the geological record have not been considered.

A no-analogue situation is where the maximum abundance of a specific diatom taxa from a down-core record exceeds its maximum abundance from a reference data set. This problem can have its source in selective dissolution or in different marine conditions that do not occur in the present day sea water and therefore such species must not be considered for quantitative reconstructions of palaeoenvironment (e.g. Ablemann, Gowing 1997; Cortese, Abelmann 2002; Kotrys 2012). In order to decrease the ratio between diatom taxa of high and low abundance the reference data set was logarithmically transferred (Kotrys 2012).

TESTING THE ARTIFICIAL NEURONAL NETWORK

For the purpose of testing the diatom reference data set and estimate down core spring SSS of the NGO ANN had to be properly calibrated. For the estimation of prediction error the Root Mean Square Error of Prediction (RMSEP) was applied. The RMSEP is the square root of the sum of the squared differences between the observed and predicted values for all observations in the test set divided by the number of such observations, to estimate the prediction error (Kotrys 2012). A minimum of 50 network training passes were applied with the cut-off for network training passes was set up to 1000. The network employed 27 inputs and 2 hidden layers.

Table 2 List of diatom taxa selected from surficial samples and plankton net for the reference data set and their ecological demands applied to core 303610-12

Achnanthes taeniata Grunow 1880; brackish marine: from 1.8 to 34 ‰.
Actinocyclus normanii (Gregory); Hustedt 1957; brackish: from 1.8 to 9.0 ‰.
Actinocyclus octonarius var. *crassus* (Smith); Hendey 1954; fresh brackish: <0.9 ‰.
Asterionella glacialis Castracane 1886; brackish marine: from 1.8 to 34 ‰.
Aulacoseira alpigena (Grunow); Krammer 1991; fresh: <0.2 ‰.
Aulacoseira ambigua (Grunow); Simonsen 1979; fresh brackish: <0.9 ‰.
Aulacoseira granulata (Ehrenberg); Simonsen 1979; fresh brackish: <0.9 ‰.
Coscinodiscus radiatus Ehrenberg 1840; brackish marine: from 1.8 to 34 ‰.
Cyclostephanos dubius (Fricke); Round 1987; brackish fresh: from 0.9 to 1.8 ‰.
Cyclostephanos tholiformis Stoermer; Håkansson, Theriot 1987; fresh: <0.2 ‰.
Cyclotella atomus Hustedt 1937; fresh brackish: <0.9 ‰.
Cyclotella choctawhatcheeana Prasad; Neinow, Livingston 1990; brackish: from 1.8 to 9.0 ‰.
Cyclotella meneghiniana Kützing 1844; fresh brackish: <0.9 ‰.
Leptocylindrus danicus Cleve 1889; brackish marine: from 1.8 to 34 ‰.
Leptocylindrus minimus Gran 1915; brackish marine: from 1.8 to 34 ‰.
Nitzschia longissima (Brébisson); Ralfs 1861; brackish marine: from 1.8 to 34 ‰.
Proboscia alata (Brightwell); Sundström 1986; brackish marine: from 1.8 to34 ‰.
Rhizosolenia fragilissima Bergon 1903; brackish marine: from 1.8 to 34 ‰.
Rhizosolenia hebetata Bailey 1856; brackish marine: from 1.8 to 34 ‰.
Skeletonema marinoi Sarno, Zingone 2005; brackish: from 1.8 to 9.0 ‰.
Staurosira elliptica (Schumann); Williams, Round 1987; brackish: from 1.8 to 9.0 ‰.
Stephanodiscus hantzschii Grunow 1880; fresh brackish: <0.9 ‰.
Stephanodiscus parvus Stoermer, Håkansson 1984; fresh brackish: <0.9 ‰.
Thalassiosira baltica (Grunow); Ostenfeld 1901; brackish: from 1.8 to 9.0 ‰.
Thalassiosira eccentrica (Ehrenberg); Cleve 1904; brackish marine: from 1.8 to 34 ‰.
Thalassiosira proschkinae Makarova 1979; brackish: from 1.8 to 9.0 ‰.
Thalassiosira visurgis Hustedt 1957; brackish: from 1.8 to 9.0 ‰.

Before application of ANN the original data were manually divided into two series (24 samples each) according to geographical distribution. This operation was carry out in order to enable the software to use equally mixed samples in training and test sets. For the 48 samples included in the reference data set, 24 samples were used as the training set, and the remaining 24 samples as the test set.

As the selected test set samples are not included in the training procedure, the error rates are based on this set. They therefore provide estimates of the prediction error rate in samples different than those used in the training set (Cortese *et al.* 2005). Thus, obtaining an RMSE of 0.5, if the estimated salinity is 8 ‰, means that the estimated error in palaeosalinity data is at least 0.5 ‰. In other words the lower RMSE is calculated by ANN the lower salinity error for down core reconstructions (Cortese *et al.* 2005).

For greater accuracy, two ANN runs using the NGO, averaging salinity estimates and RMSE from ten best networks was conducted. In the first run the training and test sets were included. Whereas in the second run the test samples were added to the training set and vice versa. In this way 20 best networks based on test and training sets within studied data set have been obtained.

In order to test down core spring SSS estimations based on diatom reference data set a well examined and dated sediment core 303610-12 located at the Eastern Gotland Basin was applied. This record has been analysed and described in detail by Harff *et al.* (2011). Core 303610-12 documents climate and environmental changes of the Baltic area and the North Atlantic region. High quality quantitative diatom analyses and measured concentration of potassium, titanium and sulphur in this core show a potential history salinity fluctuations in time spanning the last 8 kyr (Harff *et al.* 2011).

ESTIMATION FOR DIATOM REFERENCE DATA SET

To evaluate the ability of the ANN to predict salinity, the estimated spring SSS values from each NGO network were plotted against the measured spring SSS. Linear equations gave a satisfactory correlation between estimated and measured salinity values (correlation coefficients R^2=0.9885; Fig. 2). The RMSE of estimations is low 0.628 ‰, meaning that down core salinity can be predicted within relatively low error range.

To show differences between observed and estimated salinity for each sample residuals were calculated (Table 3). The residual at each sample location is defined as the observed value minus the estimated value. This means that positive values are underesti-

Table 3 Differences between estimated and observed salinity values for each surficial sample shown as residuals

Sample	Estimated salinity (‰)	Observed salinity (‰)	Residuals (‰)
AT91/2_B1_5m	21.6923	20.9690	0.7234
AT91/2_B3_5m	21.7025	21.0258	0.6767
AT91/2_B5_5m	21.5725	23.2045	-1.6320
B001	6.1296	5.4804	0.6493
B007	6.5757	6.3711	0.2046
B012	6.8366	6.9181	-0.0815
B021	7.0889	7.3166	-0.2277
B040	7.0261	7.2439	-0.2178
B101	7.3005	6.8667	0.4338
B109	7.3085	7.3599	-0.0514
B113	7.5605	7.5171	0.0434
B118	7.6266	7.5558	0.0708
B126	7.5516	7.4780	0.0736
B138	6.7684	6.8869	-0.1185
B144	7.0643	7.2759	-0.2116
B162	7.1687	7.5072	-0.3384
B171	7.4316	7.4288	0.0029
B191	7.7430	7.6379	0.1051
B194	7.5770	7.6322	-0.0551
HV01	7.3334	7.1808	0.1526
HV07	7.1282	7.1128	0.0154
HV09	6.9843	7.1350	-0.1507
HV27	7.2077	7.2155	-0.0078
HV33	7.2182	7.1398	0.0784
HV34	7.1441	7.2438	-0.0996
HV35	7.0952	7.2438	-0.1486
HV36	6.9970	7.2155	-0.2185
HV39	7.1958	7.1808	0.0150
HV57	7.1368	7.2155	-0.0787
HV59	7.0185	7.1350	-0.1165
W-3	7.6111	7.6473	-0.0362
ZG102	6.3196	6.6685	-0.3489
ZG103	7.0714	6.6119	0.4595
ZG11	6.1823	6.3450	-0.1627
ZG14	5.7606	5.5636	0.1971
ZG2	5.7299	5.4225	0.3074
ZG24	6.1589	5.6715	0.4874
ZG4	6.4416	5.9289	0.5128
ZG40	6.3041	6.2873	0.0168
ZG43	6.0829	6.7472	-0.6643
ZG47	6.9708	7.1603	-0.1895
ZG65	6.4120	6.8387	-0.4267
ZG8	5.7533	5.4225	0.3309
ZG83	5.7290	5.2583	0.4708
ZG86	6.6636	6.4486	0.2150
ZG88	6.1075	5.7821	0.3255
ZG94	6.9101	6.5768	0.3333
ZG98	5.7502	5.7817	-0.0315

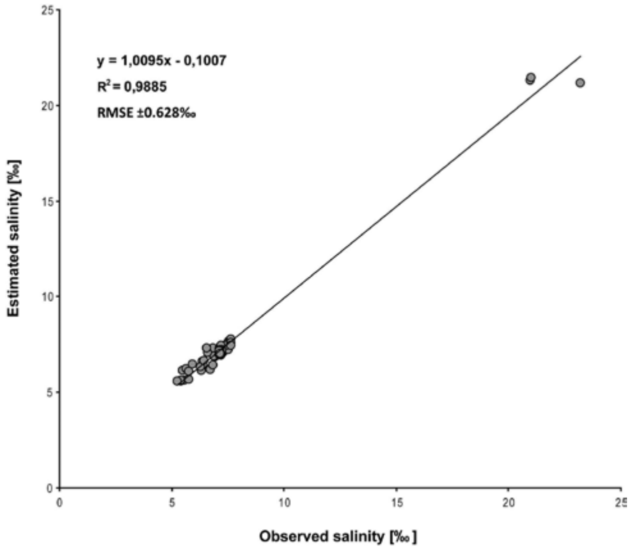

Fig. 2 Observed vs. estimated spring SSS derived from the diatom reference data set used for Artificial Neuronal Network (ANN). Regression line, R2 and RMSE show low differences between estimated and observed salinity values. Dots of low salinity values (between 5 and 10 ‰) represent modern surface sediment samples from the Baltic Sea, and dots of high salinity values (>20 ‰) stand for Kattegat. Compiled by B. Kotrys, 2014.

mating and negative values are overestimating spring SSS. In each network residuals >1.5 ‰ are only noted for one sample recovered from Kattegat. All other values are in the range between -0.9 ‰ and 0.9 ‰, with a general distribution between -0.4 and 0.4 ‰. No conspicuous latitude- longitudinal tendency to underestimate or overestimate salinity is observed.

DOWN CORE SPRING SEA SURFACE SALINITY PREDICTION

The results of palaeosalinity estimation for core 303610-12 show continued record of the last 8 kyr and can be well correlated with other proxies referring to salinity changes in time interval studied. The obtained paleosalinity projection displays slight fluctuations mainly between 8.0 and 7.2 ‰ within the last 8 kyr. The maximum salinity value exceeds 8.1 ‰ and occurs in zone B3 whereas the minimum salinity also occur in zone B3 reaching value >7.1 ‰ (Fig. 3). Within investigated palaeosalinity record of core 303610-12 following Harff *et al.* (2011) six different salinity trends (B1, B2, B3, B4, B5 and B6) are interpreted. During B1 spring SSS record displays conspicuous increase from less than 7.4 ‰ to an average of 7.7 ‰. Within B2 salinity values drop below 7.5 ‰ and increase over 7.7 ‰. Interval of B3 is characterized by rather stable spring SSS with salinity level of about 7.7 ‰. Long lasting decrease of spring SSS is, however, observed in B4. Salinity values drop from an average of 7.7 ‰ to 7.5 ‰ in the upper B4 and then increase substantially. The zone B5 is characterized by high salinity variations. General trend shows salinity increase whereas values oscillate between 8 ‰ and 7.4 ‰. The highest spring SSS amplitude in B4 is 0.6 ‰. Transition from B5 to B6 is marked by high salinity value of 8 ‰. Further salinity trend demonstrates decrease reaching the minimum of >7.4 ‰. The tendency turns over towards higher values in the middle of B6 (7.6 ‰-7.8 ‰).

The reconstructed salinity changes in core 303610-12 show rather low amplitude and low maximum values especially during the Littorina Sea transgression. This is contradictory to the other scientific studies. However, it has been assumed that the upper surface water layer was exposed to higher precipitation and riverine fresh water input to the Baltic Sea in the warm and damp Atlantic period. Therefore, higher salinity of 12-17 ‰ could occur in deeper part of sea water masses.

SPRING SEA SURFACE SALINITY ESTIMATION FOR THE CORE 303610-12

The general trend of analysed palaeosalinity distinctly correlates with diatom percentage curves based on changes in the distribution of planktonic species composition within core 303610-12 (Fig. 3). Higher salinity level is associated with increase of percentage abundance of diatom taxa that belong to brackish and marine environment. Whereas lower spring SSS corresponds to high percentage abundance of fresh and brackish taxa. However, the percentage variations of brackish diatom assemblages in some parts of studied sediment core do not demonstrate substantial similarities to reconstructed salinity. It has been assumed that it may be caused by their wide range of tolerance for high and low salinity level.

Measured concentration of potassium, titanium and sulphur in sediment core which are parallel to inorganic matter increases and identify increase in erosion and sedimentation pattern shifts (Kenna *et al.* 2011), shows similarities with the general trend of spring SSS. The higher down core concentration of K and Ti within zones B2, B4, and B6 may correspond to higher terrestrial discharge that can be triggered by enhanced precipitation (Harff *et al.* 2011). Additionally, together with pelagic deposition concentrations of K can be interpreted as an increase in the importance of aeolian sediment transport. This would lead to less saline surface water that is clearly shown in the spring SSS record (Fig. 3). However, the higher sulphur content in zones B1, B3 and B5 is interpreted as an indicator of anoxic condition (Sternbeck, Sohlenius 1997) which reflect increase of salinity and prevailing halocline. Intervals of higher salinity level reconstructed within the above mentioned zones are well correlated with high sulphur concentration and sections of laminated sediment.

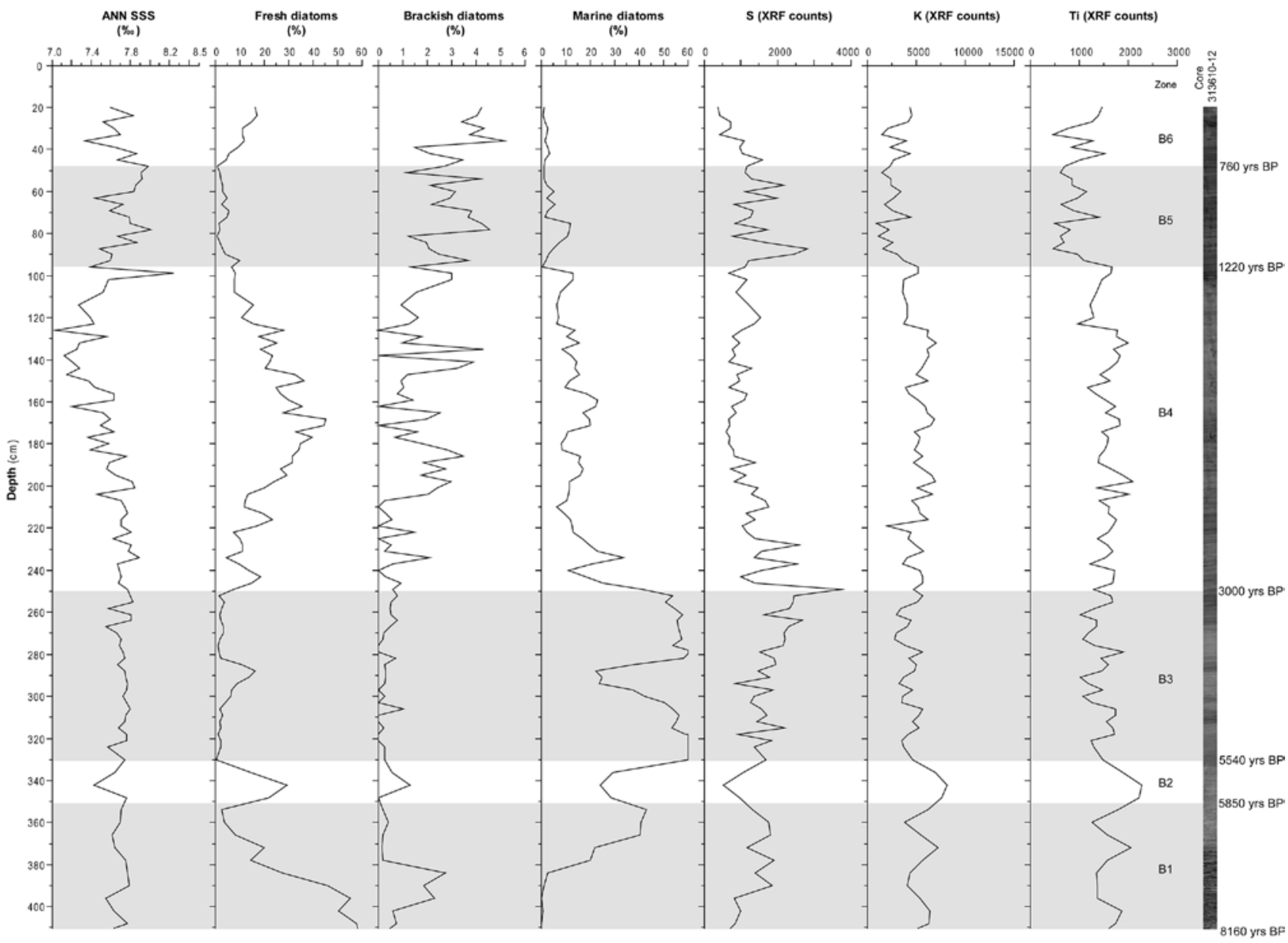

Fig. 3 Compilation of down core reconstructed spring sea surface salinity (SSS; ‰); abundance of fresh, brackish and marine diatoms (%). Content of sulphur (S), potassium (K) and titanium (Ti) at sediment core 303610-12, and physico-stratigraphic zonation from B1 to B6 presenting the post-Littorina to recent Baltic Sea climatic stages is given after Harff *et al.* (2011) ; visualization of sediment core is done by M. Tomczak (2008). Compiled by B. Kotrys, 2014.

CONCLUSIONS

On the basis of the quantitative analysis of diatom assemblages from 48 samples recovered in the Baltic Sea and Kattegat, an artificial neuronal networks for the estimation of the Holocene spring SSS have been developed.

The ANN relies on high-quality surface and net samples, modern hydrographic data and carefully chosen diatom taxa (training set). For the species selection it was considered that ecological information on salinity and habitat demands to ensure that only species classified to specific salinity range that are surface-dwelling are included. The salinity reconstruction has been conducted only for the spring period (from March to April) when the diatom blooms occur.

The spring SSS estimation for core 303610-12 shows salinity range between 7.04 ‰ and 8.25 ‰ at an averaged RMSE of 0.49 ‰ within the last 8160 yrs BP. A comparison of the palaeosalinity record to percentage diatom assemblages variations and excursion of K, Ti and S in core studied shows clear correlation to each other.

The diatom based ANN predictions can be successfully applied to document history of salinity changes of the Baltic Sea. Therefore, it can be useful either to quantify previous studies of sea surface salinity changes in Baltic Sea or where other proxies for Holocene salinity are limited.

In order to improve palaeosalinity investigations there is a need to develop diatom reference data set including samples from other regions of the Baltic Sea. Especially samples from more saline surface water masses are required.

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