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Supplement of

Salinity as a key control on the diazotrophic community composition in the southern Baltic Sea

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Supplemental materials

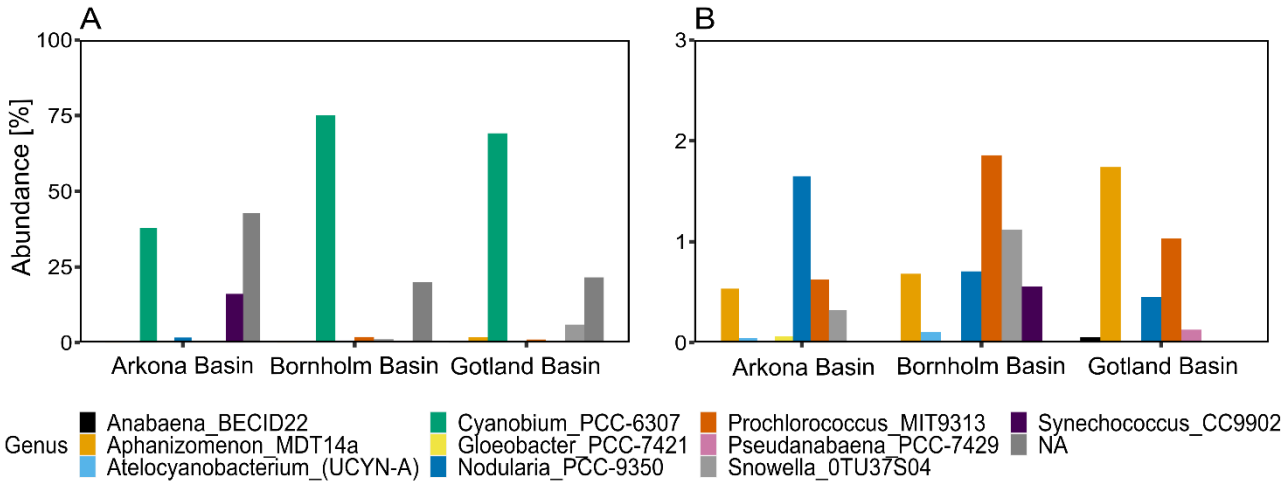

Figure S1 Relative abundance of identified cyanobacteria in the Arkona Basin, Bornholm Basin, and Gotland Basin. Cyanobacteria were identified on genus level and are color coded as indicated in legend. (A) shows all the identified groups. (B) shows the lower abundant groups (up to 3%).

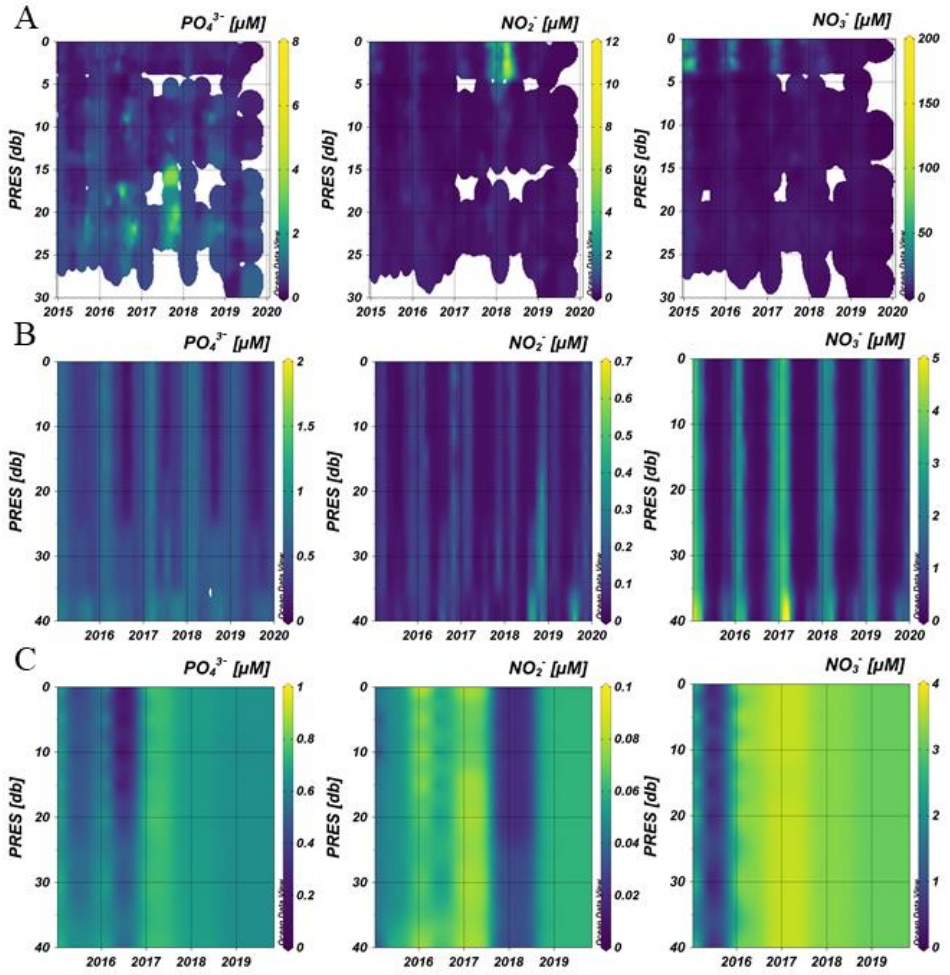

Figure S2 Nutrients records from 2015 to 2019 from the (A) Arkona, (B) Bornholm, and (C) East Gotland Basin (HELCOM stations, ICES Copenhagen, 2020).

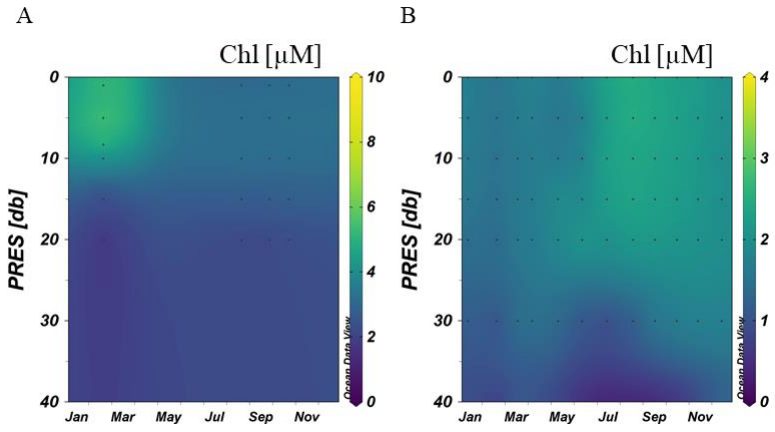

Figure S3 Distribution of chlorophyll (Chl [µM] along the pressure gradient in (A) the Arkona Basin and (B) the Bornholm Basin. Note that data points are missing for June and July in Arkona Basin. Data were derived from the HELCOM (HELCOM stations, ICES Copenhagen, 2020).

Table S1 Overview of stations from where fixation rates, nutrients, isotopes, and qPCR data were measured and used for statistical analyses.

H21	H21	H21	KB06	KB06	KB06	Area
12	6	4	10	5	3	Depth (m)
16	16	16	15	15	15	Temp (°C)
9.48	9.2	9.2	21.83	19.13	18.74	Sal
7.61	7.52	7.46	7.23	7.96	8	pH
251.0	436.4	405.2	149.1	255.1	244.5	O_2 (µM)
1.7	1.6	1.6	1.9	1.9	1.9	DIC (mmol)
NA	NA	NA	NA	0.85	NA	NO_X (µM)
NA	NA	NA	NA	0.01	NA	NO_3^- (µM)
NA	NA	NA	NA	0.84	NA	NO_2^- (µM)
NA	NA	NA	NA	0.18	NA	PO_4^{3-} (µM)
2.26	1.66	27.33	2.00	1.64	0.67	N_2 fix (nmol N L^{-1} d^{-1})
58.54	51.88	42.28	68.31	57.16	50.10	CO_2 fix (nmol C L^{-1} d^{-1})
3.94	4.02	3.72	4.95	3.59	3.60	$\delta^{15}N$ (‰)
2.71E+04	8.21E+02	1.59E+03	9.45E+02	3.76E+04	1.36E+05	Gamma-PO (Copies L^{-1})
2.56E+04	2.23E+04	1.78E+04	5.55E+04	1.85E+05	1.39E+05	Gamma-AO (Copies L^{-1})
2.17E+06	9.98E+03	3.30E+06	6.05E+06	1.67E+04	4.52E+07	UCYN-A (Copies L^{-1})
6.52E+05	2.12E+06	5.77E+05	2.32E+06	1.46E+06	3.70E+05	Nodularia (Copies L^{-1})

GB107	GB107	BB15	BB15	BB15	BB08	BB08	BB08
8	4	41	15	7	20	10	5
14	14	7	13	13	7	13	15
7.02	7.01	8.29	8.27	8.27	9.72	8.27	8.23
NA	NA	7.66	8.03	8.01	7.66	8.03	8.01
431.4	402.7	156.9	309.8	301.9	243.8	256.9	449.2
NA	NA	1.8	1.7	1.7	NA	NA	NA
NA	NA	NA	NA	5.26	NA	NA	NA
NA	NA	NA	NA	0.1	NA	NA	NA
NA	NA	NA	NA	5.16	NA	NA	NA
NA	NA	NA	NA	2.05	NA	NA	NA
0	6.04	0	0	0	0.69	5.27	3.36
43.45	37.01	31.20	26.73	29.55	5.35	51.38	33.73
5.90	6.17	5.26	5.33	6.15	2.93	2.50	4.57
5.42E+02	5.82E+02	3.48E+03	1.54E+04	5.84E+04	9.18E+03	9.35E+03	2.36E+04
6.76E+04	2.73E+04	4.90E+04	1.24E+04	7.96E+04	1.89E+04	9.03E+04	3.40E+04
3.73E+03	5.66E+04	1.52E+05	2.17E+03	6.29E+05	8.37E+03	9.97E+07	3.91E+04
1.60E+07	8.06E+05	8.64E+04	5.11E+04	1.48E+06	4.46E+06	3.46E+07	4.06E+07

GB107	18	14	7.07	NA	209.8	NA	NA	NA	NA	NA	0.72	47.10	6.32	4.33E+02	2.42E+04	4.61E+04	5.01E+05

Table S2 Overview of all stations collected in the cruise. * indicates which stations/depth 16srRNA were taken from.

Area	*Lat*	*Lan*	Depth (m)	Temp (°C)	Sal	pH	O_2 (µM)	DIC (mmol)	NO_X (µM)	NO_3^- (µM)	NO_2^- (µM)	PO_4^{3-} (µM)
KB06	54.4	10.2	3	15	18.74	8.00	244.5	1.9	NA	NA	NA	NA
			5	15	19.13	7.96	255.1	1.9	0.85	0.01	0.84	0.18
			7	15	21.6	7.35	149.1	2	NA	NA	NA	NA
			10	15	21.83	7.23	149.1	1.9	NA	NA	NA	NA
			15	15	23.65	7.73	147.2	2.3	0.27	0.27	0	0.41
			20	15	25.8	7.29	143.8	2.1	NA	NA	NA	NA
H21	54.5	13.3	4*	16	9.2	7.46	405.2	1.6	NA	NA	NA	NA
			6*	16	9.2	7.52	436.4	1.6	NA	NA	NA	NA
			12	16	9.48	7.61	251.0	1.7	NA	NA	NA	NA
			22	14	10.58	8.00	257.3	1.8	NA	NA	NA	NA
			34	16	17.11	8.02	231.7	2.1	NA	NA	NA	NA
			42*	15	18.5	8.13	233.2	2.1	NA	NA	NA	NA
H31	54.2	12.1	2	14	20.69	7.91	349.8	2.0	NA	NA	NA	NA
			4	14	21.76	7.92	377.9	2.0	NA	NA	NA	NA
			7	14	22.18	7.93	229.8	2.1	NA	NA	NA	NA
			10	15	24	7.99	217.6	2.4	NA	NA	NA	NA
			12*	15	24.22	7.96	218.5	1.9	NA	NA	NA	NA
			16	14	24.57	7.96	218.5	1.9	NA	NA	NA	NA
BB23	55.2	15.5	4*	16	8.14	NA	293.6	NA	9.04	8.98	0.06	2.7
			8	15	8.14	NA	292.3	NA	NA	NA	NA	NA
			18	15	8.19	NA	287.9	NA	NA	NA	NA	NA
			25	14	8.25	NA	292.9	NA	NA	NA	NA	NA
			32	12	8.28	NA	287.6	NA	NA	NA	NA	NA

			48*	7	10.56	NA	208.8	NA	NA	NA	NA	NA
			58	8	14.76	NA	145.1	NA	NA	NA	NA	NA
			70	8	17.14	NA	10.6	NA	NA	NA	NA	NA
			85*	9	17.95	NA	1.3	NA	0.82	0.81	0.01	0.5
BB08	55.5	15.6	5*	15	8.23	8.01	449.2	NA	NA	NA	NA	NA
			10	13	8.27	8.03	256.9	NA	NA	NA	NA	NA
			20	7	9.72	7.66	243.8	NA	NA	NA	NA	NA
BB15	55.3	16.0	7*	13	8.23	8.01	301.9	1.66	5.26	0.1	5.16	2.05
			15	13	8.27	8.03	309.8	1.70	NA	NA	NA	NA
			36	7	8.76	7.33	240.4	1.77	NA	NA	NA	NA
			41*	7	9.72	7.66	156.9	1.80	NA	NA	NA	NA
			57	10	15.11	7.52	134.7	2.00	NA	NA	NA	NA
			65*	8	16.82	7.41	2.50	2.11	0.58	0.57	0.01	0.43
BB31	55.1	15.3	10	16	8.13	NA	292.3	NA	NA	NA	NA	NA
			18	15	8.21	NA	286.7	NA	NA	NA	NA	NA
			28	14	8.26	NA	244.8	NA	NA	NA	NA	NA
			40	6	8.4	NA	282.6	NA	NA	NA	NA	NA
			10	16	8.13	NA	292.3	NA	NA	NA	NA	NA
GB84	56.2	19.0	5	13	7.63	NA	450.2	NA	8.33	8.24	0.09	2.18
			9	13	7.64	NA	503.3	NA	NA	NA	NA	NA
			15	13	7.67	NA	229.5	NA	NA	NA	NA	NA
			29*	11	7.74	NA	216.7	NA	NA	NA	NA	NA
			45	5	8.15	NA	266.0	NA	NA	NA	NA	NA
			60	5	8.45	NA	266.7	NA	NA	NA	NA	NA
			75	6	10.94	NA	257.6	NA	0.88	0.77	0.1	2.98
			90	7	11.99	NA	250.7	NA	NA	NA	NA	NA
			100	7	12.65	NA	248.5	NA	NA	NA	NA	NA
GB90a	56.3	18.5	4	12	7.7	NA	412.9	NA	NA	NA	NA	NA
			7.9	12	7.72	NA	314.8	NA	NA	NA	NA	NA
			11.9	12	7.72	NA	218.8	NA	NA	NA	NA	NA
			24.92	9	7.89	NA	236.6	NA	NA	NA	NA	NA
			45.17	4	8.27	NA	276.7	NA	NA	NA	NA	NA

			59.94	4	8.57	NA	280.7	NA	NA	NA	NA	NA
GB107	57.4	19.4	4	14	7.01	NA	402.7	NA	NA	NA	NA	NA
			8*	14	7.02	NA	431.4	NA	NA	NA	NA	NA
			18	14	7.07	NA	209.8	NA	NA	NA	NA	NA
			30	9	7.76	NA	231.3	NA	NA	NA	NA	NA
			40*	5	7.93	NA	263.5	NA	NA	NA	NA	NA
			55	4	8.31	NA	272.3	NA	NA	NA	NA	NA
			60	5	9.01	NA	268.9	NA	NA	NA	NA	NA
			112*	7	12.92	NA	241.9	NA	NA	NA	NA	NA
GB108	57.5	19.5	10	14	6.97	NA	864.7	NA	NA	NA	NA	NA
			20	14	7.08	NA	228.8	NA	NA	NA	NA	NA
			4508	7	7.84	NA	246.7	NA	NA	NA	NA	NA
			80	6	11.57	NA	257.3	NA	NA	NA	NA	NA
			115*	7	12.97	NA	247.6	NA	NA	NA	NA	NA

Table S3 Overview of N_2 fixation rates measured from 1972 to 2019. Calculated N_2 fixation rates for this study are average over 20 m water depth. Data from 1972 to 2001 was collected mainly from Wasmund et al., 2001. Data from beyond 2001 was collected by literature search in this study.

Date	Basin	Method	N_2 fixation (mmol N m^{-2} d^{-1})	Source
1972-1974	archipelago near Stockholm	Acetylene reduction	0.4-1.8	(Brattberg, 1997)
Jul/Aug-1976	Askö (Sweden)	Acetylene reduction	0.057 - 0.012	(Lindahl et al., 1978)
1977	Öregrundsgrepen SW Bothnian Sea	Acetylene reduction	0.014	(Rinne et al., 1978)
	Öregrundsgrepen SW Bothnian Sea	Acetylene reduction	0.012	(Rinne et al., 1981)
1978	Mecklenburg bay	Acetylene reduction	0.057	(Hübel H, 1984)
	Arkona Basin	Acetylene reduction	0.286	
	Bornholm Basin	Acetylene reduction	0.286	
	Gulf of Gdansk	Acetylene reduction	0.857	
	E. Gotland Basin	Acetylene reduction	0.357	
1974-1983	Arkona Basin	Acetylene reduction	0.047 - 0.301	
1980 + 82 + 84	North Baltic Proper	Acetylene reduction	0.14 - 6.3	(Niemistö et al., 1989)
	Center Baltic Proper	Acetylene reduction	27.1 - 55.7	
	South Baltic proper	Acetylene reduction	34.4	
Aug-90	E. Gotland Basin		2.44	(Haupt, 1991)
Jul/Aug-1993	Baltic Proper		0.78 - 1.42	(Stal and Walsby, 1998)
1990-1997	Baltic proper	Calculated from nutrient budget	0.21 - 2.6	(Rahm et al., 2000)
1994-1998	Baltic proper without Arkona	Calculated from nutrient budget	2.3 - 5.9	(Larsson et al., 2001)
Aug-97	Baltic Proper	N^{15} tracer method	7.113	(Wasmund et al., 2001)
Oct-97	Baltic Proper	N^{15} tracer method	0.987	
Nov-97	Baltic Proper	N^{15} tracer method	0.1	
Feb-98	Baltic Proper	N^{15} tracer method	0.02	
Mar-98	Baltic Proper	N^{15} tracer method	0.05	
May-98	Baltic Proper	N^{15} tracer method	0.055	
Jul-98	Baltic Proper	N^{15} tracer method	1.23	
Aug-98	Baltic Proper	N^{15} tracer method	1.983	
Nov-98	Baltic Proper	N^{15} tracer method	0.19	
2001	Baltic Proper	N^{15} tracer method	0.156	(Wasmund et al., 2005)
2002	Baltic Proper	N^{15} tracer method	0.252	
Jul-11	Gotland Basin	N^{15} tracer method	0.038	(Farnelid et al., 2013)

2012	Danish Strait - Great Belt	N^{15} tracer method	0.167	(Bentzon-Tilia et al., 2015)
June-Aug12	Baltic proper	N^{15} tracer method	3.6 ± 2.6	(Klawonn et al., 2016)
June-Aug13	Baltic proper	N^{15} tracer method	0.4 ± 0.1	
1999-2017	Baltic proper	biovolumes and empirical rates	3.6 ± 0.7	(Olofsson et al., 2021)
2013-2017	Baltic proper	biovolumes and empirical rates	3.7 - 0.7	
1999-2004	Bothnian sea	biovolumes and empirical rates	2.23	
2012-2017	Bothnian sea	biovolumes and empirical rates	1.98	
1999-2017	Bothnian sea	biovolumes and empirical rates	1.56 ± 0.62	
September-2019	Bornholm	N^{15} tracer method	0.15	This study
	East Gotland	N^{15} tracer method	0.026	

References

Bentzon-Tilia, M., Traving, S. J., Mantikci, M., Knudsen-Leerbeck, H., Hansen, J. L. S., Markager, S. and Riemann, L.: Significant N 2 fixation by heterotrophs, photoheterotrophs and heterocystous cyanobacteria in two temperate estuaries, ISME J., 9(2), 273–285, doi:10.1038/ismej.2014.119, 2015.

Brattberg, G.: Nitrogen Fixation in a Polluted Brackish Water Archipelago, Ambio Spec Rep 527-57, (5), 1997.

Farnelid, H., Bentzon-Tilia, M., Andersson, A. F., Bertilsson, S., Jost, G., Labrenz, M., Jürgens, K. and Riemann, L.: Active nitrogen-fixing heterotrophic bacteria at and below the chemocline of the central Baltic Sea, ISME J., 7(7), 1413–1423, doi:10.1038/ismej.2013.26, 2013.

Haupt, O.: Produktion und Stickstoffixierung von Phytoplankton in der mittleren Ostsee, Diploma thesis, Christian-Albrechts-Universität Kiel, Germany, 98, doi:https://oceanrep.geomar.de/id/eprint/52038/, 1991.

Hübel H: Die Bindung des molekularen Stickstoffs durch autotrophe und heterotrophe Mikroorganismen in Küstengewässern der DDR und an einigen Stationen der Ostsee, Greifswald., 1984.

ICES Copenhagen: International Council for the Exploration of the Sea (ICES) – Dataset on Ocean Hydrography, https://ocean.ices. dk/ (last access: 9 June 2021), 2020.

Klawonn, I., Nahar, N., Walve, J., Andersson, B., Olofsson, M., Svedén, J. B., Littmann, S., Whitehouse, M. J., Kuypers, M. M. M. and Ploug, H.: Cell-specific nitrogen- and carbon-fixation of cyanobacteria in a temperate marine system (Baltic Sea), Environ. Microbiol., 18(12), 4596–4609, doi:10.1111/1462-2920.13557, 2016.

Larsson, U., Hajdu, S., Walve, J. and Elmgren, R.: Baltic Sea Nitrogen Fixation Estimated from the Summer Increase in Upper Mixed Layer, Limnol. Oceanogr., 46(4), 811–820, 2001.

Lindahl, G., Wallström, K. and Brattberg, G.: On nitrogen fixation in a coastal area of the northern Baltic, Kieler Meeresforsch Sonderh 4:171–177, 1978.

Niemistö, L., Rinne, I., Melvasalo, T. and Niemi, Å.: Blue-green algae and their nitrogen fixation in the Baltic Sea in 1980, 1982 and 1984, Meri (Report Ser. Finn Inst Mar Res) 17 1–59, 1989.

55 Olofsson, M., Klawonn, I. and Karlson, B.: Nitrogen fixation estimates for the Baltic Sea indicate high rates for the previously overlooked Bothnian Sea, Ambio, 50(1), 203–214,
56 doi:10.1007/s13280-020-01331-x, 2021.

57 Rahm, L., Jönsson, A. and Wulff, F.: Nitrogen fixation in the Baltic proper: an empirical study, J Mar Syst 25, 239–248, 2000.

58 Rinne, I., Melvasalo, T., Niemistö, L. and Å, N.: Nitrogen fixation by blue-green algae in the Baltic Sea, Kieler Meeresforsch, Sonderh 4:178–187, 1978.

59 Rinne, I., Melvasalo, T., Niemi, Å. and Niemistö, L.: Studies on nitrogen in the Gulf of Bothnia, Finn Mar Res 248, 117–127, 1981.

60 Stal, L. and Walsby, A.: The daily integral of nitrogen fixation by planktonic cyanobacteria in the Baltic Sea, New Phytol 139, 665–671, 1998.

61 Wasmund, N., Voss, M. and Lochte, K.: Evidence of nitrogen fixation by non-heterocystous cyanobacteria in the Baltic Sea and re-calculation of a budget of nitrogen fixation, Mar. Ecol.
62 Prog. Ser., 214(April), 1–14, doi:10.3354/meps214001, 2001.

63 Wasmund, N., Nausch, G., Schneider, B., Nagel, K. and Voss, M.: Comparison of nitrogen fixation rates determined with different methods: A study in the Baltic Proper, Mar. Ecol. Prog.
64 Ser., 297(August), 23–31, doi:10.3354/meps297023, 2005.

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