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Research paper

Atlas of modern dinoflagellate cyst distribution based on 2405 data points

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ABSTRACT

Dinoflagellate cysts are useful for reconstructing upper water conditions. For adequate reconstructions detailed information is required about the relationship between modern day environmental conditions and the geographic distribution of cysts in sediments. This Atlas summarises the modern global distribution of 71 organic-walled dinoflagellate cyst species. The synthesis is based on the integration of literature sources together with data of 2405 globally distributed surface sediment samples that have been prepared with a comparable methodology and taxonomy. The distribution patterns of individual cyst species are being compared with environmental

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factors that are known to influence dinoflagellate growth, gamete production, encystment, excystment and preservation of their organic-walled cysts: surface water temperature, salinity, nitrate, phosphate, chlorophyll-*a* concentrations and bottom water oxygen concentrations. Graphs are provided for every species depicting the relationship between seasonal and annual variations of these parameters and the relative abundance of the species. Results have been compared with previously published records; an overview of the ecological significance as well as information about the seasonal production of each individual species is presented.

The relationship between the cyst distribution and variation in the aforementioned environmental parameters was analysed by performing a canonical correspondence analysis. All tested variables showed a positive relationship on the 99% confidence level. Sea-surface temperature represents the parameter corresponding to the largest amount of variance within the dataset (40%) followed by nitrate, salinity, phosphate and bottom-water oxygen concentration, which correspond to 34%, 33%, 25% and 24% of the variance, respectively. Characterisations of selected environments as well as a discussion about how these factors could have influenced the final cyst yield in sediments are included.

1. Introduction

The composition of dinoflagellate cyst associations in modern sediments is highly dependent on the biological, physical, chemical and oceanographic conditions of the water as well as the sedimentary environment. When analyzing time series data, this composition can be used to determine past variations in the upper water conditions such as (human-induced) eutrophication , changes in sea-surface salinity and temperature, turbulence and nutrient/trace element content, amongst others as well as changes in sedimentary conditions (e.g. Genovesi et al., 2011; Bringué and Rochon, 2012; Mertens et al., 2012; Zonneveld et al., 2012 and references therein). Furthermore, assemblages can provide information about the history of dinoflagellate-induced harmful algal blooms and enable postulations about the possible causes and future risks (Anderson et al., 2012; Ribeiro et al., 2012). A prerequisite for using dinoflagellate cyst assemblages is the availability of detailed information about the relationship between modern day environmental conditions and the geographic distribution of cysts in sediments. Over the last century, this information was gathered in the form of numerous regionally focused studies that enormously increased our knowledge of the palaeo-ecological significance of sedimentary dinoflagellate cyst associations. A wider super-regional overview became available to the scientific community through the publication of data compilations, such as those by Wall et al. (1977) and Harland in (1983). In 2003, the first world-wide compilation of data was published in the form of an atlas of modern organic-walled dinoflagellate cyst distribution (Marret and Zonneveld, 2003). This Atlas comprised 835 sites and provided the distribution of 61 species, as well as a sound statistical analysis with regards to the controlling environmental conditions. Since 2003, numerous studies from around the world have improved our knowledge on the modern biogeography of the cysts, their ecological affinities and their use as proxies for reconstructions of sea-surface conditions (see

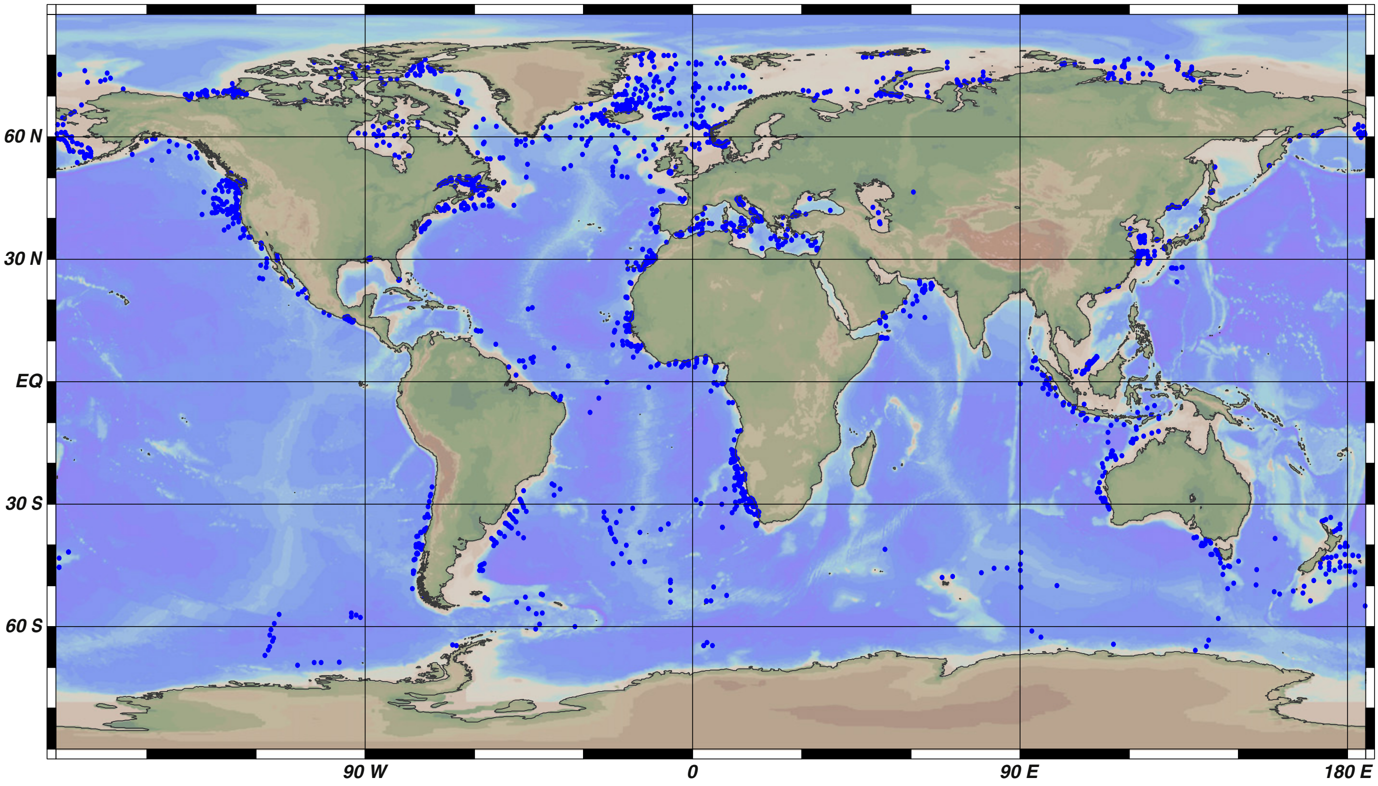

Fig. 1. Map depicting studied samples.

Table 1
Sample positions and reference to source literature.

Station	Longitude [degrees_East]	Latitude [degrees_north]	Reference
4209	−11.08	30.35	Marret and Zonneveld, 2003
4207	−11.07	30.86	Marret and Zonneveld, 2003
4206	−11.01	31.49	Marret and Zonneveld, 2003
4205	−11.64	32.18	Marret and Zonneveld, 2003
4204	−11.94	32.01	Marret and Zonneveld, 2003
4202	−13.66	32.47	Marret and Zonneveld, 2003
4211	−10.82	30.19	Marret and Zonneveld, 2003
4212	−10.95	29.60	Marret and Zonneveld, 2003
4214	−11.19	29.78	Marret and Zonneveld, 2003
4215	−11.55	30.03	Marret and Zonneveld, 2003
4221	−12.33	29.77	Marret and Zonneveld, 2003
4223	−12.46	29.01	Marret and Zonneveld, 2003
4228	−12.99	29.47	Marret and Zonneveld, 2003
4237	−13.01	28.72	Marret and Zonneveld, 2003
4239	−13.18	28.49	Marret and Zonneveld, 2003
4241	−15.46	29.15	Marret and Zonneveld, 2003
6875	8.55	−0.33	Marret and Zonneveld, 2003
6874	8.47	−0.33	Marret and Zonneveld, 2003
6873	8.30	−0.33	Marret and Zonneveld, 2003
6872	8.03	−0.33	Marret and Zonneveld, 2003
6871	6.93	−0.72	Marret and Zonneveld, 2003
6869	6.00	−0.20	Marret and Zonneveld, 2003
6868	6.02	−0.22	Marret and Zonneveld, 2003
6867	5.10	−2.20	Marret and Zonneveld, 2003
6865	6.05	2.67	Marret and Zonneveld, 2003
6864	6.28	3.15	Marret and Zonneveld, 2003
6863	6.40	3.38	Marret and Zonneveld, 2003
6862	6.48	3.53	Marret and Zonneveld, 2003
6861	6.50	3.62	Marret and Zonneveld, 2003
6860	6.48	3.72	Marret and Zonneveld, 2003
6859	6.48	3.90	Marret and Zonneveld, 2003
6856	3.40	4.80	Marret and Zonneveld, 2003
6855	3.77	5.50	Marret and Zonneveld, 2003
6854	3.60	6.02	Marret and Zonneveld, 2003
6852	3.63	6.07	Marret and Zonneveld, 2003
6850	3.67	6.10	Marret and Zonneveld, 2003
6849	3.70	6.17	Marret and Zonneveld, 2003
6848	3.73	6.27	Marret and Zonneveld, 2003
6845	1.15	5.55	Marret and Zonneveld, 2003
6844	1.15	5.72	Marret and Zonneveld, 2003
6843	1.15	5.77	Marret and Zonneveld, 2003
6842	1.15	5.32	Marret and Zonneveld, 2003
6841	1.15	5.32	Marret and Zonneveld, 2003
6838	1.18	4.65	Marret and Zonneveld, 2003
6837	0.73	3.67	Marret and Zonneveld, 2003
6836	−1.08	4.15	Marret and Zonneveld, 2003
6835	−1.15	4.23	Marret and Zonneveld, 2003
6833	−1.15	4.32	Marret and Zonneveld, 2003
6832	−1.13	4.33	Marret and Zonneveld, 2003
6831	−1.15	4.35	Marret and Zonneveld, 2003
6830	−1.15	4.35	Marret and Zonneveld, 2003
6829	−1.15	4.38	Marret and Zonneveld, 2003
6828	−1.13	4.42	Marret and Zonneveld, 2003
6827	−1.13	4.97	Marret and Zonneveld, 2003
6825	−1.78	4.67	Marret and Zonneveld, 2003
6824	−2.20	4.77	Marret and Zonneveld, 2003
6823	−2.23	4.67	Marret and Zonneveld, 2003
6821	−2.30	4.55	Marret and Zonneveld, 2003
6820	−2.30	4.50	Marret and Zonneveld, 2003
6819	−2.33	4.43	Marret and Zonneveld, 2003
6818	−2.37	4.38	Marret and Zonneveld, 2003
6817	−2.38	4.32	Marret and Zonneveld, 2003
6815	−4.52	4.97	Marret and Zonneveld, 2003
6808	−2.85	3.80	Marret and Zonneveld, 2003
6807	−3.05	3.72	Marret and Zonneveld, 2003
6806	−4.55	4.95	Marret and Zonneveld, 2003
6805	−4.58	4.80	Marret and Zonneveld, 2003
6804	−4.67	4.47	Marret and Zonneveld, 2003
6800	−6.43	4.47	Marret and Zonneveld, 2003
6799	−6.43	4.43	Marret and Zonneveld, 2003
6798	−6.40	4.33	Marret and Zonneveld, 2003
6797	−6.35	4.23	Marret and Zonneveld, 2003
6788	−9.27	4.43	Marret and Zonneveld, 2003
6778	−9.73	4.13	Marret and Zonneveld, 2003
6776	−11.38	3.73	Marret and Zonneveld, 2003
6772	−11.97	−1.33	Marret and Zonneveld, 2003
6769	−16.27	6.12	Marret and Zonneveld, 2003
6768	−15.17	7.62	Marret and Zonneveld, 2003
6767	−14.72	8.10	Marret and Zonneveld, 2003
6766	−14.53	8.28	Marret and Zonneveld, 2003
6765	−14.48	8.32	Marret and Zonneveld, 2003
6764	−14.43	8.37	Marret and Zonneveld, 2003
6558	−16.78	8.75	Marret and Zonneveld, 2003
6755	−16.85	9.25	Marret and Zonneveld, 2003
6437	−17.92	16.93	Marret and Zonneveld, 2003
6425	−19.02	9.13	Marret and Zonneveld, 2003
6421	−17.87	9.88	Marret and Zonneveld, 2003
6414	−19.25	9.97	Marret and Zonneveld, 2003
6407	−21.95	9.03	Marret and Zonneveld, 2003
6405	−21.40	12.25	Marret and Zonneveld, 2003
6404	−21.28	12.67	Marret and Zonneveld, 2003
6402	−20.57	14.42	Marret and Zonneveld, 2003
2300	11.11	−5.06	Marret and Zonneveld, 2003
2301	10.09	−5.10	Marret and Zonneveld, 2003
2303	12.45	−12.02	Marret and Zonneveld, 2003
2304	13.25	−11.93	Marret and Zonneveld, 2003
2305	13.38	−11.92	Marret and Zonneveld, 2003
2306	11.51	−14.23	Marret and Zonneveld, 2003
2307	11.03	−16.72	Marret and Zonneveld, 2003
2308	10.84	−16.57	Marret and Zonneveld, 2003
2309	12.54	−22.26	Marret and Zonneveld, 2003
301	51.42	15.13	Marret and Zonneveld, 2003
928	51.40	15.12	Marret and Zonneveld, 2003
302	51.45	15.00	Marret and Zonneveld, 2003
303	51.48	14.85	Marret and Zonneveld, 2003
304	51.52	14.78	Marret and Zonneveld, 2003
305	51.58	14.72	Marret and Zonneveld, 2003
306	51.61	14.50	Marret and Zonneveld, 2003
307	52.38	16.83	Marret and Zonneveld, 2003
308	52.50	16.13	Marret and Zonneveld, 2003
309	52.62	16.08	Marret and Zonneveld, 2003
310	52.70	16.07	Marret and Zonneveld, 2003
311	52.76	16.03	Marret and Zonneveld, 2003
313	53.02	15.88	Marret and Zonneveld, 2003
325	53.52	10.68	Marret and Zonneveld, 2003
451	66.03	23.68	Marret and Zonneveld, 2003
452	65.47	22.93	Marret and Zonneveld, 2003
453	65.73	23.23	Marret and Zonneveld, 2003
454	65.87	23.45	Marret and Zonneveld, 2003
455	65.95	23.55	Marret and Zonneveld, 2003
457	63.85	22.69	Marret and Zonneveld, 2003
458	63.50	22.00	Marret and Zonneveld, 2003
460	63.22	22.67	Marret and Zonneveld, 2003
461	63.83	22.83	Marret and Zonneveld, 2003
463	64.05	22.55	Marret and Zonneveld, 2003
464	63.58	22.25	Marret and Zonneveld, 2003
466	63.80	23.60	Marret and Zonneveld, 2003
468	62.35	24.77	Marret and Zonneveld, 2003
469	62.37	24.67	Marret and Zonneveld, 2003
470	62.37	24.60	Marret and Zonneveld, 2003
471	62.45	24.30	Marret and Zonneveld, 2003
472	62.48	24.12	Marret and Zonneveld, 2003
473	63.10	22.22	Marret and Zonneveld, 2003
475	65.45	24.08	Marret and Zonneveld, 2003
476	65.47	24.10	Marret and Zonneveld, 2003
477	65.52	24.13	Marret and Zonneveld, 2003
478	65.67	24.22	Marret and Zonneveld, 2003
483	61.48	21.03	Marret and Zonneveld, 2003
484	58.43	19.50	Marret and Zonneveld, 2003
486	60.62	19.15	Marret and Zonneveld, 2003
487	61.72	19.90	Marret and Zonneveld, 2003
491	63.92	15.83	Marret and Zonneveld, 2003
492	59.77	16.18	Marret and Zonneveld, 2003
496	57.95	17.43	Marret and Zonneveld, 2003
497	57.95	17.47	Marret and Zonneveld, 2003
902	51.57	10.76	Marret and Zonneveld, 2003
903	51.65	10.76	Marret and Zonneveld, 2003
904	51.77	10.78	Marret and Zonneveld, 2003

(continued on next page)

Table 1 (*continued*)

Station	Longitude [degrees_East]	Latitude [degrees_north]	Reference
905	51.93	10.90	Marret and Zonneveld, 2003
906	52.12	10.80	Marret and Zonneveld, 2003
907	52.23	10.80	Marret and Zonneveld, 2003
908	52.90	10.77	Marret and Zonneveld, 2003
915	53.52	10.68	Marret and Zonneveld, 2003
917	53.02	15.90	Marret and Zonneveld, 2003
918	52.83	15.97	Marret and Zonneveld, 2003
919	52.73	16.00	Marret and Zonneveld, 2003
929	53.23	13.70	Marret and Zonneveld, 2003
3808	−16.33	−31.05	Marret and Zonneveld, 2003
3808	−16.84	−31.13	Marret and Zonneveld, 2003
3810	−19.76	−31.62	Marret and Zonneveld, 2003
3821	−37.95	−27.63	Marret and Zonneveld, 2003
3824	−36.33	−26.23	Marret and Zonneveld, 2003
3824	−38.01	−25.32	Marret and Zonneveld, 2003
3826	−38.55	−25.03	Marret and Zonneveld, 2003
3897	−28.11	−7.47	Marret and Zonneveld, 2003
3897	−23.43	−0.01	Marret and Zonneveld, 2003
3908	−36.21	−3.54	Marret and Zonneveld, 2003
3907	−36.35	−4.25	Marret and Zonneveld, 2003
3910	−36.64	−4.61	Marret and Zonneveld, 2003
3910	−37.72	−3.67	Marret and Zonneveld, 2003
3911	−38.31	−2.90	Marret and Zonneveld, 2003
3911	−38.23	−2.73	Marret and Zonneveld, 2003
3915	−48.43	1.70	Marret and Zonneveld, 2003
3917	−50.41	3.71	Marret and Zonneveld, 2003
3923	−47.53	5.14	Marret and Zonneveld, 2003
3934	−59.39	12.61	Marret and Zonneveld, 2003
3934	−59.00	12.72	Marret and Zonneveld, 2003
3936	−58.77	12.56	Marret and Zonneveld, 2003
3936	−58.33	12.26	Marret and Zonneveld, 2003
3938	−58.10	12.59	Marret and Zonneveld, 2003
4398	−43.76	4.80	Marret and Zonneveld, 2003
4402	−43.74	6.06	Marret and Zonneveld, 2003
4405	−46.13	3.67	Marret and Zonneveld, 2003
4409	−44.36	5.72	Marret and Zonneveld, 2003
4412	−46.58	5.14	Marret and Zonneveld, 2003
4416	−54.06	9.26	Marret and Zonneveld, 2003
4420	−45.24	17.88	Marret and Zonneveld, 2003
4422	−44.02	18.20	Marret and Zonneveld, 2003
4305	−38.02	8.37	Marret and Zonneveld, 2003
4310	−34.14	3.99	Marret and Zonneveld, 2003
4308	−25.69	−3.91	Marret and Zonneveld, 2003
R4515A	−88.71	30.33	Marret and Zonneveld, 2003
R4517A	−88.72	30.28	Marret and Zonneveld, 2003
R4518A	−88.72	30.27	Marret and Zonneveld, 2003
R4596	−88.98	30.26	Marret and Zonneveld, 2003
R4597	−88.96	30.24	Marret and Zonneveld, 2003
R4598	−88.98	30.17	Marret and Zonneveld, 2003
R4599	−88.95	30.18	Marret and Zonneveld, 2003
R4600	−88.94	30.18	Marret and Zonneveld, 2003
R4601	−89.00	30.16	Marret and Zonneveld, 2003
R4602	−88.99	30.16	Marret and Zonneveld, 2003
R4603	−88.91	30.15	Marret and Zonneveld, 2003
R4608A	−88.38	30.19	Marret and Zonneveld, 2003
R4609	−88.37	30.17	Marret and Zonneveld, 2003
R4610	−88.37	30.12	Marret and Zonneveld, 2003
R4611	−88.51	30.07	Marret and Zonneveld, 2003
R4612	−88.51	30.11	Marret and Zonneveld, 2003
R4613	−88.77	30.13	Marret and Zonneveld, 2003
R4614	−88.79	30.21	Marret and Zonneveld, 2003
R4621	−88.61	30.23	Marret and Zonneveld, 2003
R4622	−88.66	30.24	Marret and Zonneveld, 2003
R4623	−88.66	30.27	Marret and Zonneveld, 2003
R4627	−88.60	30.32	Marret and Zonneveld, 2003
R4628	−88.53	30.27	Marret and Zonneveld, 2003
R4631	−88.50	30.27	Marret and Zonneveld, 2003
R4634	−88.53	30.26	Marret and Zonneveld, 2003
R4635	−88.43	30.35	Marret and Zonneveld, 2003
R4636	−88.43	30.34	Marret and Zonneveld, 2003
R4638	−88.47	30.31	Marret and Zonneveld, 2003
R4639	−88.48	30.30	Marret and Zonneveld, 2003
R4641	−88.38	30.30	Marret and Zonneveld, 2003
R4643	−88.38	30.26	Marret and Zonneveld, 2003
R4644	−88.38	30.23	Marret and Zonneveld, 2003
(#5)R5062C	−80.47	25.14	Marret and Zonneveld, 2003
(#4)R5061A	−80.51	25.15	Marret and Zonneveld, 2003
(#7)R5064A	−80.56	25.06	Marret and Zonneveld, 2003
(#7) R5064B	−80.56	25.06	Marret and Zonneveld, 2003
(#11) R5054A	−80.57	25.10	Marret and Zonneveld, 2003
(#9) R5108	−80.62	25.13	Marret and Zonneveld, 2003
R5032AQ	−80.64	25.19	Marret and Zonneveld, 2003
R4990	−80.63	25.17	Marret and Zonneveld, 2003
(#12) R5053A	−80.63	25.07	Marret and Zonneveld, 2003
(#12) R5053B	−80.63	25.07	Marret and Zonneveld, 2003
(#12) R5053C	−80.63	25.07	Marret and Zonneveld, 2003
(#8) R5055A	−80.63	25.17	Marret and Zonneveld, 2003
#21 R4986	−80.63	25.18	Marret and Zonneveld, 2003
R5009	−80.66	25.02	Marret and Zonneveld, 2003
(#13) R5056B	−80.66	25.02	Marret and Zonneveld, 2003
(#13) R5056A	−80.66	25.02	Marret and Zonneveld, 2003
(#13) R5111A	−80.66	25.02	Marret and Zonneveld, 2003
(#14) R5057A	−80.68	25.03	Marret and Zonneveld, 2003
(#16) R5133A	−80.76	25.01	Marret and Zonneveld, 2003
R5228A	−80.57	25.15	Marret and Zonneveld, 2003
1703	11.01	−17.45	Marret and Zonneveld, 2003
1704	11.62	−19.40	Marret and Zonneveld, 2003
1705	11.38	−19.50	Marret and Zonneveld, 2003
1706	11.18	−19.57	Marret and Zonneveld, 2003
1707	10.65	−19.70	Marret and Zonneveld, 2003
1710	11.68	−23.43	Marret and Zonneveld, 2003
1711	12.37	−23.32	Marret and Zonneveld, 2003
1712	12.80	−23.25	Marret and Zonneveld, 2003
1713	13.02	−23.22	Marret and Zonneveld, 2003
1714	13.55	−23.13	Marret and Zonneveld, 2003
1715	11.63	−26.48	Marret and Zonneveld, 2003
1716	14.00	−27.95	Marret and Zonneveld, 2003
1717	14.42	−28.20	Marret and Zonneveld, 2003
1718	15.21	−28.70	Marret and Zonneveld, 2003
1719	14.17	−28.93	Marret and Zonneveld, 2003
1720	13.83	−29.00	Marret and Zonneveld, 2003
1721	13.08	−29.18	Marret and Zonneveld, 2003
1722	11.75	−29.45	Marret and Zonneveld, 2003
1724	8.05	−29.96	Marret and Zonneveld, 2003
1728	2.40	−29.83	Marret and Zonneveld, 2003
1729	1.00	−28.90	Marret and Zonneveld, 2003
2001	16.17	−31.88	Marret and Zonneveld, 2003
2007	12.15	−30.43	Marret and Zonneveld, 2003
2008	11.72	−31.08	Marret and Zonneveld, 2003
2009	10.85	−32.08	Marret and Zonneveld, 2003
2011	8.27	−35.58	Marret and Zonneveld, 2003
3601	17.87	−34.63	Marret and Zonneveld, 2003
3602	17.75	−34.80	Marret and Zonneveld, 2003
3603	17.53	−35.12	Marret and Zonneveld, 2003
3604	15.50	−31.78	Marret and Zonneveld, 2003
3605	15.30	−31.45	Marret and Zonneveld, 2003
3606	13.08	−25.46	Marret and Zonneveld, 2003
3607	14.33	−23.88	Marret and Zonneveld, 2003
3608	12.20	−22.37	Marret and Zonneveld, 2003
3717	13.35	−24.83	Marret and Zonneveld, 2003
3718	13.17	−24.90	Marret and Zonneveld, 2003
3719	12.87	−25.00	Marret and Zonneveld, 2003
3720	12.67	−25.07	Marret and Zonneveld, 2003
3721	12.40	−25.15	Marret and Zonneveld, 2003
3723	11.53	−25.40	Marret and Zonneveld, 2003
3724	8.93	−26.13	Marret and Zonneveld, 2003
9100	−57.02	−52.85	Marret and Zonneveld, 2003
9098	−56.27	−53.33	Marret and Zonneveld, 2003
9095	−41.51	−51.94	Marret and Zonneveld, 2003
9090	−65.86	−64.46	Marret and Zonneveld, 2003
9084	−43.13	−60.48	Marret and Zonneveld, 2003
9083	−41.97	−59.37	Marret and Zonneveld, 2003
9081	−42.97	−56.74	Marret and Zonneveld, 2003
9078	−45.02	−55.55	Marret and Zonneveld, 2003
9075	−45.96	−52.68	Marret and Zonneveld, 2003
9073	−41.18	−52.15	Marret and Zonneveld, 2003
9064	−48.34	−53.87	Marret and Zonneveld, 2003
9046	−64.80	−64.60	Marret and Zonneveld, 2003
9032	−32.31	−60.00	Marret and Zonneveld, 2003
9029	−41.28	−56.70	Marret and Zonneveld, 2003
8950	−176.91	−42.68	Marret and Zonneveld, 2003
8938	−179.50	−45.08	Marret and Zonneveld, 2003

Table 1 (*continued*)

Station	Longitude [degrees_East]	Latitude [degrees_north]	Reference
8924	−171.50	−41.58	Marret and Zonneveld, 2003
8861	179.40	−40.24	Marret and Zonneveld, 2003
8657	−178.49	−42.38	Marret and Zonneveld, 2003
8575	−174.08	−45.33	Marret and Zonneveld, 2003
8219	174.99	−45.02	Marret and Zonneveld, 2003
8215	177.99	−45.39	Marret and Zonneveld, 2003
7851	144.22	−41.52	Marret and Zonneveld, 2003
7850	144.29	−41.51	Marret and Zonneveld, 2003
7849	144.34	−41.52	Marret and Zonneveld, 2003
7847	144.68	−42.18	Marret and Zonneveld, 2003
7846	144.41	−42.20	Marret and Zonneveld, 2003
7845	142.88	−42.23	Marret and Zonneveld, 2003
7844	142.53	−42.25	Marret and Zonneveld, 2003
7818	144.23	−41.39	Marret and Zonneveld, 2003
7804	145.21	−43.16	Marret and Zonneveld, 2003
7803	143.83	−41.12	Marret and Zonneveld, 2003
7802	144.10	−41.50	Marret and Zonneveld, 2003
7801	145.21	−44.33	Marret and Zonneveld, 2003
5510	139.70	−40.10	Marret and Zonneveld, 2003
5509	140.39	−40.07	Marret and Zonneveld, 2003
5508	140.68	−39.83	Marret and Zonneveld, 2003
5507	140.99	−39.68	Marret and Zonneveld, 2003
5506	141.06	−38.85	Marret and Zonneveld, 2003
5505	141.12	−38.67	Marret and Zonneveld, 2003
5504	141.12	−38.61	Marret and Zonneveld, 2003
5503	142.01	−38.88	Marret and Zonneveld, 2003
5502	142.52	−39.31	Marret and Zonneveld, 2003
5501	142.51	−39.34	Marret and Zonneveld, 2003
5325	137.77	−38.19	Marret and Zonneveld, 2003
5323	138.54	−37.98	Marret and Zonneveld, 2003
5322	138.51	−37.99	Marret and Zonneveld, 2003
5321	140.07	−39.60	Marret and Zonneveld, 2003
4406	161.35	−51.94	Marret and Zonneveld, 2003
4405	165.06	−51.26	Marret and Zonneveld, 2003
4305	−175.13	−54.82	Marret and Zonneveld, 2003
3643	168.13	−50.00	Marret and Zonneveld, 2003
3627	154.91	−49.71	Marret and Zonneveld, 2003
3625	155.13	−45.91	Marret and Zonneveld, 2003
3623	150.05	−43.89	Marret and Zonneveld, 2003
3411	147.79	−45.22	Marret and Zonneveld, 2003
3409	146.10	−45.34	Marret and Zonneveld, 2003
3407	160.24	−38.29	Marret and Zonneveld, 2003
3406	159.94	−51.35	Marret and Zonneveld, 2003
2970	52.92	−41.10	Marret and Zonneveld, 2003
2902	71.52	−47.69	Marret and Zonneveld, 2003
2901	68.67	−47.97	Marret and Zonneveld, 2003
2730	147.23	−45.07	Marret and Zonneveld, 2003
2607	90.28	−41.72	Marret and Zonneveld, 2003
2606	90.08	−44.67	Marret and Zonneveld, 2003
2604	90.25	−50.38	Marret and Zonneveld, 2003
2602	86.52	−45.59	Marret and Zonneveld, 2003
1130	93.20	−61.00	Marret and Zonneveld, 2003
1129	95.89	−62.49	Marret and Zonneveld, 2003
1125	115.70	−64.30	Marret and Zonneveld, 2003
1118	138.20	−65.75	Marret and Zonneveld, 2003
1116	141.22	−64.77	Marret and Zonneveld, 2003
1115	141.93	−63.30	Marret and Zonneveld, 2003
1113	144.58	−57.95	Marret and Zonneveld, 2003
1109	147.16	−50.59	Marret and Zonneveld, 2003
1108	148.80	−49.26	Marret and Zonneveld, 2003
1107	145.80	−47.15	Marret and Zonneveld, 2003
1104	100.10	−49.92	Marret and Zonneveld, 2003
1103	90.11	−46.07	Marret and Zonneveld, 2003
1102	82.93	−45.75	Marret and Zonneveld, 2003
1101	79.49	−46.68	Marret and Zonneveld, 2003
GDP11-3	134.61	28.08	Marret and Zonneveld, 2003
GPD 11-4	134.55	28.05	Marret and Zonneveld, 2003
GDP11-6	131.68	28.01	Marret and Zonneveld, 2003
GDP11-11	132.08	27.91	Marret and Zonneveld, 2003
KH76-2-2	132.96	27.85	Marret and Zonneveld, 2003
KH76-2-4	133.10	24.51	Marret and Zonneveld, 2003
NG	129.83	32.75	Marret and Zonneveld, 2003
OM	129.83	33.00	Marret and Zonneveld, 2003
SZ	131.16	34.41	Marret and Zonneveld, 2003
HR	135.91	35.61	Marret and Zonneveld, 2003
SD	138.41	38.08	Marret and Zonneveld, 2003

Table 1 (*continued*)

Station	Longitude [degrees_East]	Latitude [degrees_north]	Reference
HZ	139.91	39.41	Marret and Zonneveld, 2003
OG	139.83	39.83	Marret and Zonneveld, 2003
Y1	124.33	34.15	Marret and Zonneveld, 2003
Y2	123.18	34.11	Marret and Zonneveld, 2003
Y5	123.98	34.98	Marret and Zonneveld, 2003
Y6	123.83	35.81	Marret and Zonneveld, 2003
Y7	122.68	35.50	Marret and Zonneveld, 2003
Y9	124.31	35.98	Marret and Zonneveld, 2003
E4	127.08	31.00	Marret and Zonneveld, 2003
E7	125.16	29.00	Marret and Zonneveld, 2003
E8	125.65	29.58	Marret and Zonneveld, 2003
E9	125.16	30.00	Marret and Zonneveld, 2003
E10	125.16	30.98	Marret and Zonneveld, 2003
E14	123.00	35.71	Marret and Zonneveld, 2003
E15	123.00	35.00	Marret and Zonneveld, 2003
C2	124.33	34.73	Marret and Zonneveld, 2003
C4	123.66	35.48	Marret and Zonneveld, 2003
C5	124.31	35.50	Marret and Zonneveld, 2003
C6	125.11	32.00	Marret and Zonneveld, 2003
C8	127.00	31.98	Marret and Zonneveld, 2003
C14	126.00	30.00	Marret and Zonneveld, 2003
NG7	129.73	32.73	Marret and Zonneveld, 2003
NG8	129.75	32.73	Marret and Zonneveld, 2003
NG9	129.76	32.75	Marret and Zonneveld, 2003
NG10	129.76	32.73	Marret and Zonneveld, 2003
NG11	129.78	32.71	Marret and Zonneveld, 2003
NG12	129.80	32.70	Marret and Zonneveld, 2003
NG13	129.80	32.70	Marret and Zonneveld, 2003
NG14	129.83	32.70	Marret and Zonneveld, 2003
NG15	129.85	32.71	Marret and Zonneveld, 2003
NG16	129.85	32.71	Marret and Zonneveld, 2003
SZ1	131.21	34.38	Marret and Zonneveld, 2003
SZ1A	131.21	34.38	Marret and Zonneveld, 2003
SZ3	131.21	34.36	Marret and Zonneveld, 2003
SZ10	131.20	34.36	Marret and Zonneveld, 2003
SZ14	131.21	34.38	Marret and Zonneveld, 2003
OB1	129.75	33.00	Marret and Zonneveld, 2003
OB2	129.81	33.01	Marret and Zonneveld, 2003
OB3	129.86	33.05	Marret and Zonneveld, 2003
OB4	129.91	33.00	Marret and Zonneveld, 2003
OB5	129.86	33.00	Marret and Zonneveld, 2003
OB6	129.81	33.00	Marret and Zonneveld, 2003
OB7	129.90	32.93	Marret and Zonneveld, 2003
OB8	129.86	32.93	Marret and Zonneveld, 2003
OB9	129.81	32.93	Marret and Zonneveld, 2003
OB10	129.98	32.83	Marret and Zonneveld, 2003
OB11	129.96	32.85	Marret and Zonneveld, 2003
OB12	129.95	32.66	Marret and Zonneveld, 2003
OB13	129.91	32.88	Marret and Zonneveld, 2003
OB14	129.86	32.88	Marret and Zonneveld, 2003
OB15	129.85	32.88	Marret and Zonneveld, 2003
OB16	129.86	32.85	Marret and Zonneveld, 2003
OB17	129.83	32.85	Marret and Zonneveld, 2003
OB18	129.83	32.83	Marret and Zonneveld, 2003
A-5	123.98	32.00	Marret and Zonneveld, 2003
B-1	122.50	31.75	Marret and Zonneveld, 2003
B-5	123.98	31.48	Marret and Zonneveld, 2003
C-1	122.56	31.41	Marret and Zonneveld, 2003
C-3	123.23	31.16	Esper et al., 2007
GeoB2011-1	8.27	−35.58	Esper et al., 2007
GeoB2018-1	−6.55	−34.67	Esper et al., 2007
GeoB2019-2	−8.77	−36.05	Esper et al., 2007
GeoB2021-4	−14.41	−36.84	Esper et al., 2007
GeoB2022-3	−20.91	−34.44	Esper et al., 2007
GeoB6407-2	−19.50	−42.04	Esper et al., 2007
GeoB6409-2	−21.72	−44.51	Esper et al., 2007
GeoB6413-4	−17.34	−44.21	Esper et al., 2007
GeoB6414-1	−13.07	−44.00	Esper et al., 2007
GeoB6416-2	−18.16	−39.95	Esper et al., 2007
GeoB6417-2	−21.04	−39.09	Esper et al., 2007
GeoB6418-3	−21.54	−38.43	Esper et al., 2007
GeoB6420-2	−22.15	−37.16	Esper et al., 2007
GeoB6421-1	−22.45	−36.45	Esper et al., 2007
GeoB6422-5	−22.73	−35.71	Esper et al., 2007
GeoB6425-1	−23.59	−33.83	Esper et al., 2007

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Table 1 (*continued*)

Station	Longitude [degrees_East]	Latitude [degrees_north]	Reference
GeoB6427-1	−24.25	−33.18	Esper et al., 2007
GeoB6429-1	−24.25	−31.95	Esper et al., 2007
PS1451-2	5.46	−64.56	Esper et al., 2007
PS1459-4	3.19	−64.51	Esper et al., 2007
PS1460-1	3.99	−63.88	Esper et al., 2007
PS1585-1	3.12	−64.52	Esper et al., 2007
PS1650-1	3.81	−53.75	Esper et al., 2007
PS1651-2	3.84	−53.64	Esper et al., 2007
PS1652-1	5.08	−53.67	Esper et al., 2007
PS1653-2	9.49	−52.21	Esper et al., 2007
PS1654-1	5.77	−50.16	Esper et al., 2007
PS2230-1	17.36	−34.75	Esper et al., 2007
PS2366-1	−5.96	-51.01	Esper et al., 2007
PS2367−1	-6.00	−49.13	Esper et al., 2007
PS2372-1	−6.00	-54.00	Esper et al., 2007
PS2376−2	-6.00	−48.57	Esper et al., 2007
PS58/251-1	−97.12	−68.63	Esper et al., 2007
PS58/254-2	−108.45	−69.31	Esper et al., 2007
PS58/256-1	−103.90	−68.71	Esper et al., 2007
PS58/258-1	−102.09	−68.77	Esper et al., 2007
PS58/265-1	−117.44	−66.98	Esper et al., 2007
PS58/266-4	−116.63	−65.62	Esper et al., 2007
PS58/267-4	−116.16	−64.83	Esper et al., 2007
PS58/268-1	−115.39	−63.46	Esper et al., 2007
PS58/269-4	−115.08	−62.85	Esper et al., 2007
PS58/270-1	−116.12	−62.03	Esper et al., 2007
PS58/272-4	−115.84	−60.61	Esper et al., 2007
PS58/274-4	−114.89	−59.21	Esper et al., 2007
PS58/276-1	−113.57	−56.89	Esper et al., 2007
PS58/280-1	−93.83	−57.55	Esper et al., 2007
PS58/290-1	−91.16	−57.65	Esper et al., 2007
PS58/291-3	−92.38	−57.04	Esper et al., 2007
PS58/292-1	−93.79	−56.57	Esper et al., 2007
GeoB10701	17.47	40.00	Zonneveld et al., 2009
GeoB10702	17.59	40.00	Zonneveld et al., 2009
GeoB10703	17.74	40.00	Zonneveld et al., 2009
GeoB10704	17.83	40.00	Zonneveld et al., 2009
GeoB10705	17.91	39.85	Zonneveld et al., 2009
GeoB10706	17.83	39.83	Zonneveld et al., 2009
GeoB10707	17.58	39.78	Zonneveld et al., 2009
GeoB10708	17.73	39.81	Zonneveld et al., 2009
GeoB10709	17.89	39.76	Zonneveld et al., 2009
GeoB10710	17.68	39.59	Zonneveld et al., 2009
GeoB10711	17.80	39.68	Zonneveld et al., 2009
GeoB10712	17.86	39.73	Zonneveld et al., 2009
GeoB10713	18.28	39.69	Zonneveld et al., 2009
GeoB10714	18.28	39.64	Zonneveld et al., 2009
GeoB10715	18.28	39.56	Zonneveld et al., 2009
GeoB10716	18.28	39.34	Zonneveld et al., 2009
GeoB10717	18.08	39.74	Zonneveld et al., 2009
GeoB10718	18.06	39.69	Zonneveld et al., 2009
GeoB10719	18.04	39.65	Zonneveld et al., 2009
GeoB10720	17.98	39.51	Zonneveld et al., 2009
GeoB10721	16.77	42.17	Zonneveld et al., 2009
GeoB10722	16.50	42.17	Zonneveld et al., 2009
GeoB10723	16.00	42.17	Zonneveld et al., 2009
GeoB10724	16.22	42.00	Zonneveld et al., 2009
GeoB10725	16.37	42.00	Zonneveld et al., 2009
GeoB10727	16.62	41.80	Zonneveld et al., 2009
GeoB10729	17.19	41.65	Zonneveld et al., 2009
GeoB10730	17.05	41.50	Zonneveld et al., 2009
GeoB10731	16.66	41.50	Zonneveld et al., 2009
GeoB10732	16.41	41.50	Zonneveld et al., 2009
GeoB10733	16.22	41.50	Zonneveld et al., 2009
GeoB10734	16.24	41.67	Zonneveld et al., 2009
GeoB10735	17.31	41.50	Zonneveld et al., 2009
GeoB10736	18.19	40.76	Zonneveld et al., 2009
GeoB10737	18.33	40.63	Zonneveld et al., 2009
GeoB10738	18.47	40.55	Zonneveld et al., 2009
GeoB10739	18.64	40.50	Zonneveld et al., 2009
GeoB10740	18.85	40.39	Zonneveld et al., 2009
GeoB10741	18.67	40.23	Zonneveld et al., 2009
GeoB10742	18.78	39.72	Zonneveld et al., 2009
GeoB10743	18.64	39.82	Zonneveld et al., 2009
GeoB10744	18.60	39.85	Zonneveld et al., 2009
GeoB10746	16.76	39.91	Zonneveld et al., 2009
GeoB10747	16.97	39.72	Zonneveld et al., 2009
GeoB10748	17.05	39.67	Zonneveld et al., 2009
GeoB10749	17.18	39.60	Zonneveld et al., 2009
GeoB6201	−46.43	−26.67	*
GeoB6202	−47.17	−29.08	*
GeoB6203	−47.30	−28.83	*
GeoB 6204	−47.37	−28.72	*
GeoB6205	−46.92	−29.50	*
GeoB6206	−46.55	−30.20	*
GeoB6207	−46.32	−30.63	*
GeoB6208	−45.67	−31.80	*
GeoB6209	−48.15	−31.75	*
GeoB6210	−48.82	−31.52	*
GeoB6211	−50.25	−32.50	*
GeoB6212	−50.12	−32.68	*
GeoB6213	−49.57	−33.17	*
GeoB6214	−51.45	−34.53	*
GeoB6216	−51.23	−34.62	*
GeoB6217	−51.00	−34.72	*
GeoB6219	−50.57	−35.18	*
GeoB6220	−49.38	−33.35	*
GeoB6221	−49.22	−33.55	*
GeoB6222	−49.22	−33.55	*
GeoB6223	−49.68	−35.73	*
GeoB6224	−50.22	−35.40	*
GeoB6225	−48.42	−34.32	*
GeoB6226	−47.90	−37.15	*
GeoB6228	−46.38	−38.20	*
GeoB6229	−52.65	−37.20	*
GeoB6230	−51.68	−37.90	*
GeoB6231	−53.02	−36.98	*
GeoB6232	−53.13	−36.90	*
Geob6307	−53.83	−39.40	*
GeoB6308	−53.97	−39.30	*
GeoB6309	−54.15	−39.17	*
GeoB6310	−54.32	−39.05	*
GeoB6311	−54.63	−38.82	*
GeoB6312	−55.25	−38.35	*
GeoB6217	−54.60	−40.08	*
GeoB6330	−57.55	−46.15	*
GeoB6334	−58.52	−46.08	*
GeoB6336	−57.85	−46.15	*
GeoB6337	−57.77	−44.85	*
GeoB6339	−58.38	−45.15	*
GeoB6340	−58.10	−44.92	*
GeoB6341	−57.17	−44.45	*
Z802	63.53	81.12	**
Z803	57.90	80.74	**
Z254	53.83	80.66	**
Y375	−11.32	80.62	**
Z804	55.75	80.59	**
Z805	56.73	80.51	**
Y376	−13.66	80.45	**
Z253	52.27	80.28	**
Y373	−10.71	80.15	**
Z806	51.84	80.10	**
Y378	−15.76	80.08	**
Y372	−6.66	80.06	**
J291	−11.55	80.02	**
J293	−4.83	80.02	**
J292	−7.88	79.98	**
Y377	−11.00	79.89	**
J348	−14.36	79.76	**
Z811	49.27	79.71	**
Z810	47.87	79.65	**
Z499	130.54	79.65	**
Y374	−11.80	79.59	**
Z809	46.94	79.57	**
J297	7.79	79.40	**
Z511	122.91	79.22	**
Z512	119.78	79.16	**
P572	−73.33	78.99	**
J290	−13.93	78.99	**
Z521	112.70	78.76	**
Z520	112.51	78.70	**
Z513	118.74	78.67	**

Table 1 (*continued*)

Station	Longitude [degrees_East]	Latitude [degrees_north]	Reference
J289	−11.04	78.62	**
Z522	111.38	78.58	**
Z500	133.00	78.48	**
Z519	110.79	78.47	**
J349	1.06	78.41	**
P577	−74.48	78.35	**
P567	−74.70	78.34	**
Z559	70.03	78.32	**
Z743	−104.00	78.30	**
Z501	133.40	78.17	**
Z502	133.51	78.10	**
Z503	133.61	78.07	**
Z510	125.00	78.06	**
Z495	102.31	78.03	**
J285	8.72	78.01	**
J288	−1.05	78.00	**
J286	6.69	78.00	**
J368	−4.55	77.99	**
J287	2.45	77.99	**
Z514	118.57	77.98	**
Z523	105.08	77.90	**
Z497	101.59	77.89	**
P569	−74.79	77.85	**
P695	−75.21	77.79	**
P686	−74.16	76.29	**
P580	−74.24	76.28	**
P570	−74.66	76.27	**
Z737	−167.00	76.25	**
Z707	−74.66	76.22	**
Z709	−71.38	76.20	**
Z740	−86.47	76.12	**
Z708	−71.04	76.12	**
Z800	79.96	76.01	**
Z481	136.71	75.94	**
Z565	−160.86	75.73	**
Z557	56.43	75.62	**
P697	−70.79	75.58	**
Z807	56.45	75.56	**
Z530	114.50	75.54	**
J369	0.83	75.52	**
Z705	−76.26	75.51	**
Z494	115.54	75.50	**
Z483	115.25	75.49	**
Z473	123.84	75.48	**
Z808	57.17	75.48	**
Z472	119.96	75.47	**
Z727	−93.31	75.45	**
Z556	57.32	75.43	**
Z474	125.84	75.42	**
Z255	57.40	75.39	**
Z477	135.17	75.34	**
J363	−11.57	75.33	**
Z434	−173.90	75.32	**
Z720	−78.11	75.30	**
P696	−76.08	75.26	**
P579	−74.94	75.22	**
Z706	−78.43	75.13	**
Z721	−97.00	75.10	**
Z470	119.89	75.02	**
Z467	136.03	75.01	**
J305	13.96	75.00	**
Z728	−93.00	75.00	**
Z471	114.53	75.00	**
Z801	79.85	74.99	**
J304	11.14	74.88	**
J347	−9.78	74.83	**
Z543	−97.18	74.82	**
Z564	−159.98	74.51	**
Z493	114.28	74.50	**
Z546	−92.58	74.50	**
Z492	119.83	74.50	**
Z460	115.98	74.49	**
Z462	119.96	74.49	**
Z466	137.04	74.48	**
Z562	52.43	74.45	**
J344	−15.31	74.43	**
J346	−17.54	74.41	**
Z733	−99.28	74.33	**
J361	−5.18	74.33	**
Z1230	−85.60	74.28	**
J350	−10.06	74.25	**
J343	−14.47	74.19	**
Z1231	−81.20	74.19	**
Z729	−85.59	74.15	**
Z730	−83.04	74.15	**
Z561	55.52	74.14	**
Z459	137.66	74.01	**
Z598	72.66	74.00	**
Z586	81.00	74.00	**
Z563	−161.40	74.00	**
Z585	79.02	74.00	**
Z593	77.20	73.99	**
Z591	81.67	73.89	**
Z455	117.87	73.83	**
J342	−10.48	73.75	**
J362	−14.88	73.74	**
Z736	−162.66	73.69	**
Z601	74.84	73.65	**
Z453	139.65	73.63	**
Z560	50.72	73.62	**
Z597	72.95	73.61	**
Z590	79.92	73.53	**
J341	−9.18	73.52	**
Z461	117.85	73.50	**
Z432	−166.25	73.45	**
N200	−5.61	73.38	**
Z731	−85.01	73.30	**
Z599	75.62	73.22	**
Z548	58.55	73.22	**
Z596	72.89	73.21	**
Z435	−126.46	73.19	**
J314	0.81	73.17	**
Z732	−84.51	73.07	**
J303	9.74	73.06	**
Z595	73.14	72.96	**
Z797	64.57	72.69	**
Z584	73.73	72.69	**
J345	−17.85	72.66	**
Z796	59.97	72.64	**
J319	−6.59	72.62	**
J351	−13.84	72.62	**
J318	1.51	72.39	**
J317	1.80	72.38	**
J320	−10.60	72.37	**
Z549	57.64	72.29	**
J309	14.43	72.23	**
J329	−12.98	72.22	**
J308	13.10	72.18	**
J307	11.45	72.14	**
J316	0.22	72.06	**
J306	9.27	72.04	**
J315	0.62	72.04	**
J312	4.99	72.01	**
J311	7.49	71.99	**
Z1251	−125.87	71.91	**
J352	−12.57	71.81	**
Z738	−156.50	71.75	**
Z541	42.61	71.74	**
J330	−15.59	71.74	**
Z1250	−126.48	71.70	**
J328	−8.42	71.63	**
F995	−133.81	71.45	**
J313	0.66	71.44	**
Z550	30.42	71.42	**
Z551	31.97	71.39	**
Z1236	−126.72	71.39	**
B081	−64.27	71.33	**
Z1248	−127.70	71.31	**
Z1253	−131.62	71.31	**
J331	−14.07	71.29	**
F999	−128.52	71.27	**

(*continued on next page*)

Table 1 (*continued*)

Station	Longitude [degrees_East]	Latitude [degrees_north]	Reference
Z554	37.92	71.26	**
J310	15.83	71.20	**
A984	−18.47	71.19	**
J321	−5.87	71.17	**
F996	−133.52	71.15	**
F997	−133.52	71.15	**
Z382	52.55	71.14	**
Z542	45.25	71.12	**
Z1247	−128.31	71.11	**
Z553	37.05	71.07	**
Z798	64.50	71.00	**
Z1234	−125.05	71.00	**
Z381	51.75	70.99	**
Z1241	−123.42	70.97	**
Z438	−134.69	70.97	**
Z1254	−133.78	70.96	**
J327	−5.56	70.95	**
F998	−133.63	70.84	**
Z552	36.27	70.83	**
F994	−127.64	70.81	**
Z380	51.30	70.74	**
Z385	51.30	70.74	**
Z1256	−133.68	70.69	**
Z383	53.40	70.67	**
Z1259	−135.92	70.64	**
Z388	54.55	70.62	**
F1004	−122.97	70.58	**
J338	−12.73	70.57	**
Z1262	−137.60	70.55	**
Z384	53.06	70.54	**
Z1239	−124.37	70.54	**
B080	−64.52	70.52	**
Z387	54.26	70.50	**
Z390	55.08	70.50	**
Z744	−133.50	70.47	**
J332	−16.08	70.44	**
Z392	56.50	70.42	**
J333	−18.94	70.41	**
Z437	−139.08	70.41	**
F1001	−139.30	70.40	**
J334	−20.20	70.39	**
J335	−19.33	70.39	**
Z394	57.36	70.36	**
J336	−18.21	70.36	**
Z547	−133.80	70.35	**
J339	−10.63	70.34	**
Z540	34.37	70.34	**
Z1238	−124.84	70.32	**
Z379	50.45	70.32	**
Z397	54.82	70.31	**
Z745	−135.68	70.30	**
Z393	57.17	70.30	**
Z389	54.43	70.26	**
Z391	55.88	70.20	**
Z436	−133.43	70.15	**
Z395	56.49	70.07	**
Z386	51.89	70.05	**
Z1237	−126.30	70.05	**
Z396	57.02	70.03	**
Z1263	−138.60	70.02	**
Z439	−138.59	70.01	**
J337	−12.43	70.01	**
J322	0.08	70.01	**
J284	−21.11	70.00	**
F1002	−138.38	69.92	**
F993	−126.16	69.84	**
Z799	64.86	69.78	**
Z1264	−138.27	69.75	**
Z746	−137.88	69.75	**
F1003	−137.87	69.56	**
J300	3.00	69.50	**
Z539	33.83	69.49	**
N189	−14.54	69.45	**
Z741	−138.81	69.45	**
J283	−12.92	69.41	**
Z538	33.72	69.37	**
J282	−8.67	69.37	**
Z537	33.54	69.30	**
J355	−16.82	69.20	**
Z536	33.56	69.18	**
J356	−16.52	69.17	**
Z535	33.42	69.11	**
J354	−18.02	69.03	**
Z1229	−106.59	69.00	**
J359	−17.54	68.95	**
J358	−17.16	68.64	**
A952	−14.66	68.60	**
J357	−16.85	68.59	**
A951	−16.93	68.58	**
B082	−63.53	68.45	**
N190	−13.87	68.42	**
J323	1.49	68.33	**
A953	−15.75	68.33	**
J281	−3.64	68.30	**
J360	−18.30	68.17	**
N191	−11.54	68.17	**
A985	−27.86	68.10	**
A950	−17.50	68.08	**
A937	−15.38	68.08	**
A946	−20.68	68.03	**
A977	−21.78	67.98	**
J353	−18.36	67.93	**
A936	−15.45	67.91	**
A948	−18.83	67.91	**
A947	−19.35	67.91	**
A949	−17.75	67.90	**
Z739	−167.90	67.87	**
A945	−20.83	67.76	**
J326	5.87	67.69	**
A943	−20.31	67.63	**
A954	−17.85	67.60	**
A983	−17.07	67.58	**
N192	−11.66	67.50	**
A955	−18.18	67.46	**
A956	−18.36	67.31	**
A942	−19.73	67.31	**
A957	−18.83	67.26	**
A944	−20.50	67.25	**
A958	−19.50	67.21	**
A533	−30.82	67.15	**
A534	−31.88	67.14	**
N194	−8.29	67.12	**
J301	2.91	67.09	**
N195	−7.31	67.08	**
A941	−20.15	67.08	**
N196	−6.59	67.04	**
J324	7.76	67.01	**
N197	−6.21	67.00	**
N193	−9.31	67.00	**
J280	−7.12	66.99	**
A981	−17.97	66.99	**
A938	−15.73	66.98	**
A959	−17.90	66.90	**
J325	8.04	66.89	**
A960	−17.85	66.85	**
A982	−18.75	66.76	**
A939	−16.83	66.73	**
A975	−24.19	66.68	**
A976	−24.19	66.67	**
N213	1.48	66.67	**
A978	−20.86	66.64	**
A979	−20.85	66.62	**
N216	2.66	66.61	**
N214	1.55	66.61	**
N212	1.13	66.61	**
N215	2.18	66.61	**
A416	−10.46	66.60	**
A940	−18.85	66.50	**
A980	−19.50	66.50	**
A935	−17.58	66.15	**
N211	−3.23	65.75	**
A969	−25.26	65.70	**

Table 1 (*continued*)

Station	Longitude [degrees_East]	Latitude [degrees_north]	Reference
N237	−4.63	65.62	**
N236	−6.79	65.57	**
J340	−4.90	65.53	**
J299	0.11	65.52	**
N235	−7.18	65.51	**
J298	−3.01	65.50	**
A968	−26.66	65.50	**
A967	−27.51	65.48	**
N234	−7.65	65.45	**
A974	−26.31	65.44	**
N210	−4.74	65.42	**
N232	−8.03	65.39	**
N233	−8.17	65.37	**
N231	−8.81	65.27	**
N230	−9.53	65.15	**
H1116	−81.35	65.14	**
N224	2.42	65.10	**
A970	−25.86	65.03	**
N229	−10.00	65.00	**
A973	−24.44	64.96	**
N228	−10.14	64.94	**
A966	−27.21	64.91	**
N227	−10.33	64.85	**
A112	−30.18	64.67	**
A965	−27.60	64.56	**
A149	−8.83	64.52	**
L089	−57.42	64.40	**
A532	−24.23	64.30	**
A962	−25.28	64.18	**
A971	−24.02	64.03	**
A972	−24.02	64.03	**
A961	−23.55	63.96	**
A110	−28.93	63.87	**
A109	−28.94	63.87	**
A111	−28.93	63.87	**
H1120	−79.56	63.85	**
H1118	−75.50	63.83	**
N217	3.22	63.72	**
A963	−24.40	63.71	**
H132	−83.27	63.50	**
N638	9.16	63.48	**
N218	3.04	63.46	**
N209	0.02	63.44	**
A964	−24.65	63.43	**
N219	3.08	63.21	**
N208	0.57	63.16	**
N637	7.70	63.10	**
N207	0.79	63.06	**
O754	−174.45	63.05	**
H130	−81.08	63.03	**
H131	−81.08	63.03	**
O759	−173.03	63.01	**
O750	−175.00	63.00	**
O749	−177.00	63.00	**
A418	−21.62	62.95	**
N206	1.03	62.94	**
A107	−32.18	62.91	**
A154	−22.85	62.88	**
N220	3.71	62.88	**
N636	7.10	62.84	**
N221	3.90	62.78	**
A108	−30.36	62.77	**
N222	3.95	62.75	**
H135	−87.74	62.69	**
O758	−175.65	62.66	**
H1117	−75.49	62.66	**
N198	−1.67	62.65	**
L087	−53.88	62.65	**
N398	2.73	62.62	**
N635	6.60	62.60	**
N399	2.33	62.58	**
A106	−38.83	62.54	**
N402	1.25	62.53	**
L088	−59.45	62.52	**
O748	−177.03	62.49	**
N223	4.46	62.47	**

Table 1 (*continued*)

Station	Longitude [degrees_East]	Latitude [degrees_north]	Reference
A129	−20.41	62.46	**
N634	6.15	62.46	**
H1119	−75.50	62.44	**
N400	2.07	62.42	**
H133	−84.47	62.37	**
A105	−41.02	62.32	**
N401	1.71	62.30	**
N633	5.41	62.02	**
O747	−178.00	62.00	**
N632	5.15	61.84	**
N631	5.17	61.73	**
H134	−86.32	61.59	**
A150	−18.69	61.55	**
N630	5.06	61.41	**
O782	−176.50	61.30	**
N629	5.21	61.16	**
O760	−172.31	61.15	**
O783	−175.20	61.13	**
O757	−173.43	61.12	**
N628	5.00	61.00	**
O781	−176.73	60.98	**
Z735	−66.43	60.95	**
A417	−17.74	60.94	**
H1115	−91.78	60.92	**
H1114	−90.01	60.84	**
O756	−177.05	60.82	**
O784	−174.60	60.75	**
N627	4.90	60.71	**
H1112	−87.45	60.66	**
H1113	−87.45	60.66	**
O762	−175.13	60.64	**
N185	3.72	60.64	**
N186	3.73	60.63	**
H136	−81.18	60.61	**
A701	−22.07	60.58	**
A113	−22.08	60.57	**
O780	−176.53	60.56	**
O761	−172.11	60.54	**
N626	5.09	60.52	**
H1111	−85.00	60.50	**
H138	−86.03	60.36	**
H1110	−81.99	60.34	**
O779	−175.91	60.29	**
A104	−40.22	60.29	**
H137	−86.86	60.20	**
H1109	−79.00	60.17	**
O775	−170.63	60.02	**
O776	−171.03	59.98	**
O755	−176.33	59.91	**
N225	−8.33	59.87	**
A103	−39.67	59.86	**
A170	−33.58	59.85	**
A156	−27.92	59.81	**
A128	−15.86	59.81	**
O778	−174.41	59.75	**
P844	−147.58	59.68	**
A171	−30.36	59.68	**
N226	−9.30	59.67	**
N622	5.46	59.63	**
O785	−173.09	59.60	**
P843	−148.31	59.56	**
L090	−45.87	59.49	**
A168	−39.31	59.49	**
O777	−173.77	59.49	**
O786	−172.57	59.23	**
N620	5.40	59.17	**
L153	−48.38	59.15	**
P901	−143.67	59.08	**
N623	5.26	59.07	**
P841	−150.00	59.04	**
A173	−28.74	58.94	**
L091	−47.09	58.92	**
N615	7.14	58.90	**
O763	−170.44	58.90	**
N607	9.35	58.86	**

(continued on next page)

Table 1 (*continued*)

Station	Longitude [degrees_East]	Latitude [degrees_north]	Reference
N613	7.14	58.80	**
A100	−43.97	58.79	**
N249	4.85	58.76	**
L094	−57.12	58.76	**
N608	9.90	58.73	**
H139	−84.85	58.71	**
N248	4.23	58.69	**
O787	−172.02	58.57	**
N614	7.70	58.50	**
N609	8.85	58.48	**
O764	−169.22	58.46	**
N246	1.73	58.40	**
L152	−57.51	58.37	**
O765	−168.93	58.37	**
L093	−57.46	58.36	**
N610	8.61	58.35	**
N617	6.25	58.34	**
N616	6.66	58.30	**
N241	0.02	58.22	**
L092	−48.36	58.21	**
N239	0.28	58.14	**
N240	0.22	58.14	**
N238	0.39	58.14	**
P900	−141.68	58.13	**
N611	8.00	58.13	**
A126	−10.72	58.08	**
O774	−167.85	58.08	**
N245	0.55	58.07	**
N612	7.81	58.01	**
A099	−45.90	57.98	**
H145	−86.77	57.97	**
A415	−29.13	57.94	**
H140	−83.34	57.90	**
O788	−171.66	57.87	**
K275	9.01	57.85	**
P899	−138.39	57.80	**
N268	0.61	57.73	**
K277	8.33	57.61	**
A114	−21.17	57.55	**
O766	−166.06	57.30	**
O767	−165.69	57.12	**
N242	1.90	57.12	**
N269	−1.75	57.07	**
O789	−171.30	57.04	**
A699	−10.05	57.03	**
A115	−20.83	57.00	**
O790	−171.13	56.64	**
A181	−13.25	56.52	**
P898	−143.88	56.50	**
O791	−170.06	56.48	**
O768	−165.30	56.40	**
O792	−167.62	56.35	**
O773	−168.35	56.25	**
P860	−136.44	56.19	**
S158	−58.91	56.11	**
O769	−165.32	56.06	**
A116	−20.32	55.95	**
A174	−30.23	55.75	**
P845	−153.95	55.69	**
O772	−166.54	55.65	**
H144	−81.76	55.59	**
H142	−77.96	55.48	**
A182	−14.68	55.47	**
O771	−165.90	55.40	**
H141	−77.68	55.38	**
O793	−167.08	55.31	**
P861	−138.10	55.30	**
O770	−165.30	55.20	**
H143	−80.50	55.10	**
L163	−52.13	55.03	**
P862	−136.13	54.98	**
O794	−166.98	54.92	**
L164	−52.75	54.90	**
P863	−137.89	54.85	**
L162	−52.87	54.82	**
S160	−55.58	54.72	**
S159	−56.45	54.71	**
A124	−12.78	54.70	**
Z606	−148.47	54.36	**
A118	−21.08	54.08	**
O795	−169.10	53.75	**
L151	−45.26	53.33	**
A175	−33.53	53.06	**
A992	−4.46	52.73	**
A120	−21.93	52.57	**
A119	−21.93	52.57	**
A127	−35.24	52.29	**
A121	−21.88	51.72	**
A986	−6.20	51.63	**
A991	−5.83	51.50	**
A987	−6.50	51.35	**
A990	−6.06	51.28	**
A989	−5.90	51.23	**
A988	−6.15	51.20	**
P1213	−127.35	51.20	**
P1212	−127.04	51.17	**
P1211	−126.95	51.17	**
P1208	−126.72	51.04	**
P1209	−126.71	51.02	**
P1210	−126.71	51.01	**
A122	−21.73	50.65	**
A155	−19.30	50.28	**
A125	−11.57	50.27	**
G039	−64.07	50.26	**
G037	−64.08	50.25	**
L178	−45.69	50.21	**
G038	−64.08	50.21	**
G040	−61.97	50.18	**
G043	−61.87	50.14	**
G050	−61.32	50.12	**
G061	−58.73	50.12	**
G045	−61.81	50.12	**
G041	−61.91	50.11	**
G046	−61.80	50.10	**
A123	−17.92	50.10	**
G048	−61.38	50.08	**
G044	−61.84	50.07	**
G047	−61.60	50.02	**
G024	−66.30	50.00	**
G049	−61.34	49.98	**
G042	−61.90	49.95	**
E022	−66.69	49.87	**
G060	−59.46	49.80	**
G059	−59.47	49.80	**
G058	−59.47	49.80	**
G055	−61.95	49.71	**
G025	−66.20	49.60	**
G056	−60.80	49.52	**
P851	−128.14	49.40	**
P1153	−123.75	49.37	**
G027	−64.60	49.35	**
P1152	−123.29	49.33	**
P1144	−123.47	49.33	**
G057	−59.78	49.33	**
P1143	−123.35	49.32	**
P1142	−123.29	49.32	**
P1141	−123.23	49.31	**
G068	−63.99	49.29	**
P1139	−123.47	49.28	**
G023	−66.28	49.28	**
P1123	−123.29	49.26	**
E020	−67.87	49.25	**
P1130	−123.44	49.25	**
P1129	−123.37	49.24	**
P1138	−123.47	49.24	**
P1131	−123.44	49.23	**
G026	−66.10	49.23	**
P1122	−123.30	49.23	**
G054	−60.17	49.22	**
Z605	−127.31	49.22	**
P1154	−123.76	49.21	**
P1128	−123.37	49.21	**

Table 1 (*continued*)

Station	Longitude [degrees_East]	Latitude [degrees_north]	Reference
P852	−129.24	49.21	**
G028	−64.00	49.21	**
P1127	−123.43	49.20	**
P1121	−123.31	49.19	**
P1125	−123.37	49.18	**
E021	−67.24	49.16	**
P1137	−123.50	49.15	**
P1158	−123.56	49.14	**
P1126	−123.44	49.12	**
P1133	−123.34	49.09	**
G067	−67.44	49.09	**
P1215	−125.18	49.09	**
P1216	−125.18	49.09	**
P1217	−125.18	49.09	**
P1218	−125.18	49.09	**
P1219	−125.17	49.08	**
P1220	−125.16	49.07	**
P1221	−125.15	49.07	**
E019	−67.70	49.06	**
P1222	−125.15	49.06	**
P1223	−125.15	49.06	**
P1225	−125.16	49.05	**
P1226	−125.15	49.05	**
P1224	−125.16	49.05	**
P1228	−125.16	49.02	**
P1227	−125.16	49.02	**
E017	−68.36	49.02	**
P850	−127.77	49.01	**
P1148	−123.47	49.01	**
P1147	−123.34	49.00	**
Z604	−126.88	48.98	**
G029	−63.52	48.97	**
P1136	−123.06	48.93	**
E016	−68.24	48.92	**
P1160	−123.33	48.91	**
A683	−51.80	48.91	**
Z603	−126.89	48.91	**
E018	−67.52	48.89	**
P1149	−123.24	48.88	**
E014	−68.67	48.86	**
A682	−51.88	48.85	**
P1135	−123.10	48.84	**
G030	−63.10	48.81	**
Z602	−125.50	48.77	**
E013	−68.57	48.75	**
E015	−68.08	48.73	**
E1162	−68.65	48.70	**
E1161	−68.63	48.64	**
G063	−62.54	48.64	**
G064	−62.54	48.64	**
P1214	−123.50	48.63	**
E012	−68.46	48.61	**
G031	−62.10	48.57	**
G070	−61.17	48.53	**
G062	−62.63	48.52	**
G051	−60.64	48.51	**
G052	−60.64	48.51	**
E010	−69.04	48.48	**
A824	−58.64	48.44	**
P854	−129.87	48.44	**
A823	−58.64	48.44	**
A822	−58.63	48.44	**
A821	−58.63	48.44	**
G032	−61.58	48.41	**
P855	−127.15	48.39	**
P840	−124.14	48.36	**
G053	−60.24	48.33	**
E008	−69.33	48.32	**
P866	−126.06	48.30	**
E006	−69.35	48.28	**
E007	−69.44	48.28	**
E005	−69.27	48.23	**
P853	−130.03	48.23	**
P869	−125.69	48.21	**
E004	−69.58	48.20	**
P868	−125.77	48.18	**
E003	−69.53	48.17	**
G033	−60.72	48.17	**
P867	−126.02	48.10	**
P856	−128.06	48.06	**
P864	−126.27	47.95	**
P870	−125.36	47.94	**
G069	−65.21	47.92	**
G034	−60.12	47.89	**
P858	−127.12	47.80	**
A819	−58.32	47.74	**
A818	−58.34	47.74	**
A812	−57.29	47.73	**
A813	−57.31	47.69	**
A820	−58.36	47.69	**
A817	−57.93	47.67	**
A816	−57.93	47.65	**
A814	−57.35	47.60	**
P871	−125.76	47.60	**
P857	−129.51	47.59	**
A815	−57.38	47.58	**
G066	−59.88	47.52	**
G077	−56.37	47.50	**
G035	−59.53	47.40	**
P865	−124.91	47.38	**
G065	−60.03	47.35	**
G071	−60.54	47.15	**
G078	−57.05	47.07	**
P848	−131.16	47.03	**
G073	−59.08	46.99	**
A412	−8.09	46.91	**
A698	−8.67	46.80	**
A413	−8.68	46.77	**
P849	−127.54	46.72	**
G072	−60.22	46.72	**
A414	−8.97	46.68	**
P896	−129.13	46.65	**
P846	−134.27	46.63	**
P874	−125.12	46.30	**
P875	−125.61	46.30	**
P904	−124.24	46.20	**
G076	−57.94	46.19	**
G075	−57.59	45.85	**
G079	−58.57	45.84	**
C676	−60.89	45.23	**
C675	−60.90	45.22	**
P890	−125.58	45.22	**
C674	−60.87	45.21	**
C673	−60.86	45.20	**
C672	−60.84	45.17	**
C671	−60.83	45.16	**
P839	−130.93	45.12	**
C670	−60.79	45.11	**
P838	−131.67	44.88	**
A180	−3.30	44.88	**
A183	−2.13	44.85	**
C656	−55.97	44.82	**
P880	−130.16	44.73	**
C654	−55.52	44.68	**
P891	−125.28	44.67	**
A074	−55.62	44.66	**
A704	−55.62	44.65	**
C655	−55.87	44.50	**
P876	−124.90	44.50	**
P872	−129.66	44.28	**
A411	−2.70	44.26	**
P830	−127.98	44.12	**
C669	−62.80	43.88	**
A260	−62.80	43.83	**
A259	−62.81	43.83	**
A258	−62.79	43.83	**
P877	−125.32	43.67	**
A263	−62.63	43.65	**
P829	−129.23	43.58	**
P831	−128.75	43.55	**
P837	−131.57	43.53	**

(*continued on next page*)

Table 1 (*continued*)

Station	Longitude [degrees_East]	Latitude [degrees_north]	Reference
C653	−54.87	43.48	**
C661	−60.00	43.41	**
A428	−67.76	43.38	**
C677	−63.50	43.34	**
A685	−49.14	43.31	**
C658	−57.33	43.31	**
C657	−57.64	43.30	**
P878	−125.40	43.17	**
P879	−125.09	43.17	**
C660	−59.99	43.12	**
A703	−55.27	43.10	**
C652	−55.83	43.07	**
P881	−126.58	43.03	**
P835	−130.41	42.98	**
A427	−67.36	42.94	**
C666	−61.82	42.92	**
C663	−61.82	42.92	**
C665	−61.74	42.89	**
A262	−61.75	42.89	**
A261	−61.76	42.88	**
A423	−69.96	42.82	**
P889	−126.26	42.75	**
C664	−63.54	42.71	**
A421	−69.66	42.67	**
P836	−131.12	42.66	**
C662	−61.69	42.63	**
A420	−67.92	42.56	**
C667	−61.64	42.54	**
A425	−68.46	42.48	**
A424	−67.11	42.47	**
C659	−59.61	42.46	**
A410	−11.13	42.30	**
P834	−129.62	42.29	**
P883	−128.01	42.21	**
P893	−125.21	42.20	**
C668	−62.59	42.17	**
A409	−9.78	42.10	**
P888	−126.60	42.09	**
A422	−69.15	42.02	**
A426	−68.19	42.01	**
A419	−65.46	41.92	**
P882	−126.00	41.83	**
A408	−9.97	41.82	**
P884	−129.01	41.80	**
P892	−130.62	41.58	**
P895	−132.04	41.52	**
P885	−131.22	41.48	**
P897	−127.02	41.27	**
P886	−134.66	41.08	**
P873	−127.81	40.99	**
A407	−10.85	40.99	**
P832	−124.55	40.81	**
P903	−125.52	40.42	**
M1092	13.47	40.15	**
P833	−126.18	40.10	**
M1062	1.35	40.07	**
M1086	14.17	39.48	**
M1085	13.34	39.41	**
M1091	14.18	39.35	**
C651	−72.42	39.29	**
C650	−72.30	39.26	**
C648	−72.28	39.22	**
M1066	2.94	39.12	**
M1071	2.93	39.12	**
M1068	2.94	39.09	**
C913	−72.46	39.04	**
M1030	9.24	39.04	**
M1021	9.25	39.03	**
M1017	9.21	39.03	**
M1024	9.28	39.03	**
C914	−72.42	39.01	**
M1079	2.95	39.01	**
M1073	2.86	38.95	**
M1029	9.37	38.94	**
M1033	10.59	38.93	**
M1077	2.83	38.92	**
M1028	9.40	38.91	**
M1080	2.82	38.89	**
M1067	2.81	38.89	**
C909	−72.69	38.87	**
C646	−72.71	38.86	**
C911	−72.73	38.85	**
M1037	9.48	38.85	**
A406	−11.48	38.84	**
C910	−72.71	38.84	**
C907	−72.74	38.83	**
C905	−72.82	38.82	**
C908	−72.72	38.79	**
M1075	2.82	38.76	**
C906	−72.65	38.75	**
M1076	2.81	38.73	**
M1031	10.71	38.69	**
M1051	10.74	38.68	**
M1038	10.75	38.66	**
M1057	10.76	38.65	**
M1050	10.78	38.64	**
M1027	10.83	38.59	**
M1035	9.34	38.58	**
M1065	1.98	38.58	**
M1054	9.30	38.54	**
M1070	1.45	38.49	**
M1069	1.43	38.48	**
M1090	14.57	38.47	**
M1082	1.42	38.43	**
M1052	9.24	38.42	**
C645	−73.24	38.40	**
M1083	1.41	38.39	**
M1072	1.41	38.37	**
M1056	11.24	38.32	**
M1041	11.28	38.31	**
M1040	11.34	38.25	**
M1078	1.45	38.25	**
M1060	8.95	38.24	**
M1087	13.10	38.24	**
M1084	14.06	38.23	**
C919	−73.84	38.16	**
C915	−73.83	38.12	**
C917	−73.61	38.12	**
C918	−73.67	38.11	**
M1044	8.38	38.09	**
M1081	1.45	38.09	**
C916	−73.85	37.99	**
M1074	1.42	37.89	**
A265	−9.49	37.88	**
A266	−9.95	37.87	**
C923	−73.52	37.82	**
M1053	8.72	37.80	**
C927	−73.87	37.78	**
C928	−73.87	37.78	**
A179	−10.18	37.77	**
C926	−73.83	37.77	**
A264	−10.31	37.75	**
C934	−73.55	37.75	**
C925	−73.80	37.73	**
M1049	8.73	37.72	**
C929	−73.93	37.70	**
M1043	8.76	37.70	**
C924	−73.77	37.67	**
C933	−73.47	37.65	**
M1036	8.81	37.64	**
M1032	8.81	37.64	**
C930	−73.83	37.63	**
M1042	8.83	37.63	**
C920	−74.15	37.63	**
C921	−74.16	37.62	**
C931	−73.67	37.62	**
M1048	8.84	37.61	**
M1025	8.86	37.60	**
M1026	2.75	37.60	**
M1014	8.90	37.59	**
M1063	0.50	37.58	**
C912	−74.57	37.57	**

Table 1 (*continued*)

Station	Longitude [degrees_East]	Latitude [degrees_north]	Reference
C932	−73.58	37.55	**
M1055	−0.63	37.53	**
M1034	−0.63	37.53	**
M1047	−0.63	37.53	**
M1061	−0.64	37.47	**
M1058	−0.64	37.45	**
M1046	−0.65	37.40	**
M1019	9.20	37.34	**
M1016	9.21	37.30	**
M1059	−0.53	37.17	**
M1045	11.39	37.07	**
M1039	−0.49	37.05	**
C922	−74.58	36.87	**
M1013	12.33	36.83	**
M1018	2.66	36.78	**
A405	−9.85	36.76	**
M1022	2.64	36.74	**
M1007	−3.15	36.72	**
M1020	2.68	36.71	**
M1023	2.66	36.71	**
M1006	−3.13	36.70	**
M1015	2.70	36.70	**
M1008	−3.06	36.58	**
M1009	−3.00	36.48	**
M1010	−2.91	36.29	**
M1005	−4.30	36.20	**
M1012	−2.85	36.19	**
M1011	−2.85	36.08	**
M1064	−3.48	35.57	**
A184	−7.02	34.32	**
Q1098	−13.66	32.47	**
Q1096	−11.64	32.18	**
Q1097	−11.94	32.01	**
Q1095	−11.01	31.49	**
Q1094	−11.07	30.86	**
Q1093	−11.08	30.35	**
Q1099	−10.82	30.19	**
Q1102	−11.55	30.03	**
Q1101	−11.19	29.78	**
Q1103	−12.33	29.77	**
Q1100	−10.95	29.60	**
Q1105	−12.99	29.47	**
Q1108	−15.46	29.15	**
Q1104	−12.46	29.01	**
Q1106	−13.01	28.72	**
Q1107	−13.18	28.49	**
P1334	−112.77	25.33	**
P1332	−110.55	24.75	**
P1333	−110.62	24.74	**
P1330	−110.49	24.70	**
P1331	−110.38	24.70	**
P1329	−110.62	24.69	**
P1325	−110.38	24.64	**
P1326	−110.49	24.62	**
P1328	−110.72	24.62	**
P1327	−110.62	24.61	**
P1324	−110.49	24.56	**
P1322	−110.72	24.54	**
P1323	−110.61	24.54	**
P1337	−106.48	22.72	**
P1336	−107.32	22.19	**
P1335	−108.31	21.57	**
P1339	−105.94	20.62	**
P1340	−101.31	17.02	**
P1341	−99.81	16.41	**
P1350	−95.02	16.00	**
P1358	−94.60	16.00	**
P1351	−94.67	15.99	**
P1343	−95.51	15.80	**
P1352	−94.80	15.80	**
P1344	−95.32	15.79	**
P1349	−95.02	15.78	**
P1345	−95.32	15.70	**
P1342	−95.52	15.70	**
P1359	−94.41	15.62	**
P1356	−94.61	15.60	**
P1348	−95.01	15.60	**
P1353	−94.81	15.59	**
P1346	−95.34	15.58	**
P1363	−94.10	15.41	**
P1355	−94.60	15.40	**
P1354	−94.81	15.39	**
P1347	−95.01	15.36	**
P1362	−94.10	15.33	**
P1357	−94.60	15.30	**
P1364	−93.73	15.20	**
P1367	−93.34	15.12	**
P1360	−94.41	15.11	**
P1361	−94.10	15.11	**
P1368	−93.09	15.10	**
P1366	−93.34	15.02	**
P1365	−93.72	15.01	**
P1338	−93.69	14.82	**
P1369	−93.33	14.76	**
FR10/95 GC-1	128.00	−12.04	***
FR10/95 GC-2	126.25	−12.55	***
FR10/95 GC-3	124.00	−13.24	***
FR10/95 GC-4	122.03	−13.92	***
FR10/95 GC-5	121.03	−14.01	***
FR10/95 GC-6	121.16	−14.33	***
FR10/95 GC-7	120.55	−14.71	***
FR10/95 GC-8	120.96	−14.92	***
FR10/95 GC-9	118.02	−18.13	***
FR10/95 GC-10	116.02	−18.15	***
FR10/95 GC-11	115.00	−17.64	***
FR10/95 GC-12	114.99	−18.25	***
FR10/95 GC-13	113.97	−18.82	***
FR10/95 GC-14	112.66	−20.05	***
FR10/95 GC-16	112.99	−21.00	***
FR10/95 GC-17	113.50	−22.13	***
FR10/95 GC-18	112.83	−22.99	***
FR10/95 GC-20	111.83	−24.74	***
FR10/95 GC-21	111.63	−26.00	***
FR10/95 GC-22	112.01	−26.99	***
FR10/95 GC-23	112.78	−28.75	***
FR10/95 GC-24	113.06	−28.75	***
FR10/95 GC-25	113.37	−28.73	***
FR10/95 GC-26	113.56	−29.24	***
FR10/95 GC-27	114.28	−30.50	***
FR10/95 GC-28	114.14	−30.08	***
FR10/95 GC-29	114.59	−30.99	***
FR2/96 GC-1	114.55	−31.11	***
FR2/96 GC-2	112.95	−29.35	***
FR2/96 GC-3	112.94	−29.30	***
FR2/96 GC-4	113.39	−28.72	***
FR2/96 GC-5	113.16	−28.39	***
FR2/96 GC-6	112.29	−28.42	***
FR2/96 GC-7	111.34	−26.98	***
FR2/96 GC-19	114.28	−12.38	***
FR2/96 GC-21	114.27	−14.81	***
FR2/96 GC-25	115.27	−16.91	***
FR2/96 GC-26	115.52	−16.90	***
FR2/96 GC-27	116.27	−18.56	***
FR2/96 GC-28	116.34	−18.80	***
FR2/96 GC-29	116.39	−18.96	***
SHI-9011	122.38	−7.45	***
SHI-9013	125.09	−6.43	***
SHI-9014	126.97	−5.78	***
SHI-9016	128.24	−8.46	***
SHI-9017	128.28	−8.99	***
SHI-9018	126.08	−8.10	***
SHI-9019	122.82	−8.72	***
SHI-9020	121.97	−10.99	***
SHI-9022	122.06	−11.59	***
SHI-9025	118.66	−10.40	***
SHI-9028	114.96	−10.52	***
SHI-9029	116.68	−9.25	***
SHI-9034	111.01	−9.16	***
SHI-9035	111.39	−8.71	***
SHI-9037	108.35	−8.92	***
SHI-9038	108.11	−9.30	***

(*continued on next page*)

Table 1 (*continued*)

Station	Longitude [degrees_East]	Latitude [degrees_north]	Reference
SHI-9039	107.91	−9.43	***
SHI-9040	107.46	−7.69	***
SHI-9041	107.12	−7.78	***
SHI-9042	106.72	−8.04	***
SHI-9043	104.54	−7.33	***
SHI-9045	101.90	−5.65	***
SHI-9047	102.13	−4.99	***
SHI-9048	107.66	−5.54	***
B-9403	103.62	−5.49	***
B-9407	96.83	−0.44	***
B-9409	96.67	1.54	***
B-9411	97.61	−0.46	***
B-9412	97.90	−0.82	***
B-9415	98.19	0.84	***
B-9420	93.45	3.54	***
B-9422	93.74	5.18	***
B-9426	94.39	5.90	***
B-9427	94.31	5.34	***
B-9429	94.77	3.29	***
B-9430	96.06	1.94	***
B-9431	96.24	1.74	***
B-9432	97.30	0.41	***
B-9433	99.69	−1.37	***
B-9434	98.46	−1.75	***
B-9435	98.36	−1.72	***
B-9436	96.27	−1.63	***
B-9437	96.35	−1.52	***
B-9438	97.74	−2.91	***
B-9439	99.99	−3.32	***
B-9440	100.02	−3.17	***
B-9441	101.85	−5.11	***
B-9450	104.97	−6.03	***
B-9451	104.84	−6.23	***
B-9452	104.99	−6.34	***
U2278	17.90	−32.40	Holzwarth et al., 2010
U2282	17.10	−32.49	Holzwarth et al., 2010
U2340	18.02	−31.93	Holzwarth et al., 2010
U2341	18.21	−31.93	Holzwarth et al., 2010
U2682	17.31	−30.46	Holzwarth et al., 2010
U2684	16.93	−30.55	Holzwarth et al., 2010
U2687	16.55	−30.57	Holzwarth et al., 2010
U2727	14.60	−30.10	Holzwarth et al., 2010
U2736	15.42	−29.95	Holzwarth et al., 2010
U2753	15.83	−29.78	Holzwarth et al., 2010
U2861	16.42	−29.63	Holzwarth et al., 2010
U2865	16.93	−29.63	Holzwarth et al., 2010
U3091	18.12	−32.73	Holzwarth et al., 2010
U3175	13.40	−27.20	Holzwarth et al., 2010
U3177	13.72	−27.03	Holzwarth et al., 2010
U3179	14.10	−27.03	Holzwarth et al., 2010
U3183	14.67	−26.95	Holzwarth et al., 2010
U3255	13.78	−26.22	Holzwarth et al., 2010
U3292	17.01	−29.69	Holzwarth et al., 2010
U3318	18.01	−31.51	Holzwarth et al., 2010
U3347	15.03	−31.05	Holzwarth et al., 2010
U3457	13.40	−24.10	Holzwarth et al., 2010
U3513	14.39	−22.94	Holzwarth et al., 2010
U3540	14.40	−23.10	Holzwarth et al., 2010
U3634	16.44	−28.97	Holzwarth et al., 2010
U3639	16.44	−28.80	Holzwarth et al., 2010
U3651	16.08	−28.37	Holzwarth et al., 2010
U3664	11.39	−17.26	Holzwarth et al., 2010
U3666	11.06	−17.26	Holzwarth et al., 2010
U3674	11.70	−17.94	Holzwarth et al., 2010
U3700	10.72	−18.92	Holzwarth et al., 2010
U3807	13.61	−21.25	Holzwarth et al., 2010
U3816	12.58	−21.25	Holzwarth et al., 2010
U3820	11.80	−21.27	Holzwarth et al., 2010
U3821	11.63	−20.92	Holzwarth et al., 2010
U3844	12.23	−20.58	Holzwarth et al., 2010
U3883	11.40	−17.07	Holzwarth et al., 2010
U3884	11.12	−17.57	Holzwarth et al., 2010
U3885	11.28	−17.57	Holzwarth et al., 2010
U3886	11.45	−17.57	Holzwarth et al., 2010
U3889	11.57	−17.53	Holzwarth et al., 2010
U3901	11.33	−18.38	Holzwarth et al., 2010
U3902	11.50	−18.38	Holzwarth et al., 2010
U3908	11.87	−18.40	Holzwarth et al., 2010
U3917	11.53	−18.93	Holzwarth et al., 2010
U3918	11.32	−18.92	Holzwarth et al., 2010
U4649	16.56	−28.92	Holzwarth et al., 2010
U4668	16.03	−28.54	Holzwarth et al., 2010
U4687	14.45	−22.58	Holzwarth et al., 2010
U4724	12.36	−18.88	Holzwarth et al., 2010
u4741	11.70	−17.07	Holzwarth et al., 2010
U4804	12.67	−24.15	Holzwarth et al., 2010
U6314	15.99	−28.84	Holzwarth et al., 2010
U6320	15.80	−28.81	Holzwarth et al., 2010
GeoB4024-1	−13.43	27.68	Holzwarth et al., 2007
GeoB4025-2	−13.49	27.75	Holzwarth et al., 2007
GeoB4026-1	−13.54	27.81	Holzwarth et al., 2007
GeoB4213-1	−11.08	29.70	Holzwarth et al., 2007
GeoB4216-2	−12.40	30.63	Holzwarth et al., 2007
GeoB4225-3	−11.78	29.28	Holzwarth et al., 2007
GeoB4226-1	−11.83	29.32	Holzwarth et al., 2007
GeoB4230-1	−12.60	29.13	Holzwarth et al., 2007
GeoB4231-2	−12.56	29.09	Holzwarth et al., 2007
GeoB4233-2	−13.33	28.98	Holzwarth et al., 2007
GeoB4236-2	−13.10	28.78	Holzwarth et al., 2007
GeoB5530-3	−17.90	29.30	Holzwarth et al., 2007
GeoB5533-1	−17.69	27.68	Holzwarth et al., 2007
GeoB5536-3	−16.14	27.54	Holzwarth et al., 2007
GeoB5539-2	−14.36	27.54	Holzwarth et al., 2007
GeoB5540-3	−14.18	27.54	Holzwarth et al., 2007
GeoB5548-3	−13.52	27.99	Holzwarth et al., 2007
GeoB5549-2	−13.70	27.98	Holzwarth et al., 2007
GeoB5553-2	−14.65	28.28	Holzwarth et al., 2007
GeoB6005-1	−10.90	30.88	Holzwarth et al., 2007
GeoB6006-2	−10.63	30.87	Holzwarth et al., 2007
GeoB6007-1	−10.27	30.85	Holzwarth et al., 2007
GeoB6008-2	−10.10	30.85	Holzwarth et al., 2007
GeoB6009-1	−10.28	30.68	Holzwarth et al., 2007
GeoB6010-1	−10.08	30.25	Holzwarth et al., 2007
GeoB6011-2	−10.29	30.32	Holzwarth et al., 2007
GeoB7413-2	−17.85	20.65	Holzwarth et al., 2007
GeoB7414-1	−18.00	20.72	Holzwarth et al., 2007
GeoB7415-1	−18.26	20.81	Holzwarth et al., 2007
GeoB7420-1	−16.79	24.17	Holzwarth et al., 2007
GeoB7423-2	−17.07	24.34	Holzwarth et al., 2007
GeoB7424-1	−16.84	24.21	Holzwarth et al., 2007
S-Y1	127.82	34.93	Kim et al., 2009
S-Y2	127.81	34.91	Kim et al., 2009
S-Y3	127.80	34.90	Kim et al., 2009
S-Y4	127.79	34.88	Kim et al., 2009
S-Y5	127.78	34.88	Kim et al., 2009
S-Y6	127.75	34.89	Kim et al., 2009
S-Y7	127.72	34.91	Kim et al., 2009
S-Y8	127.69	34.90	Kim et al., 2009
S-Y9	127.67	34.89	Kim et al., 2009
S-Y10	127.68	34.88	Kim et al., 2009
S-Y11	127.62	34.89	Kim et al., 2009
S-Y12	127.62	34.86	Kim et al., 2009
S-Y13	127.65	34.86	Kim et al., 2009
S-Y14	127.67	34.85	Kim et al., 2009
S-Y15	127.74	34.87	Kim et al., 2009
S-Y16	127.79	34.86	Kim et al., 2009
S-Y17	127.81	34.89	Kim et al., 2009
S-Y18	127.84	34.91	Kim et al., 2009
S-Y19	127.83	34.92	Kim et al., 2009
S-Y20	127.85	34.94	Kim et al., 2009
KG1	9.35	58.86	Grøsfjeld and Harland, 2001
KG2	9.09	58.73	Grøsfjeld and Harland, 2001
KG3	8.85	58.48	Grøsfjeld and Harland, 2001
KG4	8.61	58.35	Grøsfjeld and Harland, 2001
KG5	8.00	58.13	Grøsfjeld and Harland, 2001
KG6	7.81	58.07	Grøsfjeld and Harland, 2001
KG7	7.14	58.08	Grøsfjeld and Harland, 2001
KG8	7.07	58.05	Grøsfjeld and Harland, 2001
KG9	7.80	58.09	Grøsfjeld and Harland, 2001
KG10	6.66	58.28	Grøsfjeld and Harland, 2001
KG11	6.26	58.34	Grøsfjeld and Harland, 2001
KG12	5.99	58.44	Grøsfjeld and Harland, 2001

Table 1 (*continued*)

Station	Longitude [degrees_East]	Latitude [degrees_north]	Reference
KG13	5.73	58.98	Grøsfjeld and Harland, 2001
KG14	5.40	59.17	Grøsfjeld and Harland, 2001
KG15	5.30	59.36	Grøsfjeld and Harland, 2001
KG16	5.46	59.63	Grøsfjeld and Harland, 2001
KG17	5.26	59.80	Grøsfjeld and Harland, 2001
KG18	5.17	60.11	Grøsfjeld and Harland, 2001
KG19	5.32	60.40	Grøsfjeld and Harland, 2001
KG20	5.09	60.52	Grøsfjeld and Harland, 2001
KG21	4.90	60.71	Grøsfjeld and Harland, 2001
KG22	5.00	61.00	Grøsfjeld and Harland, 2001
KG23	5.21	61.16	Grøsfjeld and Harland, 2001
KG24	5.06	61.41	Grøsfjeld and Harland, 2001
KG25	5.17	61.73	Grøsfjeld and Harland, 2001
KG26	5.16	61.85	Grøsfjeld and Harland, 2001
KG27	5.41	62.02	Grøsfjeld and Harland, 2001
KG28	6.15	62.47	Grøsfjeld and Harland, 2001
KG29	6.60	62.60	Grøsfjeld and Harland, 2001
KG30	7.10	62.84	Grøsfjeld and Harland, 2001
KG31	7.72	63.10	Grøsfjeld and Harland, 2001
KG32	9.16	63.48	Grøsfjeld and Harland, 2001
GS1	−123.31	49.19	Radi et al., 2007
GS2	−123.30	49.23	Radi et al., 2007
GS3	−123.29	49.26	Radi et al., 2007
GS4	−123.38	49.14	Radi et al., 2007
GS5	−123.37	49.18	Radi et al., 2007
GS6	−123.44	49.12	Radi et al., 2007
GS7	−123.43	49.20	Radi et al., 2007
GS8	−123.37	49.21	Radi et al., 2007
GS9	−123.37	49.24	Radi et al., 2007
GS10	−123.44	49.25	Radi et al., 2007
GS11	−123.44	49.23	Radi et al., 2007
GS12	−123.45	49.22	Radi et al., 2007
GS13	−123.34	49.09	Radi et al., 2007
GS14	−123.05	48.89	Radi et al., 2007
GS15	−123.10	48.84	Radi et al., 2007
GS16	−123.06	48.93	Radi et al., 2007
GS17	−123.50	49.15	Radi et al., 2007
GS18	−123.47	49.24	Radi et al., 2007
GS19	−123.47	49.28	Radi et al., 2007
GS20	−123.16	49.29	Radi et al., 2007
GS21	−123.23	49.31	Radi et al., 2007
GS22	−123.29	49.32	Radi et al., 2007
GS23	−123.35	49.32	Radi et al., 2007
GS24	−123.47	49.33	Radi et al., 2007
GS25	−123.31	49.29	Radi et al., 2007
GS26	−123.38	49.29	Radi et al., 2007
GS27	−123.34	49.00	Radi et al., 2007
GS28	−123.47	49.01	Radi et al., 2007
GS29	−123.24	48.88	Radi et al., 2007
GS31	−123.19	49.30	Radi et al., 2007
GS32	−123.29	49.33	Radi et al., 2007
GS33	−123.75	49.37	Radi et al., 2007
GS34	−123.75	49.21	Radi et al., 2007
GS35	−123.78	49.18	Radi et al., 2007
GS36	−123.71	49.17	Radi et al., 2007
GS37	−123.63	49.12	Radi et al., 2007
GS38	−123.56	49.14	Radi et al., 2007
GS39	−123.57	49.12	Radi et al., 2007
GS40	−123.32	48.91	Radi et al., 2007
EFF1	−125.18	49.09	Radi et al., 2007
EFF2	−125.18	49.09	Radi et al., 2007
EFF3	−125.18	49.09	Radi et al., 2007
EFF4	−125.18	49.09	Radi et al., 2007
EFF5	−125.18	49.09	Radi et al., 2007
EFF6	−125.16	49.07	Radi et al., 2007
EFF7	−125.16	49.07	Radi et al., 2007
EFF8	−125.15	49.06	Radi et al., 2007
EFF9	−125.15	49.06	Radi et al., 2007
EFF10	−125.16	49.05	Radi et al., 2007
EFF11	−125.16	49.05	Radi et al., 2007
EFF12	−125.15	49.05	Radi et al., 2007
EFF13	−125.16	49.02	Radi et al., 2007
EFF14	−125.16	49.02	Radi et al., 2007
SB1	−126.72	51.04	Radi et al., 2007
SB2	−126.71	51.02	Radi et al., 2007
SB3	−126.71	51.01	Radi et al., 2007
SB4	−126.95	51.17	Radi et al., 2007
SB5	−127.04	51.17	Radi et al., 2007
SB6	−127.35	51.20	Radi et al., 2007
Taou-E39	−93.69	14.82	Vásquez-Bedoya et al., 2008
Taou-E1	−95.52	15.70	Vásquez-Bedoya et al., 2008
Taou-E2	−95.51	15.80	Vásquez-Bedoya et al., 2008
Taou-E3	−95.32	15.79	Vásquez-Bedoya et al., 2008
Taou-E4	−95.32	15.70	Vásquez-Bedoya et al., 2008
Taou-E5	−95.34	15.58	Vásquez-Bedoya et al., 2008
Taou-E6	−95.01	15.36	Vásquez-Bedoya et al., 2008
Taou-E7	−95.01	15.60	Vásquez-Bedoya et al., 2008
Taou-E8	−95.02	15.78	Vásquez-Bedoya et al., 2008
Taou-E9	−95.02	16.00	Vásquez-Bedoya et al., 2008
Taou-E10	−94.67	15.99	Vásquez-Bedoya et al., 2008
Taou-E11	−94.80	15.80	Vásquez-Bedoya et al., 2008
Taou-E12	−94.81	15.59	Vásquez-Bedoya et al., 2008
Taou-E13	−94.81	15.39	Vásquez-Bedoya et al., 2008
Taou-E18	−94.60	15.40	Vásquez-Bedoya et al., 2008
Taou-E17	−94.61	15.60	Vásquez-Bedoya et al., 2008
Taou-E15	−94.60	15.30	Vásquez-Bedoya et al., 2008
Taou-E20	−94.60	16.00	Vásquez-Bedoya et al., 2008
Taou-E21	−94.41	15.62	Vásquez-Bedoya et al., 2008
Taou-E23	−94.41	15.11	Vásquez-Bedoya et al., 2008
Taou-E24	−94.10	15.11	Vásquez-Bedoya et al., 2008
Taou-E25	−94.10	15.33	Vásquez-Bedoya et al., 2008
Taou-E26	−94.10	15.41	Vásquez-Bedoya et al., 2008
Taou-E30	−93.73	15.20	Vásquez-Bedoya et al., 2008
Taou-E31	−93.72	15.01	Vásquez-Bedoya et al., 2008
Taou-E32	−93.34	15.02	Vásquez-Bedoya et al., 2008
Taou-E33	−93.34	15.12	Vásquez-Bedoya et al., 2008
Taou-E35	−93.09	15.10	Vásquez-Bedoya et al., 2008
Taou-E38	−93.33	14.76	Vásquez-Bedoya et al., 2008
GeoB 9501	−16.73	16.84	Boumetarhan et al., 2009
GeoB 9502	−16.67	16.28	Boumetarhan et al., 2009
GeoB 9503	−16.65	16.07	Boumetarhan et al., 2009
GeoB 9504	−16.68	15.88	Boumetarhan et al., 2009
GeoB 9505	−16.73	15.68	Boumetarhan et al., 2009
GeoB 9506	−18.35	15.61	Boumetarhan et al., 2009
GeoB 9508	−17.95	15.50	Boumetarhan et al., 2009
GeoB 9510	−17.65	15.42	Boumetarhan et al., 2009
GeoB 9512	−17.37	15.34	Boumetarhan et al., 2009
GeoB 9513	−17.30	15.32	Boumetarhan et al., 2009
GeoB 9515	−17.05	15.27	Boumetarhan et al., 2009
GeoB 9516	−18.42	13.67	Boumetarhan et al., 2009
GeoB 9517	−18.19	13.72	Boumetarhan et al., 2009
GeoB 9518	−17.79	13.79	Boumetarhan et al., 2009
GeoB 9519	−17.68	13.81	Boumetarhan et al., 2009
GeoB 9520	−17.59	13.83	Boumetarhan et al., 2009
GeoB 9521	−17.49	13.85	Boumetarhan et al., 2009
GeoB 9522	−17.45	13.86	Boumetarhan et al., 2009
GeoB 9525	−17.88	12.64	Boumetarhan et al., 2009
GeoB 9526	−18.06	12.44	Boumetarhan et al., 2009
GeoB 9527	−18.22	12.43	Boumetarhan et al., 2009
GeoB 9528	−17.66	9.17	Boumetarhan et al., 2009
GeoB 9529	−17.37	9.35	Boumetarhan et al., 2009
GeoB 9531	−16.90	8.94	Boumetarhan et al., 2009
GeoB 9532	−14.89	8.95	Boumetarhan et al., 2009
GeoB 9533	−14.91	8.93	Boumetarhan et al., 2009
GeoB 9534	−14.94	8.90	Boumetarhan et al., 2009
GeoB 9535	−14.96	8.88	Boumetarhan et al., 2009
GeoB 9536	−15.13	8.71	Boumetarhan et al., 2009
GeoB 9537	−15.22	8.60	Boumetarhan et al., 2009
GeoB 9538	−15.83	8.71	Boumetarhan et al., 2009
GeoB 9539	−13.73	9.02	Boumetarhan et al., 2009
GeoB 9544	−17.07	12.38	Boumetarhan et al., 2009
GeoB 9545	−17.08	12.85	Boumetarhan et al., 2009
GeoB 9546	−17.09	13.45	Boumetarhan et al., 2009
Reh70-1 (sum)	24.70	33.70	Elshanawany et al., 2010
Reh71-1 (sum)	23.18	34.80	Elshanawany et al., 2010
Reh77a-1	16.15	37.00	Elshanawany et al., 2010
Reh77b-1	16.00	37.38	Elshanawany et al., 2010
Reh73-2	18.97	39.52	Elshanawany et al., 2010
Reh76-5	21.50	35.22	Elshanawany et al., 2010
Reh83-1	3.48	42.45	Elshanawany et al., 2010
Reh78-2	13.18	37.30	Elshanawany et al., 2010

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Table 1 (*continued*)

Station	Longitude [degrees_East]	Latitude [degrees_north]	Reference
Reh66-2	25.90	35.60	Elshanawany et al., 2010
Reh65-1	25.55	36.13	Elshanawany et al., 2010
Reh69-1	24.85	33.85	Elshanawany et al., 2010
Reh67-3	27.28	34.80	Elshanawany et al., 2010
Reh75-1	22.67	35.80	Elshanawany et al., 2010
Reh68-3	27.27	34.68	Elshanawany et al., 2010
Reh74-1	18.98	39.93	Elshanawany et al., 2010
Reh88-1	4.60	38.93	Elshanawany et al., 2010
Reh86-1	2.83	41.20	Elshanawany et al., 2010
Reh90-1	1.93	36.20	Elshanawany et al., 2010
Reh89-2	5.33	38.75	Elshanawany et al., 2010
Reh5845 (sum)	34.15	32.32	Elshanawany et al., 2010
Reh5847-1	34.15	32.82	Elshanawany et al., 2010
Reh572-2	34.63	32.73	Elshanawany et al., 2010
Reh570	32.98	33.52	Elshanawany et al., 2010
Reh577-1 (sum)	28.50	35.90	Elshanawany et al., 2010
Reh560-1	14.10	35.85	Elshanawany et al., 2010
Reh575-6	31.78	34.52	Elshanawany et al., 2010
Reh566-3	25.65	34.47	Elshanawany et al., 2010
Reh561	12.98	35.78	Elshanawany et al., 2010
Reh576-3	30.45	35.57	Elshanawany et al., 2010
Reh564-2	23.62	33.00	Elshanawany et al., 2010
Reh565-1	23.73	34.92	Elshanawany et al., 2010
Reh569-3	32.57	33.45	Elshanawany et al., 2010
Reh574-2	33.85	34.43	Elshanawany et al., 2010
Reh562-5	19.18	32.77	Elshanawany et al., 2010
L21204	175.53	−33.18	Crough et al., 2010
L21205	174.15	−33.65	Crough et al., 2010
L21206	173.51	−34.02	Crough et al., 2010
L21207	173.04	−34.19	Crough et al., 2010
L21208	178.00	−34.91	Crough et al., 2010
L21209	177.95	−35.98	Crough et al., 2010
L21210	177.47	−35.94	Crough et al., 2010
L21211	176.80	−36.32	Crough et al., 2010
L21212	176.24	−36.69	Crough et al., 2010
L21213	183.59	−39.46	Crough et al., 2010
L21214	181.51	−39.94	Crough et al., 2010
L21215	179.99	−40.33	Crough et al., 2010
L21216	177.99	−40.40	Crough et al., 2010
L21217	188.90	−41.58	Crough et al., 2010
L21218	186.00	−43.20	Crough et al., 2010
L21219	181.51	−42.53	Crough et al., 2010
L21220	179.36	−42.22	Crough et al., 2010
L21221	176.91	−42.72	Crough et al., 2010
L21222	175.57	−43.02	Crough et al., 2010
L21223	174.50	−43.00	Crough et al., 2010
L21224	173.36	−43.33	Crough et al., 2010
L21225	185.92	−45.33	Crough et al., 2010
L21226	179.51	−45.08	Crough et al., 2010
L21227	178.00	−44.13	Crough et al., 2010
L21228	174.98	−44.29	Crough et al., 2010
L21229	172.65	−44.35	Crough et al., 2010
L21230	172.69	−45.34	Crough et al., 2010
L21231	182.08	−46.60	Crough et al., 2010
L21232	180.76	−46.45	Crough et al., 2010
L21234	176.49	−46.08	Crough et al., 2010
L21235	175.06	−45.96	Crough et al., 2010
L21236	174.08	−47.04	Crough et al., 2010
L21237	182.01	−49.67	Crough et al., 2010
L21238	174.98	−48.95	Crough et al., 2010
L21239	170.81	−48.67	Crough et al., 2010
L21240	169.87	−53.63	Crough et al., 2010
L21241	167.83	−51.72	Crough et al., 2010
CP04	51.61	38.72	*****
CP14	51.40	39.27	*****
CP18	51.10	41.47	*****
GS18	51.10	41.47	*****
CP21	49.58	42.84	*****
US02	51.48	39.27	*****
GS05	51.54	38.81	*****
AS17−5	60.69	46.52	*****
St1B	−73.28	−52.78	Verleye and Louwye, 2010
St2A	−73.29	−52.79	Verleye and Louwye, 2010
St3A	−73.26	−52.75	Verleye and Louwye, 2010
St4A	−73.48	−52.78	Verleye and Louwye, 2010
St5A	−73.65	−52.79	Verleye and Louwye, 2010

Table 1 (*continued*)

Station	Longitude [degrees_East]	Latitude [degrees_north]	Reference
ODP 1232c	−75.90	−39.88	Verleye and Louwye, 2010
ODP1233b	−74.45	−41.00	Verleye and Louwye, 2010
ODP1234a	−73.68	−36.22	Verleye and Louwye, 2010
ODP1235a	−73.57	−36.15	Verleye and Louwye, 2010
FD75-3 01	−72.72	−32.96	Verleye and Louwye, 2010
FD75-3 03	−72.63	−30.57	Verleye and Louwye, 2010
FD75-3 04	−71.93	−27.47	Verleye and Louwye, 2010
M8011-1	−71.54	−25.70	Verleye and Louwye, 2010
M8011-2	−72.02	−27.91	Verleye and Louwye, 2010
M8011-3	−72.32	−29.28	Verleye and Louwye, 2010
M8011-4	−75.59	−42.11	Verleye and Louwye, 2010
M8011-5	−75.45	−42.07	Verleye and Louwye, 2010
M8011-7	−75.74	−42.07	Verleye and Louwye, 2010
M8011-8	−75.81	−42.04	Verleye and Louwye, 2010
M8011-9	−75.68	−41.97	Verleye and Louwye, 2010
M8011-10	−75.54	−42.08	Verleye and Louwye, 2010
M8011-11	−75.24	−40.48	Verleye and Louwye, 2010
M8011-12	−75.15	−40.50	Verleye and Louwye, 2010
M8011-13	−75.17	−39.66	Verleye and Louwye, 2010
M8011-14	−75.19	−39.66	Verleye and Louwye, 2010
M8011-15	−75.25	−39.67	Verleye and Louwye, 2010
M8011-16	−74.98	−39.75	Verleye and Louwye, 2010
M8011-17	−74.65	−36.90	Verleye and Louwye, 2010
M8011-18	−74.42	−36.85	Verleye and Louwye, 2010
M8011-19	−74.49	−36.87	Verleye and Louwye, 2010
M8011-20	−72.70	−32.52	Verleye and Louwye, 2010
M8011-21	−72.50	−33.01	Verleye and Louwye, 2010
RR9702A-01	−76.96	−50.65	Verleye and Louwye, 2010
RR9702A-06	−76.60	−46.88	Verleye and Louwye, 2010
RR9702A-08	−76.67	−46.35	Verleye and Louwye, 2010
RR9702A-10	−76.54	−46.32	Verleye and Louwye, 2010
RR9702A-12	−76.25	−43.42	Verleye and Louwye, 2010
RR9702A-14	−76.48	−43.54	Verleye and Louwye, 2010
RR9702A-20	−74.47	−39.97	Verleye and Louwye, 2010
RR9702A-22	−74.12	−40.01	Verleye and Louwye, 2010
RR9702A-27	−75.92	−40.48	Verleye and Louwye, 2010
RR9702A-29	−75.75	−37.85	Verleye and Louwye, 2010
RR9702A-31	−75.43	−37.67	Verleye and Louwye, 2010
RR9702A-34	−73.45	−36.53	Verleye and Louwye, 2010
RR9702A-39	−73.57	−36.17	Verleye and Louwye, 2010
RR9702A-42	−73.68	−36.17	Verleye and Louwye, 2010
RR9702A-44	−73.01	−35.76	Verleye and Louwye, 2010
RR9702A-46	−73.53	−33.28	Verleye and Louwye, 2010
KM1	90.19	−0.45	Marret and Zonneveld, 2003
KM2	90.19	−0.45	Marret and Zonneveld, 2003
KM3	90.19	−0.45	Marret and Zonneveld, 2003
KM5	90.19	−0.45	Marret and Zonneveld, 2003
KMDA2	122.50	32.00	Wang et al., 2004a
KMDA4	123.50	32.00	Wang et al., 2004a
KMDB6	122.50	31.50	Wang et al., 2004a
KMDC9	122.00	31.00	Wang et al., 2004a
KMDC10	122.50	31.00	Wang et al., 2004a
KMDC11	123.00	31.00	Wang et al., 2004a
KMDD14	122.50	30.50	Wang et al., 2004a
KMDD15	123.00	30.50	Wang et al., 2004a
KMDE17	122.00	30.00	Wang et al., 2004a
KMDE18	122.50	30.00	Wang et al., 2004a
KMDD19	123.00	30.00	Wang et al., 2004a
KMDG26	122.50	29.00	Wang et al., 2004a
18269-1	109.43	4.77	Kawamura, 2004
18270-1	109.47	4.72	Kawamura, 2004
18271-1	109.54	4.63	Kawamura, 2004
18272-1	109.56	4.63	Kawamura, 2004
18273-1	109.56	4.62	Kawamura, 2004
18274-1	109.58	4.60	Kawamura, 2004
18275-1	109.59	4.59	Kawamura, 2004
18276-1	109.74	4.74	Kawamura, 2004
18277-1	109.93	4.93	Kawamura, 2004
18279-1	110.04	5.03	Kawamura, 2004
18280-1	110.10	5.09	Kawamura, 2004
18281-1	110.13	5.13	Kawamura, 2004
18282-1	110.24	5.24	Kawamura, 2004
18283-1	110.42	5.42	Kawamura, 2004
18284-1	110.53	5.54	Kawamura, 2004
18284-1	110.53	5.53	Kawamura, 2004
18285-1	110.57	5.56	Kawamura, 2004

Table 1 (*continued*)

Station	Longitude [degrees_East]	Latitude [degrees_north]	Reference
18286-1	110.60	5.60	Kawamura, 2004
18287-1	110.66	5.66	Kawamura, 2004
18288-1	110.73	5.73	Kawamura, 2004
18289-1	110.83	5.83	Kawamura, 2004
18290-1	110.91	5.92	Kawamura, 2004
18291-1	110.96	5.96	Kawamura, 2004
18292-1	111.06	6.06	Kawamura, 2004
18293-1	111.15	6.15	Kawamura, 2004
18294-1	111.30	6.13	Kawamura, 2004
18295-3	109.29	4.93	Kawamura, 2004
18296-1	109.23	4.99	Kawamura, 2004
18297-1	109.03	4.73	Kawamura, 2004
18300-1	108.65	4.36	Kawamura, 2004
18301-1	108.64	4.35	Kawamura, 2004
18302-1	108.57	4.16	Kawamura, 2004
18303-1	108.93	4.43	Kawamura, 2004
18304-1	109.00	4.36	Kawamura, 2004
18305-1	109.08	4.28	Kawamura, 2004
18306-1	108.44	3.58	Kawamura, 2004
18307-1	108.53	3.63	Kawamura, 2004
18308-1	108.78	3.29	Kawamura, 2004
18309-1	108.68	3.46	Kawamura, 2004
18310-1	108.53	3.52	Kawamura, 2004
18312-1	108.70	3.70	Kawamura, 2004
18313-1	108.87	3.87	Kawamura, 2004
18314-1	108.98	3.98	Kawamura, 2004
18315-1	107.03	2.03	Kawamura, 2004
18316-1	107.38	2.48	Kawamura, 2004
18317-1	107.38	2.61	Kawamura, 2004
18318-1	105.38	2.61	Kawamura, 2004
18319-1	107.38	2.61	Kawamura, 2004
18321-1	107.42	2.30	Kawamura, 2004
18322-1	107.63	2.30	Kawamura, 2004
18293-1	107.88	2.78	Kawamura, 2004
KMO1	131.78	43.03	Orlova et al., 2004
KMO2	130.84	42.54	Orlova et al., 2004
KMO3	130.82	42.62	Orlova et al., 2004
KMO4	130.93	42.55	Orlova et al., 2004
KMO5	130.83	42.65	Orlova et al., 2004
KMO6	130.78	42.67	Orlova et al., 2004
KMO7	131.13	42.62	Orlova et al., 2004
KMO8	130.93	42.59	Orlova et al., 2004
KMO9	130.86	42.60	Orlova et al., 2004
KMO10	131.83	43.25	Orlova et al., 2004
KMO11	131.87	43.07	Orlova et al., 2004
KMO12	131.99	43.08	Orlova et al., 2004
KMO13	132.77	42.83	Orlova et al., 2004
KMO14	133.00	42.75	Orlova et al., 2004
KMO15	133.81	42.82	Orlova et al., 2004
KMO16	133.86	42.88	Orlova et al., 2004
KMO17	135.24	43.67	Orlova et al., 2004
KMO18	135.83	44.35	Orlova et al., 2004
KMO19	142.43	46.58	Orlova et al., 2004
KMO20	142.43	46.58	Orlova et al., 2004
KMO21	142.69	46.63	Orlova et al., 2004
KMO22	142.38	46.41	Orlova et al., 2004
KMO23	142.87	46.61	Orlova et al., 2004
KMO24	143.12	46.87	Orlova et al., 2004
KMO25	143.57	52.71	Orlova et al., 2004
KMO26	143.56	52.71	Orlova et al., 2004
KMO27	143.73	52.73	Orlova et al., 2004
KMO28	158.58	53.03	Orlova et al., 2004
KMO29	158.60	53.02	Orlova et al., 2004
KMO30	158.60	53.00	Orlova et al., 2004
KMO31	164.28	59.11	Orlova et al., 2004
KMO32	164.28	59.23	Orlova et al., 2004
KMO33	166.80	60.22	Orlova et al., 2004
KMO34	167.06	60.43	Orlova et al., 2004
KMO35	170.63	60.35	Orlova et al., 2004
KMO36	171.70	60.43	Orlova et al., 2004
KMO37	172.11	61.02	Orlova et al., 2004
KMO38	172.26	61.12	Orlova et al., 2004
KMO39	172.91	61.44	Orlova et al., 2004
KMO40	−172.52	64.64	Orlova et al., 2004
KMO41	−173.15	64.77	Orlova et al., 2004
KMO42	−169.82	66.17	Orlova et al., 2004

Table 1 (*continued*)

Station	Longitude [degrees_East]	Latitude [degrees_north]	Reference
KMO43	−170.52	65.85	Orlova et al., 2004
KMO44	−170.88	65.63	Orlova et al., 2004
KMW1	113.78	22.20	Wang et al., 2004c
KMW2	113.87	22.45	Wang et al., 2004c
KMW3	114.28	22.57	Wang et al., 2004c
KMW4	114.53	22.58	Wang et al., 2004c
KMW5	114.52	22.67	Wang et al., 2004c
KMW6	117.03	23.48	Wang et al., 2004c
KMW7	117.06	23.53	Wang et al., 2004c
KMW8	123.00	29.98	Wang et al., 2004c
KMW9	120.27	36.13	Wang et al., 2004c
KMW10	120.47	37.50	Wang et al., 2004c
MC613	14.11	35.86	****
MC614	13.00	35.81	****
MC615	19.20	32.78	****
MC616	23.50	33.72	****
MC617	23.64	33.00	****
MC624	33.93	34.31	****
CHS	12.40	45.09	****
CH3	12.88	45.00	****
CH37	12.53	44.54	****
CH38	12.42	44.54	****
CH47	12.88	44.54	****
CH50	12.77	44.54	****
CH51	12.64	44.54	****
CH52	12.65	44.07	****
CH55	12.64	44.71	****
CH56	12.76	44.70	****
CH61	12.88	44.79	****
CH63	12.07	44.79	****
CH64	12.53	44.79	****
CH67	12.65	44.87	****
AN4b	13.42	44.00	****
AN6b	13.25	43.84	****
AN10	13.37	43.89	****
AN19	13.37	43.78	****
AN32	13.60	43.87	****
AN33	13.68	43.84	****
AN35	13.59	43.76	****
AN48	13.74	43.79	****
AN49	13.84	43.74	****
AN54	13.66	43.62	****
AN65	13.94	43.67	****
AN66	13.00	43.60	****
AN68	13.04	43.57	****
AN71	13.77	43.54	****
AN75	13.66	43.50	****
AN80	13.80	43.47	****
AN83	13.90	43.50	****
AN85	14.03	43.54	****
G5	26.20	37.40	*****
G20	24.50	38.50	*****
K3	24.90	40.20	*****
10	27.39	40.53	*****
2	27.60	40.90	*****
12	27.80	40.80	*****
5	28.10	40.90	*****
11	28.40	40.70	*****
9	28.90	40.90	*****
4	29.30	41.50	*****
77	28.85	41.33	*****
4 G	31.13	41.17	*****
45 T	28.32	41.69	*****
H10	32.19	44.95	*****
H18	32.17	44.89	*****
B13	37.90	42.00	*****
2004-804-106	−122.63	70.60	Richerol et al., 2008
2004-804-109	−123.43	70.66	Richerol et al., 2008
2004-804-115	−125.05	70.85	Richerol et al., 2008
2004-804-118	−125.85	70.94	Richerol et al., 2008
2004-804-124	−126.72	71.40	Richerol et al., 2008
2004-804-200	−126.30	70.05	Richerol et al., 2008
2004-804-206	−124.84	70.32	Richerol et al., 2008
2004-804-209	−124.37	70.54	Richerol et al., 2008
2004-804-212	−123.89	70.76	Richerol et al., 2008

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Table 1 (*continued*)

Station	Longitude [degrees_East]	Latitude [degrees_north]	Reference
2004-804-215	−123.42	70.97	Richerol et al., 2008
2004-804-250	−125.42	70.45	Richerol et al., 2008
2004-804-309	−125.83	71.13	Richerol et al., 2008
2004-804-312	−125.19	71.30	Richerol et al., 2008
2004-804-315	−124.54	71.49	Richerol et al., 2008
2004-804-400	−128.93	70.92	Richerol et al., 2008
2004-804-403	−128.31	71.11	Richerol et al., 2008
2004-804-406	−127.70	71.31	Richerol et al., 2008
2004-804-409	−127.09	71.51	Richerol et al., 2008
2004-804-412	−126.48	71.69	Richerol et al., 2008
2004-804-415	−125.87	71.91	Richerol et al., 2008
2004-804-609	−130.52	70.94	Richerol et al., 2008
2004-804-650	−131.62	71.31	Richerol et al., 2008
2004-804-709	−133.78	70.64	Richerol et al., 2008
2004-804-711	−133.80	70.82	Richerol et al., 2008
2004-804-712	−133.69	70.69	Richerol et al., 2008
2004-804-718	−133.53	70.17	Richerol et al., 2008
2004-804-750	−134.14	71.35	Richerol et al., 2008
2004-804-803	−135.92	70.64	Richerol et al., 2008
2004-804-805	−135.42	70.39	Richerol et al., 2008
2004-804-809	−135.34	70.10	Richerol et al., 2008
2004-804-850	−137.60	70.55	Richerol et al., 2008
2004-804-906	−138.60	70.02	Richerol et al., 2008
2004-804-909	−138.27	69.27	Richerol et al., 2008
2004-804-912	−137.94	69.49	Richerol et al., 2008
1916-6	−125.20	42.41	Pospelova et al., 2008
1917-1	−125.02	41.09	Pospelova et al., 2008
1917-2	−125.40	40.75	Pospelova et al., 2008
1917-3	−124.61	39.16	Pospelova et al., 2008
1917-4	−125.76	42.09	Pospelova et al., 2008
1917-5	−127.60	42.26	Pospelova et al., 2008
1917-6	−124.67	43.03	Pospelova et al., 2008
1918-1	−127.57	42.15	Pospelova et al., 2008
1918-2	−127.60	42.26	Pospelova et al., 2008
1918-3	−125.42	40.36	Pospelova et al., 2008
1918-4	−125.66	40.35	Pospelova et al., 2008
1918-5	−125.55	40.35	Pospelova et al., 2008
1918-6	−125.61	40.34	Pospelova et al., 2008
1919-1	−125.46	40.34	Pospelova et al., 2008
1919-4	−124.65	40.90	Pospelova et al., 2008
1919-6	−124.47	40.90	Pospelova et al., 2008
1920-1	−124.48	40.09	Pospelova et al., 2008
1920-2	−124.41	40.10	Pospelova et al., 2008
1920-3	−124.69	40.08	Pospelova et al., 2008
1920-4	−124.63	40.90	Pospelova et al., 2008
1920-5	−121.40	35.50	Pospelova et al., 2008
1920-6	−121.52	35.46	Pospelova et al., 2008
1921-1	−122.01	35.50	Pospelova et al., 2008
4-189	−114.02	29.98	Pospelova et al., 2008
4-190	−117.00	29.22	Pospelova et al., 2008
4-191	−119.03	25.41	Pospelova et al., 2008
4-192	−118.05	25.23	Pospelova et al., 2008
4-193	−114.00	29.98	Pospelova et al., 2008
4-194	−114.18	29.95	Pospelova et al., 2008
4-195	−114.02	30.16	Pospelova et al., 2008
4-196	−114.17	31.01	Pospelova et al., 2008
4-197	−114.10	30.56	Pospelova et al., 2008
1998-1	−123.41	37.22	Pospelova et al., 2008
1998-4	−123.24	37.22	Pospelova et al., 2008
1998-6	−123.41	37.53	Pospelova et al., 2008
1999-1	−123.33	37.45	Pospelova et al., 2008
1999-2	−123.24	37.43	Pospelova et al., 2008
1999-3	−123.15	37.31	Pospelova et al., 2008
1999-6	−123.15	37.31	Pospelova et al., 2008
2000-1	−123.07	37.24	Pospelova et al., 2008
2000-2	−123.25	37.36	Pospelova et al., 2008
1997-1	−118.58	33.98	Pospelova et al., 2008
1997-2	−118.65	33.97	Pospelova et al., 2008
1997-4	−118.55	33.84	Pospelova et al., 2008
1997-5	−118.48	33.89	Pospelova et al., 2008
1997-6	−118.51	33.93	Pospelova et al., 2008
2100-1	−118.59	32.89	Pospelova et al., 2008
2100-2	−118.37	32.76	Pospelova et al., 2008
5-280	−126.24	38.76	Pospelova et al., 2008
5-281	−118.70	28.58	Pospelova et al., 2008
5-282	−124.27	35.30	Pospelova et al., 2008
5-283	−123.35	35.85	Pospelova et al., 2008
5-284	−127.55	38.05	Pospelova et al., 2008
5-285	−128.68	37.22	Pospelova et al., 2008
5-287	−117.01	30.19	Pospelova et al., 2008
5-288	−117.23	28.08	Pospelova et al., 2008
T-161	−123.38	49.29	Pospelova et al., 2008
T-20	−123.38	49.14	Pospelova et al., 2008
T-25	−123.22	49.31	Pospelova et al., 2008
T-5	−123.30	49.23	Pospelova et al., 2008

Rochon et al., 2008). The wealth of data that became available led us to establish a new, updated version of the Atlas that now includes information from 2405 sites. The original 835 sites form the backbone of this new Atlas, but the number of sites is extended, in particular by the addition of sites from regions that were previously not well-covered by the 2003 version of the Atlas. These regions are: the northern and eastern margins of the Pacific Ocean, the Northern Passage and Beaufort Sea, the Mediterranean, Marmara, Black and Caspian Seas, the tropical eastern Indian Ocean, the regions off Australia and Indonesia, and the Arctic Ocean (Fig. 1). In the new Atlas we have also increased the number of species to 71; distribution maps are provided for the individual species and the cyst distribution is discussed.

By establishing the first global Atlas in 2003, it was clear that not only surface water conditions,such as temperature, salinity, nitrate and phosphate were important steering factors influencing the cyst distribution, but that the sedimentary conditions, such as the redox state of the bottom and sedimentary pore waters, had important effects as well (Zonneveld et al., 2008). Furthermore, it was clear that the cyst distribution might have been influenced by similar environmental factors that affect the total phytoplankton production in the upper waters. However, at that time, no high quality digital information about these abiotic factors was available with a global coverage. Over the last decade, this information became available from online ocean and remote sensing databases (see e.g. Giovanny; http://gdata1.sci.gsfc.nasa.gov/daac-bin/G3/gui.cgi?instance_id=ocean_month, and the NOAA World Ocean Atlas WOA; http://www.nodc.noaa.gov/OC5/WOA09/). In this new version of the Atlas, we therefore expanded the information about the environmental characteristics at the sampling sites by including information regarding the present day redox state of the bottom waters as well as the annual upper water biological (phytoplankton) production as reflected by satellite derived chlorophyll-*a* determination. As a result, the steering effects of temperature, salinity, nitrate, phosphate, chlorophyll-*a* and bottom water oxygen on the planktonic population growth, the gamete production, zygote formation, encystment and encystment processes are now a part of the discussion.

The present Atlas has a similar structure to the 2003 version. The general introduction and descriptions of the datasets are followed by the geographic distribution of individual species, which is summarised based on our compiled dataset and literature-based information. When available, additional information is given about the seasonal cyst production in relationship to the upper water environmental conditions based on sediment trap studies is provided. Furthermore, extra emphasis is given to the distribution of species that are known to produce toxins by including literature-based information about the distribution of their motile/planktonic stage when available.

The aims for presenting a global dataset of the modern organic-walled dinoflagellate cyst species are similar to those we based our studies on in 2003:

(a) To illustrate the known global present day distribution of dinoflagellate cyst species in marine surface sediments.

(b) To make the data available using standardised taxonomy and methodology available.
(c) To describe the relationships between the distribution of individual dinoflagellate cyst species (as relative abundances of the total cyst populations) and the (physical) environmental conditions of the upper water masses.

2. Material and methods

2.1. Material

The present Atlas includes 2405 data points compiled form previously unpublished and published datasets (Table 1). All data presented originate from original count data except for the data of de Vernal et al. (2001, 2005; marked with * in Table 1), which were provided to this database in the form of calculated relative abundances and not in the form of count data. Relative abundances of all species were calculated by dividing the counted numbers of individual species by the total number of counted specimens in the sample. Samples containing less than 50 counts have been excluded. Not all contributors separated specimens of *Operculodinium centrocarpum* with “normal” processes from those with “reduced” processes: the figures and graphs depicting the distribution of *Operculodinium centrocarpum* with “normal” processes are based on the combined counts of specimens with “normal” and “reduced” processes. An extra set of figures and graphs has been added depicting the distribution of specimens with reduced processes and include only the sites where the different morphotypes are distinguished. For those sites, the number of specimens with reduced processes is divided by the total number of specimens counted for that sample. Since not all samples contain information about these two different morphotypes, the “reduced” morphotypes were not included into the statistical analyses.

Background information on material recovery and preparation methods of published data are given in the corresponding literature (Table 1, Grøsfjeld and Harland, 2001; Marret and Scourse, 2002; Marret and Zonneveld, 2003; Kawamura, 2004; Mudie et al., 2004; Orlova et al., 2004; Wang et al., 2004a,b,c; de Vernal et al., 2005; Pena-Mañjarrez et al., 2005; Pospelova et al., 2006; Esper and Zonneveld, 2007; Holzwarth et al., 2007; Radi et al., 2007; Pospelova et al., 2008; Richerol et al., 2008; Vásquez-Bedoya et al., 2008; Bouimetarhan et al., 2009; Elshanawany et al., 2009; Kim et al., 2009; Zonneveld et al., 2009; Crouch et al., 2010; Holzwarth et al., 2010; Verleye and Louwye, 2010; Mudie et al., 2011) were used. Preparation methods have been standardized such that no oxidative agents (such as acetolysis) have been performed. Quality control on the GEOTOP dataset (marked with * in Table 1) has been performed by de Vernal et al. (2001, 2005) and co-authors. Unfortunately, the distribution and relative abundances of species occurring only sporadically in the northern latitudes or in very low numbers can be underestimated in this dataset. The quality control on all other datasets has been performed by the first three authors of this manuscript.

2.2. Previously unpublished data

Material from the South Atlantic Ocean (marked with ** in Table 1) was recovered during R.V. METEOR cruise M46/2 and M46/3 with a multi-core device. The upper centimetre of sediments was processed using standard palynological methods described in Zonneveld et al. (2001).

Cores from Indonesia and NW Australia (marked with *** in Table 1) were collected during four cruises in the Indonesian archipelago and along the west coast of Australia. Samples were retrieved from piston cores taken during the SHIVA 1990 and BARAT 1994 expeditions of the ‘RV Baruna Jaya,’ and from gravity cores taken during the 'RV Franklin' cruises in 1995 (Fr10/95) and 1996 (Fr2/96). The upper 1–2 cm of sediment from each core was analysed for dinoflagellate cysts according to the method of de Vernal et al. (2005).

Samples from the Adriatic Sea, Central Mediterranean Sea (marked with **** in Table 1) were collected during the PRISMA1 (Programma di Ricerca e Sperimentazione per il Mare Adriatico) cruises in 1996 and 1997 using a box-core device. Upper centimetre samples were collected and processed using standard palynological preparation methods with the addition of *Lycopodium* spores (Zonneveld et al., 2001; Marret and Zonneveld, 2003).

Samples from the Eastern Mediterranean Sea, Marmara Sea and Black Sea (marked with ***** in Table 1) are core-top samples that have been processed according to the “*Lycopodium*” method described in Mudie et al. (2004). Samples H10 and H18 were processed with cold HCl, sieved over a 10 μm sieve, and followed by Zn-Cl heavy liquid separation. A known amount of *Lycopodium* spores was added prior to processing.

2.3. Taxonomy

Within this Atlas, 75 types of organic-walled dinoflagellate cyst-types were distinguished. The taxonomical concept is consistent to that cited in Rochon et al. (2009) and Radi and de Vernal (2008). Throughout the Atlas, the cyst name is used with the exception of the species for which no cyst name is available. In those cases, the vegetative stage name is used. During several workshops, the contributors have standardised the taxonomy of the species. Species for which different taxonomic concepts exist are grouped.

The distinction between cysts of *Gymnodinium catenatum* and those of *Gymnodinium nolleri* and *Gymnodinium microreticulatum* is based on size and morphology (Bolch et al., 1999). Only brown, microreticulate cysts > 38 μm with paracingular bands at the border of a cingulum consisting of two or more rows of oriented, primarily five or six sided paravesicles, were categorised as *G. catenatum* cysts. *G. catenatum* cysts with a diameter of less than 38 μm and paracingular bands that consist of two or fewer rows of paravesicles were grouped into the “*G. microreticulatum/nolleri*” group. In several datasets, no size separation was made between *G. catenatum* and *G. microreticulatum/nolerri* during the counting process. These recordings have been included in the *G. microreticulatim/nolleri* group. The taxonomy of *Polykrikos schwartzii* and *Polykrikos kofoidii* is based on Matsuoka et al. (2009).

Taxonomy of species characteristic for the southern Hemisphere or endemic to the Arabian Sea, Caspian Sea and Mediterranean Sea is based on Head et al. (2001), Esper and Zonneveld (2002), Head (2002), Marret et al. (2004), Marret and Kim (2009), Zonneveld (1997), respectively.

The majority of the datasets included in this Atlas do not differentiate *Operculodinium aguinawense* and *Operculodinium israelianum* (the only distinctive characteristics between the species isgreater process length and an oval shape for *O. aguinawense*). Both species are grouped into *O. israelianum*.

A brief description of the cyst morphology based on field characteristics as well as a key to identify the cyst species by light microscopy is given in the appendix.

Species list:

Cyst	Motile	Grouped in this Atlas as	Abbreviation
Achomosphaera spp.	*Gonyaulax* sp. indet.	*Spiniferites* spp.	
Ataxiodinium choane	*Gonyaulax* sp. indet.		Acho
Bitectatodinium spongium	unknown		Bspo
Bitectatodinium tepikiense	*Gonyaulax digitale*		Btep
Brigantedinium cariacoense	*Protoperidinium avellanum*	*Brigantedinium* spp.	
Brigantedinium simplex	*Protoperidinium conicoides*	*Brigantedinium* spp.	

(continued on next page)

(*continued*)

Cyst	Motile	Grouped in this Atlas as	Abbreviation
Brigantedinium spp.	Peridiniaceae		Bspp
Caspidinium rugosum	unknown		Crug
Cryodinium meridianum	unknown		Cmer
Cyst of *Alexandrium tamaranse*	*Alexandrium tamarense*		Atam
Cyst of *Archaeperidinium minutum*	*Archaeperidinium minutum*	*Echinidinium* spp.	
Cyst of *Diplopelta parva*	*Oblea acanthocysta*	*Echinidinium* spp.	
Cyst of *Diplopsalis lebourae*	*Diplopsalis lebourae*	*Brigantedinium* spp.	
Cyst of *Diplopsalis lenticulata*	*Diplopsalis lenticulata*	*Brigantedinium* spp.	
Cyst of *Diplopsalis* spp.	*Diplopsalis* sp. indet.	*Brigantedinium* spp.	
Cyst of *Gymnodinium catenatum*	*Gymnodinium catenatum*		Gcat
Cyst of *Gymnodinium nolleri*	*Gymnodinium nolleri*		Gnol
Cyst of *Gymnodinium microreticulatum*	*Gymnodinium microreticulatum*	*Gymnodinium nolleri*	
Cyst of *Pentapharsodinium dalei*	*Pentapharsodinium dalei*/ *Ensiculifera imariense*		Pdal
Cyst of *Peridinium ponticum*	*Peridinium ponticum*		Ppon
Cyst of *Polykrikos hartmannii*	*Polykrikos hartmannii*	*Echinidinium* spp.	
Cyst of *Polykrikos kofoidii*	*Polykrikos kofoidii*		Pkof
Cyst of *Polykrikos schwartzii*	*Polykrikos schwartzii*		Psch
Cyst of *Polykrikos* morphotype arctica	*Polykrikos* sp. indet.		Parc
Cyst of *Protoperidinium americanum*	*Protoperidinium americanum*		Pame
Cyst of *Protoperidinium avellana*	*Protoperidinium avellana*	*Brigantedinium* spp.	
Cyst of *Protoperidinium conicoides*	*Protoperidinium conicoides*	*Brigantedinium* spp.	
Cyst of *Protoperidinium monospinum*	*Protoperidinium monospinum*		Pmon
Cyst of *Protoperidinium nudum*	*Protoperidinium nudum*	*Selenopemphix quanta*	
Dalella chathamensis	*Gonyaulax* sp. indet.		Dcha
Dubridinium caperatum	*Preperidinium meunieri*		Dcap
Echinidinium aculeatum	Unknown		Eacu
Echinidinium bispiniformum	Unknown		Ebis
Echinidinium delicatum	Unknown		Edel
Echinidinium granulatum	Unknown		Egra
Echinidinium karaense	Unknown		Ekar
Echinidinium transparantum	Unknown		Etra
Echinidinium spp.	Unknown		Espp
Echinidinium zonneveldii	Unknown	*Echinidinium transparantum*	
Impagidinium aculeatum	*Gonyaulax* sp. indet.		Iacu

(*continued*)

Cyst	Motile	Grouped in this Atlas as	Abbreviation
Impagidinium cantabrigiense	Unknown	*Impagidinium* spp.	
Impagidinium caspienense	Unknown		Icas
Islandinium brevispinosum	*Protoperidinium* sp. indet.	*Echinidinium* spp.	
Islandinium minutum	*Protoperidinium* sp. indet.		Imin
Islandinium minutum morphotype *cesare*	*Protoperidnium* sp. indet.		Icez
Impagidinium japonicum	*Gonyaulax sp. indet.*		Ijap
Impagidinium pacificum	*Gonyaulax* sp. indet.	*Impagidinium velorum*	
Impagidinium pallidum	*Gonyaulax* sp. indet.		Ipal
Impagidinium paradoxum	*Gonyaulax* sp. indet.		Ipar
Impagidinium patulum	*Gonyaulax* sp. indet.		Ipat
Impagidinium plicatum	*Gonyaulax* sp. indet.		Ipli
Impagidinium sphaericum	*Gonyaulax* sp. indet.		Isph
Impagidinium spp.	*Gonyaulax* sp. indet.		Ispp
Impagidinium strialatum	*Gonyaulax* sp. indet.		Istr
Impagidinium variaseptum	*Gonyaulax* sp. indet.		Ivar
Impagidinium velorum	*Gonyaulax* sp. indet.		Ivel
Leipokatium invisitatum	Unknown	*Peridiniacean* cysts	
Lejeunecysta oliva	Unknown		Loli
Lejeunecysta sabrina	?*Protoperidinium leonis*		Lsab
Lingulodinium machaerophorum	*Lingulodinium polyedrum*		Lmac
Lingulodinium hemicystum	Unknown	*Lingulodinium machaerophorum*	
Nematosphaeropsis labyrinthus	*Gonyaulax spinifera complex*		Nlab
Nematosphaeropsis rigida	*Gonyaulax* sp. indet.		Nrig
Operculodinium aguinawense	*O. israelianum*		
Operculodinium centrocarpum	*Protoceratium reticulatum*		Ocen
O.centrocarpum short process form	*Protoceratium reticulatum*		Ocss
O.centrocarpum arctic morphotype	Unknown		Oarc
O.centrocarpum cezare morphotype	Unknown	*Operculodinium centrocarpum*	
O.centrocarpum nodosa morphotype	Unknown	*Operculodinium centrocarpum*	
Operculodinium israelianum	Unknown		Oisr
Operculodinium janduchenei	Unknown		Ojan
Operculodinium longispinigerum	Unknown		Olon
Operculodinium psilata	Unknown	*Pyxidinopsis psilata*	
Peridiniacean cysts	*Peridiniaceae*		Peri
Polysphaeridium zoharyi	*Pyrodinium bahamense*		Pzoh
Pyxidinopsis psilata	Unknown		Ppsi
Pyxidinopsis reticulata	Unknown		Pret
Quinquecuspis concreta	?*Protoperidinium leonis*		Qcon

(continued)

Cyst	Motile	Grouped in this Atlas as	Abbreviation
Selenopemphix antarctica	Unknown		Sant
Selenopemphix nephroides	*Protoperidinium subinerme*		Snep
Selenopemphix quanta	*Protoperidinium conicum*		Squa
Selenopemphix undulata	Peridiniaceae	*Peridiniacean* cysts	
Spiniferites belerius	*Gonyaulax scrippsae*	*Spiniferites* spp.	
Spiniferites bentorii	*Gonyaulax* sp. indet.		Sben
Spiniferites bulloideus	*Gonyaulax baltica*	*Spiniferites* spp.	
Spiniferites cruciformis	*Gonyaulax* sp. indet.		Scru
Spiniferites delicatus	*Gonyaulax* sp. indet.		Sdel
Spiniferites elongatus	*Gonyaulax elongata*		Selo
Spiniferites hyperacanthus	*Gonyaulax* sp. indet.	*Spiniferites mirabilis*	
Spiniferites lazus	*Gonyaulax* sp. indet.		Slaz
Spiniferites membranaceus	*Gonyaulax membranacea*		Smem
Spiniferites mirabilis	*Gonyaulax spinifera* complex		Smir
Spiniferites pachydermus	*Gonyaulax* sp. indet.		Spac
Spiniferites ramosus	*Gonyaulax spinifera* complex		Sram
Spiniferites spp.	*Gonyaulax* sp. indet.		Sspp
Stelladinium bifurcatum	Peridiniaceae	*Stelladinium stellatum*	
Stelladinium reidii	Peridiniaceae	*Stelladinium stellatum*	
Stelladinium reductum	Peridiniaceae	*Stelladinium stellatum*	
Stelladinium robustum	Peridiniaceae		Srob
Stelladinium stellatum	*Protoperidinium stellatum*		Sste
Tectatodinium pellitum	*Gonyaulax spinifera* complex		Tpel
Trinovantedinium applanatum	*Protoperidinium pentagonum*		Tapp
Trinovantedinium variable	*Peridiniaceae*	*Peridiniacean* cysts	
Tuberculodinium vancampoae	*Pyrophacus steinii*		Tvan
Votadinium calvum	*Protoperidinium oblongum*		Vcal
Votadinium spinosum	*Protoperidinium claudicans*		Vspi
Xandarodinium xanthum	*Protoperidinium divaricatum*		Xxan

2.4. Environmental data

Chlorophyll-*a* data was derived from the MODIS-Aqua.R1.1 satellite dataset available from the NASA ocean colour radiometry online visualisation and analysis project Giovanni: (http://gdata1.sci.gsfc.nasa.gov/daac-bin/G3/gui.cgi?instance_id=ocean_month). The data represent mean daily values compiled from 01.09.2002 to 31.08.2009 on a 0.1° resolution. Seasonal surface ocean temperature (°C) and salinity (psu) data as well as annual sea-surface values for temperature (SST), salinity (SSS), phosphate (μmol/l), nitrate (μmol/l) and bottom water oxygen concentrations (ml/l) have been derived from the World Ocean Atlas 2005 ODV dataset. The following seasons are defined:

Winter: Northern Hemisphere; January–March, Southern Hemisphere; July–September.
Spring: Northern Hemisphere; April–June, Southern Hemisphere; October–December.
Summer: Northern Hemisphere; July–September, Southern Hemisphere; January–March.
Autumn: Northern Hemisphere; October–December, Southern Hemisphere; April–June.

2.5. Creation of graphs and multivariate analysis

The maps were created with the free software program Ocean Data View (ODV) version 4.4.2. (Schlitzer, 2012). Colour shadings refer to the relative abundances of species at the sampling sites and were established by using the "DIVA" gridding method with setpoint 12 and a quality limit of 3.6. For detailed information about this method, please refer to: http://odv.awi.de/.

The points shown on the maps refer to locations where a species has been documented. To maintain the clarity of the maps, sample locations where a species has not been observed are omitted.

Graphs were created with the program KaleidaGraph version 4.1.2. Within the graphs, dots on the base line represent species recordings of 0%. Samples and seasons for which no environmental data are available, for instance during the dark season for polar samples, have not been included in the graphs.

Relative abundances have been compared with seasonal SST and SSS as well as with mean annual sea-surface phosphate, nitrate, chlorophyll-*a* concentrations and bottom water oxygen concentrations using the multivariate ordination methods Detrended Correspondence Analysis (DCA) and Canonical Correspondence Analysis (CCA) from the CANOCO for Windows software package (Jongman et al., 1987; Legendre et al., 2011).

2.6. Oceanography

Background on the oceanography of the study regions are discussed in the corresponding literature: Grøsfjeld and Harland (2001), Marret and Scourse (2002), Marret and Zonneveld (2003), Kawamura (2004), Mudie et al. (2004), Orlova et al. (2004), Sangiorgi and Donders (2004), Wang et al. (2004a,b,c), de Vernal et al. (2005), Pena-Mañjarrez et al. (2005), Pospelova et al. (2006), Esper and Zonneveld (2007), Holzwarth et al. (2007), Radi et al. (2007), Pospelova et al. (2008), Richerol et al. (2008), Vásquez-Bedoya et al. (2008), Bouimetarhan et al. (2009), Elshanawany et al. (2009), Kim et al. (2009), Zonneveld et al. (2009), Crouch et al. (2010), Holzwarth et al. (2010), Ledu et al. (2010), Verleye and Louwye (2010), Mudie et al. (2011), Bringué and Rochon (2012). Climate zones are been defined after Gross and Gross (1994; Fig. 2). The positions of the major frontal systems, river discharge plumes and upwelling regions are given in Fig. 3.

2.7. Geographical distribution

The geographic distribution of individual species and the relationship of their relative abundances with environmental parameters at the sampling sites are given in Figs. 4–292. The stars represent reportings in the literature from regions that are not covered by the datasets incorporated in this Atlas. Green stars represent occurrences of cysts in surface sediments or in sediment traps whereas blue stars represent recordings of the motile stage of the dinoflagellate cyst species. For logistical reasons, the information from plankton records is restricted to toxin producing species.

Information about the geographic distribution of the species from the regions not covered by the datasets in this Atlas along with information about the seasonal distribution of the species is based on the references cited in Marret and Zonneveld (2003) and the following literature (in alphabetical order):

Azanza et al. (2004), Bakken and Dale (1986), Bolch and de Salas (2007), Bolch and Hallegraeff (1990), Bolch and Reynolds (2002), Borel et al. (2006), Bravo, et al. (2006), Cho et al. (2003), Dale

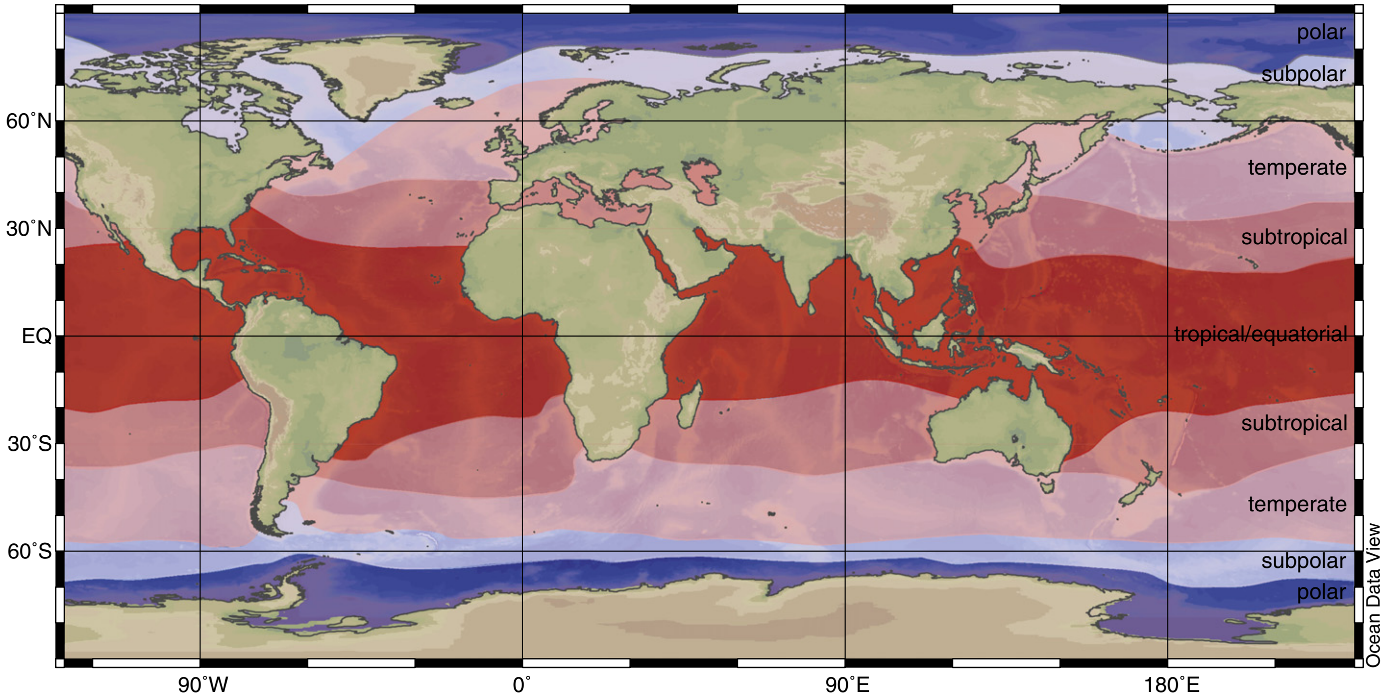

Fig. 2. Climatic zones over the oceans (redrawn after Gross and Gross, 1994).

(1985), Dale et al. (2002), Dale and Dale (1992), Della Tommasa et al. (2004), de Vernal et al. (1998), D'Costa et al. (2008), Furio et al. (2012), Fujii and Matsuoka (2006), Genovesi et al. (2009), Gayoso and Fulco (2006), Giannakourou et al. (2005), Golovnina and Polyakova (2004), Grill and Guerstein (1995), Grøsfjeld and Harland (2001), Grøsfjeld et al. (2009), Harland and Pudsey (1999), Harland et al. (2004a, 2004b), Harland et al. (2006), Harland and Nordberg (2011), Howe et al. (2010), Joyce (2004), Joyce et al. (2005), Kawamura (2004), Kholeif and Mudie (2009), Kouli et al. (2001), Krepakevich and Pospelova (2010), Limoges et al., 2010), Fujii and Matsuoka (2006), McCauley et al. (2009), Mertens et al. (2009), Mohamed and Al-Shehri (2011), Montresor et al. (1998), Morquecho and Lechuga-Deveze (2003), Mudie et al. (2001), Novichkova and Polyakova (2007), Patterson et al. (2011), Pitcher

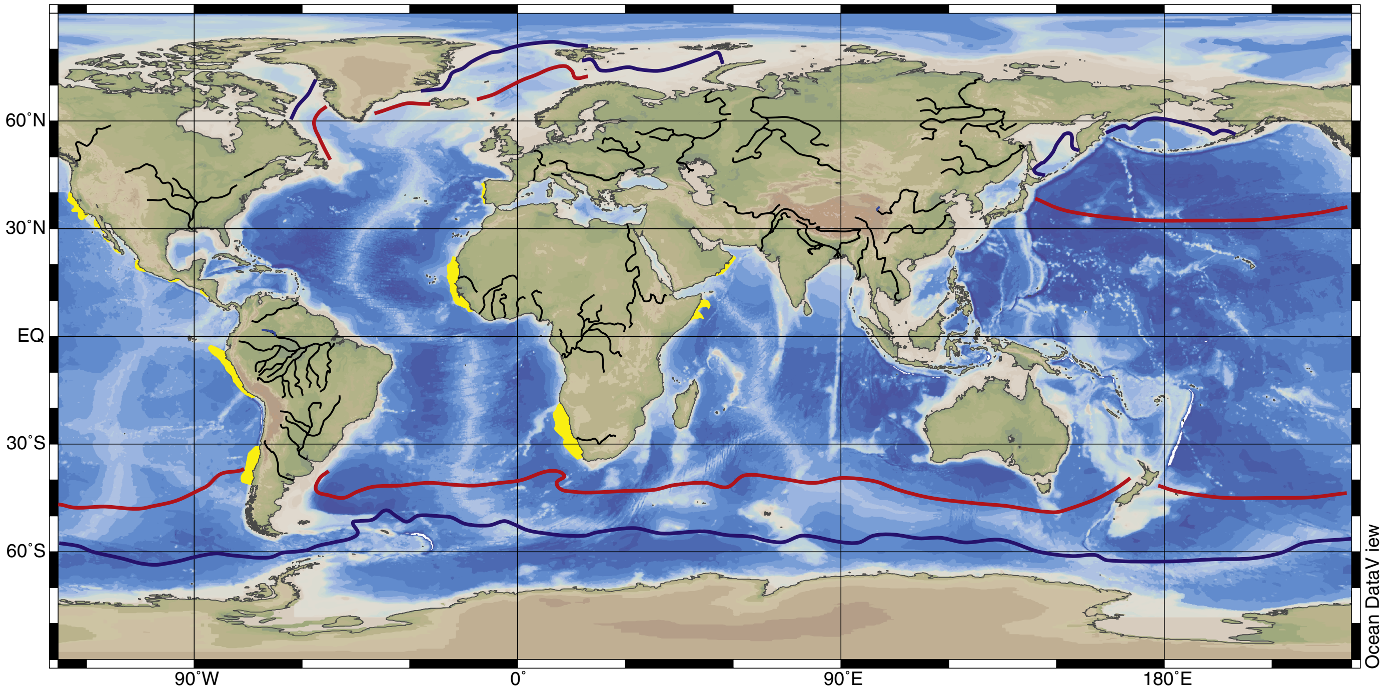

Fig. 3. Map of the world depicting the major river systems (black lines), polar fronts (blue line), subtropical front (red line) and major upwelling regions (marked in yellow).

and Joyce (2009), Pospelova and Kim (2010), Pospelova et al. (2010), Price and Pospelova (2011), Radi and de Vernal (2008), Ribeiro and Amorim (2008), Rørvik et al. (2009), Rubino et al. (2002), Rubino et al. (2010), Satta et al. (2010), Shin et al. (2007, 2010), Smayda and Trainer (2010), Solignac et al. (2009), Sprangers et al. (2004), Susek et al. (2005), Trainer et al. (2010), Usup et al. (2012), Yamaguchi et al. (2002), Wang et al. (2004a,b,c), Zonneveld and Brummer (2000), Zonneveld et al. (2010).

The term "full-marine" is used for non-brackish environments (SSS > 20).

The term "coastal sites" is used for sites that are located in the vicinity of continents. These sites are often, but not always, located on the shelves or along shelf breaks. Although the water depths at these sites are generally less than 500 m, in cases where the shelf is very narrow they might be up to several thousand metres.

The environmental parameter ranges given in the geographic distribution description of each individual species is defined by the minimum and maximum values at the sample locations. Information about the season in which these values are observed is provided in brackets. All data are freely available in the PANGAEA database (www.pangaea.de).

3. Geographic distribution

1. Cysts of *Alexandrium tamarense* (Lebour 1925) Balech 1985
Figs. 4–7.

Distribution:

On the Northern Hemisphere cysts of *A. tamarense* are observed in temperate coastal sediments of the North Atlantic and Pacific Oceans south of the Polar Front. It can form up to 99% of the association in the Bering Sea (northwestern Pacific Ocean). On the Southern Hemisphere it is only registered in coastal sediments of the tropical and subtropical eastern Indian Ocean.

Environmental parameter range:

SST: −0.9–29.7 °C (winter–spring). SSS: 23.6–24.0 (summer–winter) with exception of three samples from the Black Sea and Marmara Sea where salinities vary between 17.5–18.4 (summer–winter), [P]: 0.1–1.6 μmol/l, [N]: 0.23–18.6 μmol/l, chlorophyll-*a*: 0.09–19.9 ml/l, bottom water [O_2]: 1.0–7.1 ml/l.

High relative abundances of > 50% are observed in cold/temperate regions with SST: between −0.2–24.2 °C (winter–summer).

It is observed in oligotrophic to eutrophic environments and with highest abundances in mesotrophic and eutrophic settings. In the dataset of this Atlas the species is absent in regions where anoxic and hypoxic bottom waters prevail.

Comparison with other records:

Additional to the recordings in this Atlas, *A. tamarense* has been found in sediments of shallow marine coastal agricultural sites of South Korea, Japan and Patagonia (Argentina) (Gayoso and Fulco, 2006; Kamikawa et al., 2007; Pospelova and Kim, 2010).

New genetic techniques show that the species has a wider geographic distribution than indicated by this Atlas. Apart from the regions covered in this Atlas, the species has been observed in the plankton of coastal waters of South America, South Africa, western Mediterranean Sea, Australia, Tasmania, New Zealand and India (Borel et al., 2006; Bravo et al., 2006; Bolch and de Salas, 2007; McCauley et al., 2009).

Part of the underrepresentation in this Atlas may result from the fact that cysts of this species are difficult to determine at the light microscope. Cysts of *A. tamarense* are morphologically very similar to those of *Alexandrium acatenella* and *Alexandriun catenella* (e.g. Yoshida et al., 2003). Furthermore, they can be easily destroyed during palynological treatment. In many studies no separation is made between cysts of *A. tamarense*, *A. catenella* and *A. acatenella* as for several sites in Europe (references in Marret and Zonneveld, 2003; Genovesi et al., 2009), the Benguela upwelling area, South Africa (Joyce et al., 2005; Pitcher and Joyce, 2009), the Red Sea (Mohamed and Al-Shehri, 2011), India (Godhe et al., 2000), South Australia and Tasmania (Bolch and Hallegraeff, 1990) and the coast of British Columbia, Canada (Price and Pospelova, 2011). Cysts of *Alexandrium* spp. with cell content are common in the Saanich Inlet where anoxic bottom water prevail. However, sporadic earlier records (1935–1993) for cysts of *A. catenella* were compiled for the Saanich Inlet area by Mudie et al. (2002) and compared to cysts in corresponding varved sediment records obtained from frozen finger cores. It is therefore not clear yet which *Alexandrium* species inhabits these regions and if cysts of *A. tamarense* avoid anoxic and hypoxic environments. If plankton records would become available from these regions we would be able to determine the nature of the cyst recordings.

Culture experiments have shown that resting cysts of this species complex are able to germinate between 4 and 22 °C (Genovesi et al., 2009). We observe a wider distribution with the species occurring in areas with SST seasonally being below 0 °C and areas with SST > 25 °C throughout the year. It is not observed in regions that are seasonally covered by sea ice. Culture experiments reveal that cyst germination is inhibited by anoxia (Genovesi et al., 2009 and references therein), which agrees with our observation that *A. tamarense* is absent in regions with anoxic to hypoxic bottom waters. However, as discussed above future research has to be carried out to conform our observation.

Concluding remarks:

Cysts of *A. tamarense* can be observed in full marine and coastal sediments of temperate regions although they are not restricted to these areas. It is observed in areas with a broad range of temperature, nutrient and upper water chlorophyll-*a*: concentrations with the highest relative abundances in mesotrophic to eutrophic environments. It is restricted to regions with well-ventilated bottom waters.

2. *Ataxiodinium choane* Reid 1974
Figs. 8–11.

Distribution:

A. choane accounts for up to 3% of the association and occurs in temperate and sub-polar regions of the Northern Hemisphere, notably south of the polar front. It is also reported from a few sites in the tropical upwelling areas of the Arabian Sea and the temperate South Atlantic Ocean. Highest abundances are observed in the central Mediterranean Sea and western part of the Black Sea. Although the species is observed regularly in coastal sites, it is not restricted to these regions. It is not recorded in areas with reduced upper water salinities such as river plumes.

Environmental parameter range:

SST: −2.0–28.4 °C (winter–spring). SSS: 36.6–38.5 (summer–summer) with exception of two samples from the Black Sea where salinities vary between 17.5–18.4 (summer–winter), [P]: 0.09–1.06 μmol/l, [N]: 0.15–9.86 μmol/l, chlorophyll-*a*: 0.09–20.9 ml/l, bottom water [O_2]: 1.0–7.2 ml/l. *A. choane* has its highest abundances (> 1%) in temperate regions with SST: between 1.2–10.0 °C (winter–summer). The species is absent where SSS < 23.6 (summer) with exception of two sites from the Black Sea where SSS ranges between 17.5 and 18.4 (summer–winter). Highest abundances occur in oligotrophic to mesotrophic environments with [P]: < 0.53 and [N]: < 1.86 μmol/l. The species is absent in regions where bottom waters are anoxic or hypoxic.

Comparison with other records:

Apart from observations given in this Atlas, *A. choane* has been observed in low amounts in the western Barents Sea where waters can be seasonally covered by sea ice (Solignac et al., 2009). It can be observed in areas with up to six months per year sea ice cover (de Vernal et al., 1998). However, the length of seasonal sea ice cover anti-correlates with the relative abundance of this species (Radi and de Vernal, 2008).

Concluding remarks:

A. choane is characteristically present in temperate to sub-polar, coastal to oceanic regions. It is observed in full marine environments and regions with reduced upper water salinities. It is restricted to sites with well-ventilated bottom waters where the upper waters

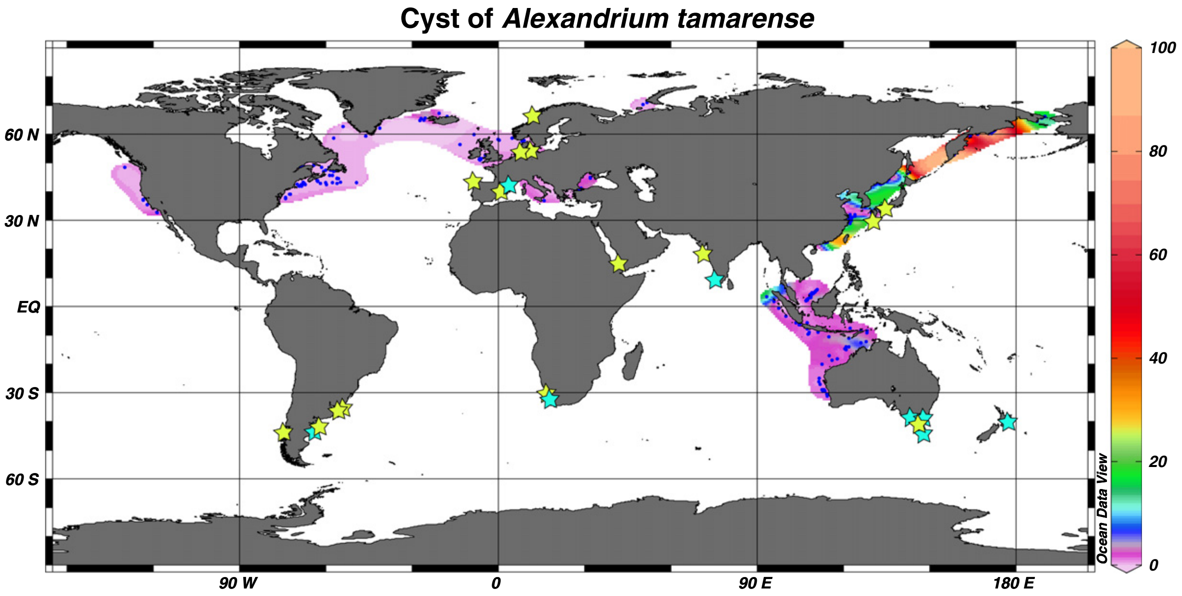

Fig. 4. Geographic distribution of cysts of *Alexandrium tamarense*.

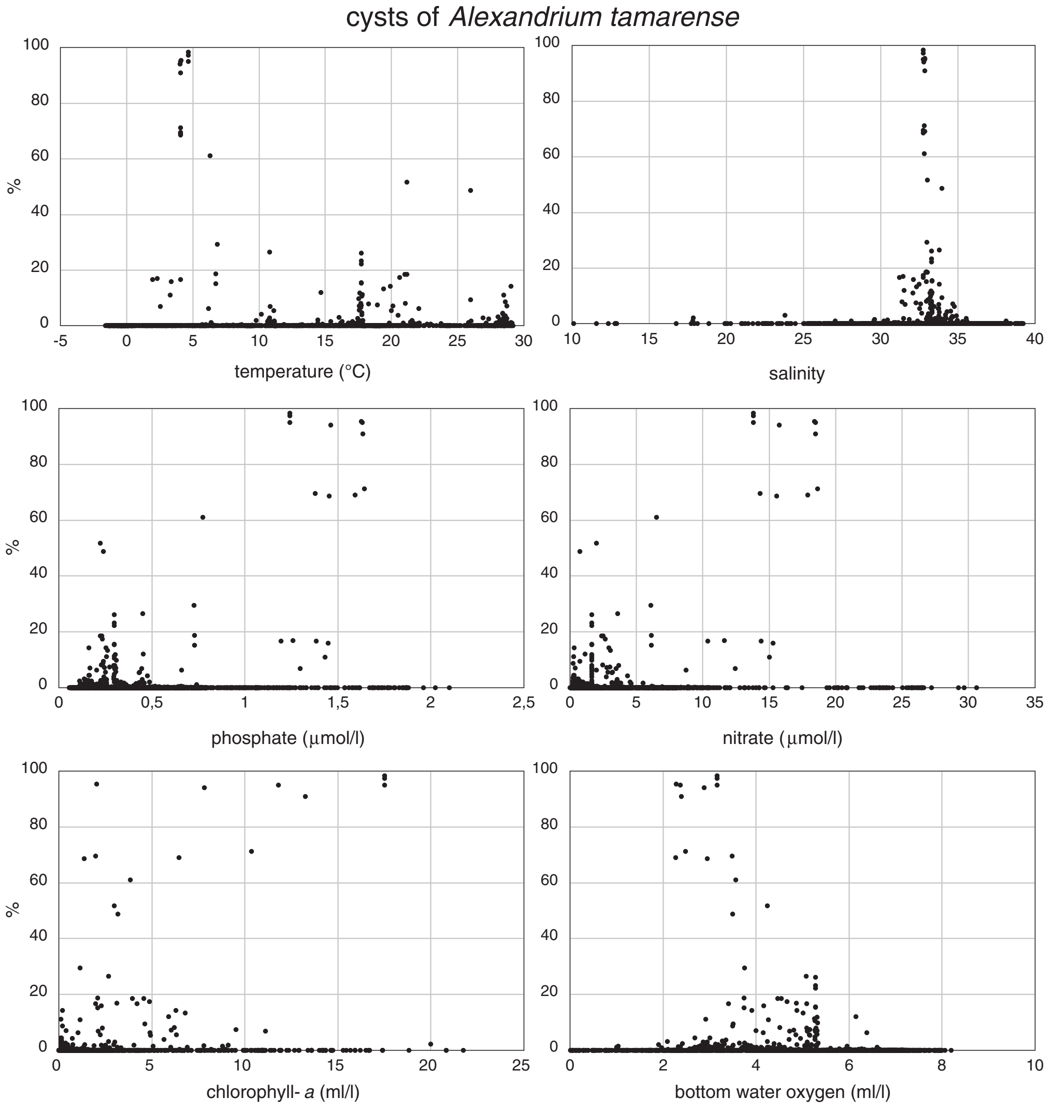

Fig. 5. Relative abundances of cysts of *Alexandrium tamarense* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

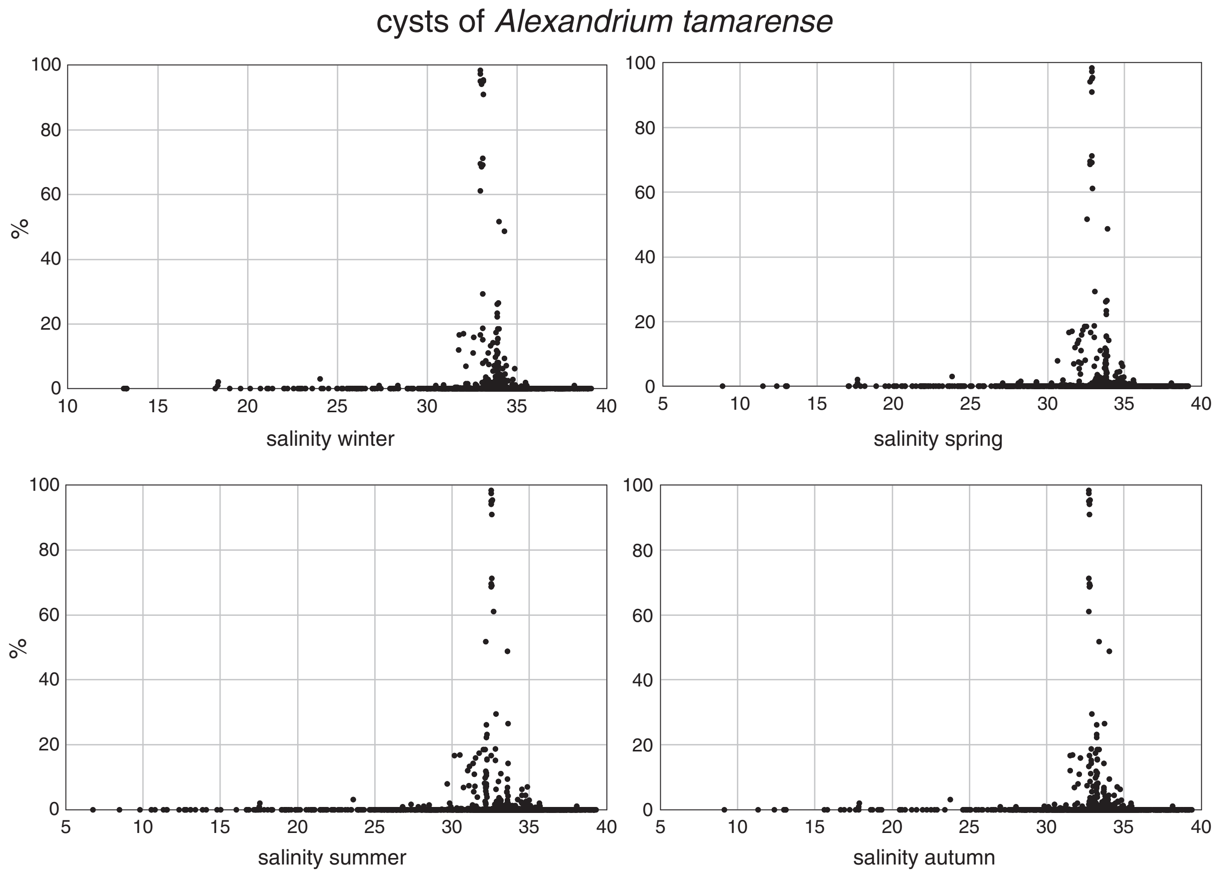

Fig. 6. Relative abundances of cysts of *Alexandrium tamarense* in relationship to seasonal salinity in surface waters.

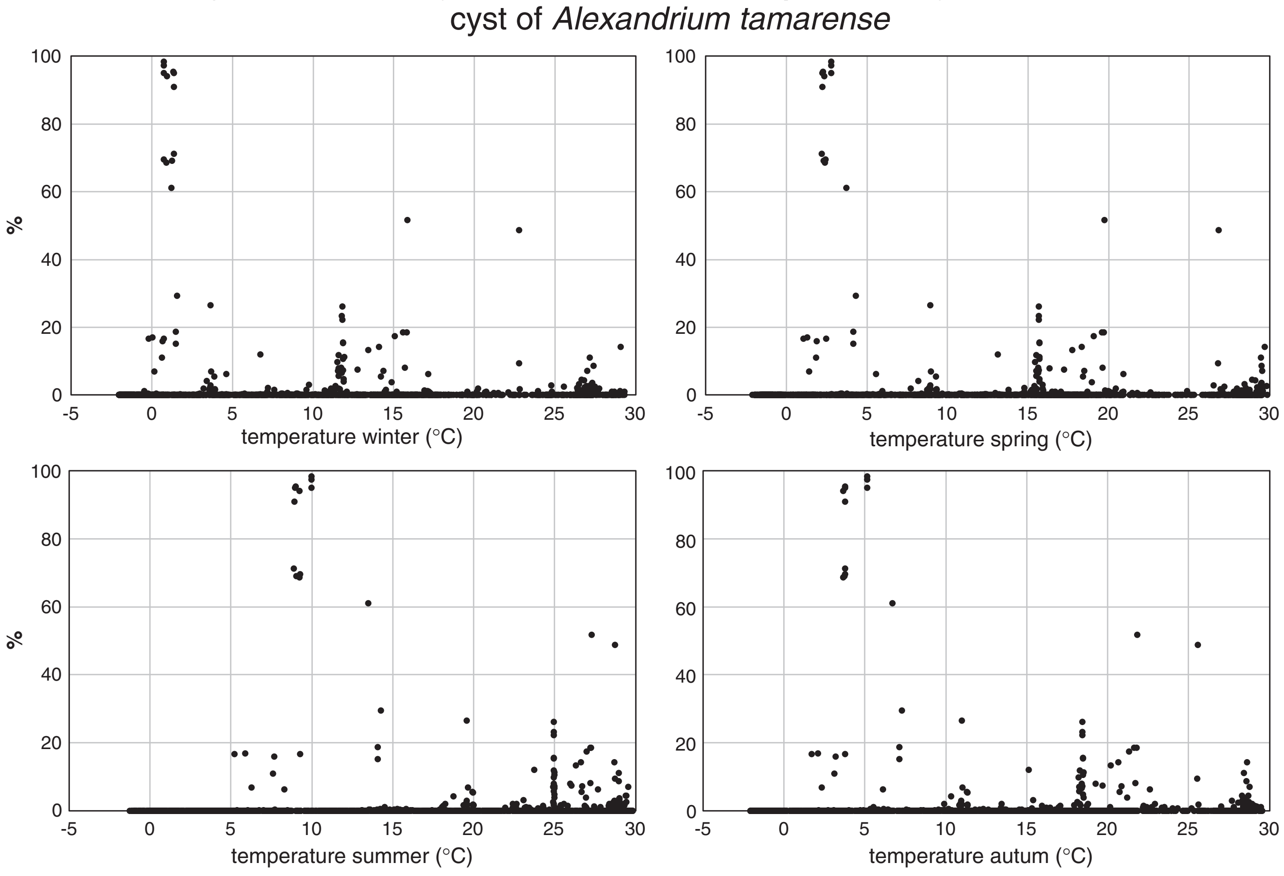

Fig. 7. Relative abundances of cysts of *Alexandrium tamarense* in relationship to seasonal temperature in surface waters.

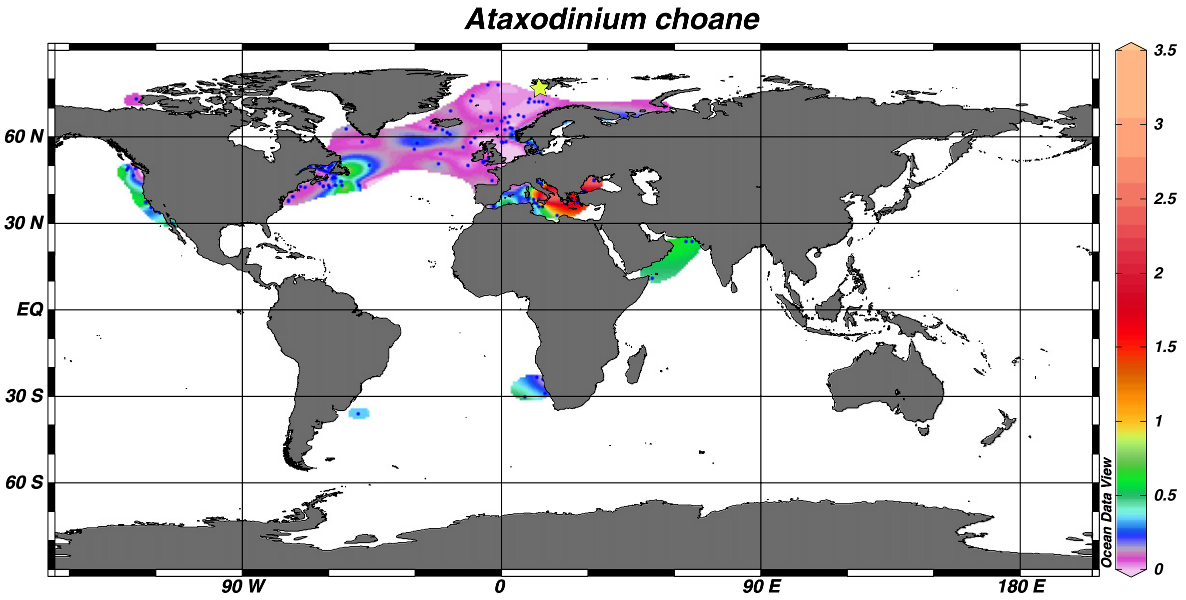

Fig. 8. Geographic distribution of *Ataxodinium choane*.

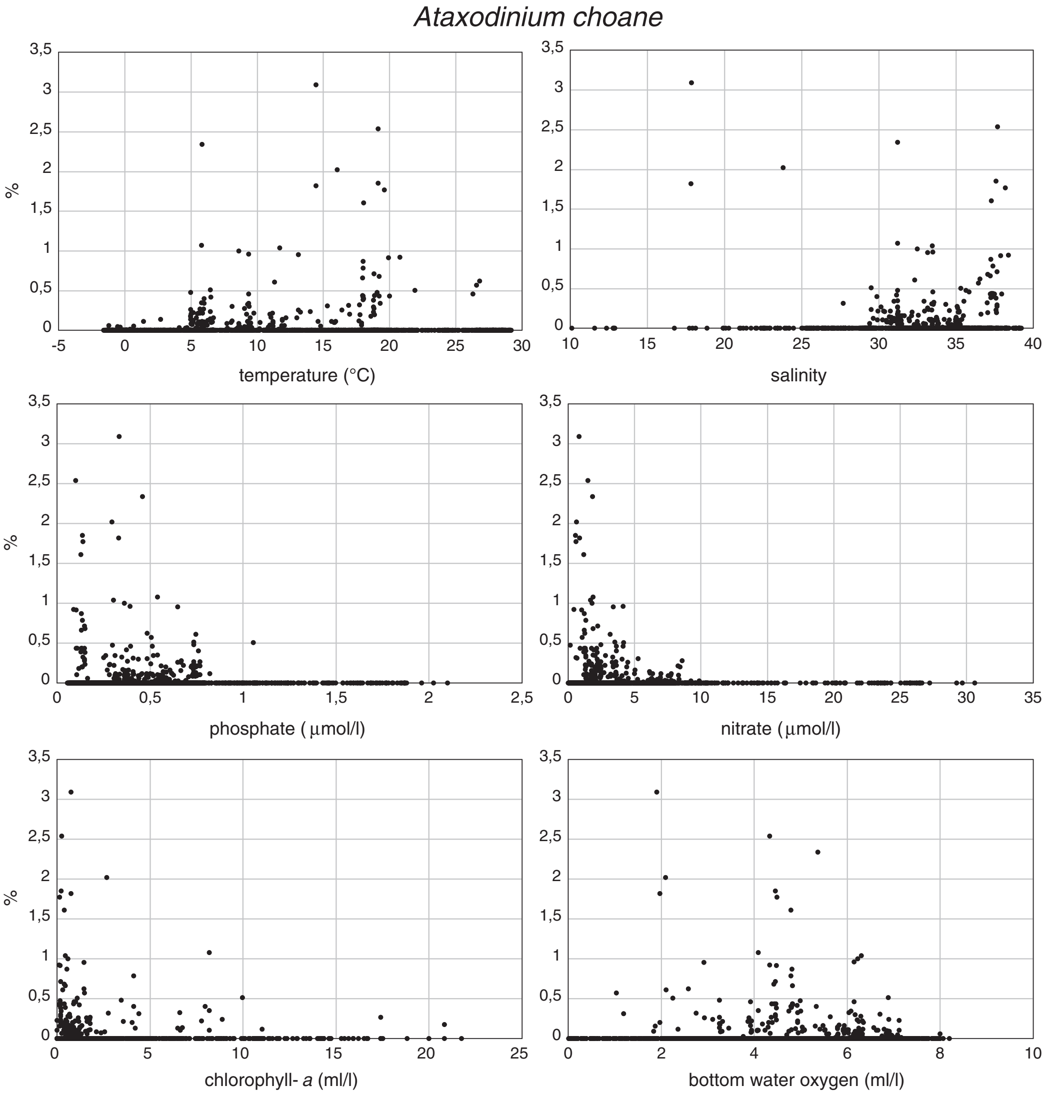

Fig. 9. Relative abundances of *Ataxodinium choane* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

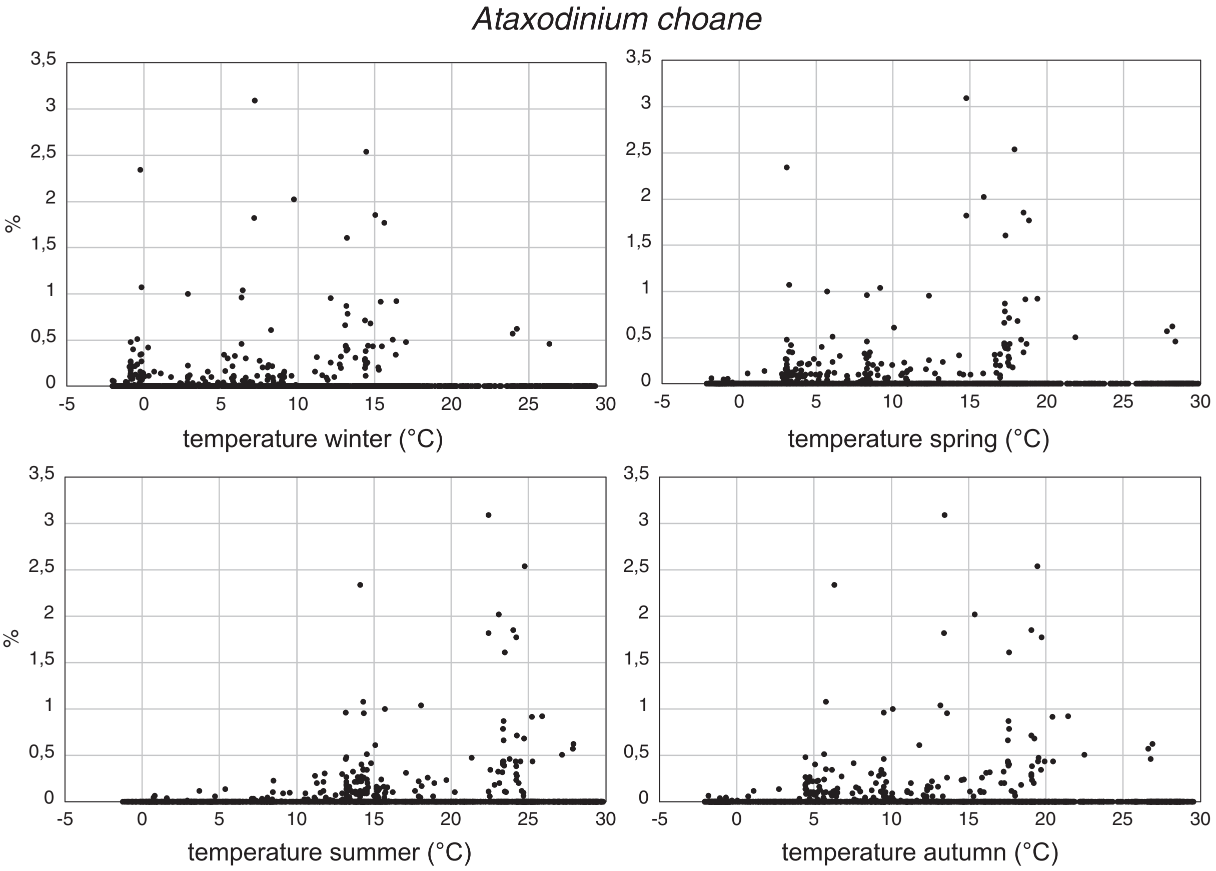

Fig. 10. Relative abundances of *Ataxiodinium choane* in relationship to seasonal salinity in surface waters.

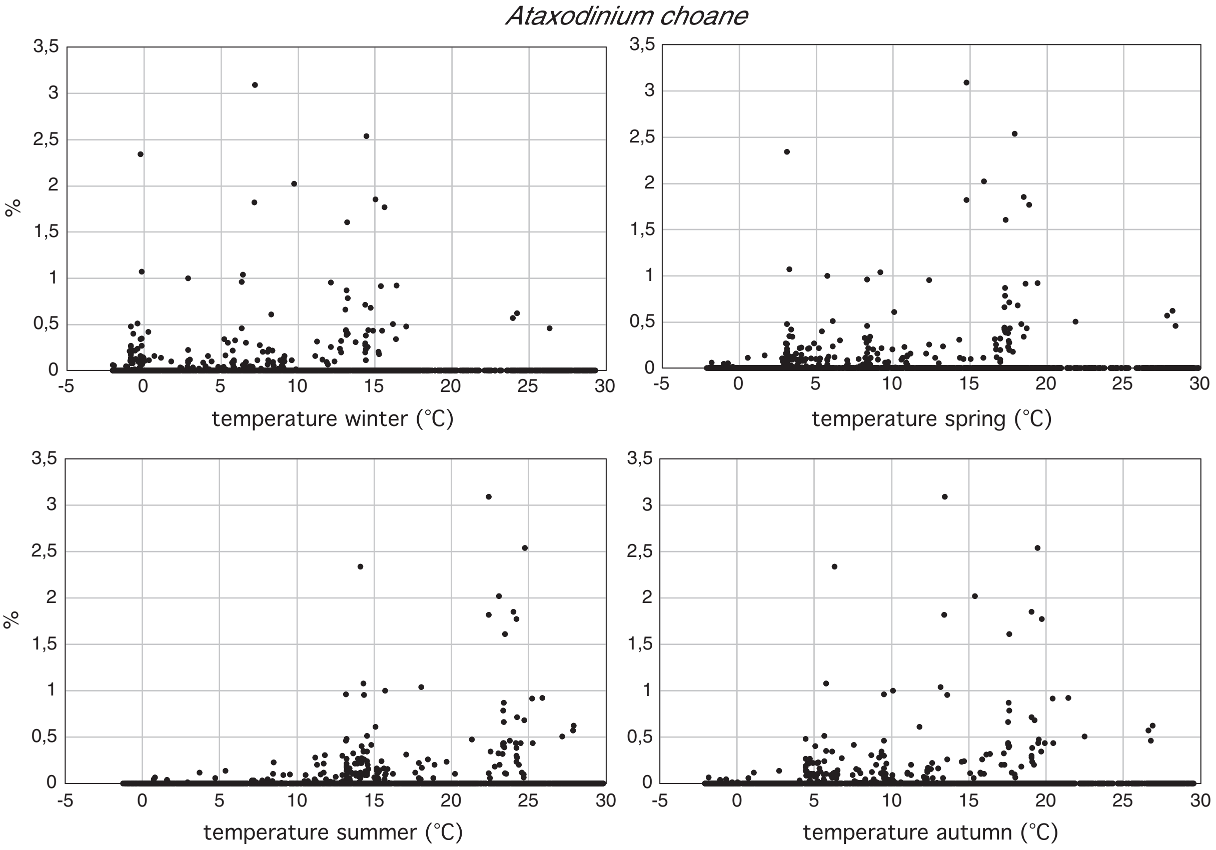

Fig. 11. Relative abundances of *Ataxiodinium choane* in relationship to seasonal temperature in surface waters.

are oligotrophic to eutrophic although highest relative abundances can be found in oligotrophic/mesotrophic environments.

3. *Bitectatodinium spongium* (Zonneveld 1997) Zonneveld et Jurkschat 1999

Figs. 12–15.

Distribution:

B. spongium is restricted to equatorial and subtropical areas that are generally characterised by the presence of coastal upwelling. It can form up to 62.5% of the association in the eastern Pacific Ocean.

Environmental parameter range:

SST: 10.7–29.8 °C (summer–summer). SSS: 31.9–38.3 (summer–winter), [P]: 0.1–1.1 μmol/l, [N]: 0.04–8.7 μmol/l, chlorophyll-*a*: 0.13–12.2 ml/l, bottom water [O_2]: <6 ml/l.

Highest abundances (>10%) are observed in regions where SST>20 °C throughout the year. Cysts are reported mainly from upwelling regions where large inter-annual variability in the trophic state of the upper waters can occur with eutrophic conditions during active upwelling, upwelling relaxation or when upwelling filaments cross the sampling site and oligotrophic conditions when upwelling is absent. The species is most abundant in areas where bottom waters are anoxic or hypoxic conditions and is absent from well-ventilated regions.

Comparison with other records:

Apart from the recordings in this Atlas *B. spongium* has been reported from coastal areas of Vietnam (South China Sea, Mizushima, 2007). Sediment trap studies off NW Africa and in the Indian Ocean reveal that cysts of this species are produced during times of active upwelling with upwelling cells located in the vicinity of the sampling site (Zonneveld and Brummer, 2000; Susek et al., 2005; Zonneveld et al., 2010). In the Arabian Sea the occurrence of upwelling is restricted to the south-east monsoon in June-September, off NW Africa upwelling can occur throughout the year and is not bound to a certain season.

Concluding remarks:

B. spongium can be considered to be typical for tropical to subtropical full marine upwelling areas. It is abundant in areas with anoxic and hypoxic bottom waters.

4. *Bitectatodinium tepikiense* Wilson 1973

Figs. 16–19.

Distribution:

B. tepikiense is restricted to sub-polar and temperate areas of both hemispheres with highest abundances in the North Sea, off eastern Canada and off Argentina near the subtropical front.

Environmental parameter range:

SST: −2.0–26.9 °C (winter–summer), SSS: 17.4–39.3 (spring–autumn), [P]: 0.1–1.8 μmol/l, [N]: 0.07–23.3 μmol/l, chlorophyll-*a*: 0.08–20.8 ml/l, bottom water [O_2]: >1.7 ml/l.

Abundances >10% are observed in regions where SST ranges between −0.2–26.9 °C (winter–summer). It is exclusively registered in regions where SSS>25.6 (summer) except for a site in the East Siberian Sea (Arctic Ocean) where SSS ranges between 17.4 and 19.0 (spring–summer). Abundances >10% are observed in regions where SSS>30.3 (spring).

Cysts have been reported from oligotrophic to eutrophic environments whereby the majority of the observations and abundances >10% occur in oligotrophic to mesotrophic environments with [P]: <0.6 μmol/l and [N]: <3.3 μmol/l. It is exclusively observed in regions where bottom waters are well ventilated.

Comparison with other records:

So far *B. tepikiense* is not reported from areas other than those covered by this Atlas. Although it can be observed in regions that are seasonally covered by sea ice for less than 4 months a year, it is absent where SSS are seasonally reduced by meltwater (de Vernal et al., 1998). Dale (1985) and Bakken and Dale (1986) have suggested that this species is characteristic for the polar front. The Atlas data suggest that the polar front may be important distribution boundary on both hemispheres although highest relative abundances occur near the sub-tropical front rather than the polar front of the western Atlantic Ocean. It has, however, not been reported from the sub-tropical front systems of the central Atlantic, the central Indian Ocean and the central Pacific.

Concluding remarks:

B. tepikiense has a restricted bipolar distribution and can be found in sub-polar and temperate regions generally between the sub-tropical and arctic frontal systems on both hemispheres. It occurs in both eutrophic and oligotrophic environments in regions where bottom waters are well ventilated.

5. *Brigantedinium* spp.

Figs. 20–24.

Distribution:

Brigantedinium spp. is recorded in 91% of the studied samples. It has a global distribution and can form up to 99% of the association. It can dominate the association from coastal regions to the central parts of the Oceans and is observed in oligotrophic to eutrophic and brackish to hypersaline environments.

Environmental parameter range:

SST: −2.1 –29.8 °C (winter–summer), SSS: 6.7–39.4 (summer–autumn), [P]: 0.1–2.1 μmol/l, [N]: 0.01–30.6 μmol/l, chlorophyll-*a*: 0.01–21.8 ml/l, bottom water [O_2]: 0.01–8.2 ml/l.

These ranges represent the full ranges for the parameters considered in this Atlas. Since high relative abundances of *Brigantedinium* spp. may occur anywhere, within these ranges environmental gradients do not seem to limited the distribution of this taxon.

Comparison with other records:

So far *Brigantedinium* spp. has been reported from all studied regions, from the tropics to regions permanently covered by sea ice (de Vernal et al., 1998; references in Marret and Zonneveld, 2003). In sediment trap studies increased cyst production occurs during or just after increased phytoplankton production due to increased nutrient/trace element availability; for instance as a result of upwelling, frontal activity or input of river and/or melt waters (e.g. Montresor et al., 1998; de Vernal and Hillaire-Marcel, 2000; Zonneveld and Brummer, 2000; Fujii and Matsuoka, 2006; Pospelova et al., 2010; Zonneveld et al., 2010). In the central Strait of Georgia and Saanich Inlet (Canada) as well as the Omura Bay (Japan) the production of diatoms and cyst production of *Brigantedinium* spp. clearly correlate (Fujii and Matsuoka, 2006; Pospelova et al., 2010; Price and Pospelova, 2011). In the upwelling region off NW Africa enhanced cyst production correlates to enhanced fluxes of diatom valves, calcium carbonate and total organic carbon suggesting that the production of cysts is related to the presence of more than one food source (Zonneveld et al., 2010). This seems logical as *Brigantedinium* spp. can be produced by a number of heterotrophic dinoflagellate species that are likely to have differential food preferences.

Concluding remarks:

Brigantedinium spp. can be considered cosmopolitan.

6. *Caspidinium rugosum* Marret et al. 2004

Figs. 24–27.

Distribution:

C. rugosum is restricted to the Caspian Sea where it accounts for up to 4.4% of the association.

Environmental parameter range:

SST: 4.7–24.4 °C (winter–summer), SSS: 11.2–13.3, [P]: 0.1–0.4 μmol/l, [N]: 0.1–0.3 μmol/l, chlorophyll-*a*: 1.4–1.7 ml/l, bottom water [O_2]: 6.5–6.7 ml/l.

Nutrient concentrations are low at these sites whereas bottom waters are well ventilated.

Comparison with other records:

It is not registered from regions other than covered by this Atlas.

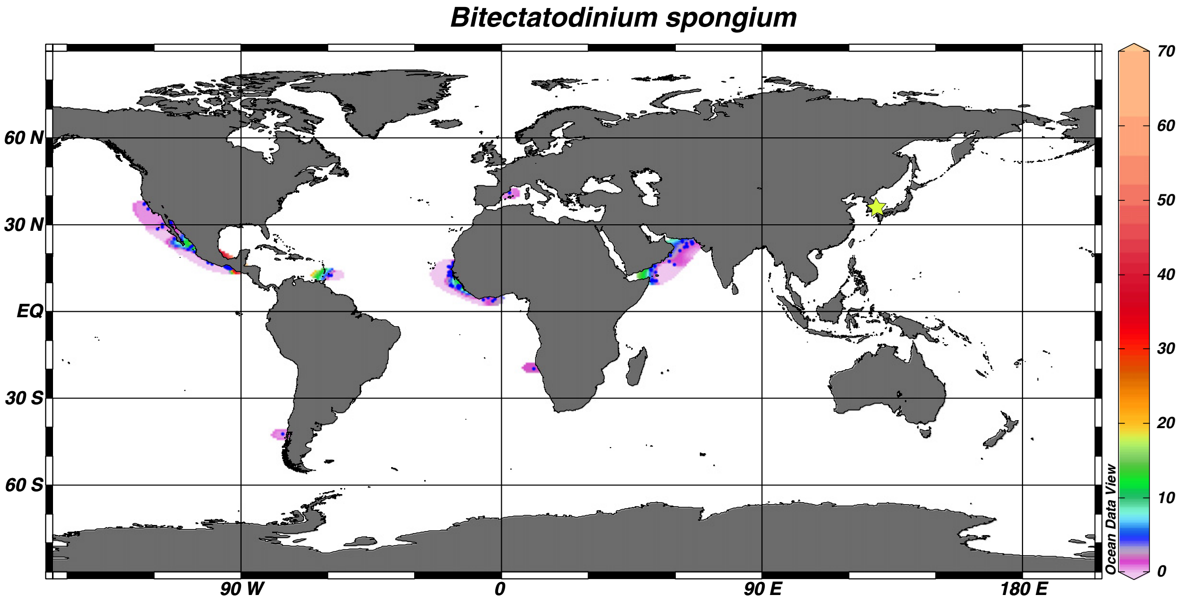

Fig. 12. Geographic distribution of *Bitectatodinium spongium*.

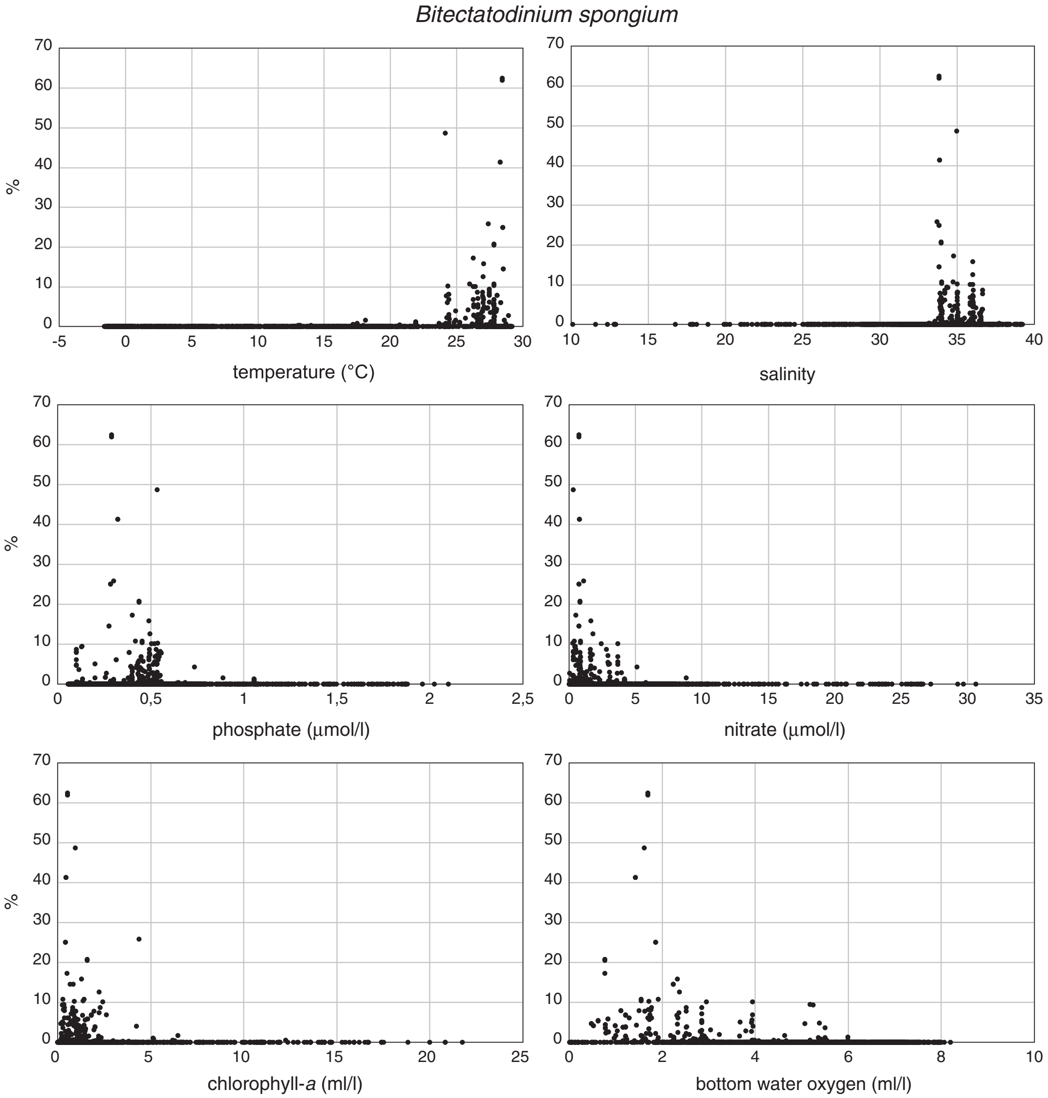

Fig. 13. Relative abundances of *Bitectatodinium spongium* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

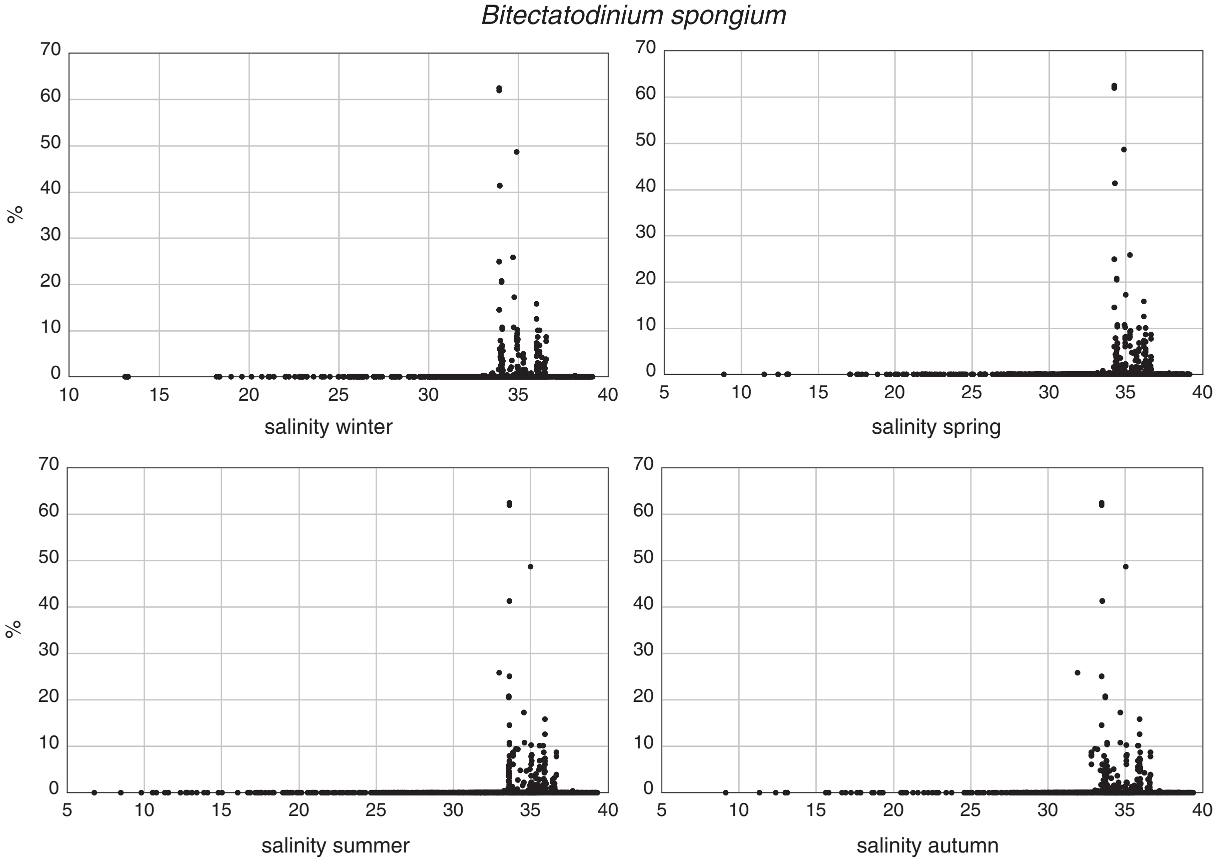

Fig. 14. Relative abundances of *Bitectatodinium spongium* in relationship to seasonal salinity in surface waters.

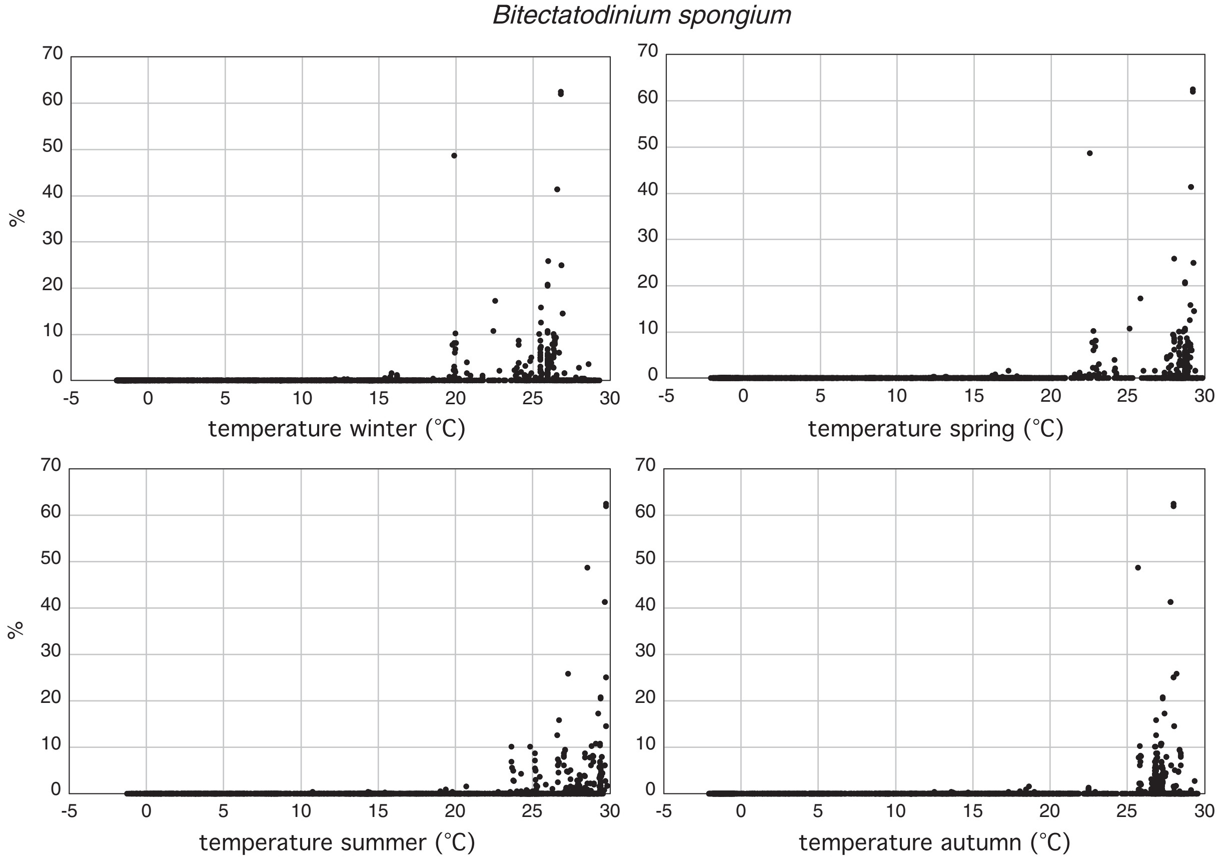

Fig. 15. Relative abundances of *Bitectatodinium spongium* in relationship to seasonal temperature in surface waters.

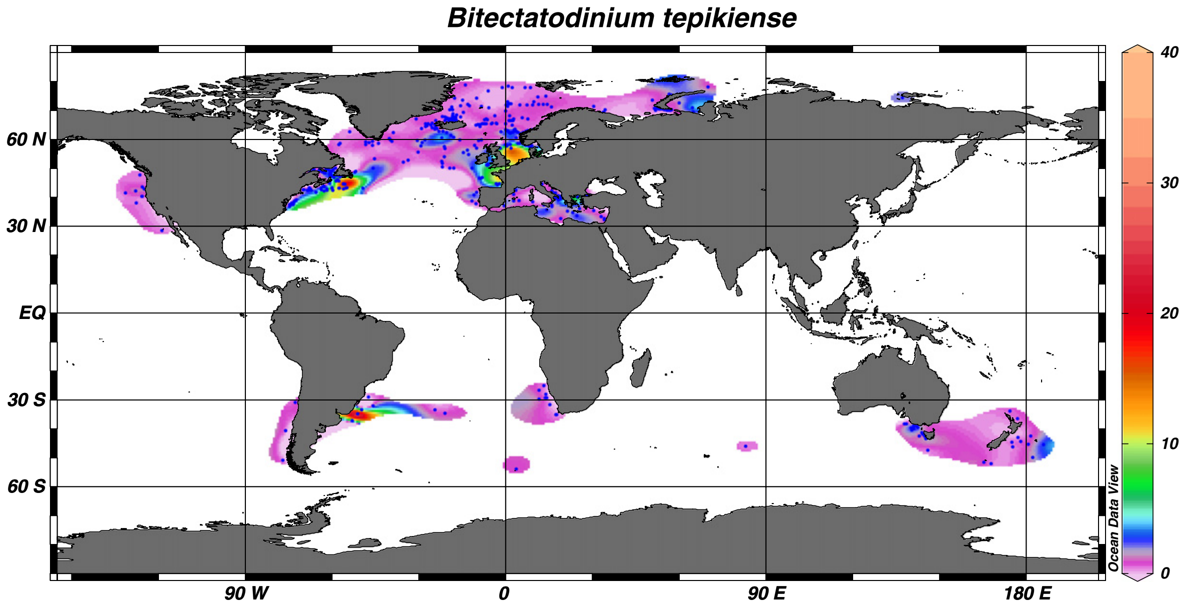

Fig. 16. Geographic distribution of *Bitectatodinium tepikiense*.

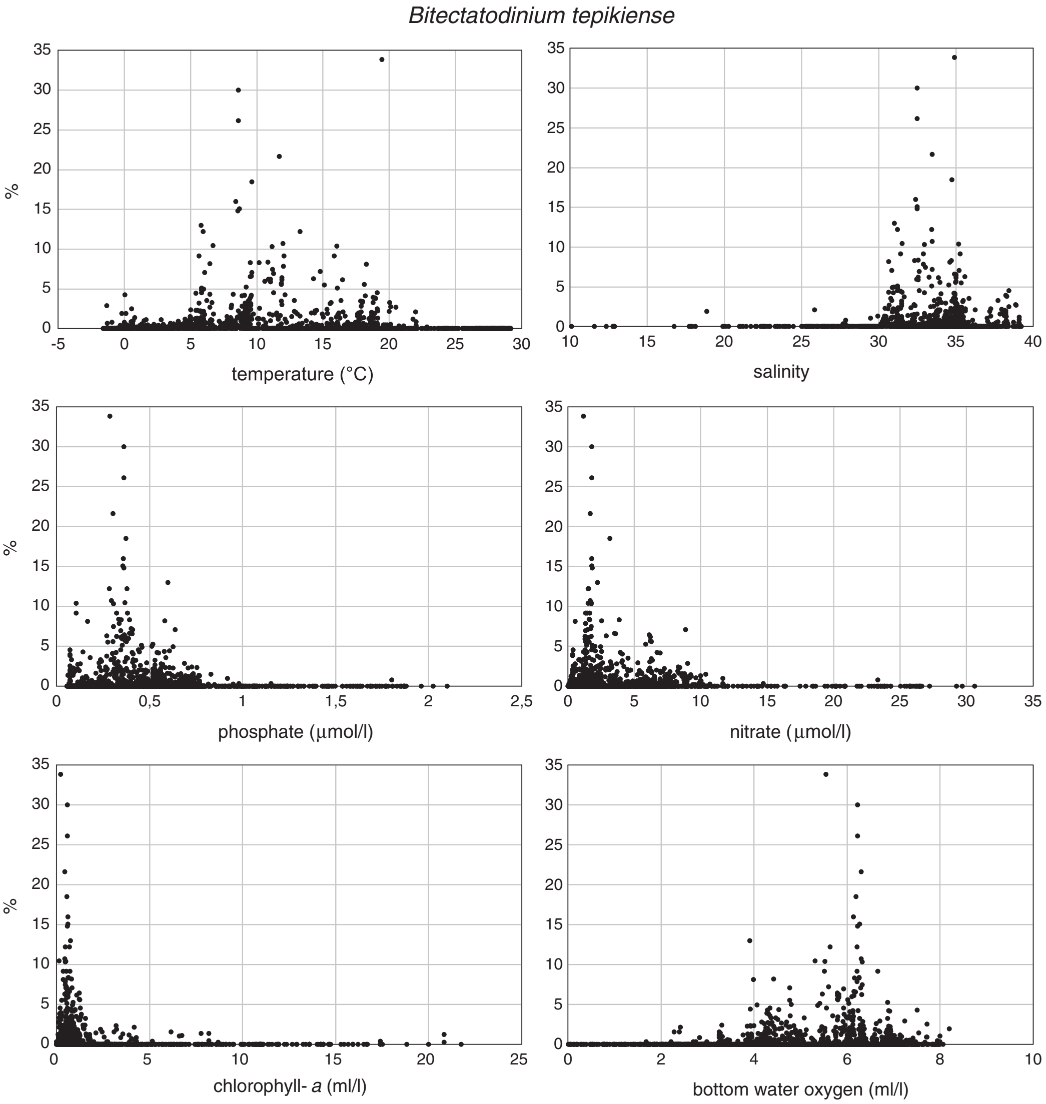

Fig. 17. Relative abundances of *Bitectatodinium tepikiense* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

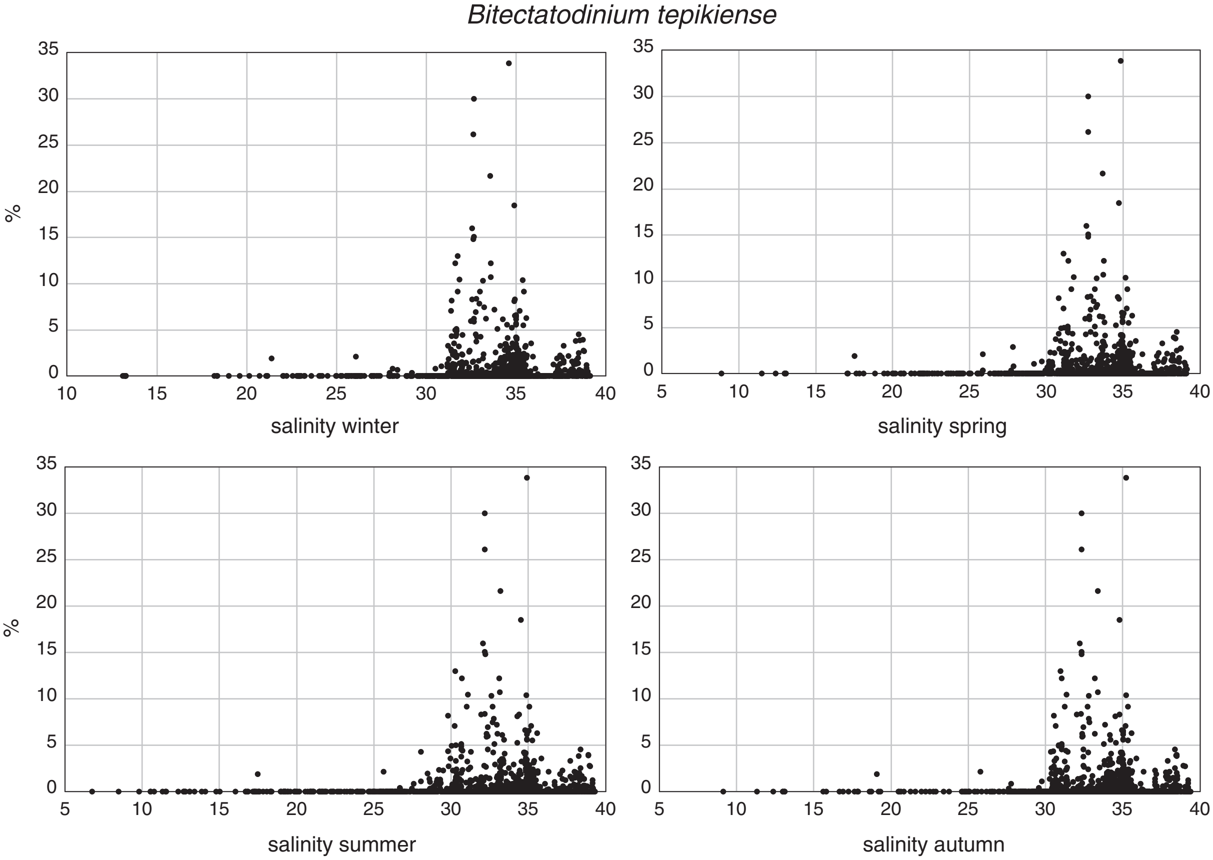

Fig. 18. Relative abundances of *Bitectatodinium tepikiense* in relationship to seasonal salinity in surface waters.

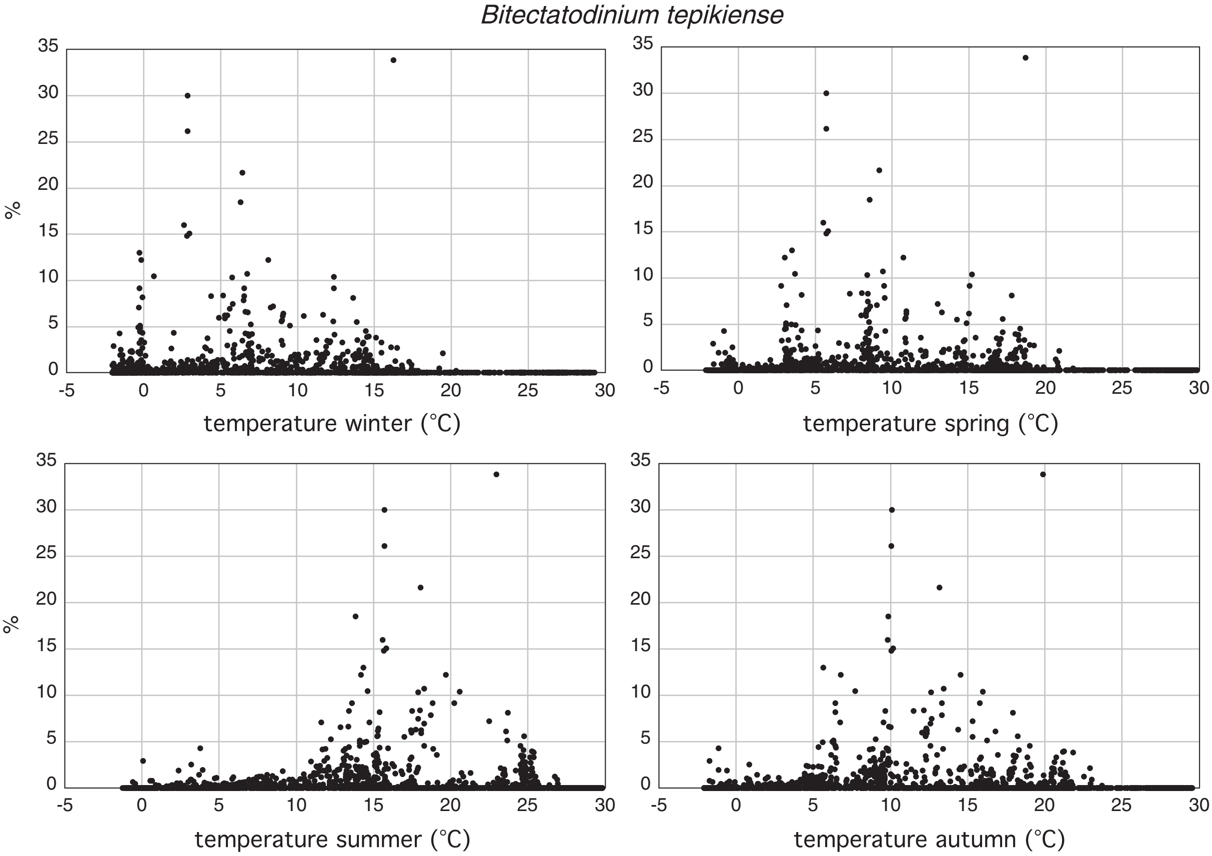

Fig. 19. Relative abundances of *Bitectatodinium tepikiense* in relationship to seasonal temperature in surface waters.

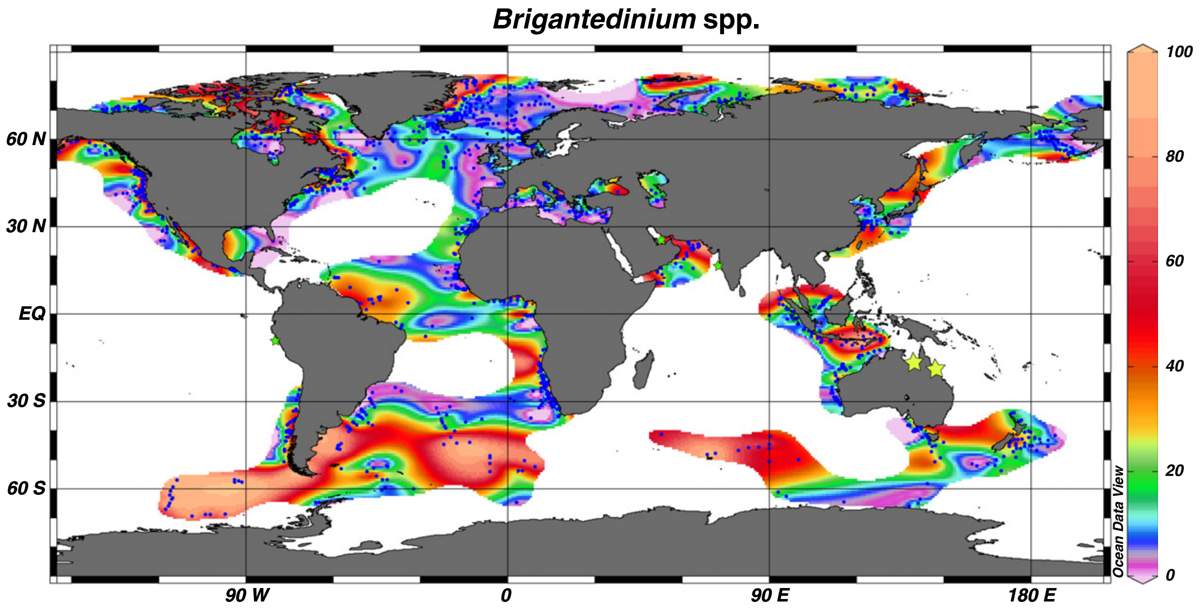

Fig. 20. Geographic distribution of *Brigantedinium* spp.

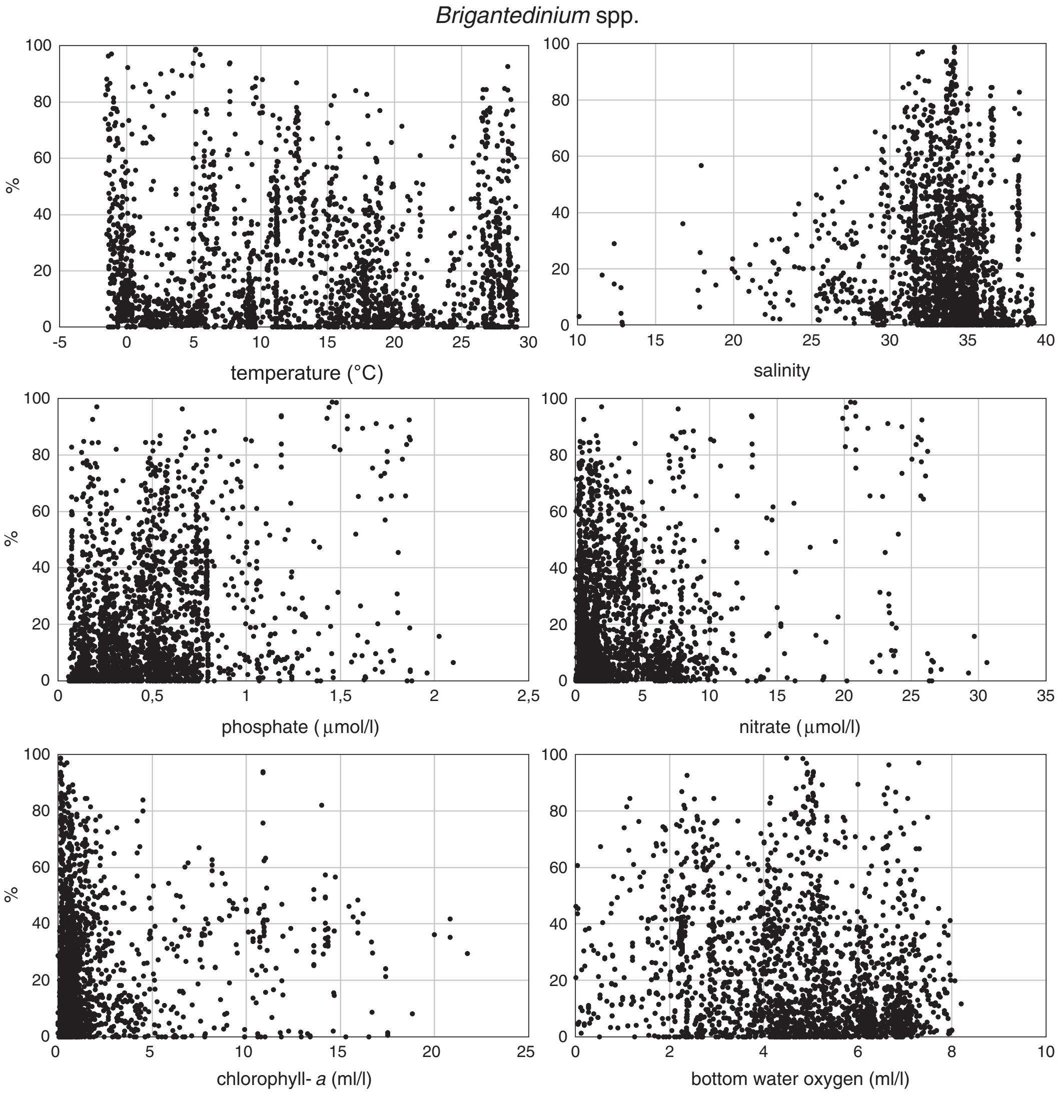

Fig. 21. Relative abundances of *Brigantedinium* spp. in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

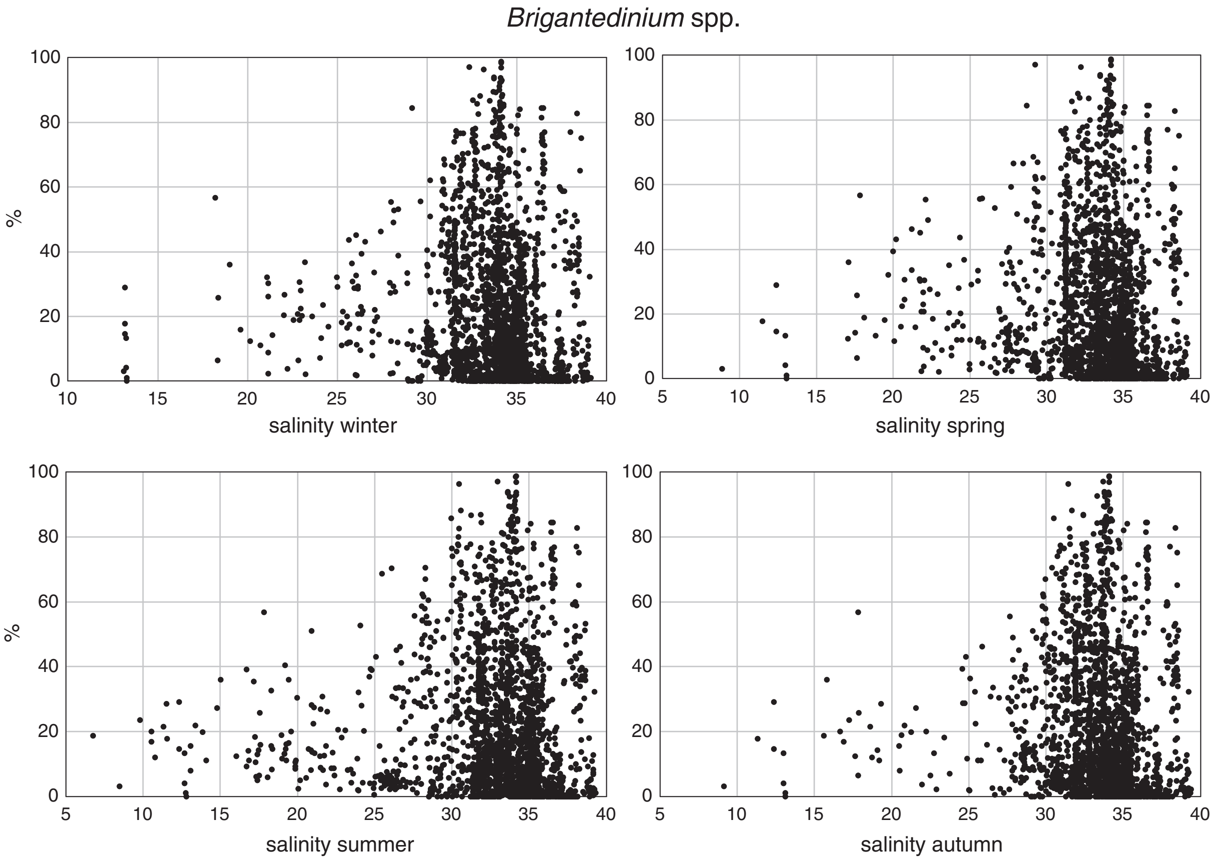

Fig. 22. Relative abundances of *Brigantedinium* spp. in relationship to seasonal salinity in surface waters.

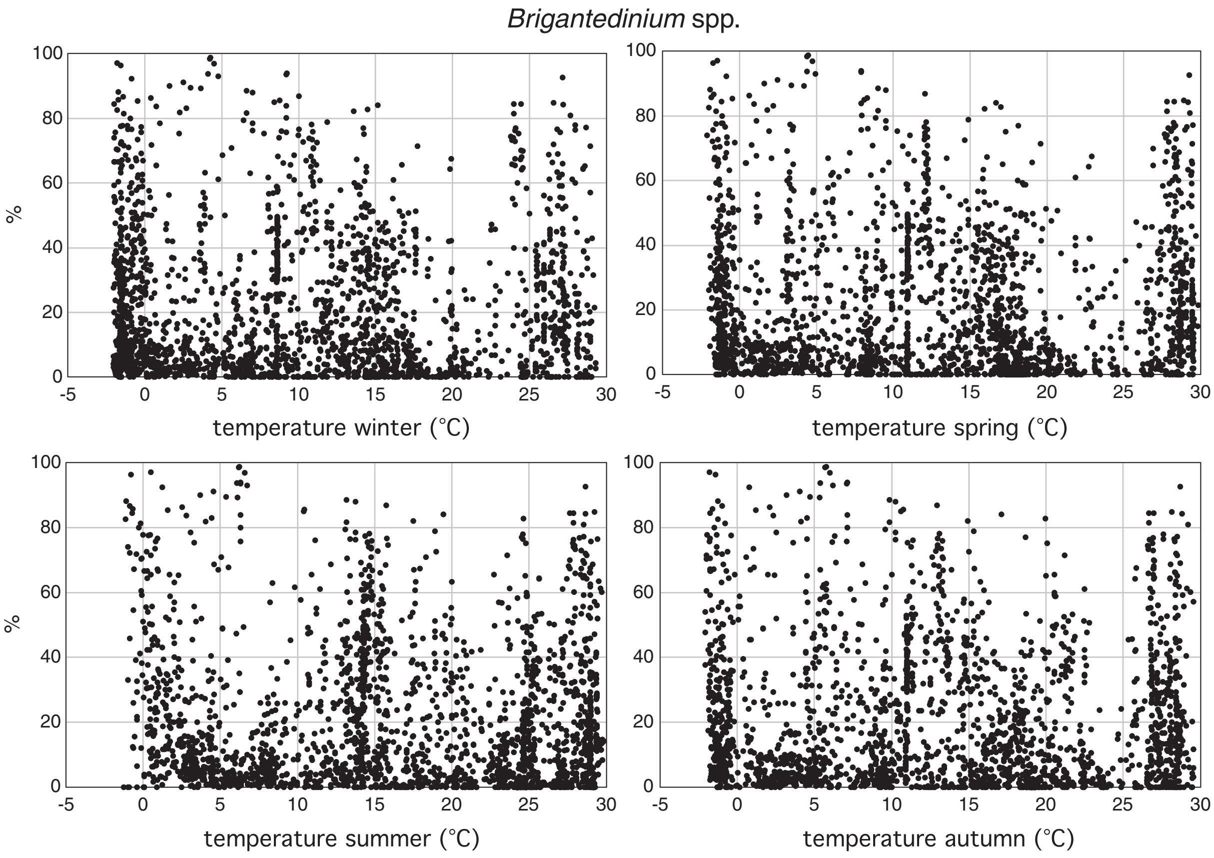

Fig. 23. Relative abundances of *Brigantedinium* spp. in relationship to seasonal temperature in surface waters.

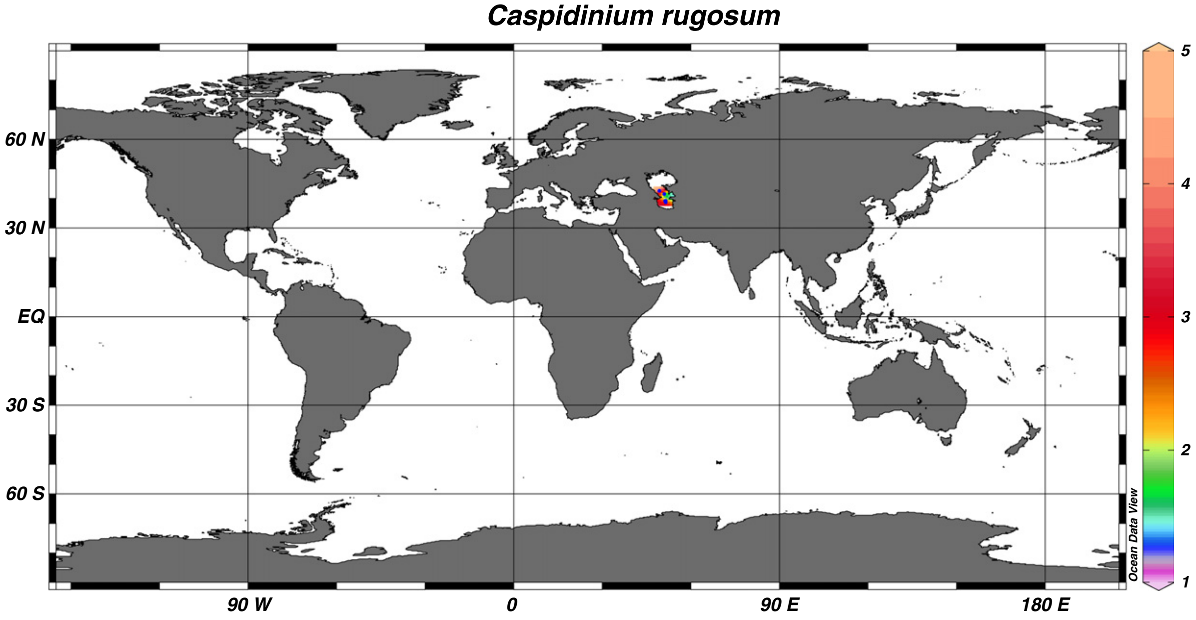

Fig. 24. Geographic distribution of *Caspidinium rugosum*.

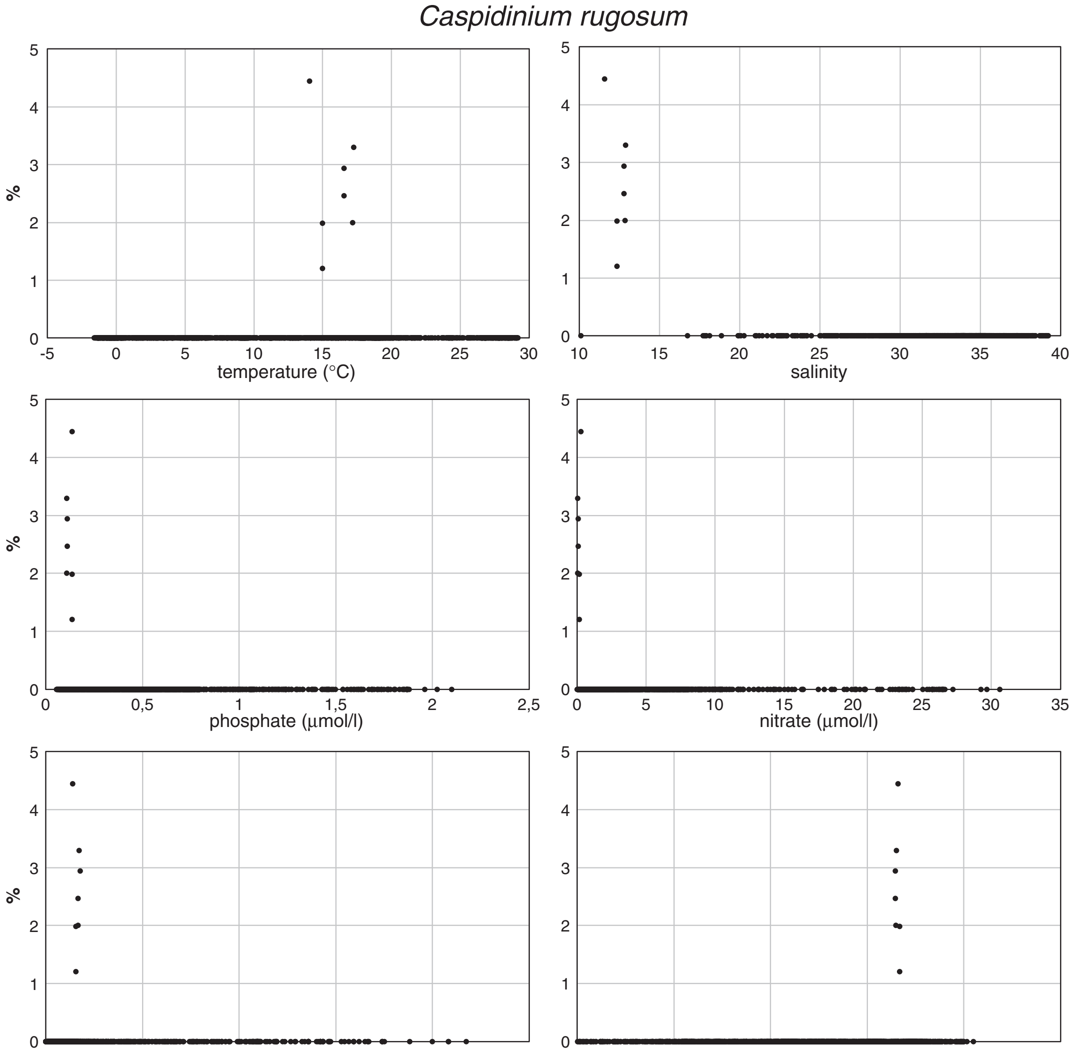

Fig. 25. Relative abundances of *Caspidinium rugosum* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

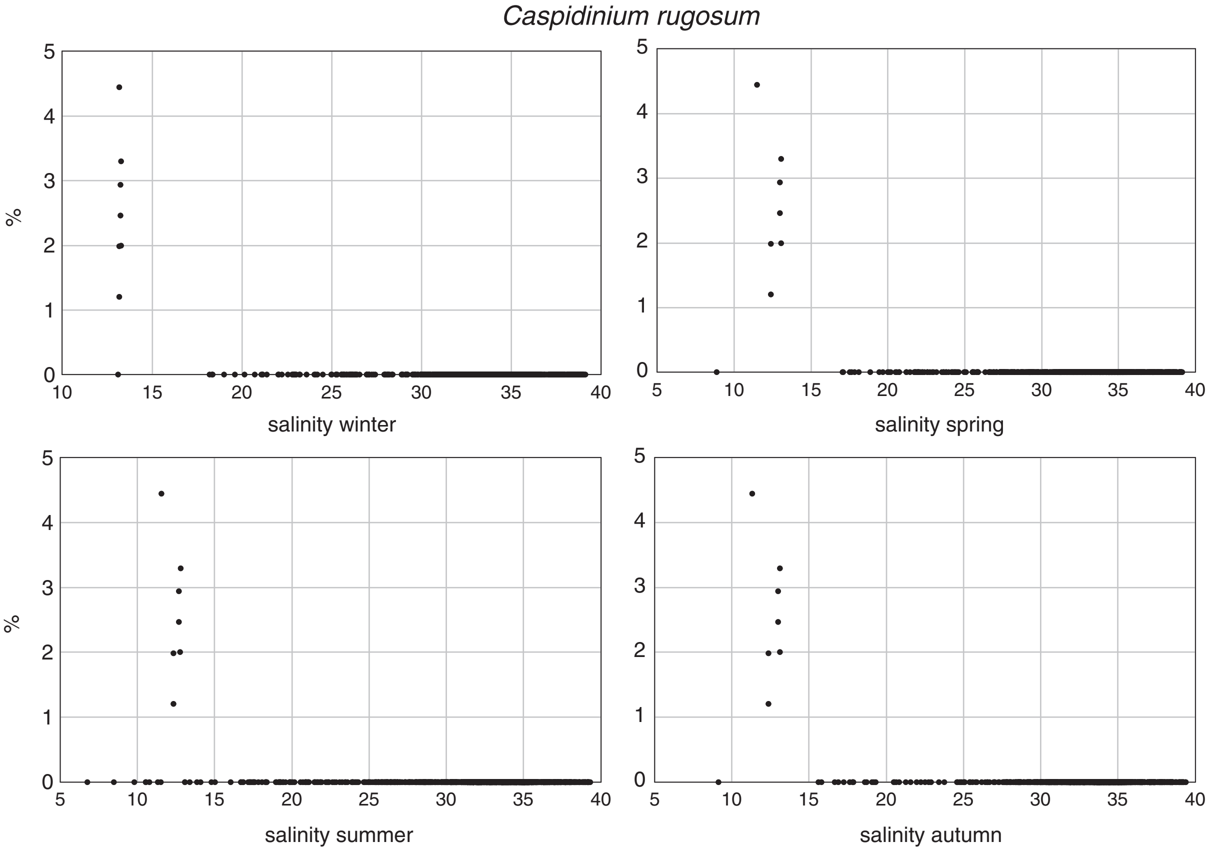

Fig. 26. Relative abundances of *Caspidinium rugosum* in relationship to seasonal salinity in surface waters.

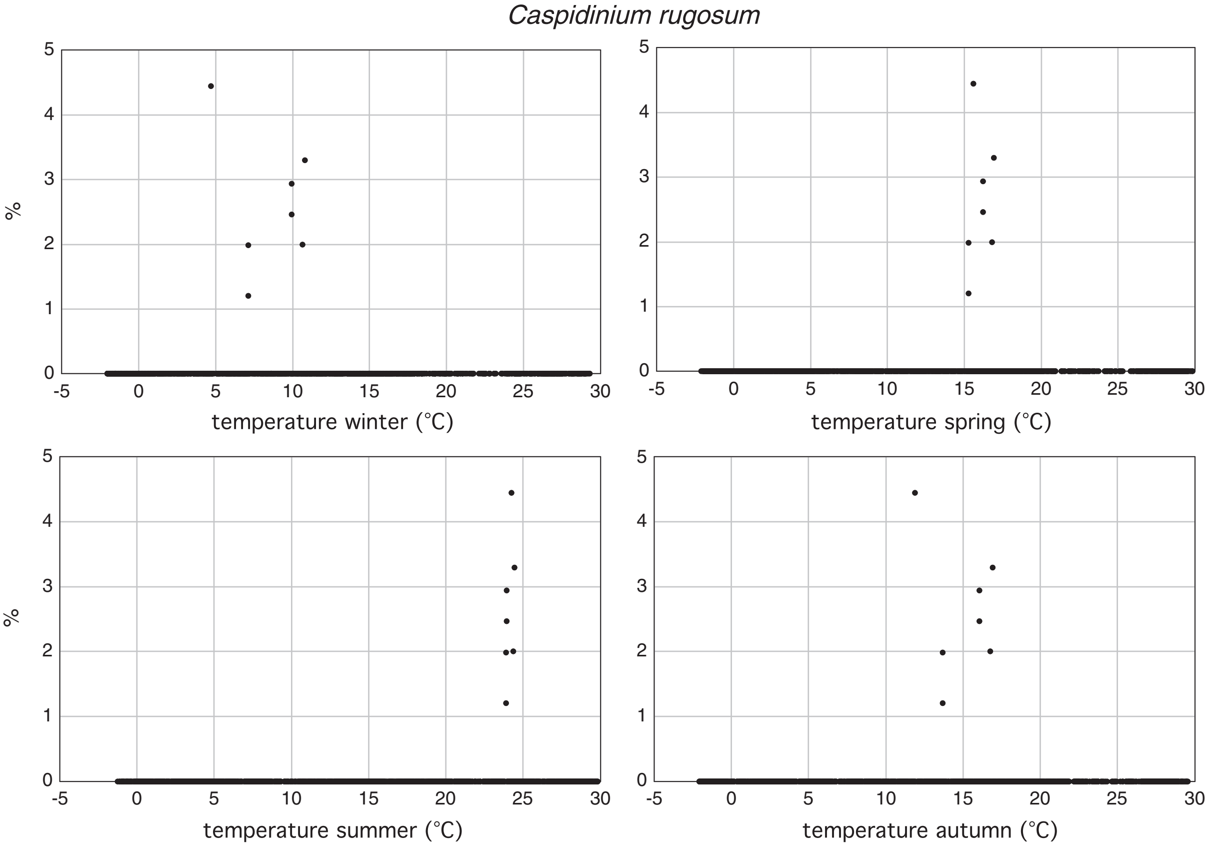

Fig. 27. Relative abundances of *Caspidinium rugosum* in relationship to seasonal temperature in surface waters.

Concluding remarks:

C. rugosum is endemic for the Caspian Sea and is observed in regions where reduced salinities, oligotrophic conditions and well ventilated bottom waters prevail.

7. *Cryodinium meridianum* Esper and Zonneveld 2002

Figs. 28–31.

Distribution:

C. meridianum is exclusively observed in the Antarctic Circumpolar Current of the Pacific and western South Atlantic parts of the Antarctic Ocean. In the Pacific sector its distribution is restricted between the Antarctic Polar Front in the north and the Weddell Gyre Boundary in the south.

Environmental parameter range:

SST: −1.6–13.8 °C (winter–summer), SSS: 33.3–34.2 (summer–winter), [P]: 0.9–1.9 μmol/l, [N]: 7.9–25.7 μmol/l, chlorophyll-*a*: 0.15–0.73 ml/l, bottom water [O_2]: 4.6–5.1 ml/l.

Highest relative abundances *C. meridianum* is restricted to regions with cold surface waters <13.7 °C (summer). Its distribution is restricted to regions with salinities > 33.2 and where upper waters are characterised by low Chlorophyll-*a*: and high nutrient conditions. At these sites bottom waters are well ventilated.

Comparison with other records:

It is not registered from regions other than covered by this Atlas.

Concluding remarks:

Cryodinium meridianum is endemic for the Antarctic Circumpolar Current south of the Antarctic Polar Front.

8. *Dalella chathamensis* McMinn and Sun 1994

Figs. 32–35.

Distribution:

D. chathamensis is abundant in the temperate to equatorial regions of the Southern Hemisphere north of the maximal extension of sea ice. In the northern Hemisphere it is restricted to the eastern Pacific Ocean and a few sites just north of the equator in the central Atlantic Ocean. Highest relative abundances are observed along the Antarctic sub-tropical and Antarctic Polar Fronts at the northern rim of the Antarctic Circumpolar Current. Although it is observed at a few coastal sites, it is mainly present in high abundances in the open oceans far away from the continental margins.

Environmental parameter range:

SST: −1.5–28.4 °C (winter–summer), SSS: 32.1–36.9 (summer–autumn), [P]: 0.1–1.9 μmol/l, [N]: 0.04–25.8 μmol/l, chlorophyll-*a*: 0.1–3.1 ml/l, bottom water [O_2]: <6.1 ml/l.

D. chathamensis is restricted to cold/temperate to tropical regions with abundances > 5% where SST: are between 4.5–22.1 °C (winter–summer). The SSS: range is small and it is absent in vicinity of river discharge plumes or other regions with reduced salinities. Cysts have been reported from oligotrophic to eutrophic environments. Bottom waters at few sites are anoxic/hypoxic but mostly bottom waters are well ventilated.

Comparison with other records:

This species is not reported from regions other than covered by this Atlas.

Concluding remarks:

D. chathamensis can be regarded as an open oceanic species with highest abundances along the frontal systems of the southern Ocean north of the maximal extension of sea ice. With exception of the eastern Pacific it is restricted to the southern Hemisphere.

9. *Dubridinium caperatum* Reid 1977

Figs. 36–39.

Distribution:

D. caperatum is restricted to the temperate to equatorial coastal upwelling regions off northwestern Africa and western North and South America. It also occurs in the mixed waters of the Irish Sea, the East China Sea as well as in unstratified heavily polluted embayments of Massachuchetts (USA). Highest abundances (up to 17%) are observed in the vicinity of active upwelling cells and relative abundances decrease rapidly with distance from these cells.

Environmental parameter range:

SST: 6.3–29.7 °C (summer–summer) with exception of two northeastern Pacific sits where winter SST is −1.3 and −0.7 °C. SSS: 26.8–38.1 (summer–autumn), [P]: 0.1–1.8 μmol/l, [N]: 0.4–13.2 μmol/l, chlorophyll-*a*: 0.2–15.9 ml/l and bottom water [O_2]: 0.3–6.3 ml/l.

The SSS range is small and *D. caperatum* has not been observed in the vicinity of river plumes or other regions with reduced SSS. Cysts of this species are mainly observed in eutrophic environments characterised with high chlorophyll-*a* concentrations. However, these regions are mainly upwelling areas or areas where upper waters are seasonally turbulent where large inter-annual variability in the trophic state may occur with eutrophic conditions during active upwelling/turbulence or when upwelling filaments cross the sampling site and oligotrophic conditions when upwelling is absent or upper waters are stratified. It is exclusively present in regions where bottom waters are hypoxic to well ventilated.

Comparison with other records:

Apart from the recordings in this Atlas, *D. caperatum* has been observed in high relative abundances in coastal bays of southern Korea, Southern Vancouver Island (Canada) (Cho et al., 2003; Shin et al., 2007, 2010a, 2010b; Krepakevich and Pospelova, 2010; Pospelova and Kim, 2010). All these sites have unstratified eutrophic surface waters often as a result of pollution. Sediment trap and seasonal distribution studies from the upwelling area off Portugal and the central Strait of Georgia (BC, Canada) document highest cyst production during active coastal upwelling and in spring/summer (Ribeiro and Amorim, 2008; Pospelova et al., 2010). In the Saanich Inlet (BC, Canada) cyst production did not show a seasonal pattern but occurred when the biogenic silica flux was elevated by diatom production (Price and Pospelova, 2011).

Concluding remarks:

D. caperatum is restricted to full marine settings with unstratified surface waters and where nutrient concentrations can be (seasonally) enhanced for instance by upwelling or pollution.

10. *Echinidinium aculeatum* Zonneveld 1997

Figs. 40–43.

Distribution:

With the exception of a few sites, *E. aculeatum* is restricted to the coastal regions of temperate to equatorial regions. Highest abundances (up to 19%) occur in the vicinity of the active upwelling cells off Mexico, off Chili and off NW Africa.

Environmental parameter range:

SST: 7.8–29.8 °C (winter–summer) with the exception of one site in the northeastern Pacific with SST: −1.3, −0.8, 4.4 and −0.8 °C (winter, spring, summer, autumn), SSS: 26.8–38.5, [P]: 0.1–1.1 μmol/l, [N]: 0.4–9.6 μmol/l, chlorophyll-*a*: 0.1–18.8 ml/l, bottom water [O_2]: 0.3–6.1 ml/l.

Abundances > 5% occur in subtropical/tropical regions with SST of 19.9–29.7 °C (winter–summer) with mesotrophic to eutrophic conditions where [P]: 0.3–0.8 μmol/l [N]: 0.3–5.0 μmol/l and high chlorophyll-*a* concentrations of 0.5–17.4 ml/l. These are mainly upwelling areas where large inter-annual variability in the trophic state of the surface waters can occur with eutrophic conditions during active upwelling or when upwelling filaments cross the sampling site and oligotrophic conditions when upwelling is absent.

E. aculeatum is restricted to sites with a small seasonal salinity range. It is not observed in the vicinity of river plumes or other regions where SSS are reduced. Highest relative abundances occur in regions with hypoxic bottom waters.

Comparison with other records:

Apart from the observations presented in this Atlas *E. aculeatum* has recently been reported from eutrophic bays with unstratified upper waters in southern Korea (Krepakevich and Pospelova, 2010; Pospelova and Kim, 2010; Shin et al., 2010a, b), British Columbia (Krepakevich and Pospelova, 2010) and the upwelling area off Portugal (Ribeiro and

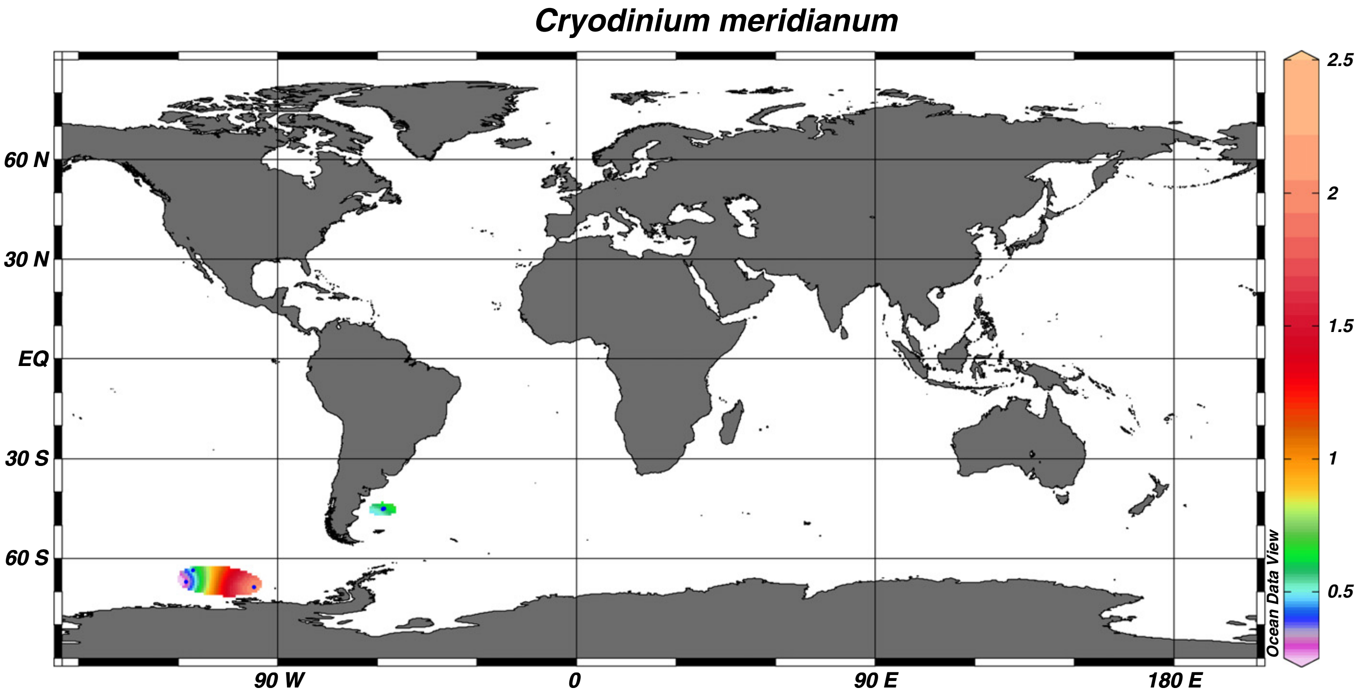

Fig. 28. Geographic distribution of *Cryodinium meridianum*.

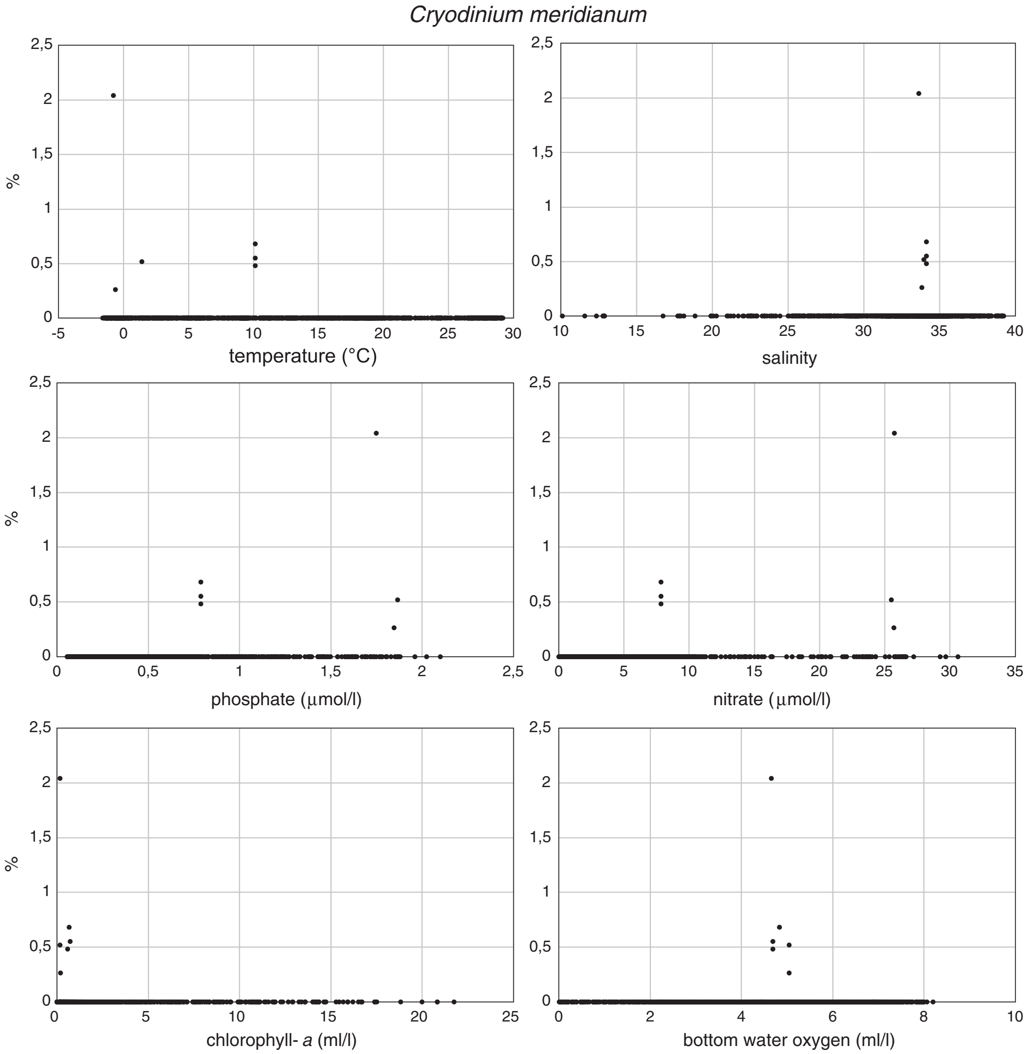

Fig. 29. Relative abundances of *Cryodinium meridianum* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

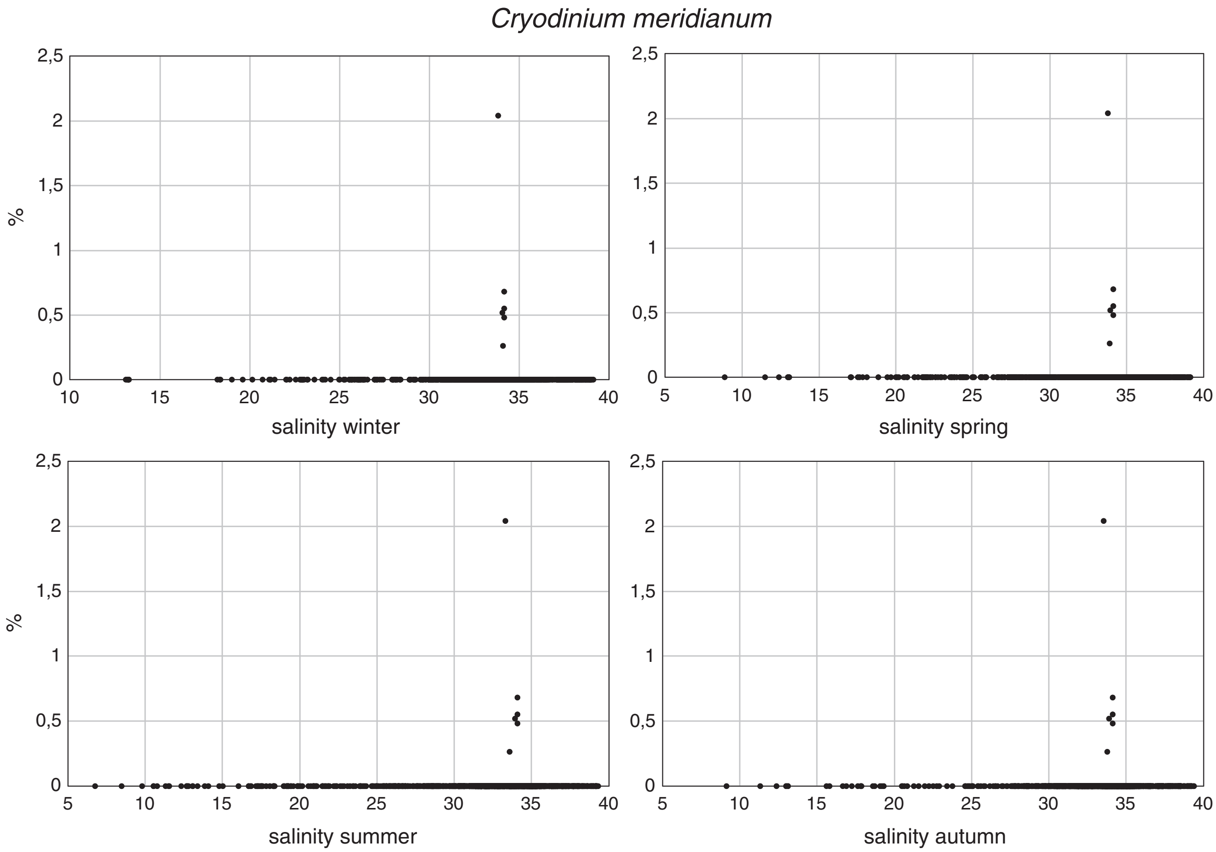

Fig. 30. Relative abundances of *Cryodinium meridianum* in relationship to seasonal salinity in surface waters.

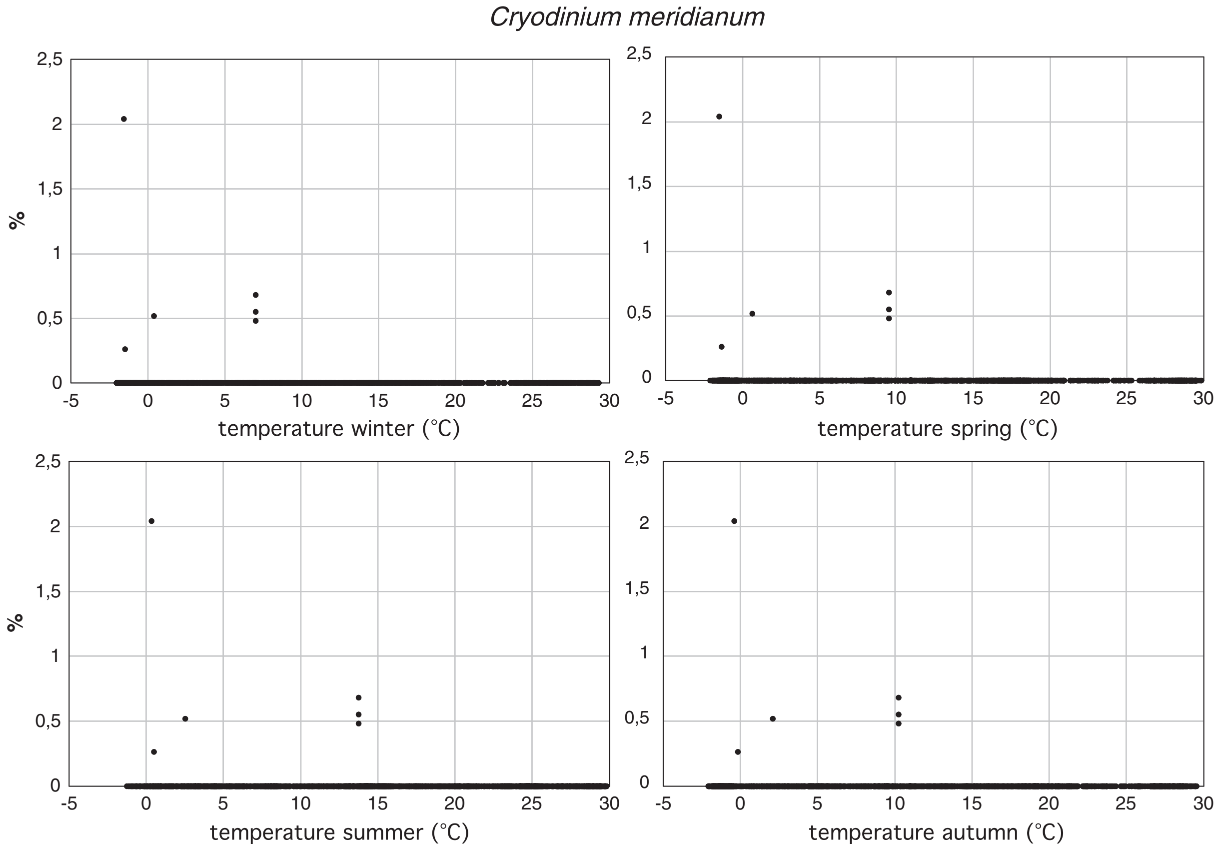

Fig. 31. Relative abundances of *Cryodinium meridianum* in relationship to seasonal temperature in surface waters.

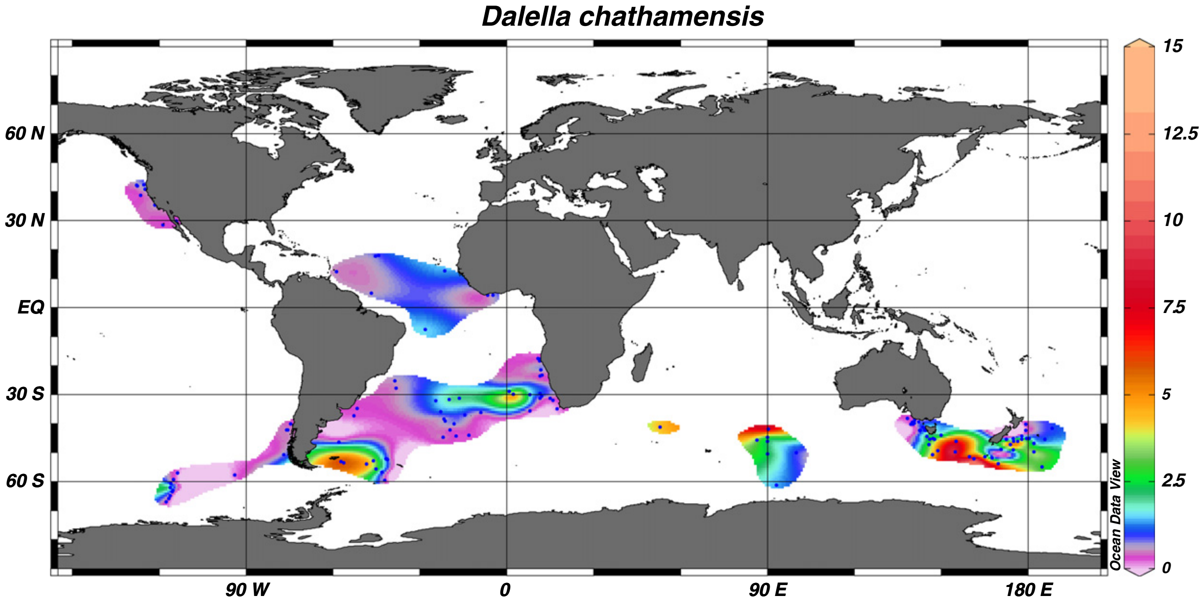

Fig. 32. Geographic distribution of *Dalella chathamensis*.

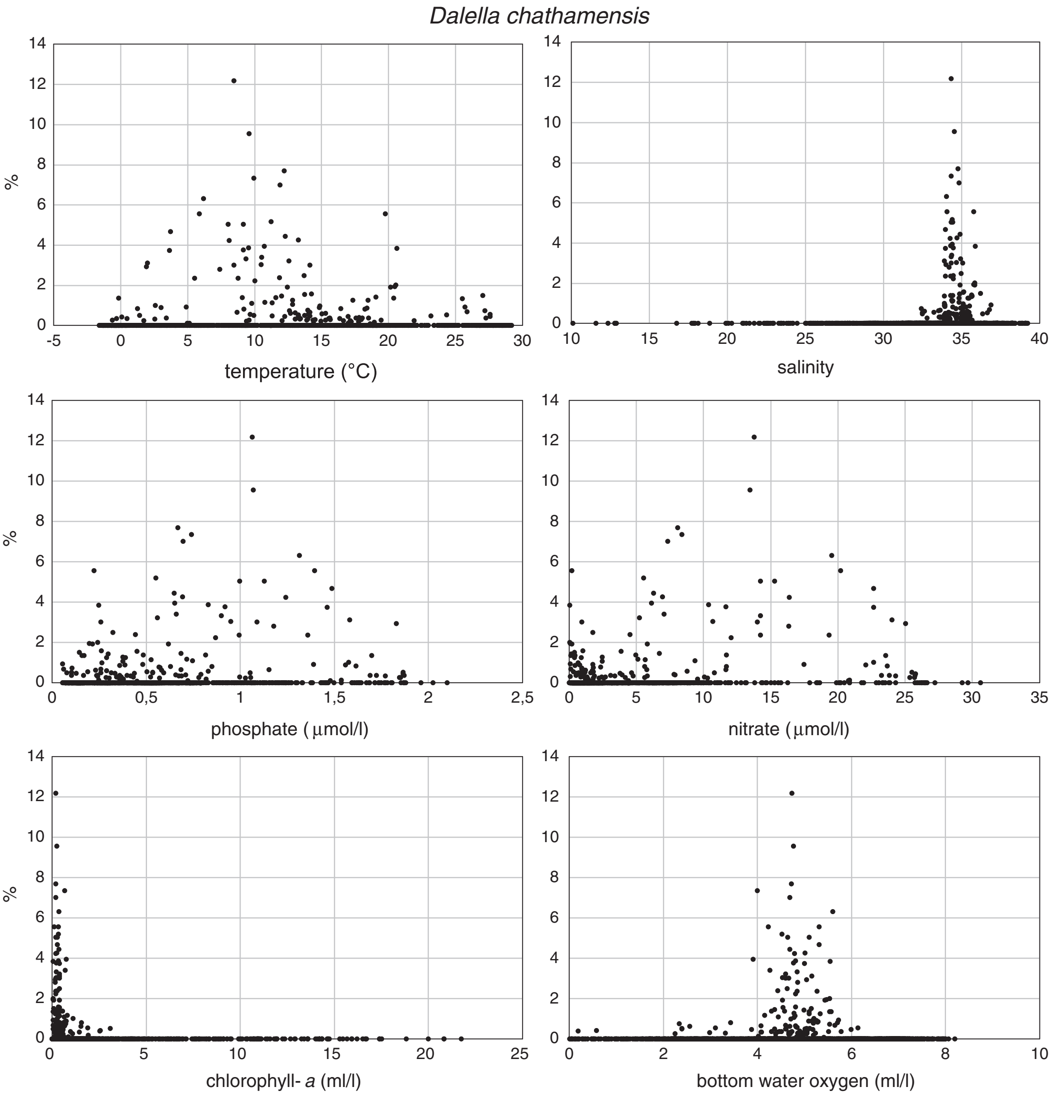

Fig. 33. Relative abundances of *Dalella chathamensis* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

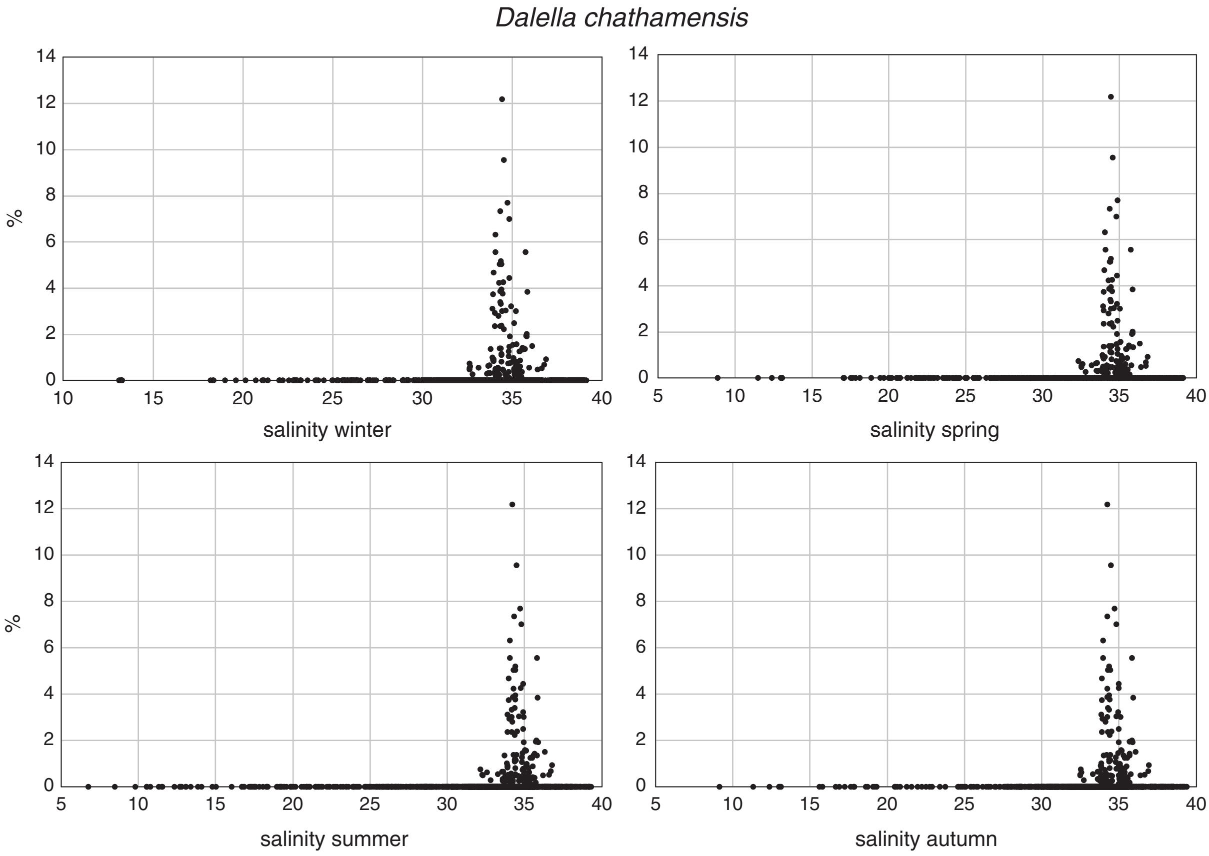

Fig. 34. Relative abundances of *Dalella chathamensis* in relationship to seasonal salinity in surface waters.

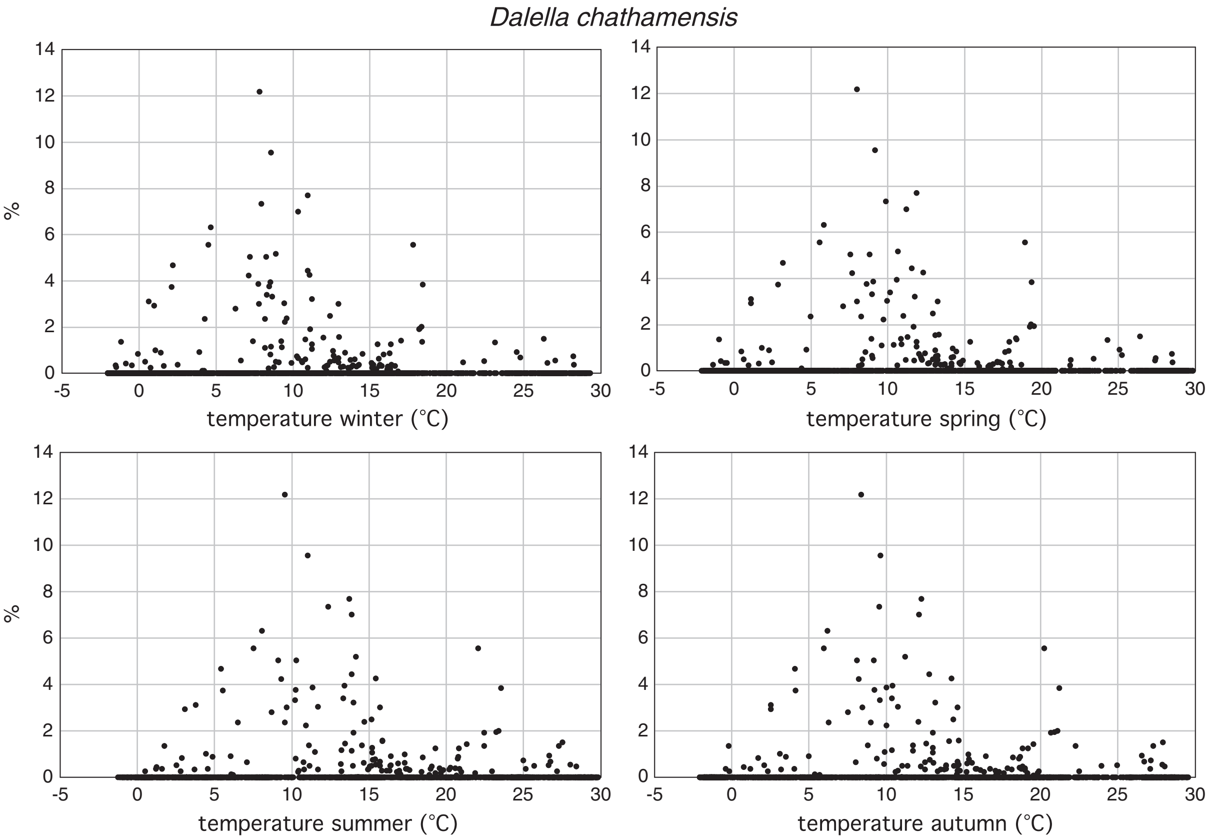

Fig. 35. Relative abundances of *Dalella chathamensis* in relationship to seasonal temperature in surface waters.

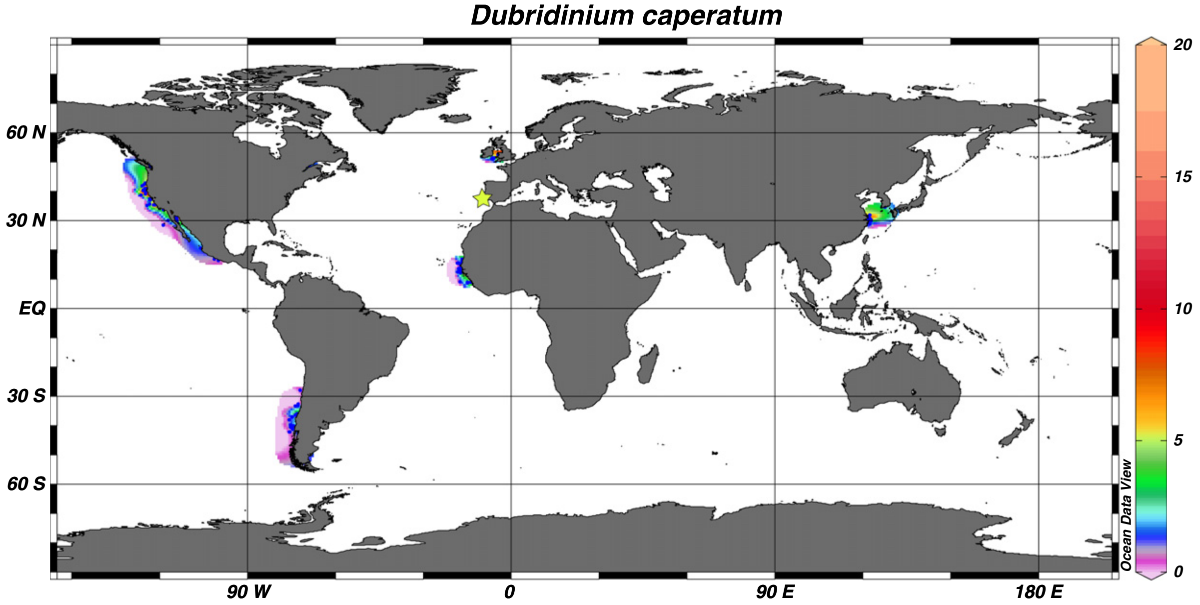

Fig. 36. Geographic distribution of *Dubridinium caperatum*.

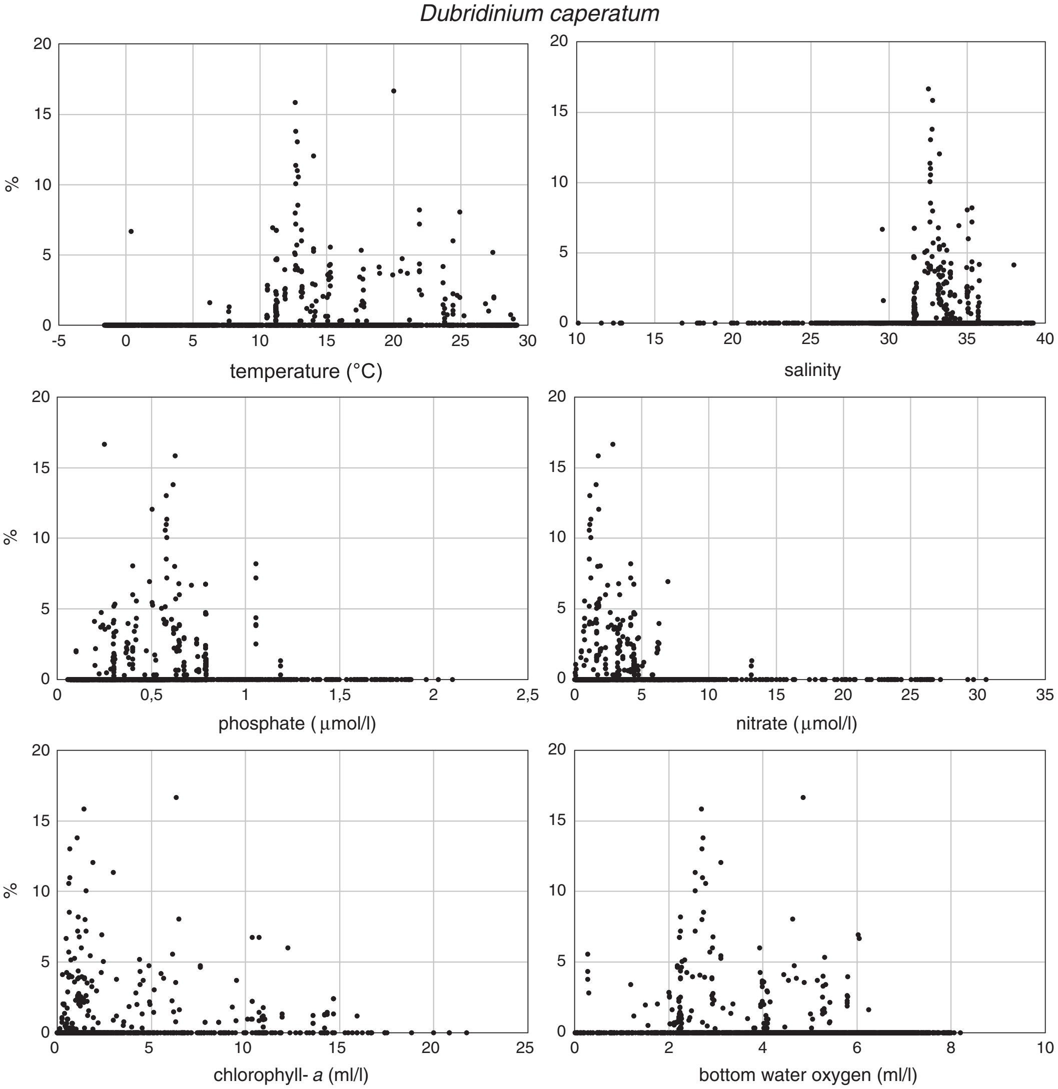

Fig. 37. Relative abundances of *Dubridinium caperatum* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

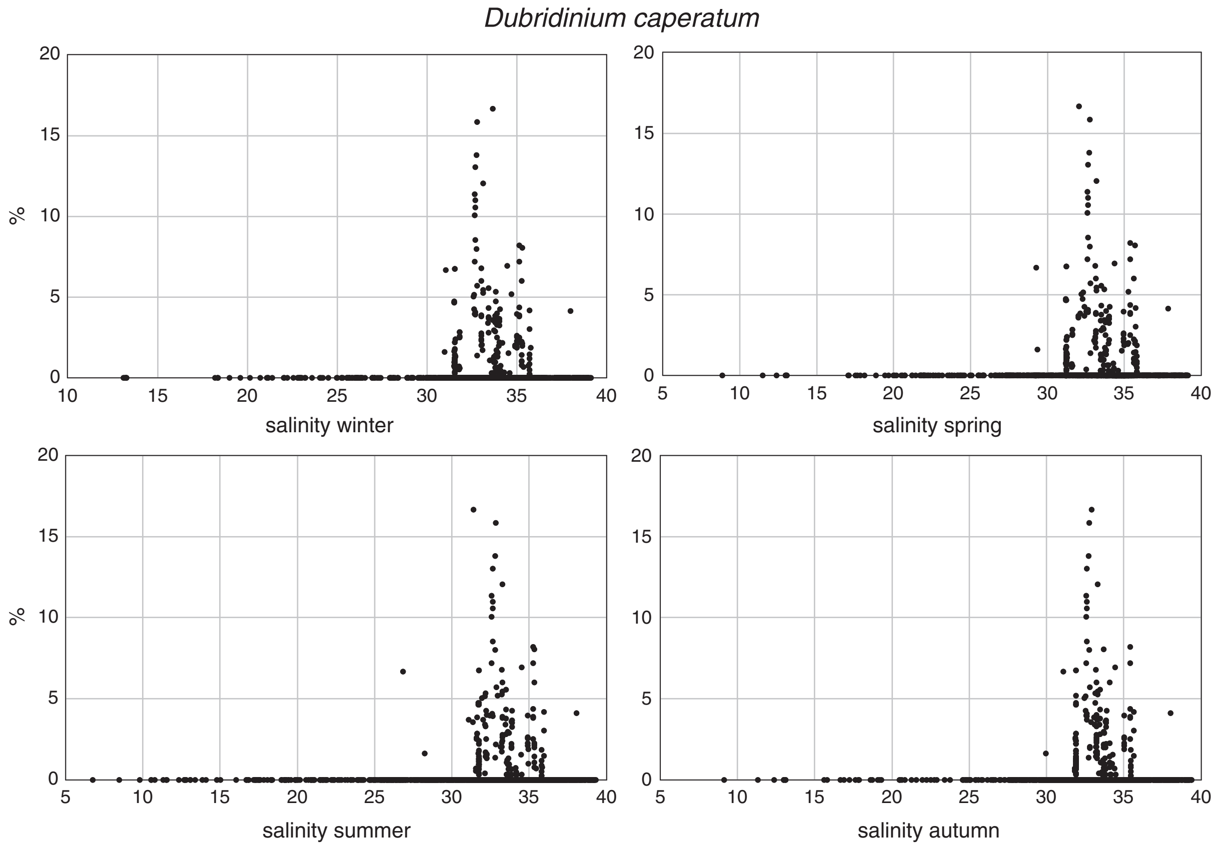

Fig. 38. Relative abundances of *Dubridinium caperatum* in relationship to seasonal salinity in surface waters.

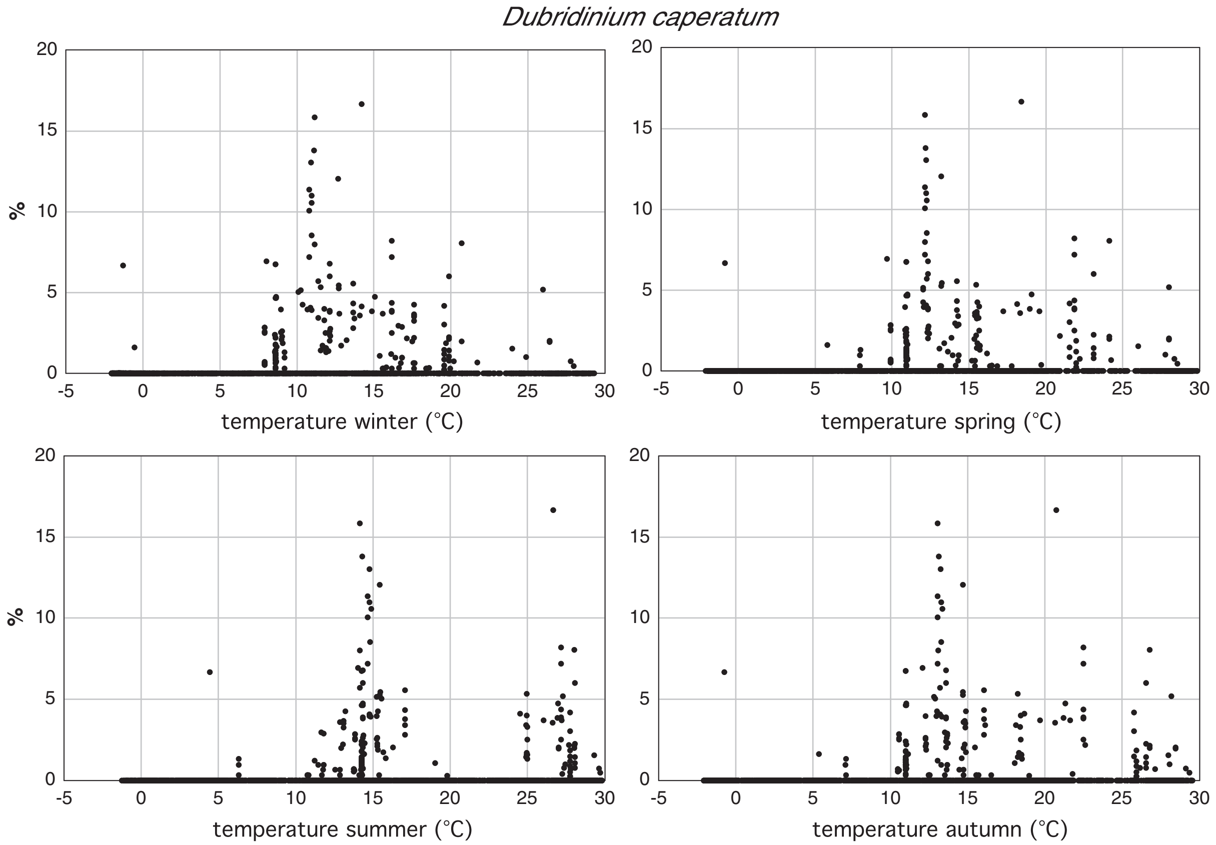

Fig. 39. Relative abundances of *Dubridinium caperatum* in relationship to seasonal temperature in surface waters.

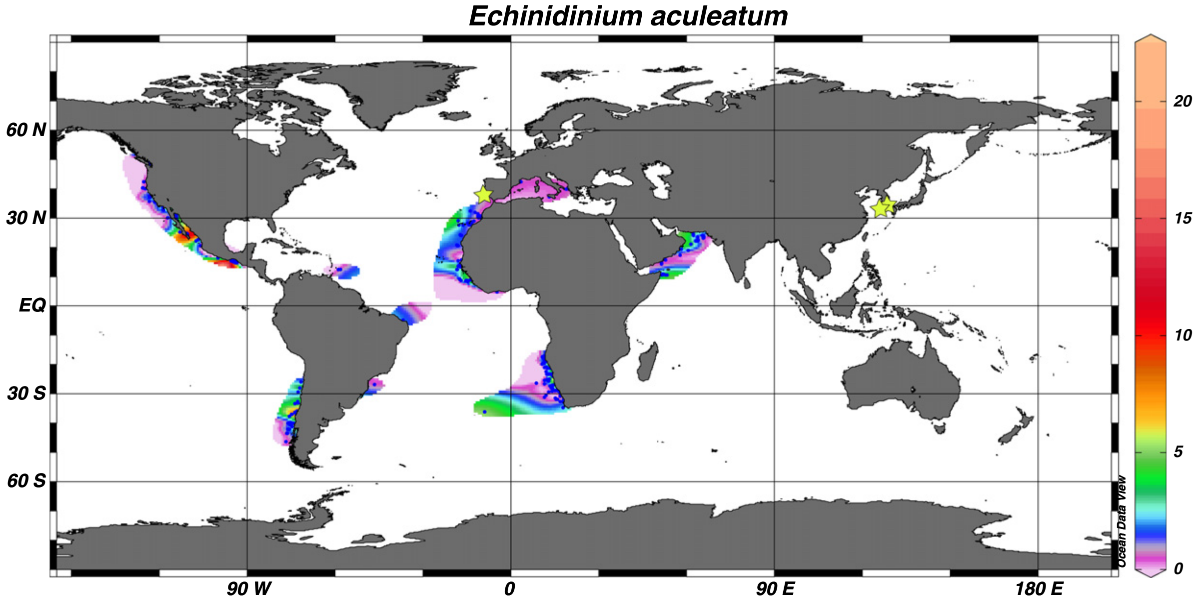

Fig. 40. Geographic distribution of *Echinidinium aculeatum*.

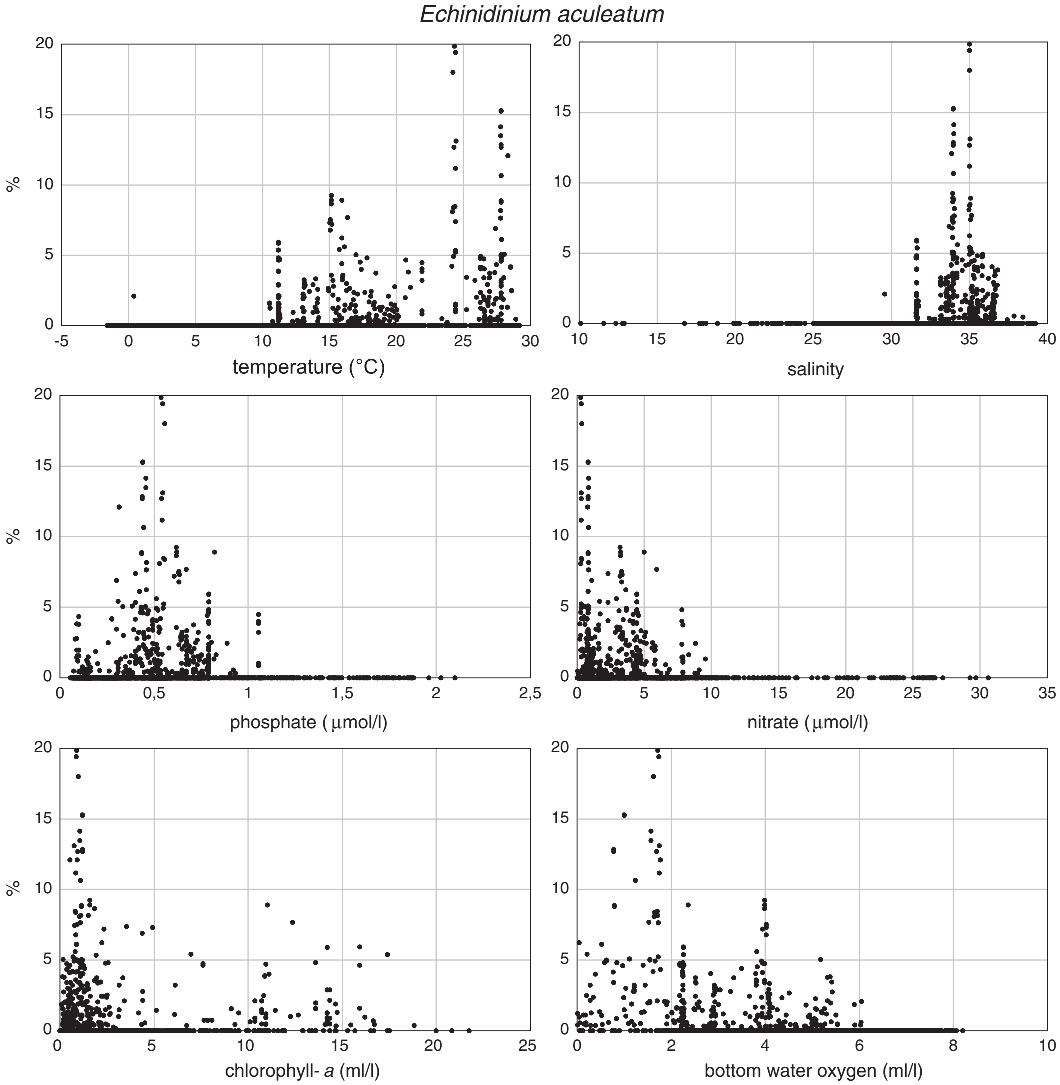

Fig. 41. Relative abundances of *Echinidinium aculeatum* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

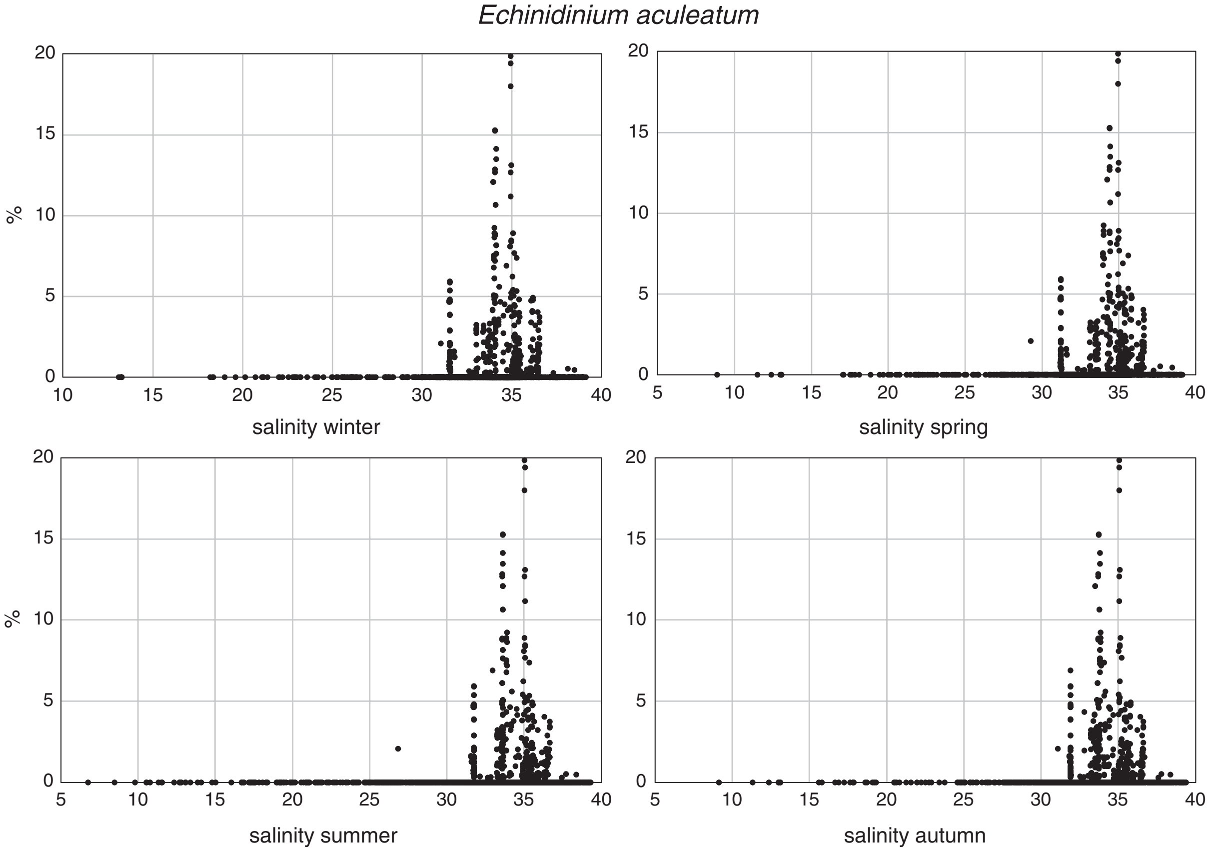

Fig. 42. Relative abundances of *Echinidinium aculeatum* in relationship to seasonal salinity in surface waters.

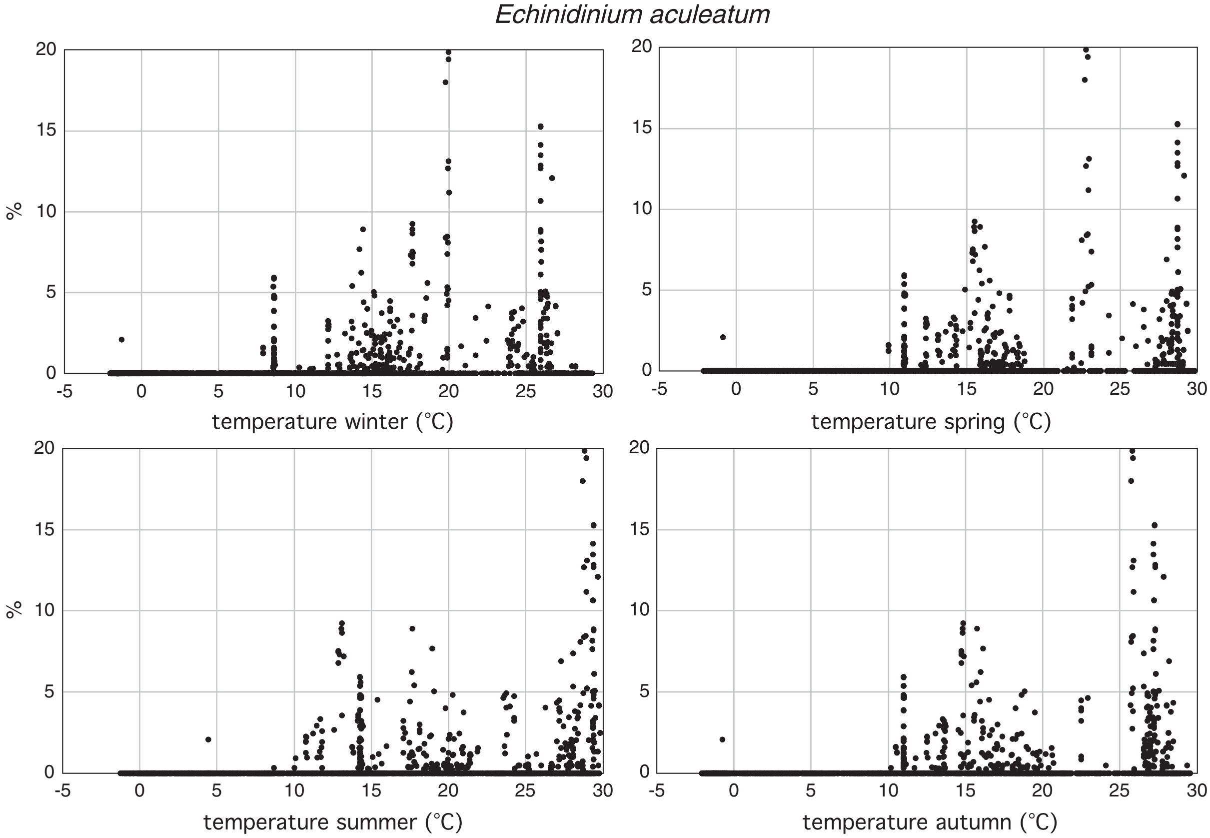

Fig. 43. Relative abundances of *Echinidinium aculeatum* in relationship to seasonal temperature in surface waters.

Amorim, 2008). In the North Pacific *E. aculeatum* has not been observed in regions with sea ice (Radi and de Vernal, 2008). A sediment trap study of the central Georgia Strait (BC, Canada) documents cyst production in spring when Fraser River outflow is highest but with upper water salinities >24 (Pospelova et al., 2010). In the nearby Saanich Inlet (BC, Canada) higher production of this species occurs when diatom production is enhanced (Price and Pospelova, 2011). In the upwelling areas off Somalia and off NW Africa, *E. aculeatum* is produced during active upwelling and the upwelling initiation phase respectively (Zonneveld and Brummer, 2000; Zonneveld et al., 2010).

Concluding remarks:

Echinidinium aculeatum can be regarded as a mesotrophic/eutrophic temperate to equatorial species occurring only in regions with unstratified upper waters. It is not observed in areas with well-ventilated bottom waters.

11. *Echinidinium bispiniformum* Zonneveld 1997

Figs. 44–47.

Distribution:

E. bispiniformum is restricted to the tropical western Arabian Sea where it can form up to 2.7% of the association in upwelling areas.

Environmental parameter range:

SST: 23.6–29.0 °C (summer–spring), SSS: 35.5–36.3 (summer–spring), [P]: 0.01–0.5 μmol/l, [N]: 1.6–3.7 μmol/l, chlorophyll-*a*: 0.5–2.6 ml/l, bottom water [O_2]: 2.3 and 3.9 ml/l.

Bottom water oxygen concentrations are relatively low.

Comparison with other records:

So far *B. bispiniformum* has only been observed in sediments from the Arabian Sea where it is present in regions characterised by active seasonal upwelling. Cysts with cell contents have been captured in sediment traps during active upwelling (Zonneveld and Brummer, 2000).

Concluding remarks:

E. bispiniformis is endemic for the Arabian Sea and characteristic for eutrophic conditions during upwelling.

12. *Echinidinium delicatum* Zonneveld 1997

Figs. 48–51.

Distribution:

The distribution *E. delicatum* is almost completely restricted to the coastal environments of temperate to equatorial regions. Highest relative abundances (up to 11%) occur in the vicinity of active upwelling cells off North America, NW Africa, SW Africa and the Arabian Sea. It also has been reported with low relative abundances in few sites from the Amazon River Plume.

Environmental parameter range:

SST: 8.6–29.4 °C (winter–summer) except for one site in in the northeastern Pacific with SST −1.3, −0.8, 4.4 and −0.8 °C (Winter, spring, summer, autumn), SSS: 32.2–36.7 (summer–summer) except for a few sites with SSS is seasonally reduced to 24.1 in summer, [P]: 0.1–1.1 μmol/l, [N]: 0.07–8.8 μmol/l, chlorophyll-*a*: 0.07–14.7 ml/l, bottom water [O_2]: 0.3–6.1 ml/l.

The species has been reported mainly from upwelling regions where large inter-annual variability in the trophic state of the upper waters occurs with eutrophic conditions during active upwelling or when upwelling filaments cross the site and with oligotrophic conditions when upwelling is absent. The species is most abundant in regions with hypoxic bottom waters.

Comparison with other records:

Additional to the regions covered by the Atlas, *E. delicatum* has also been reported from unstratified and partly strongly nutrient enriched coastal bays in southern South Korea (Pospelova and Kim, 2010). In coastal bays of Southern Vancouver Island highest relative abundances occur at sites with the highest nutrient concentrations (Krepakevich and Pospelova, 2010). Highest cyst production in this area occurs in summer when SSS is relative low and influence of the Fraser river is relative high (Pospelova et al., 2010). In the nearby Saanich Inlet production is increased when SST and diatom production are increased (Price and Pospelova, 2011). In the upwelling areas of the Arabian Sea and off NW Africa cyst production occurs during active upwelling (Zonneveld and Brummer, 2000; Zonneveld et al., 2010).

Concluding remarks:

E. delicatum can be observed in temperate to equatorial eutrophic coastal regions that are generally characterised by well mixed upper waters such as upwelling regions. In these regions bottom waters are hypoxic to well-ventilated.

13. *Echinidinium granulatum* Zonneveld 1997

Figs. 52–55.

Distribution:

E. granulatum is observed in sub-polar to equatorial coastal regions and upwelling areas of the eastern Pacific, North and South Atlantic Ocean, the central Mediterranean Sea and the Arabian Sea. Highest relative abundances up to 31% are observed in the subtropical and tropical eastern Pacific Ocean and Gulf of California.

Environmental parameter range:

SST: 6.3–29.8 °C (summer-summer) and SST>7.9 °C in winter. Exception is formed by one site in the Hudson Strait (northwestern North Atlantic) where SST: −1.9, −0.01, 2.0 and 0.5 °C (Winter, spring, summer, autumn). SSS: 28.4–38.9 (winter–summer), [P]: 0.6–1.2 μmol/l, [N]: 0.1–13.2 μmol/l, chlorophyll-*a*: 0.14–16.7 ml/l, bottom water [O_2]: 0–5.3 ml/l.

E. granulatum is absent where SSS is reduced. It is present in an eutrophic environment with mostly anoxic/hypoxic conditions.

Comparison with other records:

Apart from the records in this Atlas, *E. granulatum* has been documented from unstratified highly polluted waters of South Korean bays (Pospelova and Kim, 2010). In coastal bays of southern Vancouver Island, *E. granulatum* cysts are most abundant in sediments with high organic matter concentrations (Krepakevich and Pospelova, 2010). Cysts are produced during active upwelling in the Arabian Sea whereas off NW Africa the cyst production is not linked to upwelling (Zonneveld and Brummer, 2000; Zonneveld et al., 2010). Off NW Africa cysts are abundant in traps when the trap sediments contain high Nitrate and total organic matter concentrations. In the Saanich Inlet (BC, Canada) its production can be related to enhanced diatom production (Price and Pospelova, 2011).

Concluding remarks:

E. granulatum is observed in fully-marine sub-polar to equatorial regions with enhanced primary production in the upper waters. Bottom waters are anoxic/hypoxic as a result of the presence of upwelling or coastal eutrophication.

14. *Echinidinium karaense* Head et al. 2001

Figs. 56–59.

Distribution:

Echinidinium karaense is observed in coastal sites of the Arctic regions of the Beaufort Sea, Baffin Bay, the northwestern Passages and the northern part of the Hudson Bay. In the Beaufort Sea it can form up to 8.5% of the assemblage.

Environmental parameter range:

SST: −2.0–8.6 °C (winter–summer), SSS: 20.5-33.8 (spring–summer), [P]: 0.5–1.3 μmol/l, [N]: 1.0–13.2 μmol/l, chlorophyll-*a*: 0.25–10.9 ml/l, bottom water [O_2]: 2.3–7.9 ml/l.

The species occurs in a narrow temperature range in eutrophic environments, which may have low spring SSS due to ice melting. Bottom waters are well ventilated.

Comparison with other records:

Apart from the data included in this Atlas the species has been registered from the shallow water of the White Sea (Golovnina and Polyakova, 2004; Novichkova and Polyakova, 2007) and shallow waters

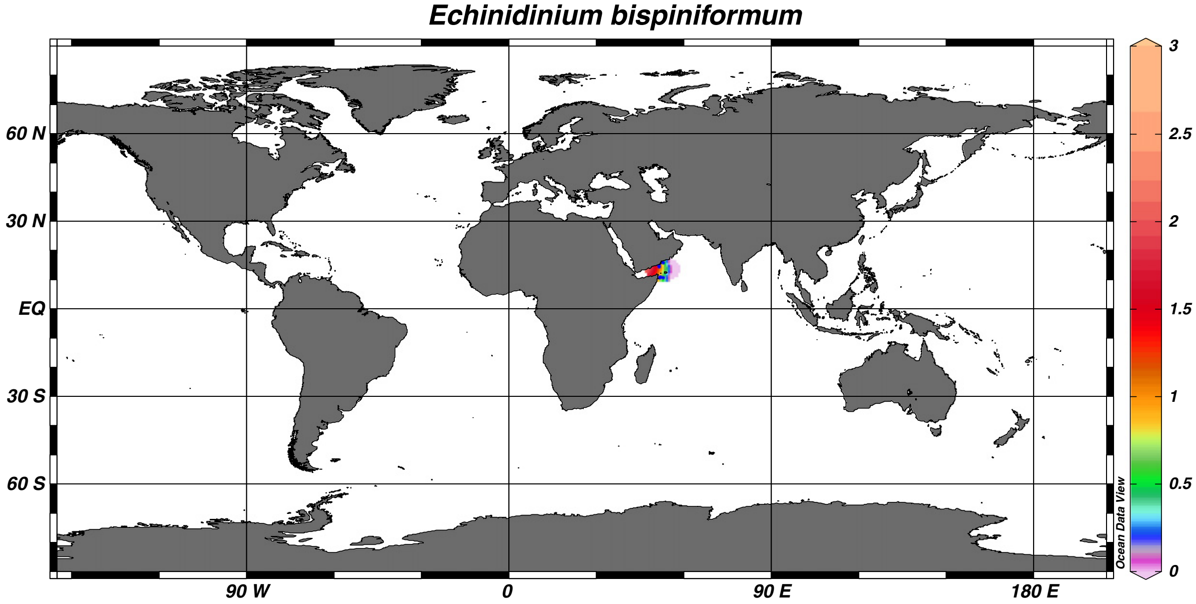

Fig. 44. Geographic distribution of *Echinidinium bispiniformum*.

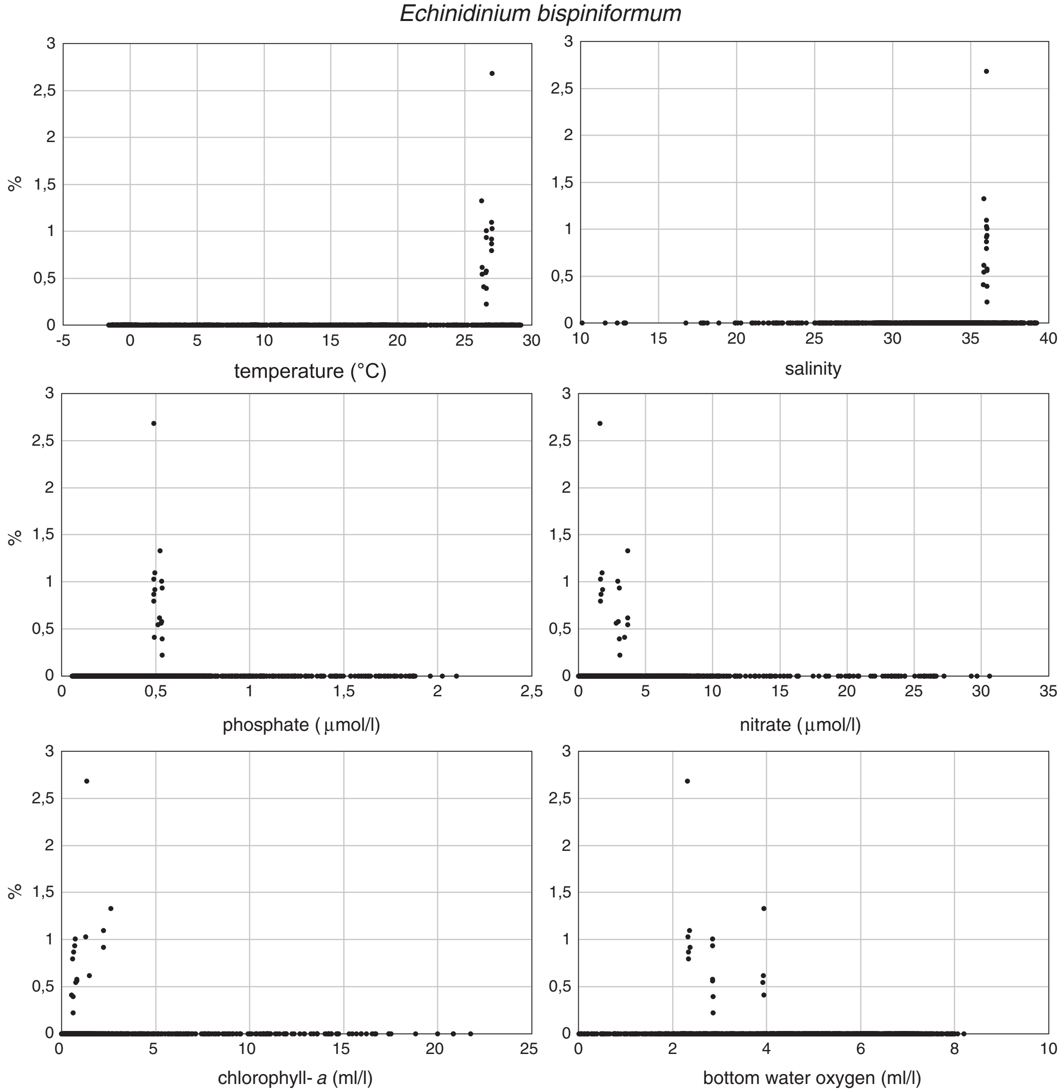

Fig. 45. Relative abundances of *Echinidinium bispiniformum* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

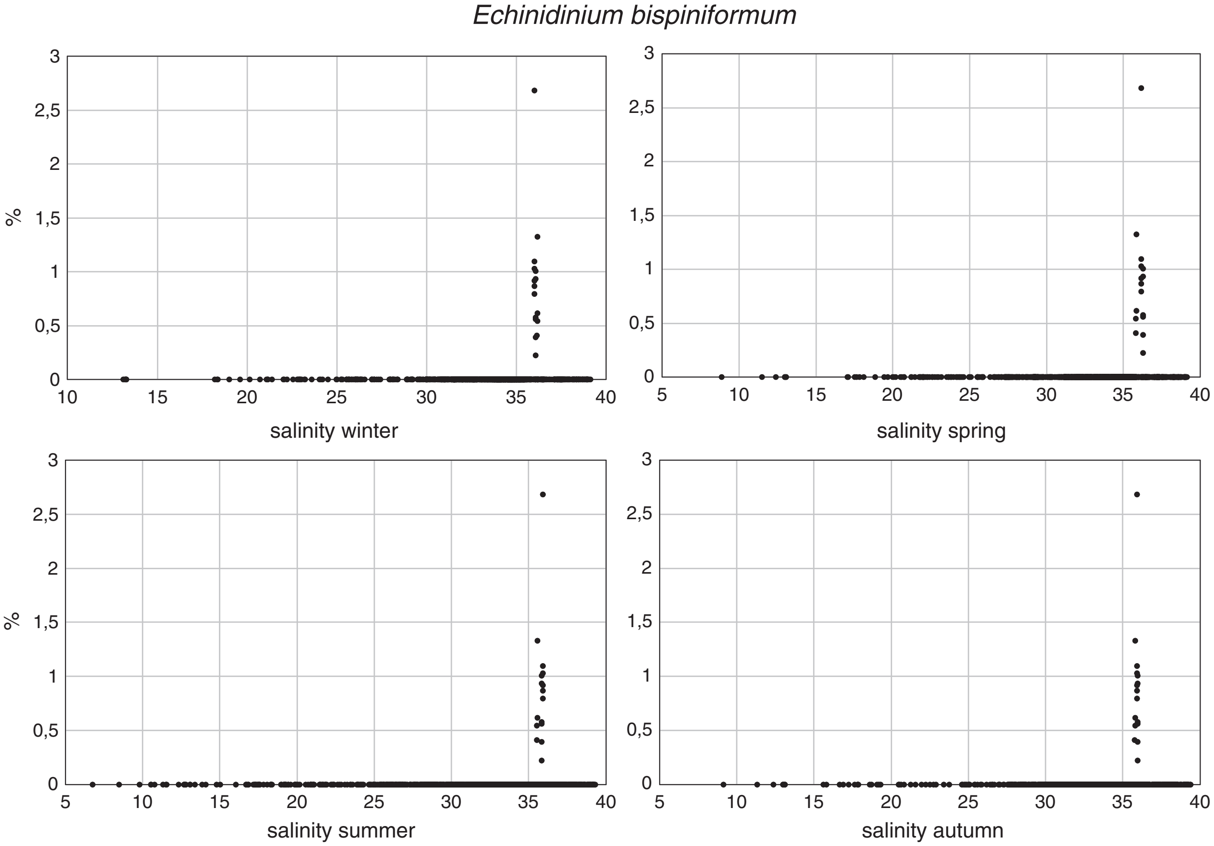

Fig. 46. Relative abundances of *Echinidinium bispiniformum* in relationship to seasonal salinity in surface waters.

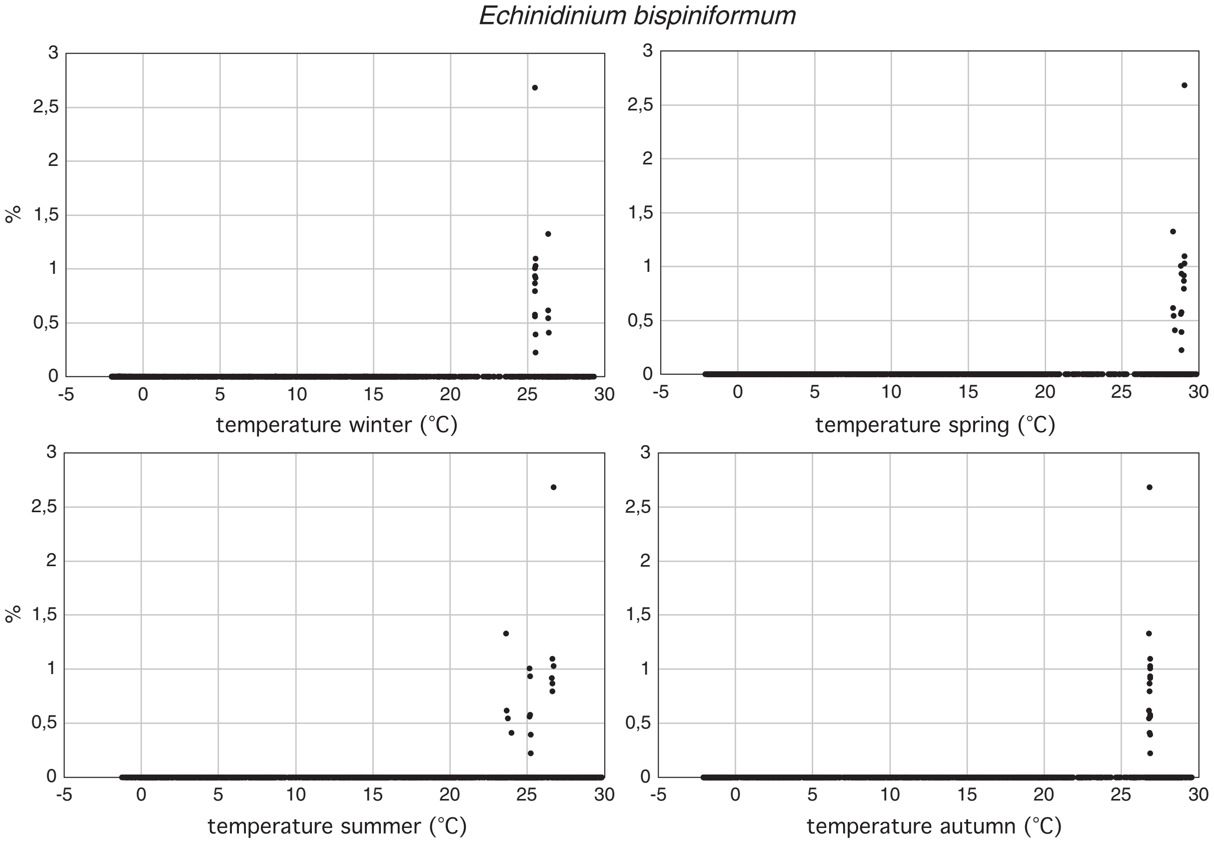

Fig. 47. Relative abundances of *Echinidinium bispiniformum* in relationship to seasonal temperature in surface waters.

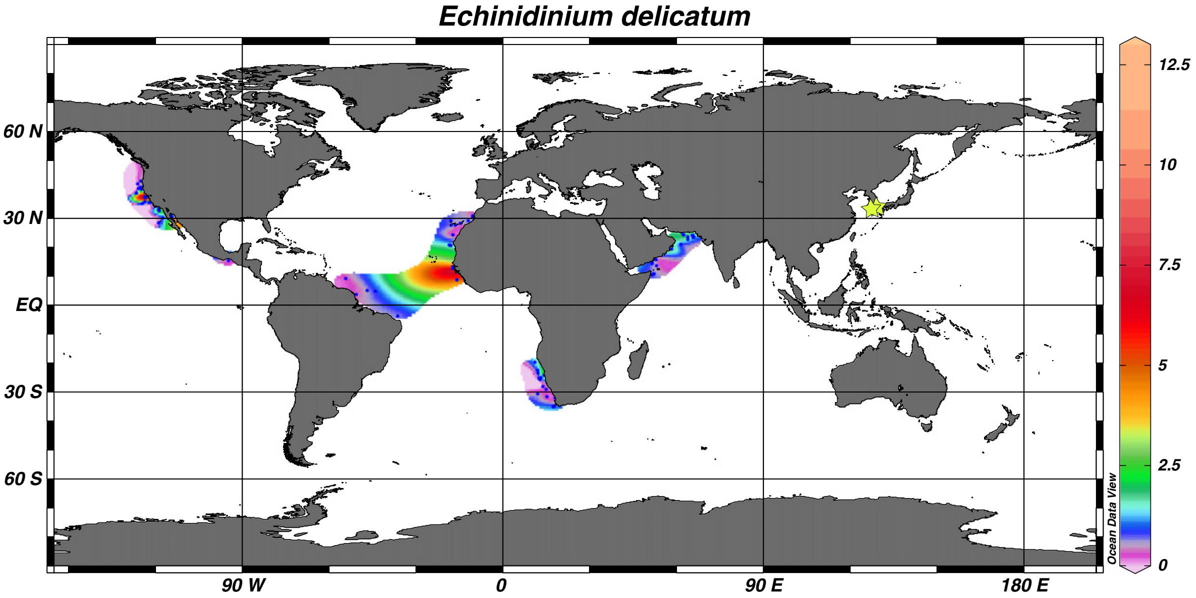

Fig. 48. Geographic distribution of *Echinidinium delicatum*.

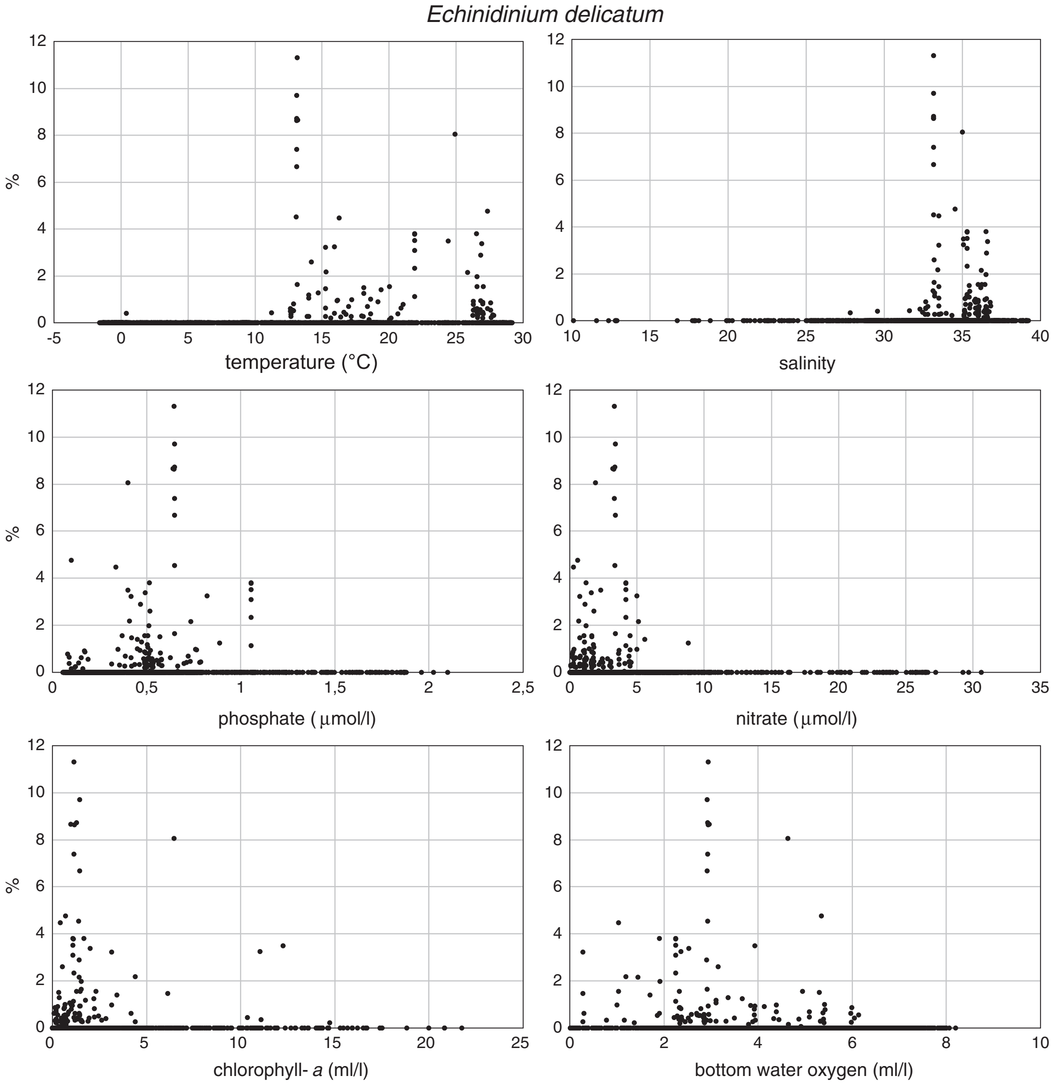

Fig. 49. Relative abundances of *Echinidinium delicatum* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

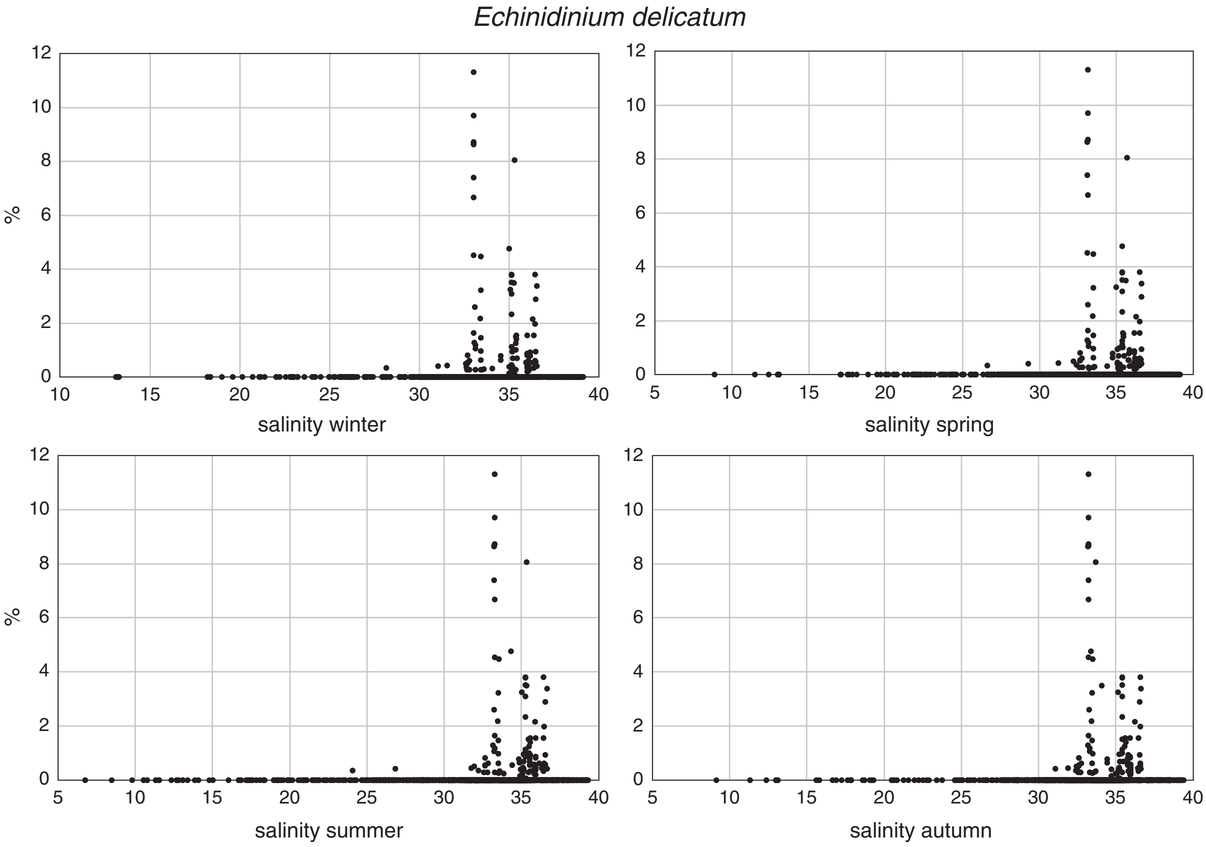

Fig. 50. Relative abundances of *Echinidinium delicatum* in relationship to seasonal salinity in surface waters.

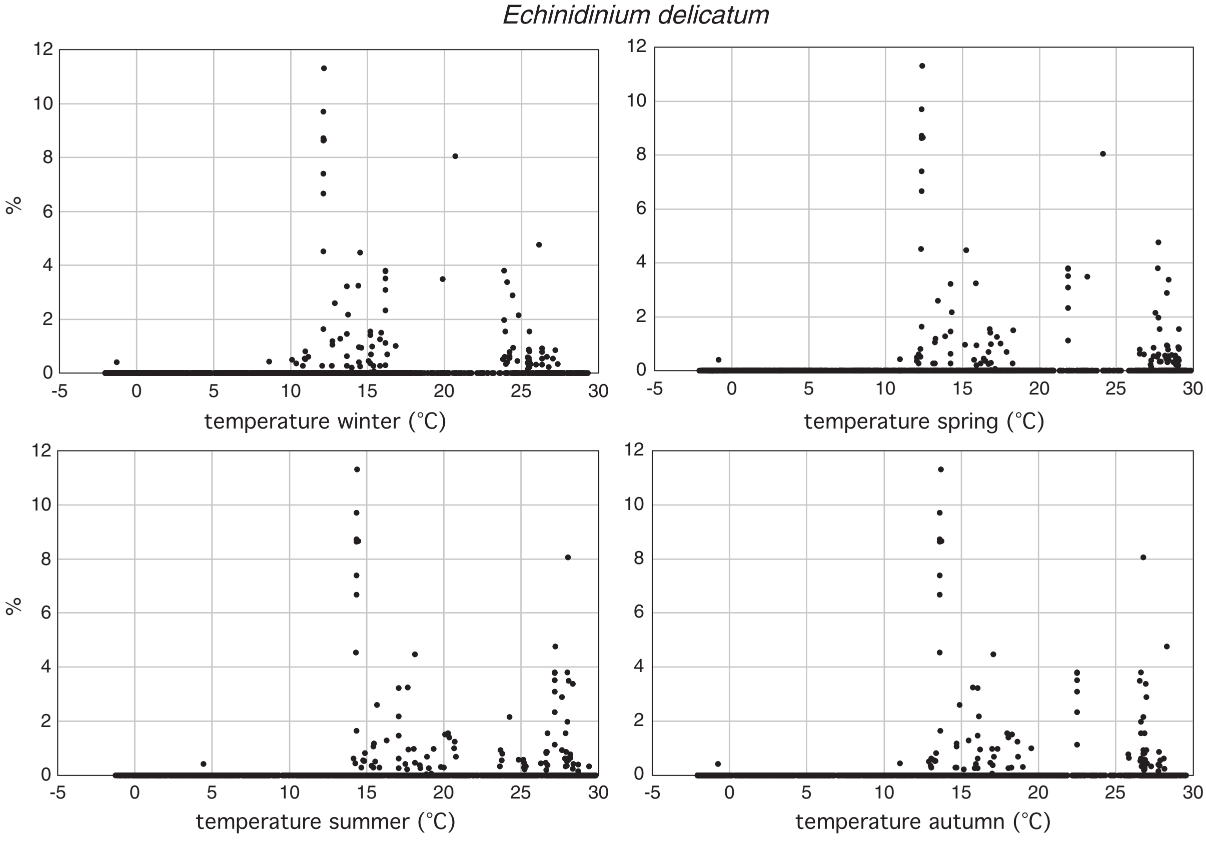

Fig. 51. Relative abundances of *Echinidinium delicatum* in relationship to seasonal temperature in surface waters.

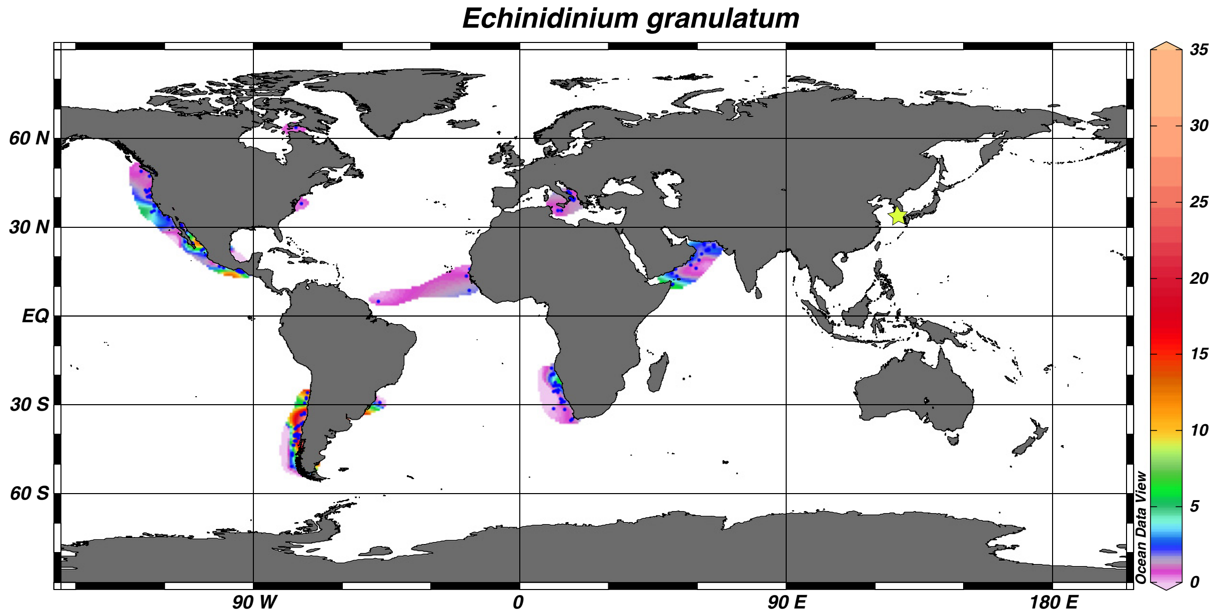

Fig. 52. Geographic distribution of *Echinidinium granulatum*.

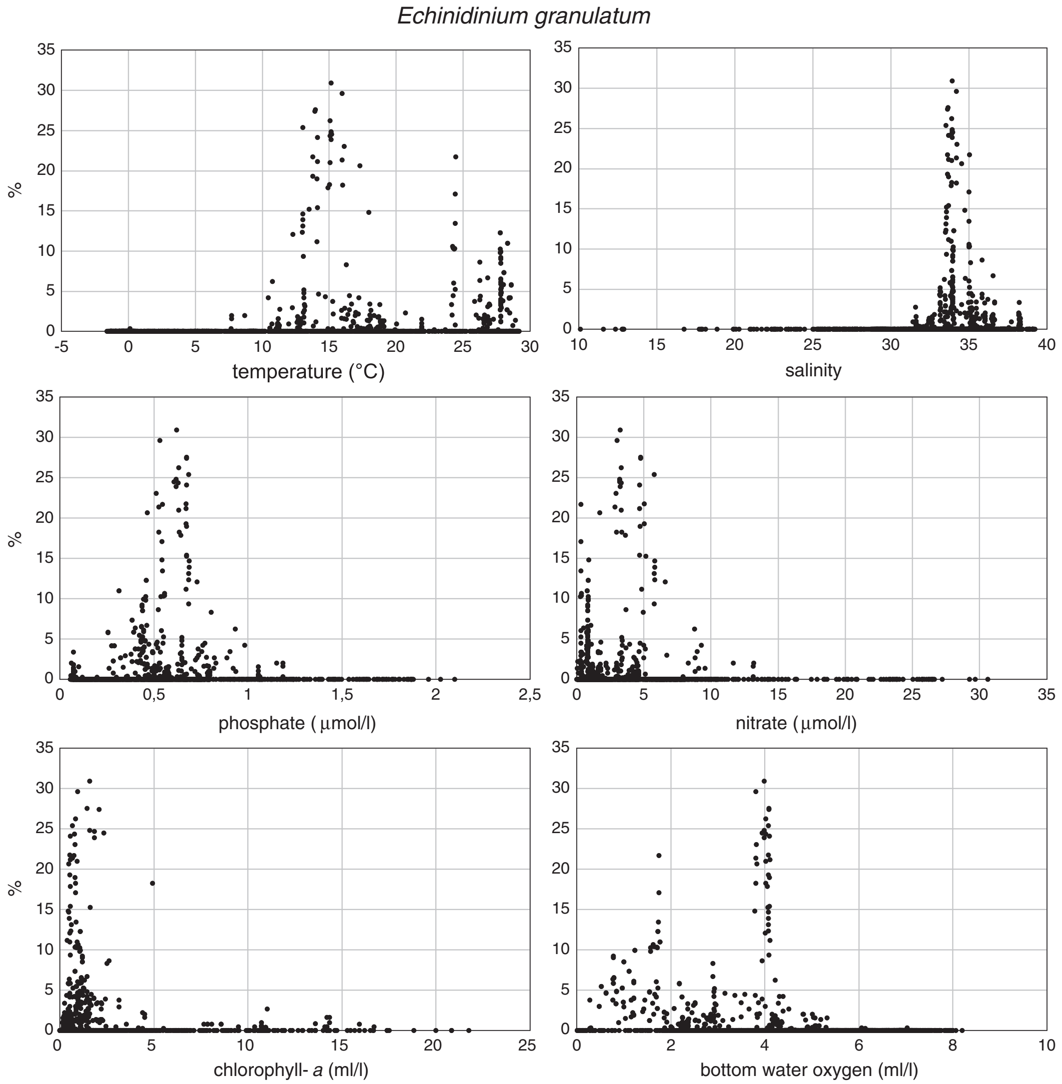

Fig. 53. Relative abundances of *Echinidinium granulatum* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

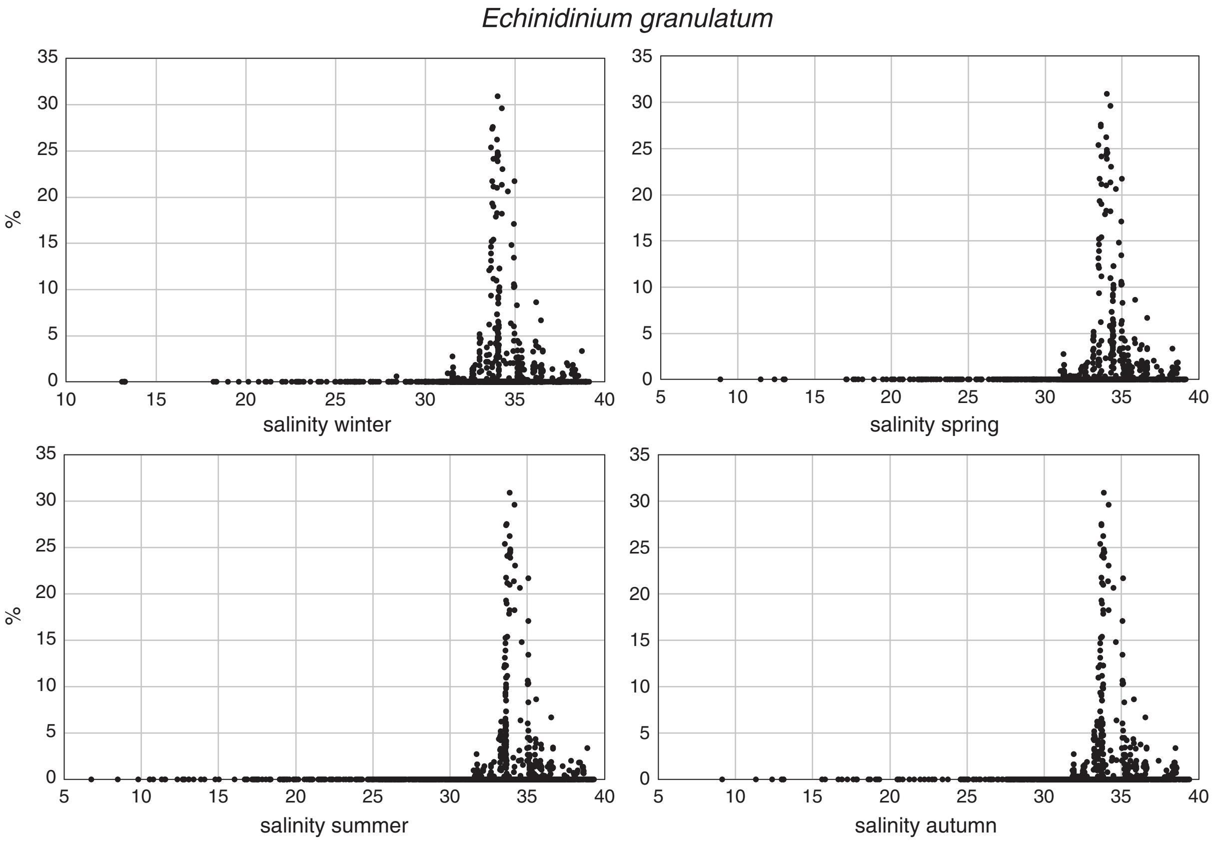

Fig. 54. Relative abundances of *Echinidinium granulatum* in relationship to seasonal salinity in surface waters.

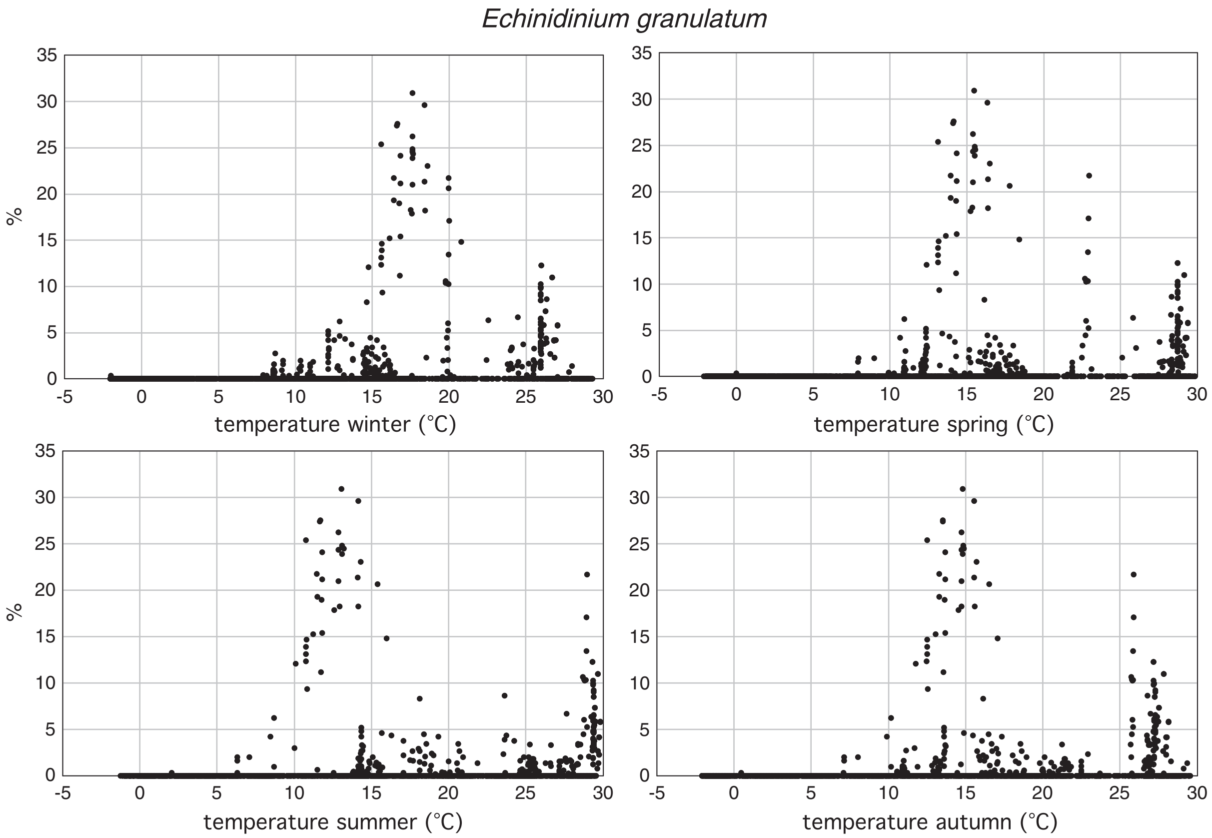

Fig. 55. Relative abundances of *Echinidinium granulatum* in relationship to seasonal temperature in surface waters.

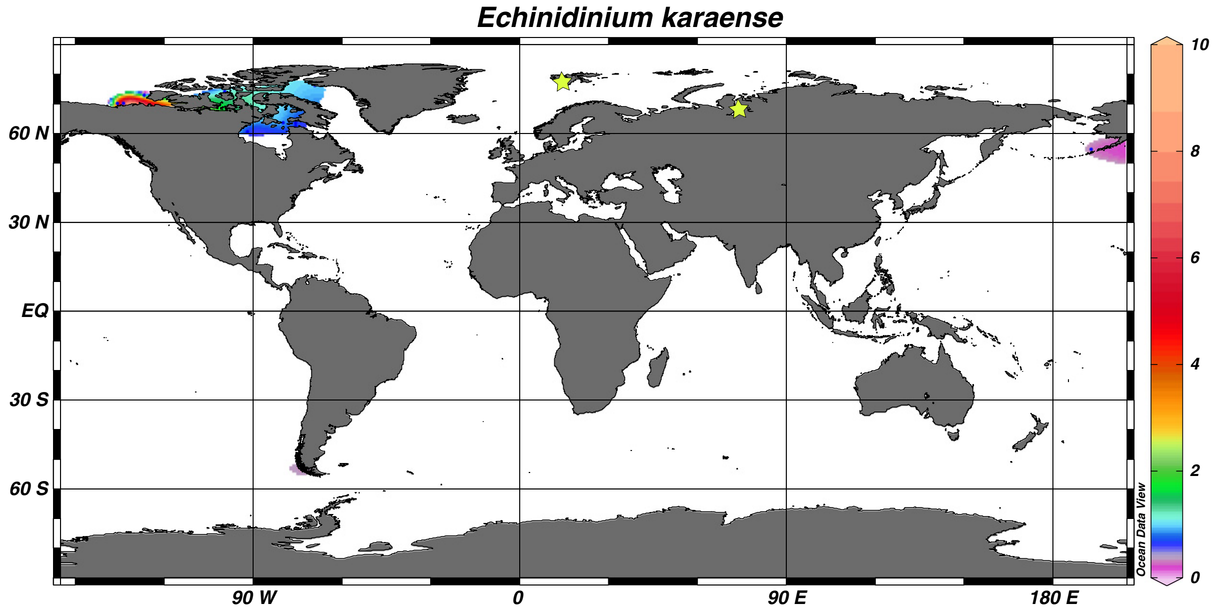

Fig. 56. Geographic distribution of *Echinidinium karaense*.

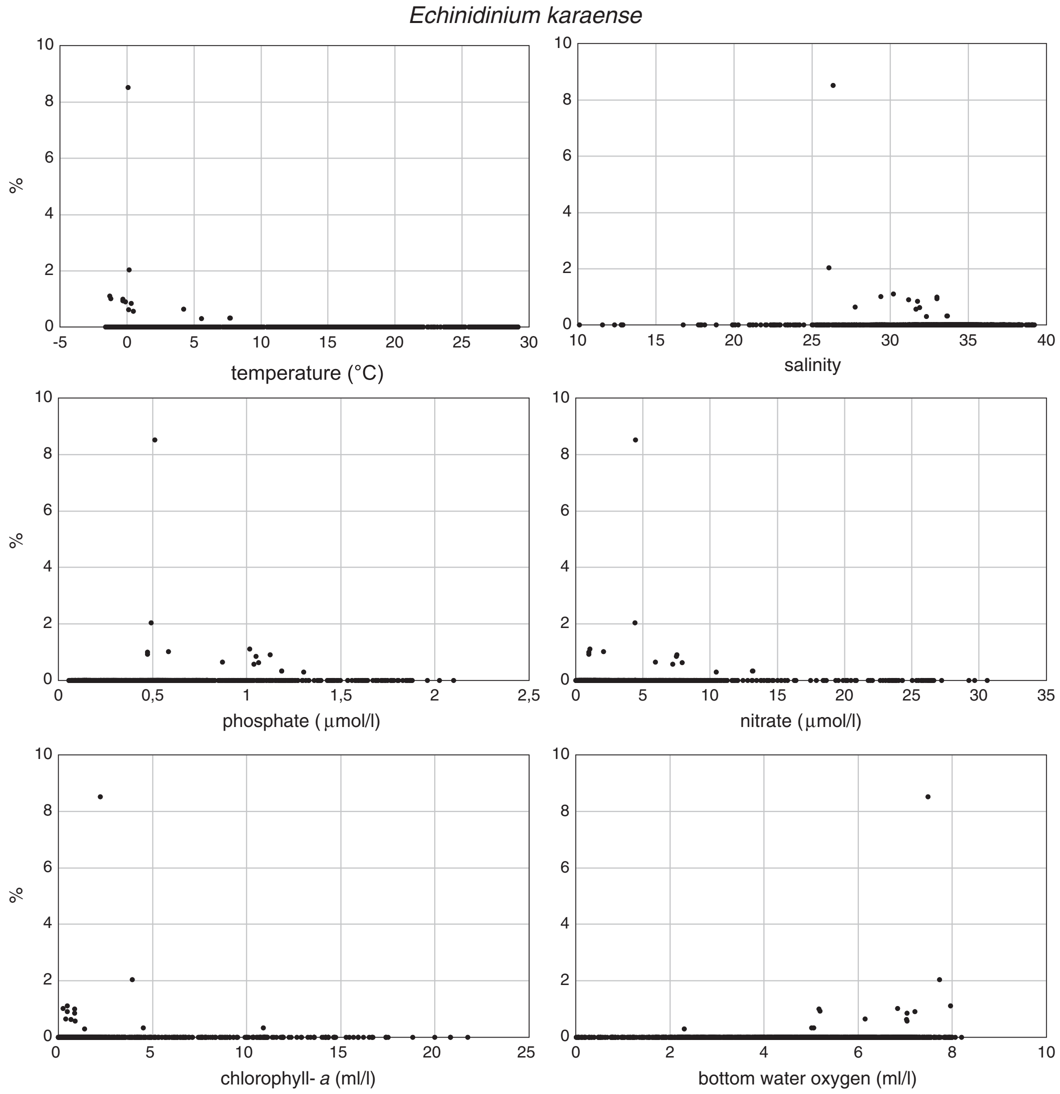

Fig. 57. Relative abundances of *Echinidinium karaense* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

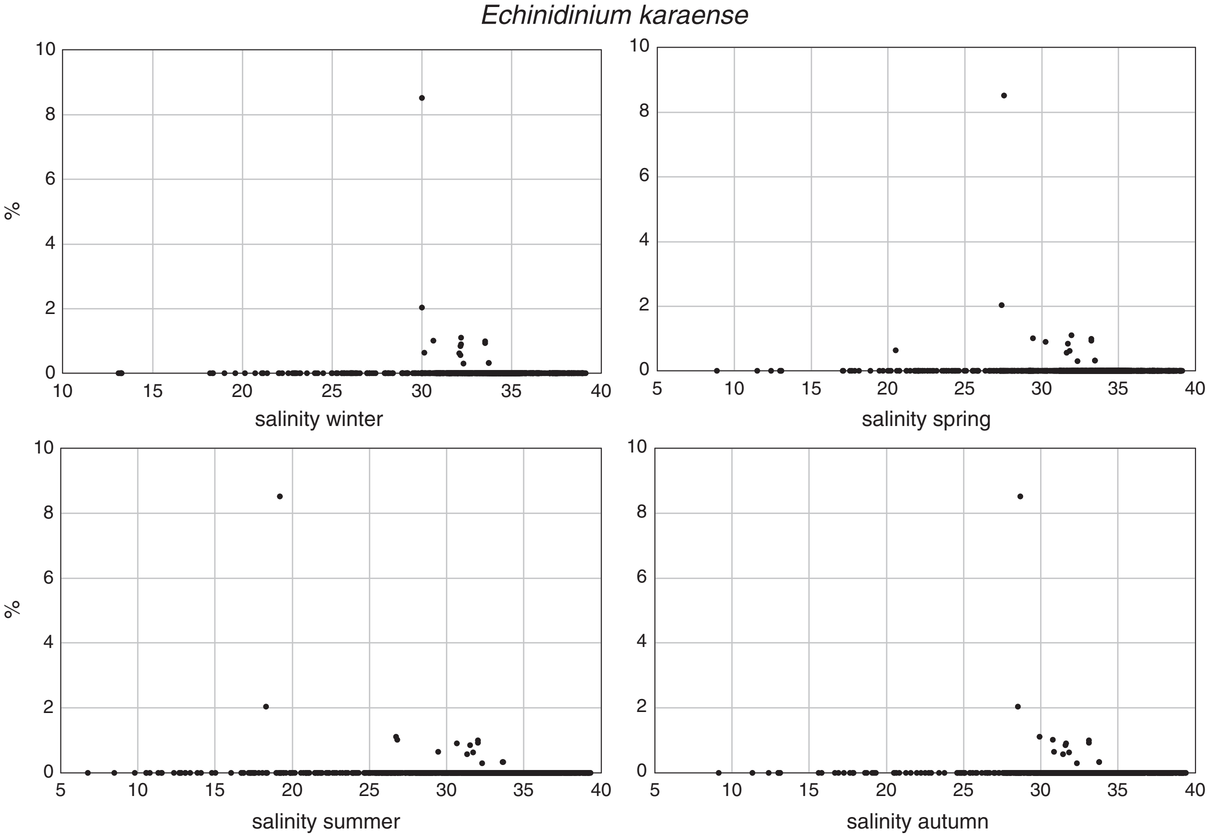

Fig. 58. Relative abundances of *Echinidinium karaense* in relationship to seasonal salinity in surface waters.

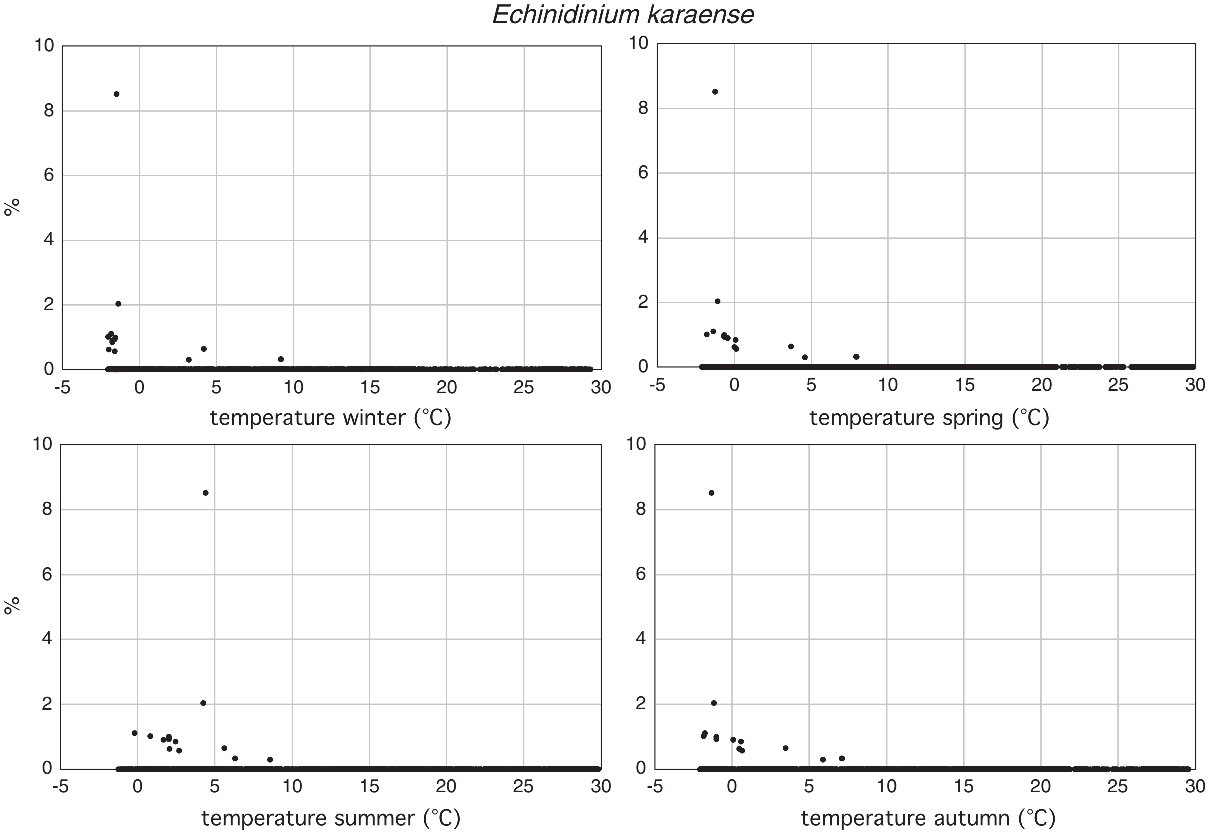

Fig. 59. Relative abundances of *Echinidinium karaense* in relationship to seasonal temperature in surface waters.

off Svalbard (northern Barents Sea) as well as its fjords (Grøsfjeld et al., 2009). The White Sea has an estuarine circulation where salinity of the upper waters is seasonally reduced as a result of river outflow and/or ice melting and can be covered with sea ice up to 7 months a year. Near Svalbard the species is observed in regions that are influenced by relatively cold, fresh Arctic Waters where salinities can be reduced due to ice melting.

Concluding remarks:

Echinidinium karaense can be considered as an Arctic species characteristically present in coastal eutrophic environments where upper waters can seasonally be covered by ice and salinities can be reduced as a result of ice melting or river discharge. It is restricted to regions with well ventilated bottom waters.

15. *Echinidinium* spp.

Figs. 60–63.

Distribution:

Echinidinium spp. have a global distribution from sub-polar to equatorial regions. Abundances up to 48% are observed in coastal sites of the East China Sea, the Gulf of Mexico and near the upwelling cells off the Canary Islands and off NW Africa. It can be found in high relative abundances in regions that are influenced by river discharge such as below the Po-river plume (Italy) and the Amazon plume (South America).

Environmental parameter range:

SST: 0–29.8 °C (winter–summer) and SST > 10 °C in summer. Exception is formed by one site in the Beaufort Sea with SST: −2.0, −1.6, 2.7 and −1.6 °C (winter, spring, summer, autumn). SSS: 31.2–39.2 (sspring–autumn) except for a few sites where SSS drop to 17.5 in summer, [P]: 0.1–1.2 μmol/l, [N]: 0.07–13.8 μmol/l, chlorophyll-*a*: 0.07–21.7 ml/l, bottom water [O_2]: 0–6.6 ml/l.

Cysts of this species are observed in oligotrophic to eutrophic environments. The species is abundant in areas where anoxic and hypoxic conditions prevail.

Comparison with other records:

Brown spiny cysts are reported world-wide but the authors often do not differentiate the species. Therefore, it is often not clear if these cysts belong to *Echinidinium* or related genera such as *Islandinium*. Apart from the regions covered by this Atlas *Echidinium* spp. has been registered from surface sediments from the upwelling regions off the Iberian peninsula (Sprangers et al., 2004; Ribeiro and Amorim, 2008) from the Barents Sea (Solignac et al., 2009) and the Canadian Arctic Archipelgo (Pienkowski et al., 2010). Cyst production is reported for the active upwelling period in the Arabian Sea whereas in upwelling areas off NW Africa, the Iberian Peninsula, the Strait of Georgia and the Saanich Inlet, cysts are produced throughout the year (Zonneveld and Brummer, 2000; Ribeiro and Amorim, 2008; Pospelova et al., 2010; Zonneveld et al., 2010; Price and Pospelova, 2011).

Concluding remarks:

Echinidinium spp. occurs from sub-polar to equatorial regions. It has a cosmopolitan distribution with its highest relative abundances at sites with high upper water bioproductivity such as upwelling regions and river plumes. Bottom waters may be anoxic to suboxic.

16. *Echinidinium transparantum* Zonneveld 1997

Figs. 64–67.

Distribution:

E. transparantum is observed in subtropical to tropical coastal regions and upwelling areas of the North and South Eastern Pacific, North and South Atlantic Ocean, the Mediterranean Sea, the Arabian Sea and the southeastern Indian Ocean with enhanced upper water productivity. Highest abundances up to 11% occur in the Amazon River discharge area, off NW Africa and in the eastern Mediterranean Sea.

Environmental parameter range:

SST: 8.5–29.8 °C (winter–summer) and exceed 10.3 °C in summer. Exception is formed by two site in the northeastern Pacific with SST: −1.3, −0.8, 4.4 and −0.8 °C (winter, spring, summer, autumn) and 6.3 °C. SSS: 31.0–39.2 (winter–autumn) except for two sites where SSS is reduced to 19.6. [P]: 0.1–1.2 μmol/l, [N]: 0.2–13.1 μmol/l, chlorophyll-*a*: 0.14–16.7 ml/l, bottom water [O_2]: 0–6.1 ml/l.

Comparison with other records:

So far *Echinidnium transparantum* not been registered from regions other than those covered by this Atlas. Cysts are produced during active upwelling in the Arabian Sea (Zonneveld and Brummer, 2000).

Concluding remarks:

E. transparantum is a tropical to subtropical species that is typically present in upwelling regions or regions influenced by river discharge. These regions are oligotrophic to eutrophic with anoxic to well ventilated bottom waters.

17. Cysts of *Gymnodinium catenatum* Graham 1943

Figs. 68–71.

Distribution:

Cysts of *Gymnodinium catenatum* are observed in coastal sediments from temperate to sub-tropical regions of the eastern Atlantic and adjacent seas such as the North Sea and the Mediterranean Sea. They are furthermore observed in the subtropical to tropical western Pacific (East China Sea and South China Sea) and the equatorial Arabian Sea. Highest abundances up to 49% occur in the Yellow Sea, China Sea and off NW Africa.

Environmental parameters:

SST: 3.4–29.0 °C (winter–spring). SSS: 31.0–36.7 (summer–autumn) apart from a few Black Sea sites where SSS can be as low as 17.5 (summer) and 18.4 (winter). [P]: 0.08–0.8 μmol/l, [N]: 0.18–6.94 μmol/l, chlorophyll-*a*: <9.31 ml/l, bottom water [O_2]: 1.1–6.1 ml/l.

With exception of one site, abundances of > 10% occur when SST: 15.8–27.3 (winter–summer). Highest relative abundances are observed in full-marine sites with low [P] and [N] but with high chlorophyll-*a* and well ventilated bottom waters.

Comparison with other records:

Apart from the recordings in the datasets included in this Atlas, *G. catenatum* cysts occur in coastal sediments off Australia and Tasmania (Bolch and Reynolds, 2002), the west coast of India (Godhe et al., 2000; D'Costa et al., 2008), the Gulf of California and the south-western Mexican coast (Morquecho and Lechuga-Deveze, 2003; Limoges et al., 2010). The plankton (motile) distribution in upper waters is wider than that reported from the cysts. Motile stages have been observed in coastal waters from the western South Atlantic Ocean, the Gulf of Mexico, southern Australia, Tasmania, New Zealand, northern Indonesia, the South China Sea and the Atlantic coasts of the Iberian Peninsula (see reviews in Bolch and de Salas, 2007; Trainer et al., 2010). Sediment trap and seasonal distribution studies indicate that cysts are often produced during upwelling and upwelling relaxation in the Gulf of California, off and along the Iberian peninsula and in the Arabian Sea (Zonneveld and Brummer, 2000; Morquecho and Lechuga-Devéze, 2004; Ribeiro and Amorim, 2008; Bravo et al., 2010a and references in Smayda and Trainer, 2010). However, our dataset shows that at least the cysts are not restricted to upwelling areas.

In general, the cysts are reported from coastal samples although they have also been reported from more offshore sites of the Arabian Sea, off NW Africa and from the Benguela upwelling area.

Concluding remarks:

G. catenatum occurs in temperate to equatorial regions which are generally full marine, coastal or in the vicinity of upwelling cells. It is restricted to sites where bottom waters are moderately to well-ventilated. In upwelling regions its cysts are produced during active upwelling or upwelling relaxation.

18. Cysts of *Gymnodinium nolleri*/*microreticulatum* Ellegaard et Moestrup 1999/Bolch et Hallegraef 1999

Figs. 72–75.

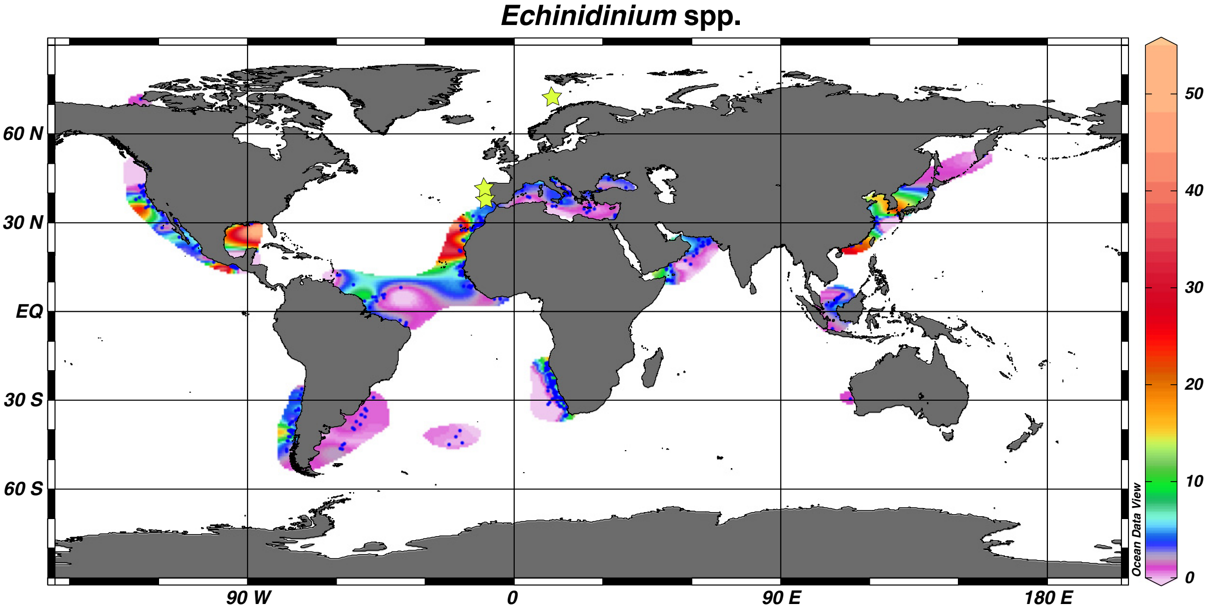

Fig. 60. Geographic distribution of *Echinidinium* spp.

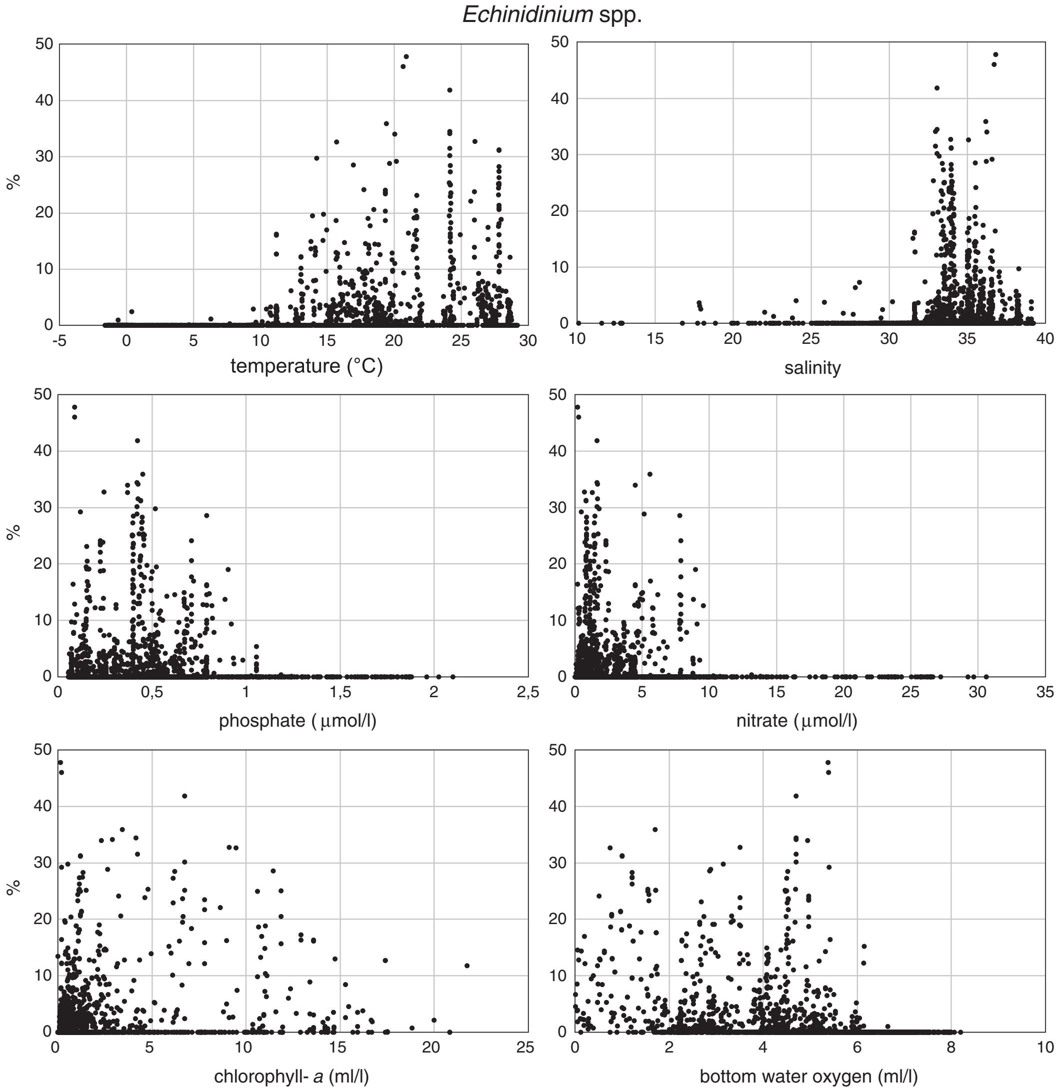

Fig. 61. Relative abundances of cysts of *Gymnodinium catenatum* in relationship to seasonal temperature in surface waters.

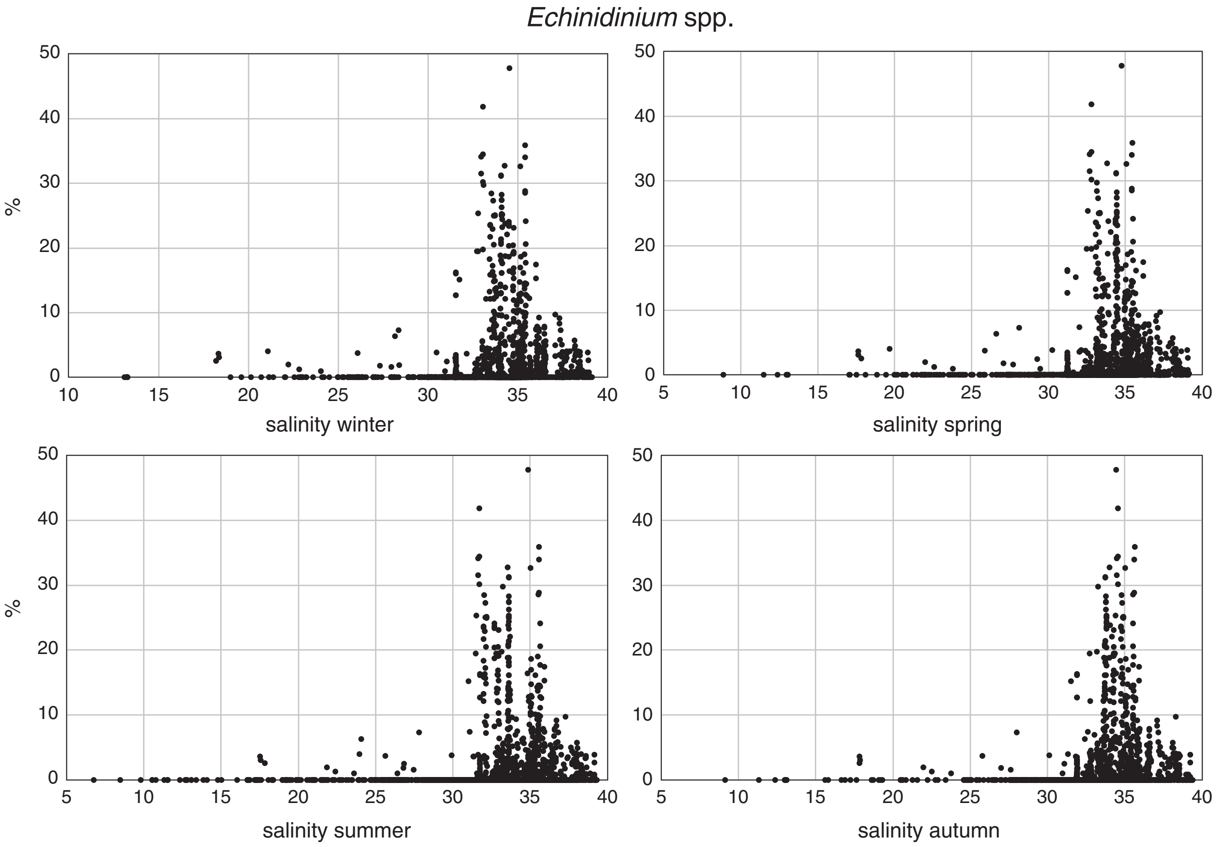

Fig. 62. Relative abundances of *Echinidinium* spp. in relationship to seasonal salinity in surface waters.

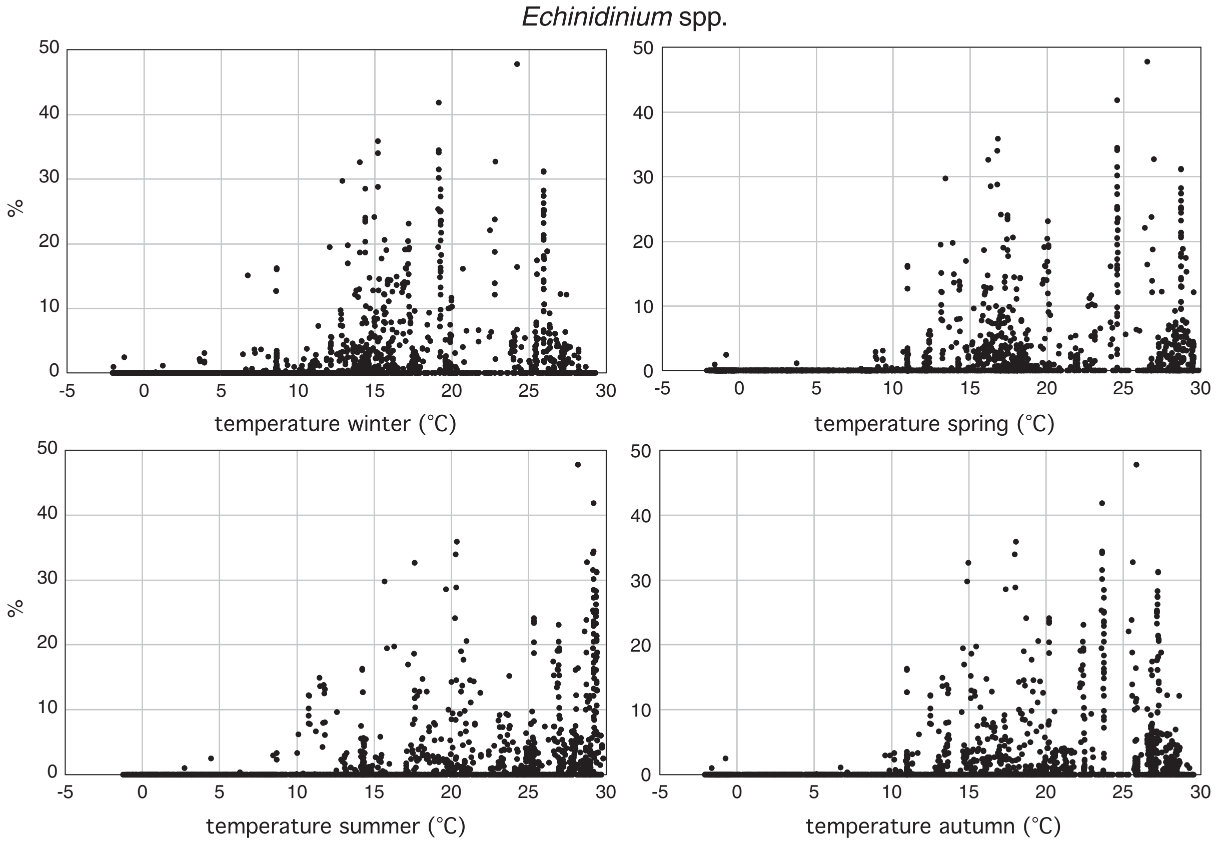

Fig. 63. Relative abundances of *Echinidinium* spp. in relationship to seasonal temperature in surface waters.

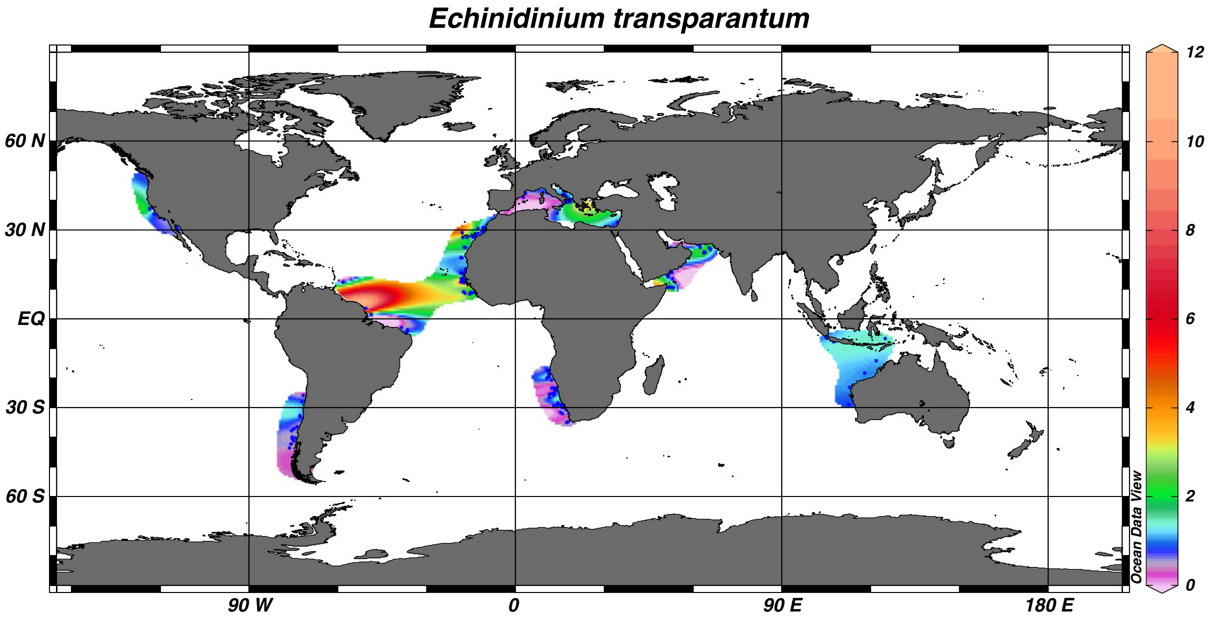

Fig. 64. Geographic distribution of *Echinidinium transparantum*.

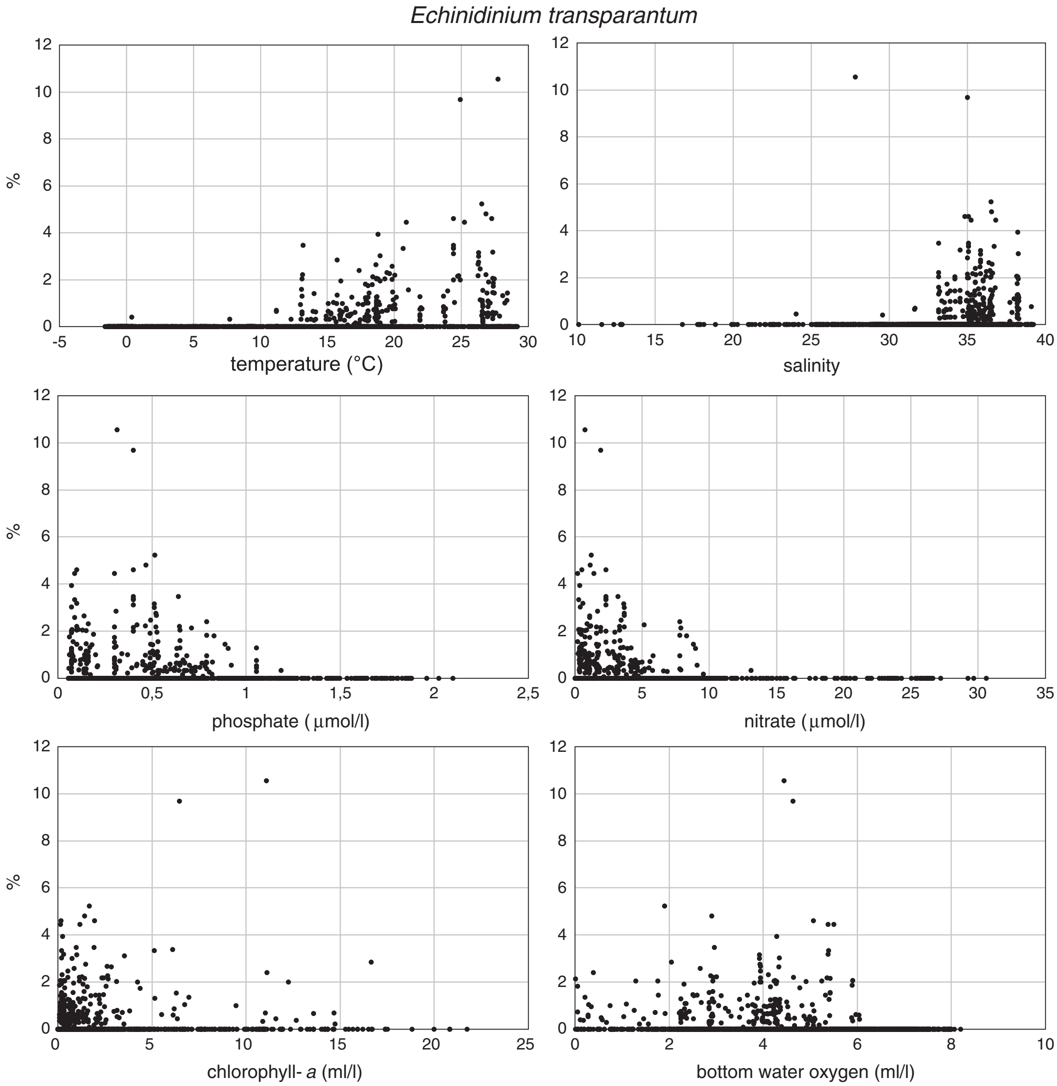

Fig. 65. Relative abundances of *Echinidinium transparantum* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

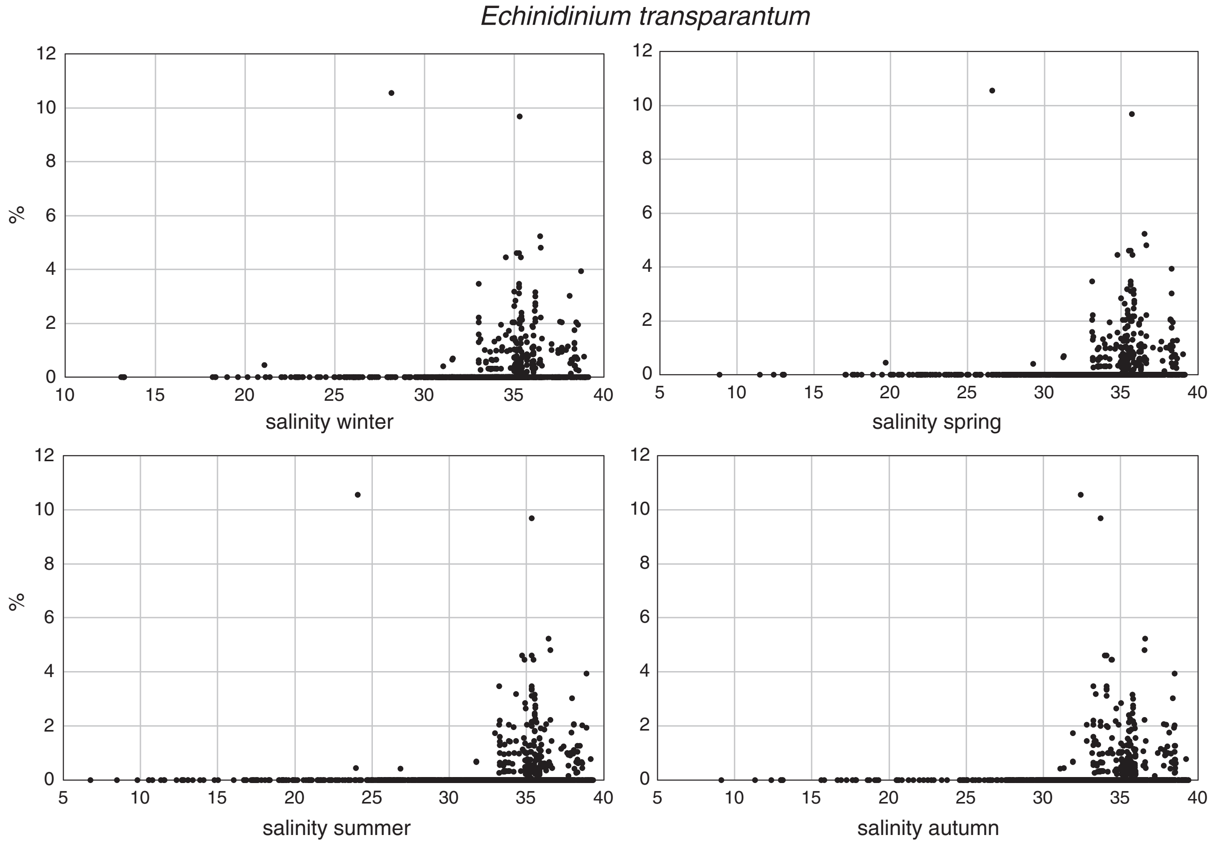

Fig. 66. Relative abundances of *Echinidinium transparantum* in relationship to seasonal salinity in surface waters.

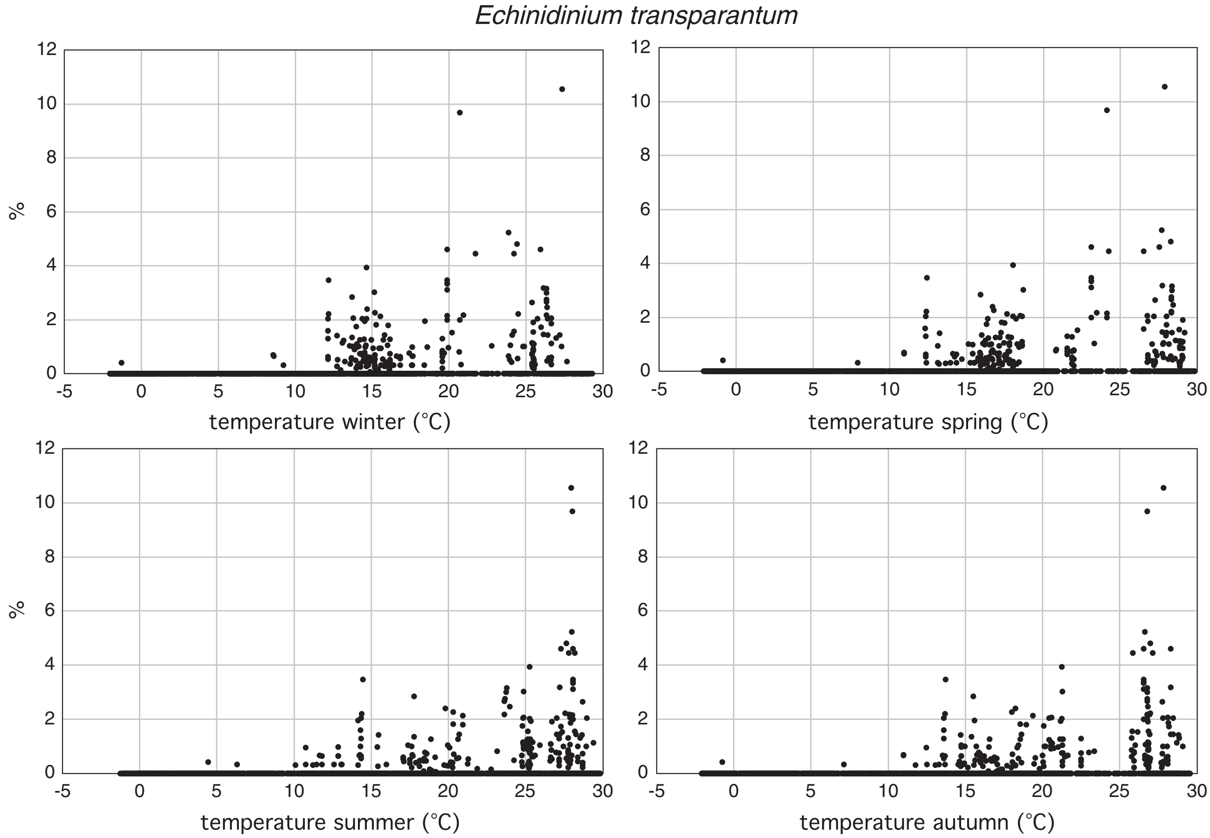

Fig. 67. Relative abundances of *Echinidinium transparantum* in relationship to seasonal temperature in surface waters.

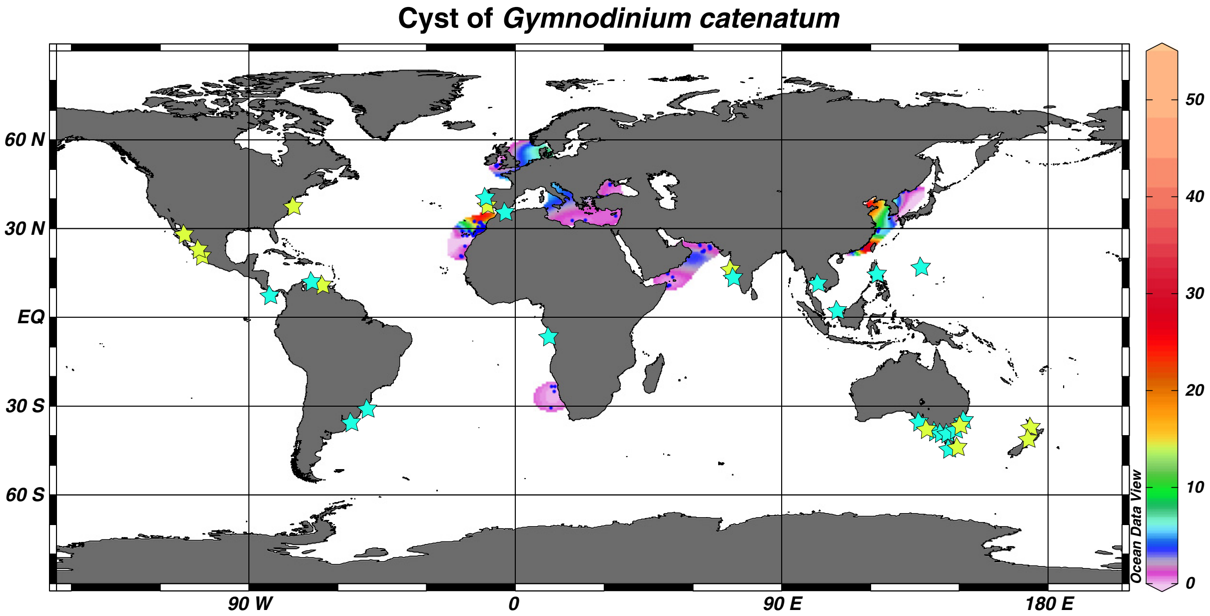

Fig. 68. Geographic distribution of cysts of *Gymnodinium catenatum*.

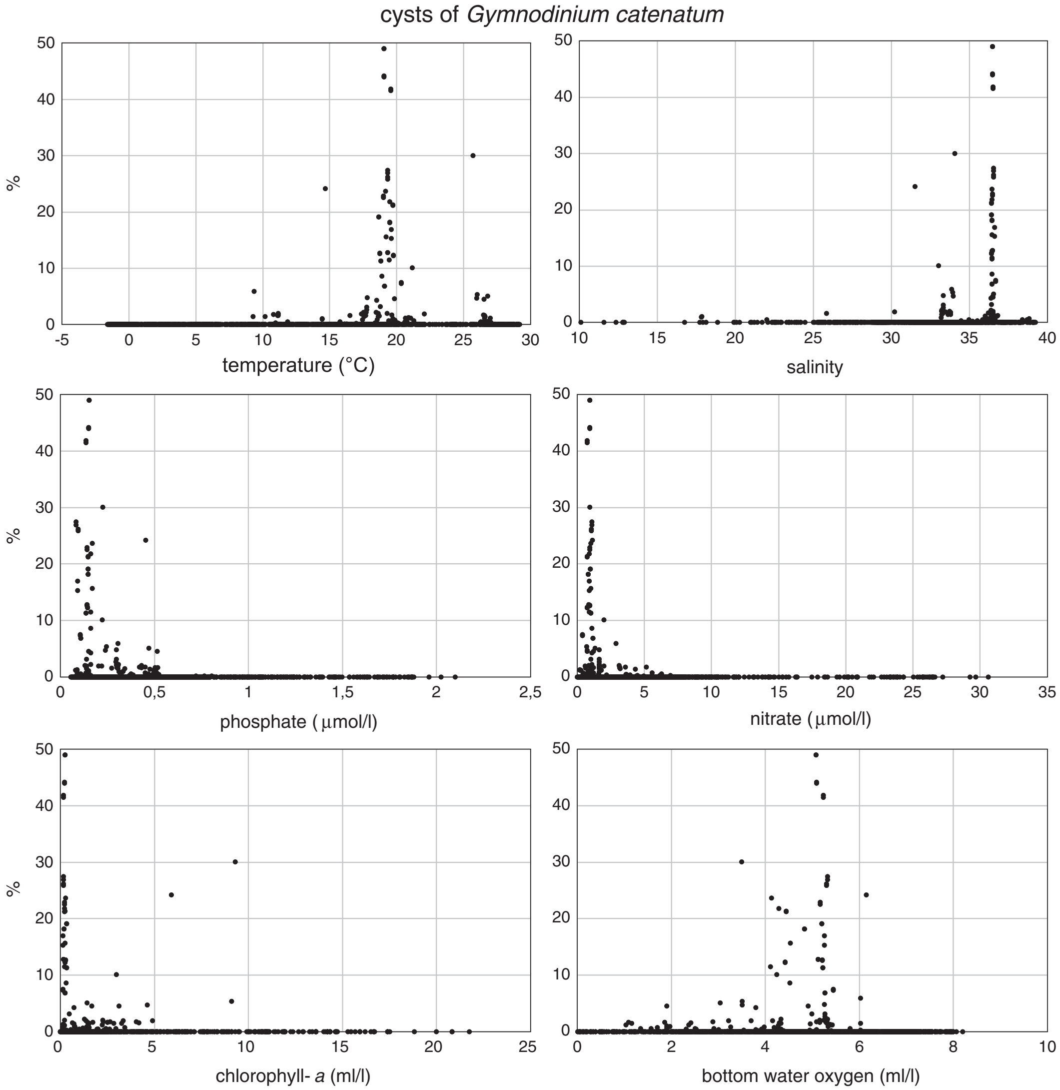

Fig. 69. Relative abundances of *Echinidinium* spp. in relationship to seasonal temperature in surfaces waters.

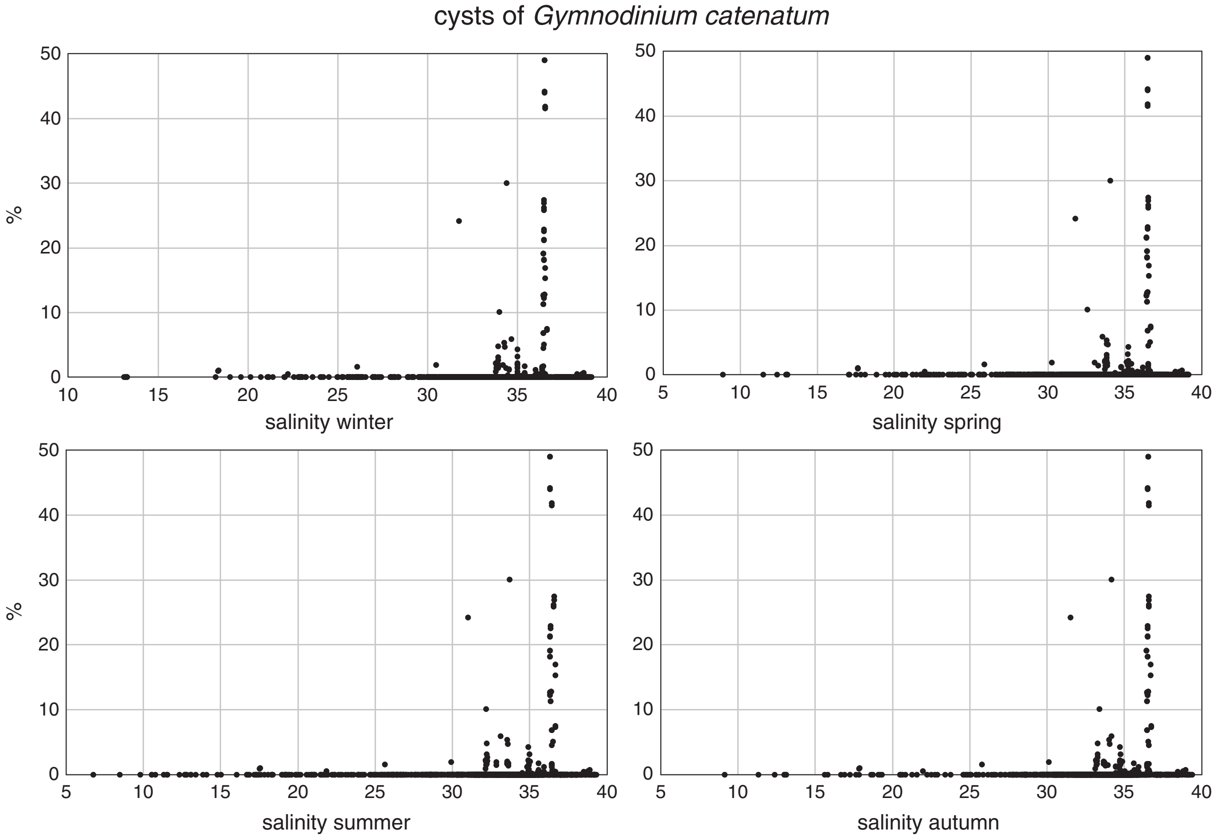

Fig. 70. Relative abundances of cysts of *Gymnodinium catenatum* in relationship to seasonal salinity in surface waters.

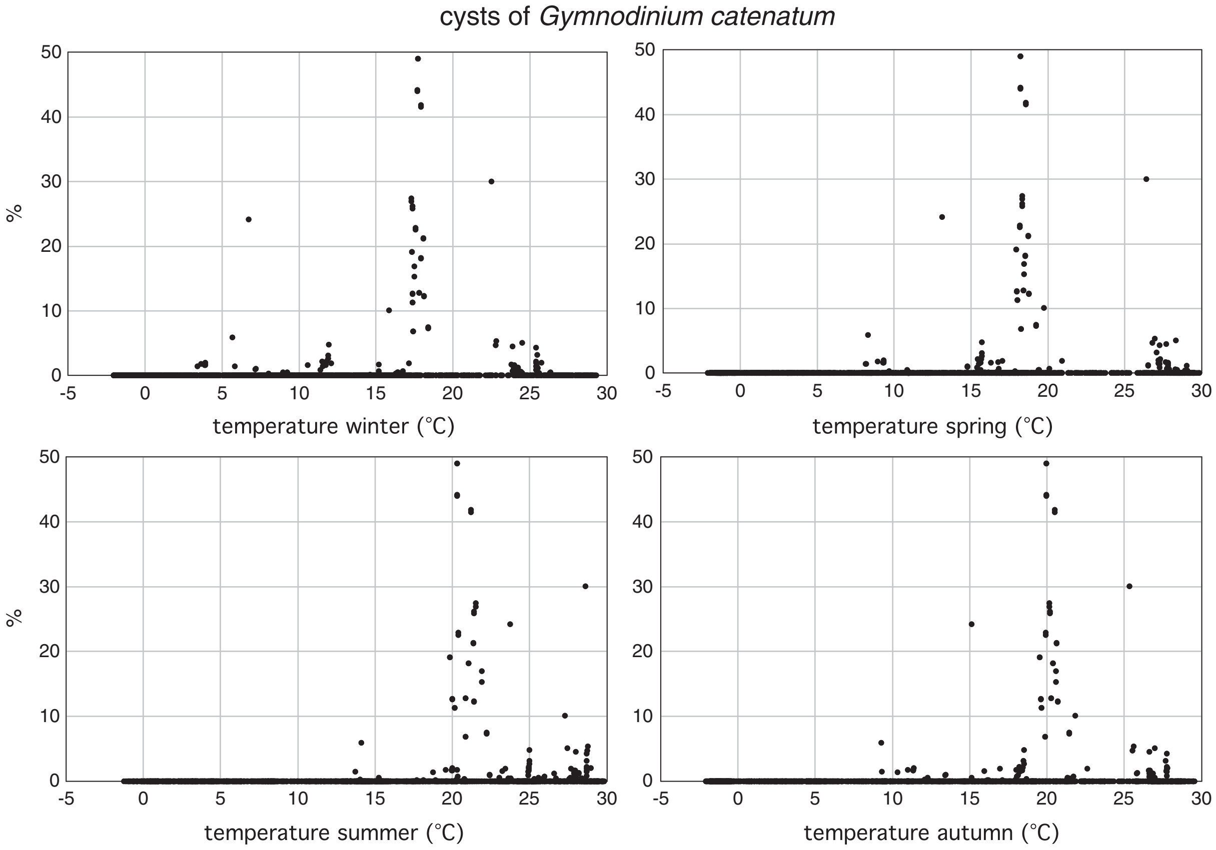

Fig. 71. Relative abundances of cysts of *Gymnodinium catenatum* in relationship to seasonal temperature in surface waters.

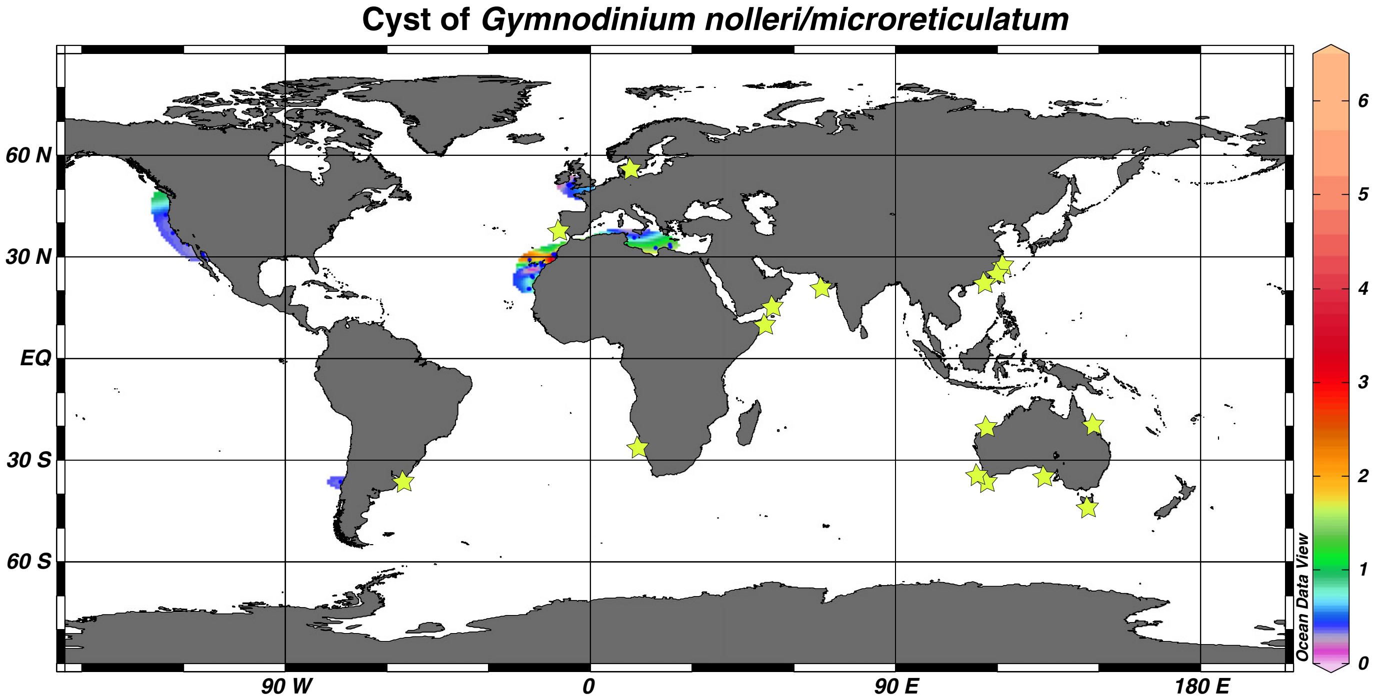

Fig. 72. Geographic distribution of cysts of *Gymnodinium nolleri/microreticulatum*.

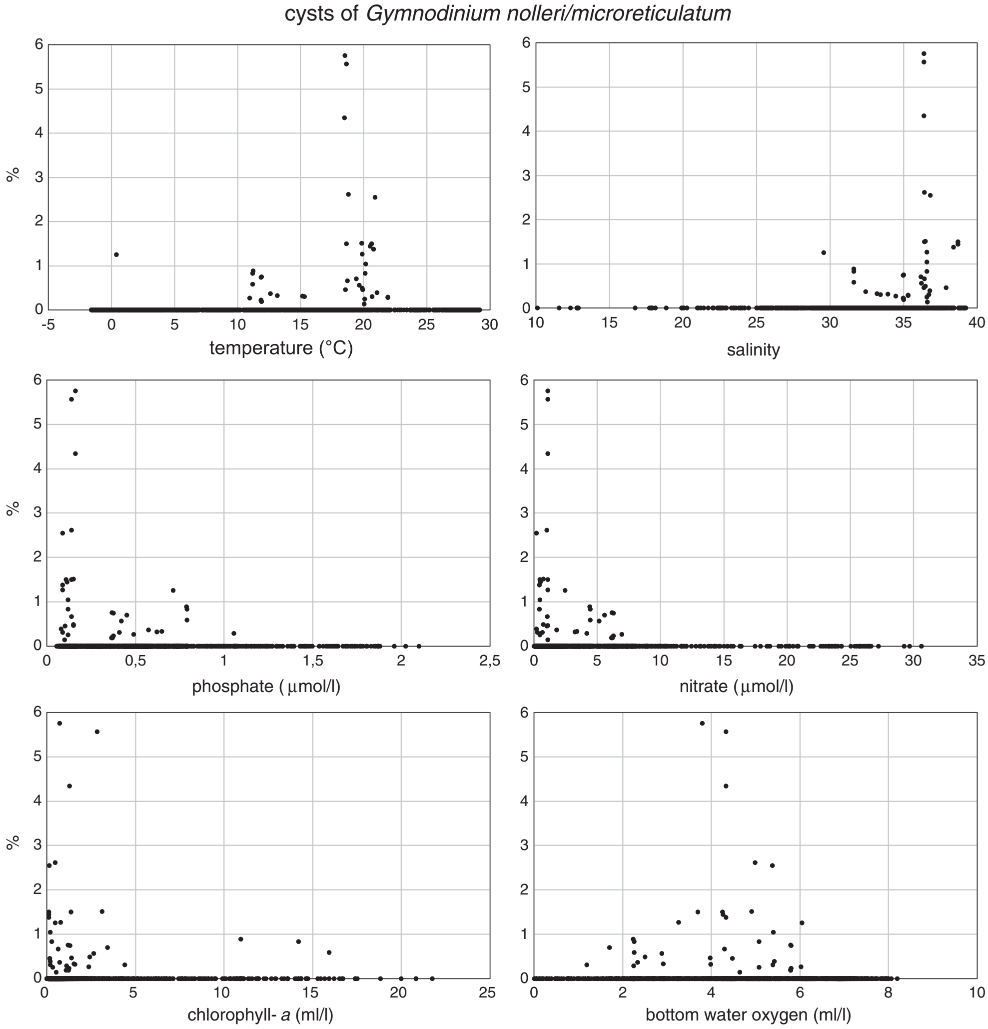

Fig. 73. Relative abundances of cysts of *Gymnodinium nolleri/microreticulatum* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

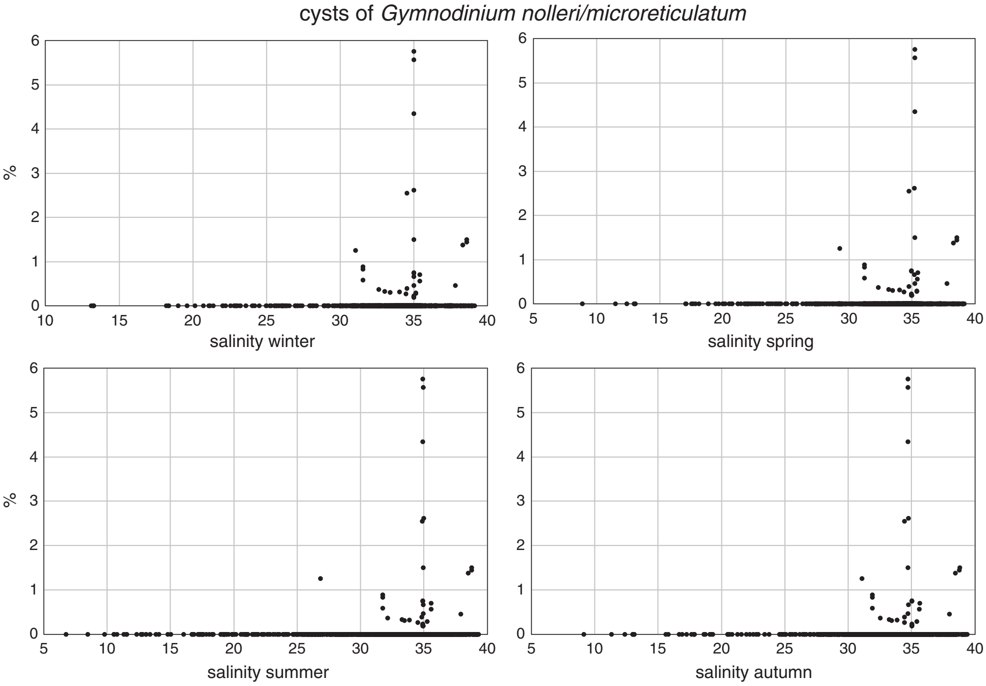

Fig. 74. Relative abundances of cysts of *Gymnodinium nolleri/microreticulatum* in relationship to seasonal salinity in surface waters.

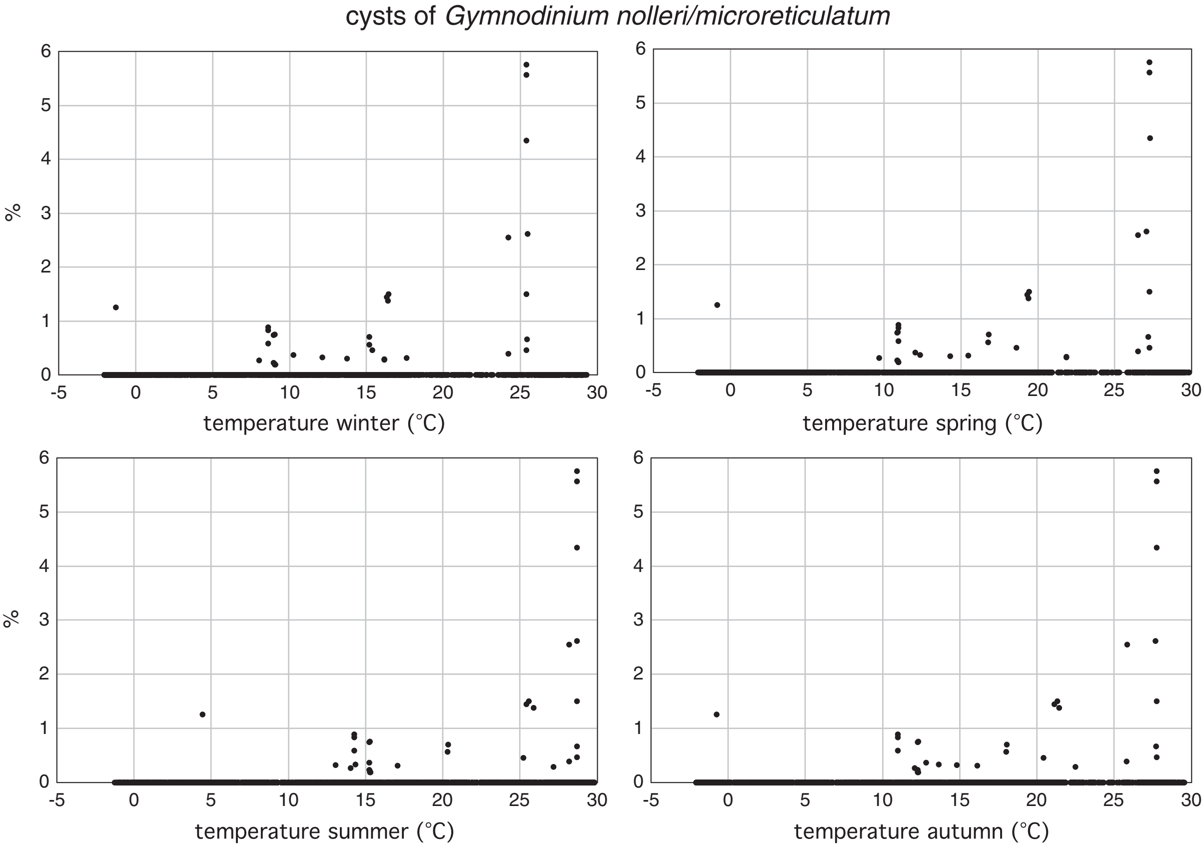

Fig. 75. Relative abundances of cysts of *Gymnodinium nolleri/microreticulatum* in relationship to seasonal temperature in surface waters.

Distribution:

Cysts of *Gymnodinium nolleri*/*microreticulatum* are observed in coastal sediments from temperate to sub-tropical regions of the eastern Atlantic Ocean and adjacent seas such the Mediterranean Sea, and the eastern Pacific. Highest abundances up to 6% occur off NW Africa.

Environmental parameters

SST: 8.0–28.7 °C (winter–summer) and SST > 14.0 °C in summer. Exception is formed by one site in the northeastern Pacific where SST: −1.3, −0.8, 4.4 and −0.8 °C (winter, spring, summer, autumn). SSS: 31.2–38.8 (winter–summer) except for one northeastern Pacific site where SSS: 26.8 in summer. [P]: 0.08–1.1 μmol/l, [N]: 0.18–6.95 μmol/l, chlorophyll-*a*: 0.1–15.9 ml/l, bottom water [O_2]: 1.1–6.1 ml/l.

Abundances > 2% occur when SST: 24.2–28.7 °C (winter–summer). Highest relative abundances are observed oligotrophic/mesotrophic regions where bottom waters are moderately to well ventilated.

Comparison with other records:

Cysts of *G. nolleri*/*microreticulatum* have additionally been registered from coastal sites of the Skagerrak (Ellegaard and Moestrup, 1999; Harland and Nordberg, 2011), the western South Atlantic, the East China Sea and South China Sea, the Arabian Sea and around Australia/Tasmania (Bolch and Reynolds, 2002). A seasonal distribution study in Lisbon Bay (Portugal) documents that production occurs mainly in winter/early spring (Ribeiro and Amorim, 2008).

Concluding remarks:

G. nolleri/*microreticulatum* is observed in coastal sites of temperate to sub-tropical, oligotrophic to mesotrophic regions which are full marine and have bottom waters which are moderately to well ventilated.

19. *Impagidinium aculeatum* (Wall 1967) Lentin and Williams 1981

Figs. 76–79.

Distribution:

Impagidinium aculeatum is observed between the arctic sub-tropical front and the antarctic polar-front. Although the species is observed from coastal sediments to the open ocean, highest abundances up to 80% occur in the sub-tropical, tropical and equatorial central oceans.

Environmental parameters:

SST: −1.6–29.6 °C (winter–autumn). SSS: 31.0-39.4 (spring–autumn) except for one North Atlantic site where SSS: 19.6 (spring). [P]: 0.06–1.87 μmol/l, [N]: 0.04–26.4 μmol/l, chlorophyll-*a*: 0.05–11.5 ml/l, bottom water [O_2]: 1.3–6.9 ml/l except for one site where bottom water [O_2]: 0.33

Abundances > 50% occur when SST: 31.0–26.7 °C (spring–summer) and [P]: 0.06–0.27 μmol/l, [N]: 0.04–2.8 μmol/l and Chlorophyll-*a*: 0.05–0.43 ml/l. Although it occurs at sites with anoxic bottom waters relative abundances increase with increasing bottom water oxygen concentrations.

Comparison with other records:

Apart from the records included in this Atlas, *I. aculeatum* has been documented from a fjord in the northern part of Norway (Rørvik et al., 2009). Although this fjord is not influenced by glaciers, salinities can be strongly reduced seasonally and vary between 11–34.6. Although it occurs at sites with winter SST: <0 °C, it is absent from sites that are covered seasonally by sea ice (Mudie, 1992; de Vernal and Hillaire-Marcel, 2000; Radi and de Vernal, 2008). Highest relative abundances occur in oligotrophic environments. However, sediment trap studies have shown that its cyst production increases with increasing nutrient availability and bioproduction in the upper waters (Zonneveld and Brummer, 2000; Susek et al., 2005; Zonneveld et al., 2010).

Concluding remarks:

I. aculeatum has a widespread distribution outside of the Arctic and Antarctic and low salinity waters. Although it has been reported from oligotrophic to eutrophic environments and shallow-water coastal regions to the central oceans, highest relative abundances occur in central oceanic oligotrophic environments that are characterised by well-ventilated bottom waters.

20. *Impagidinium caspienense* Marret et al. 2004

Figs. 80–83.

Distribution:

Impagidinium caspienense is restricted to the Caspian Sea and Aral Sea where it can account for 73% of the association.

Environmental parameters:

SST: 1.6–24.4 °C (winter–summer). SSS: 8.5–13.3 (summer–winter), [P]: 0.10–0.13 μmol/l, [N]: 0.06–0.27 μmol/l, chlorophyll-*a*: 1.39–8.30 ml/l, bottom water [O2]: 6.2–6.7 ml/l.

Comparison with other records:

I. caspienense has not been recorded from regions not covered by this Atlas.

Concluding remarks:

I. caspienense is endemic for the Caspian Sea and Aral Sea where oligotrophic conditions, low productivity, reduced salinities and well ventilated bottom waters are present.

21. *Impagidinium pallidum* Bujak 1984

Figs. 84–89.

Distribution:

With exception of two recordings in the central Mediterranean and equatorial Atlantic, the distribution of *Impagidinium pallidum* is bipolar with maximal relative abundances up to 39% in Arctic and Antarctic polar waters and in the vicinity of the polar fronts. It has high relative abundances in regions where large seasonal contrasts exist. It can be observed in coastal sites as well as in the central oceans.

Environmental parameters:

SST: −2.1–25.7 °C (spring–spring). SSS: 17.4–38.0 (summer–summer), [P]: 0.09–2.10 μmol/l, [N]: 0.19–30.6 μmol/l, chlorophyll-*a*: 0.05–3.56 ml/l, bottom water [O_2]: > 1.7 ml/l.

Highest relative abundances > 20% can be observed in regions with temperatures between −1.7–5.4 °C (winter–summer). *I. pallidum* is observed in sites where salinities can be seasonally reduced as a result of melting of ice. It is characteristically observed in regions with high upper water [P] and [N] but low chlorophyll-*a* concentrations. It is restricted to sites where bottom waters are well ventilated.

Comparison with other records:

In records other than included in this Atlas, *I. pallidum* is generally observed in polar to temperate regions in consistence with our observations (Mudie, 1992; Solignac et al., 2009; Patterson et al., 2011). It is abundant in sediment trap samples recovered below the East Greenland Current and can be observed in areas that are covered with sea ice up to 12 months a year that can be characterised by reduced salinities in spring and summer as a result of melting events (de Vernal et al., 1998; Dale et al., 2002; Radi and de Vernal, 2008; Solignac et al., 2009).

Concluding remarks:

I. pallidum can be considered as a polar species that is typically present in regions that have high phosphate and nitrate concentrations but low Chlorophyll-*a* concentrations in upper waters and well ventilated bottom waters. It can be present in high relative abundances in sites that are seasonally covered with sea ice and where upper water salinities can be reduced seasonally.

22. *Impagidinium paradoxum* (Wall 1967) Stover et Evitt 1978

Figs. 88–91.

Distribution:

The distribution of *Impagidinium paradoxum* is restricted to temperate to equatorial full-marine regions between the sub-tropical frontal systems of both hemispheres. Although it can be observed in coastal sites, highest relative abundances up to 34% of the association can be observed in the sub-tropical, tropical and equatorial central oceans.

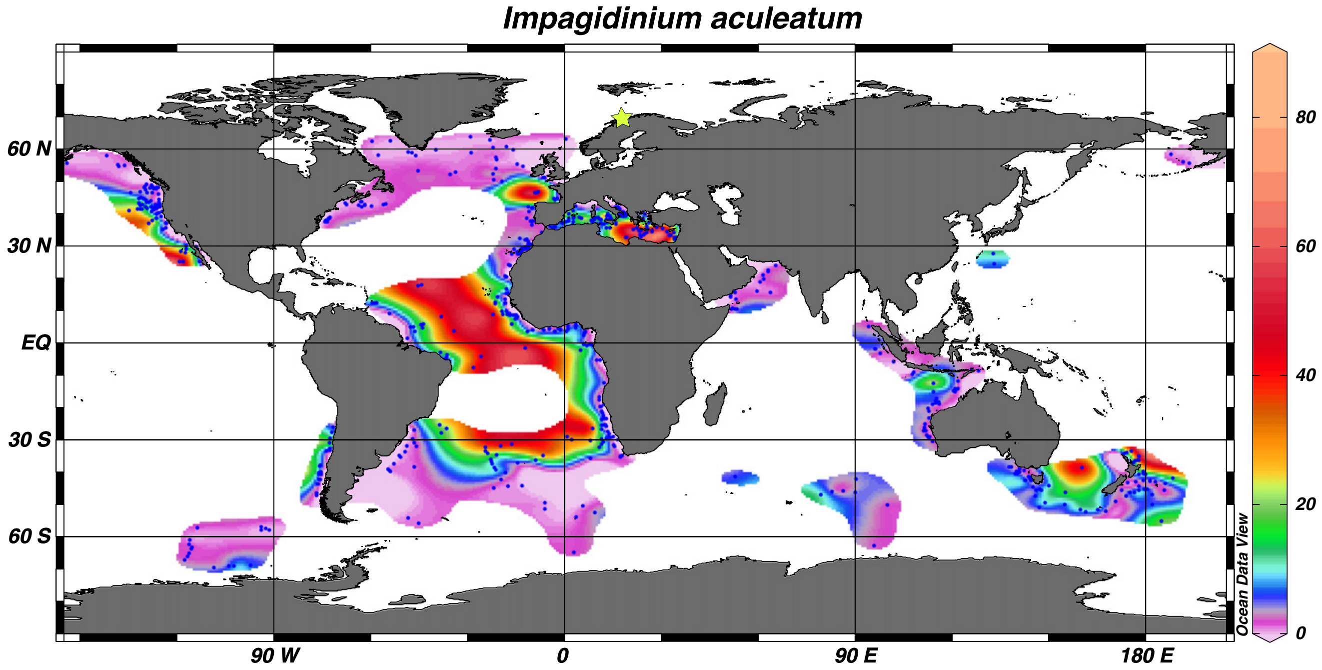

Fig. 76. Geographic distribution of *Impagidinium aculeatum*.

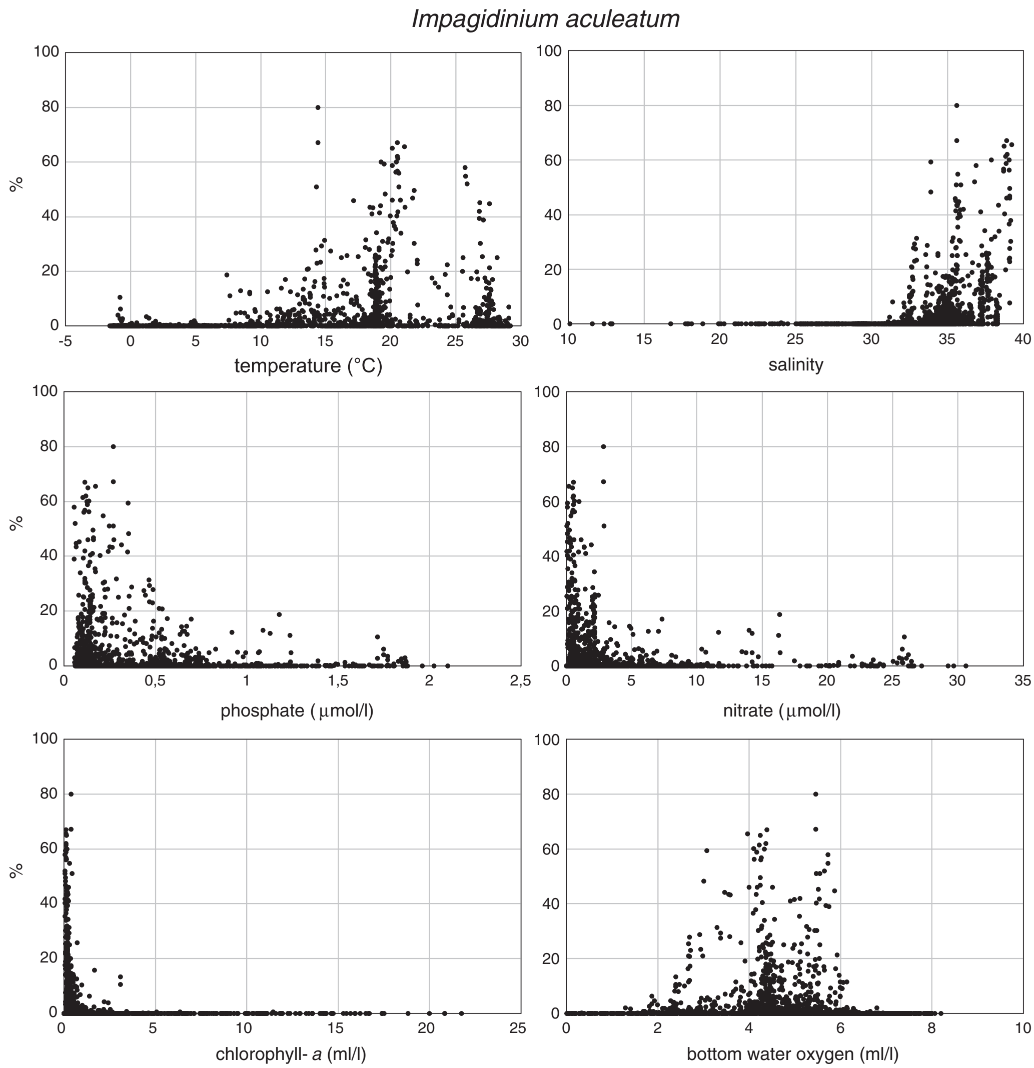

Fig. 77. Relative abundances of *Impagidinium aculeatum* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

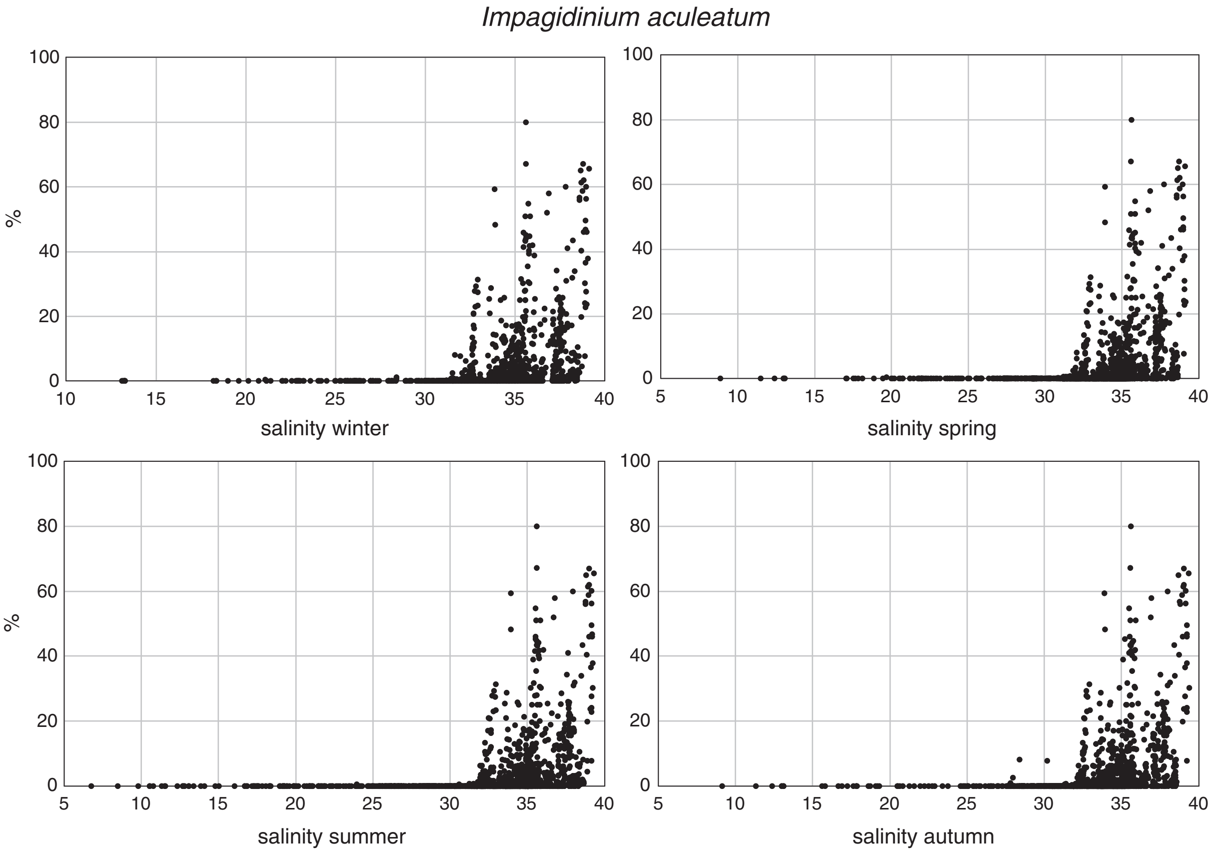

Fig. 78. Relative abundances of *Impagidinium aculeatum* in relationship to seasonal salinity in surface waters.

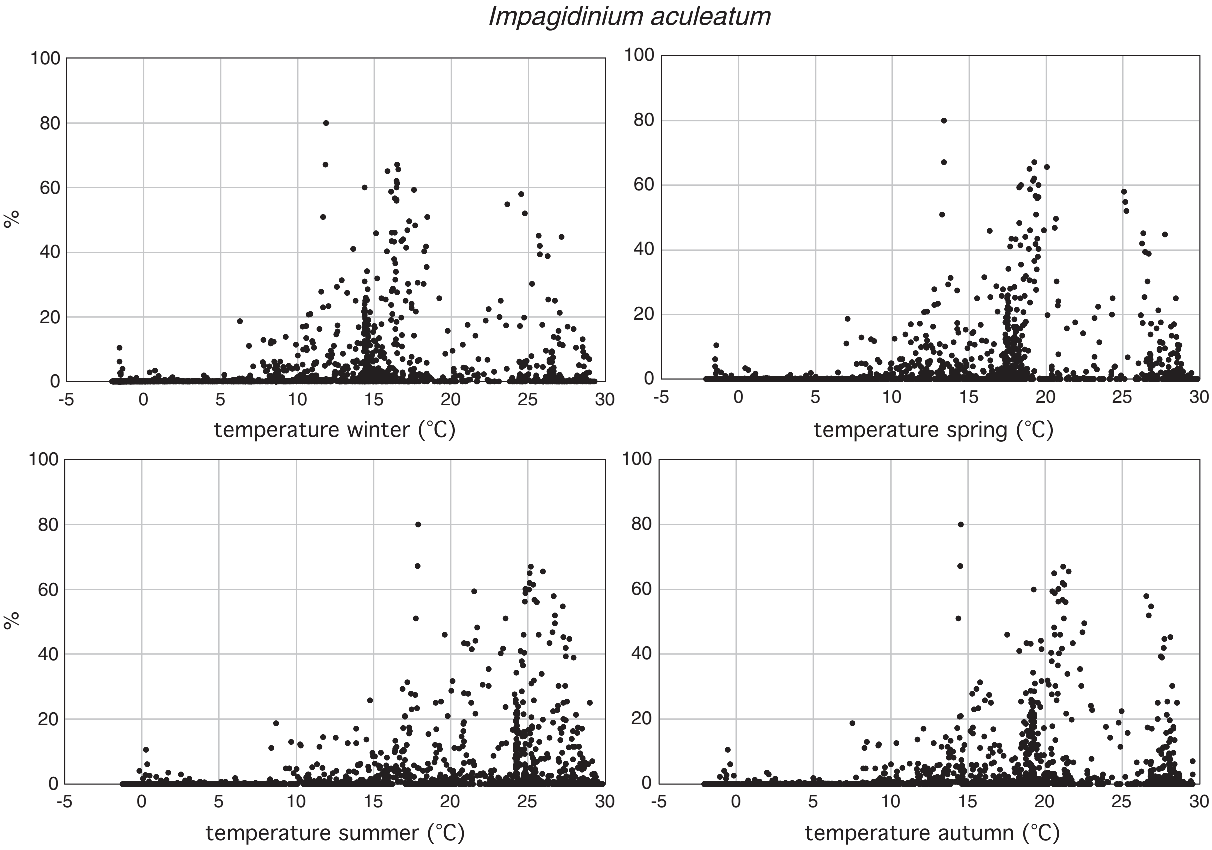

Fig. 79. Relative abundances of *Impagidinium aculeatum* in relationship to seasonal temperature in surface waters.

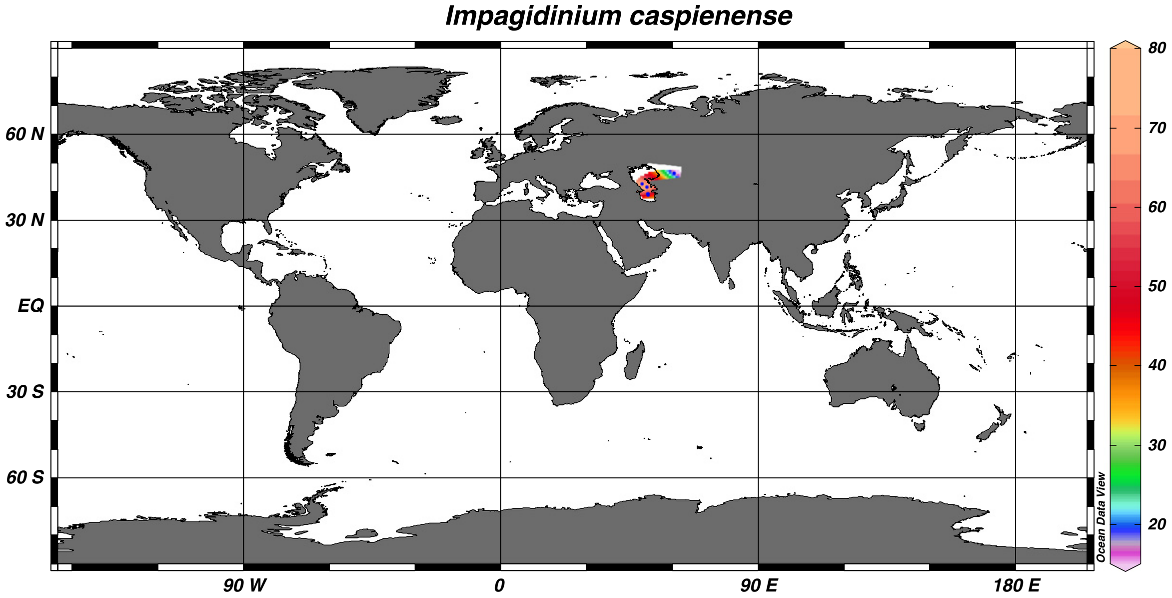

Fig. 80. Geographic distribution of *Impagidinium caspienense*.

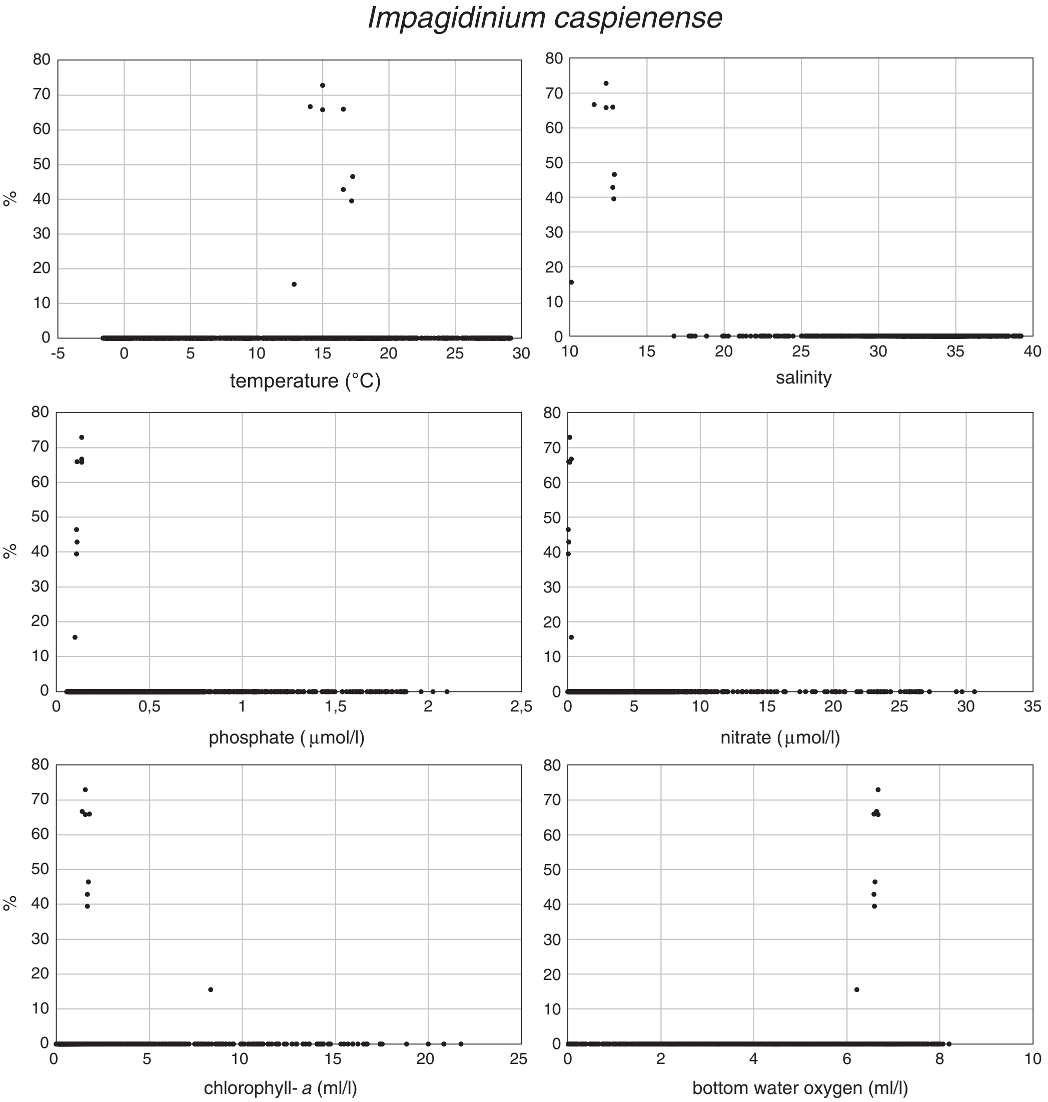

Fig. 81. Relative abundances of *Impagidinium caspienense* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

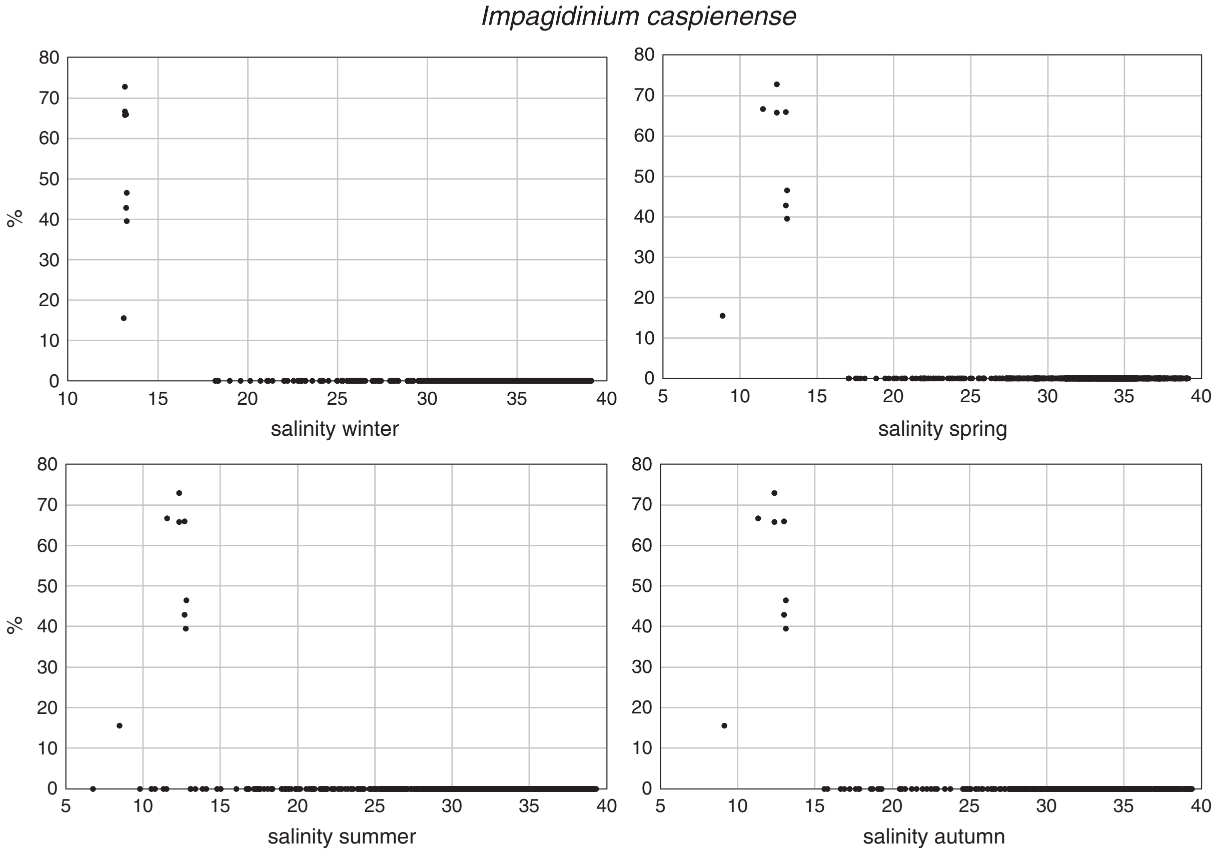

Fig. 82. Relative abundances of *Impagidinium caspienense* in relationship to seasonal salinity in surface waters.

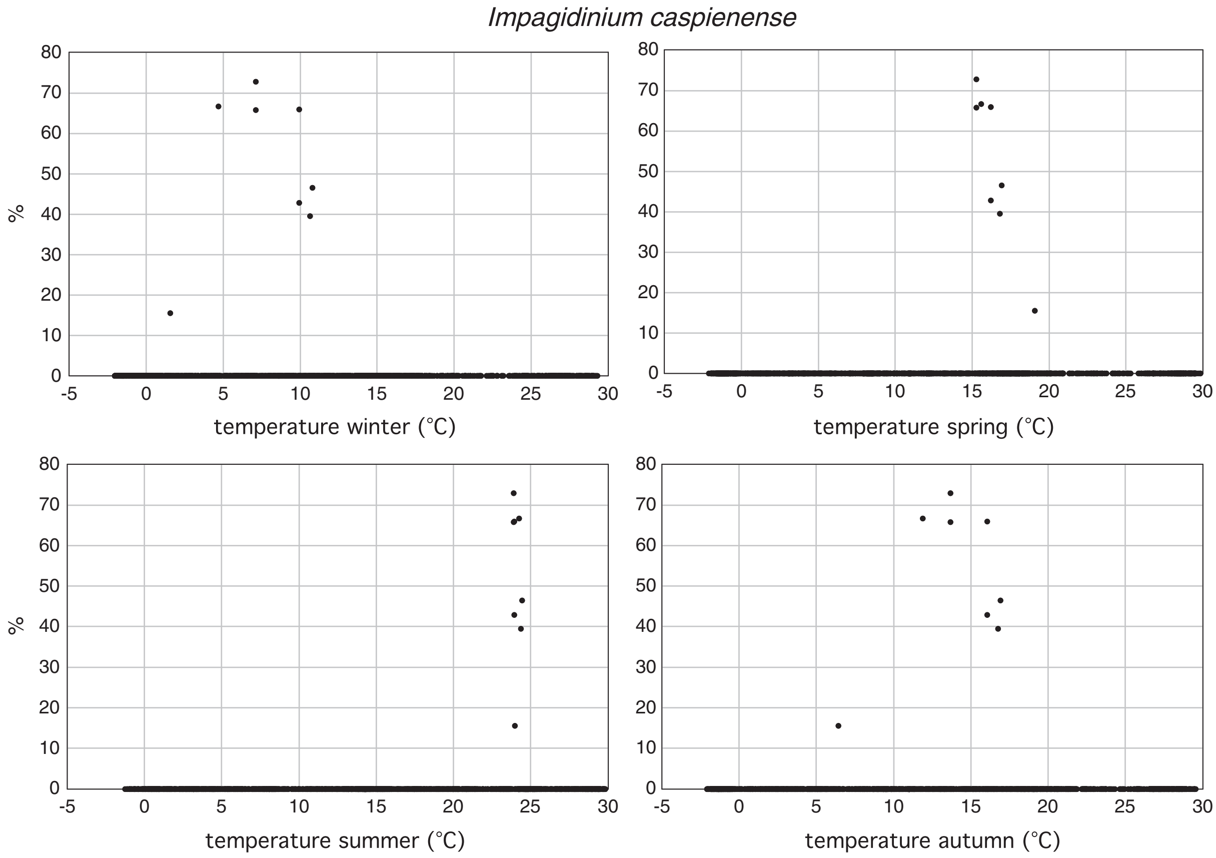

Fig. 83. Relative abundances of *Impagidinium caspienense* in relationship to seasonal temperature in surface waters.

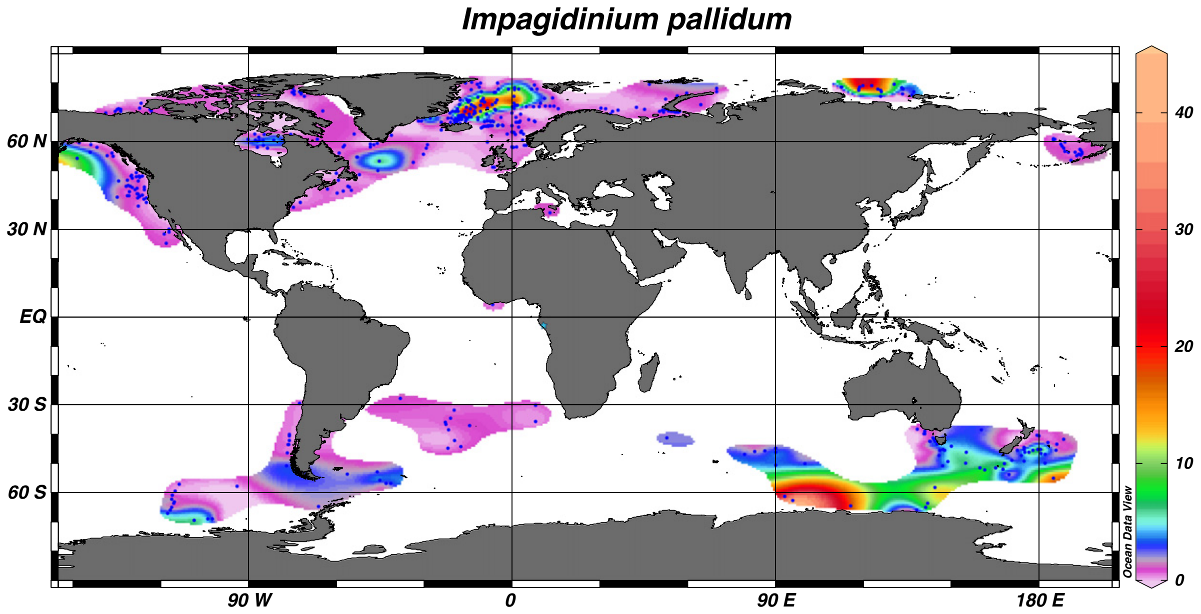

Fig. 84. Geographic distribution of *Impagidinium pallidum*.

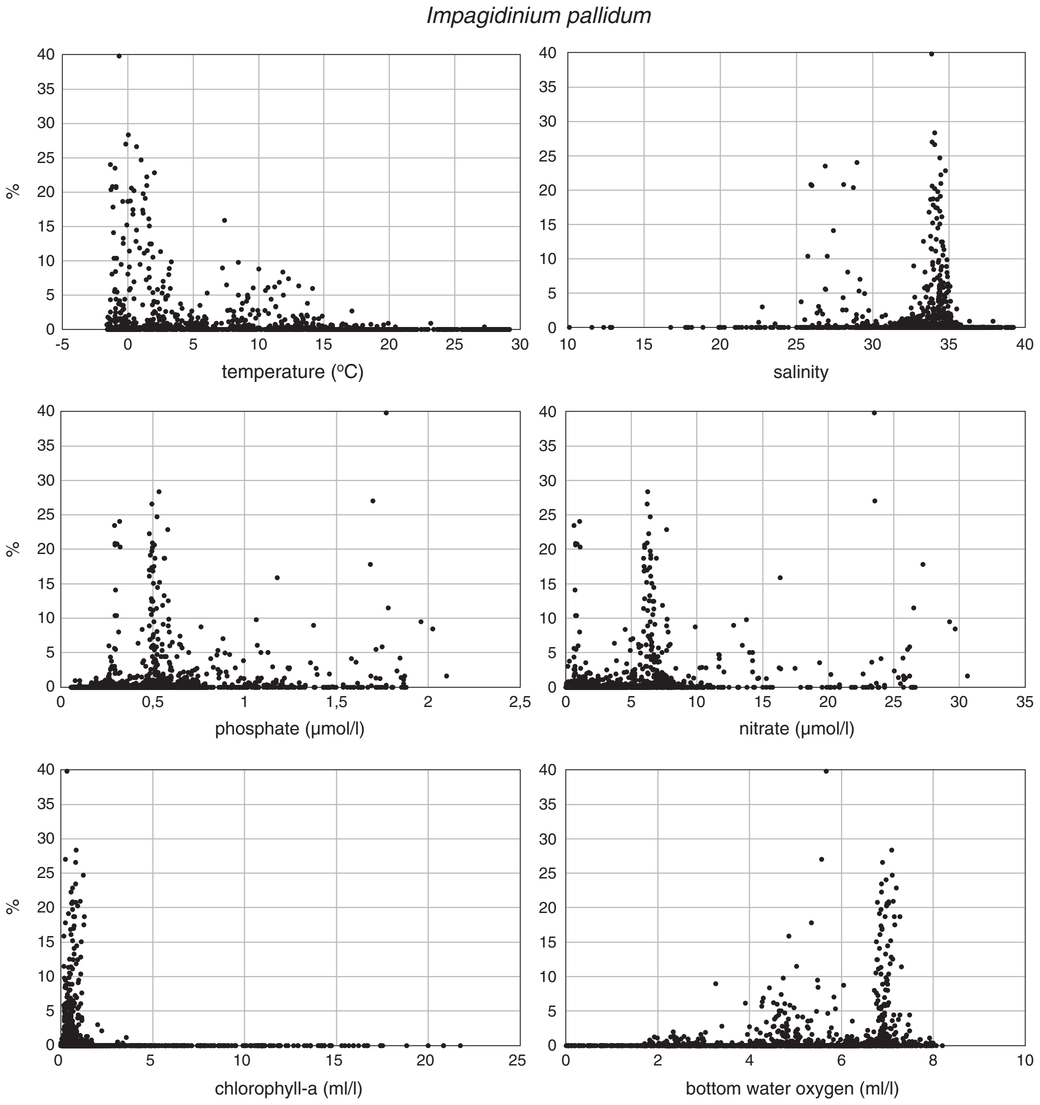

Fig. 85. Relative abundances of *Impagidinium pallidum* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

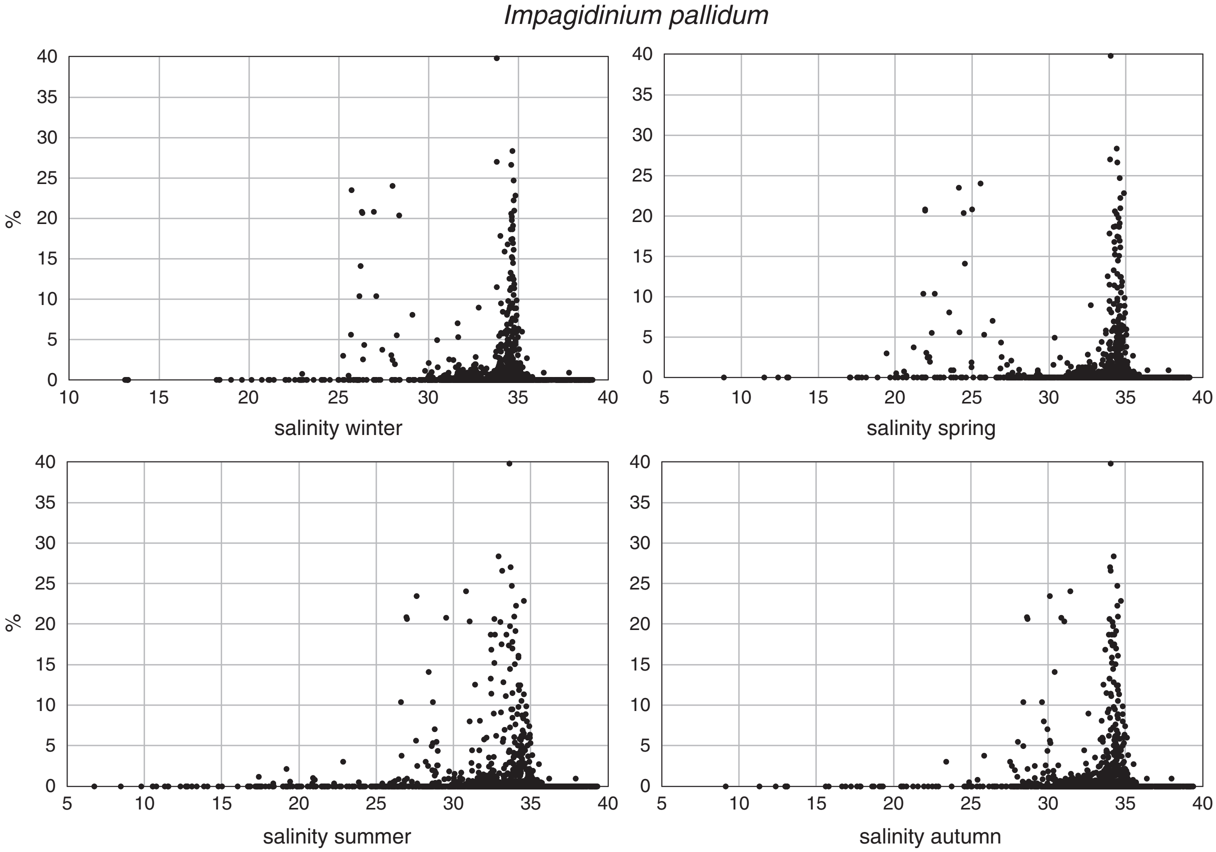

Fig. 86. Relative abundances of *Impagidinium pallidum* in relationship to seasonal salinity in surface waters.

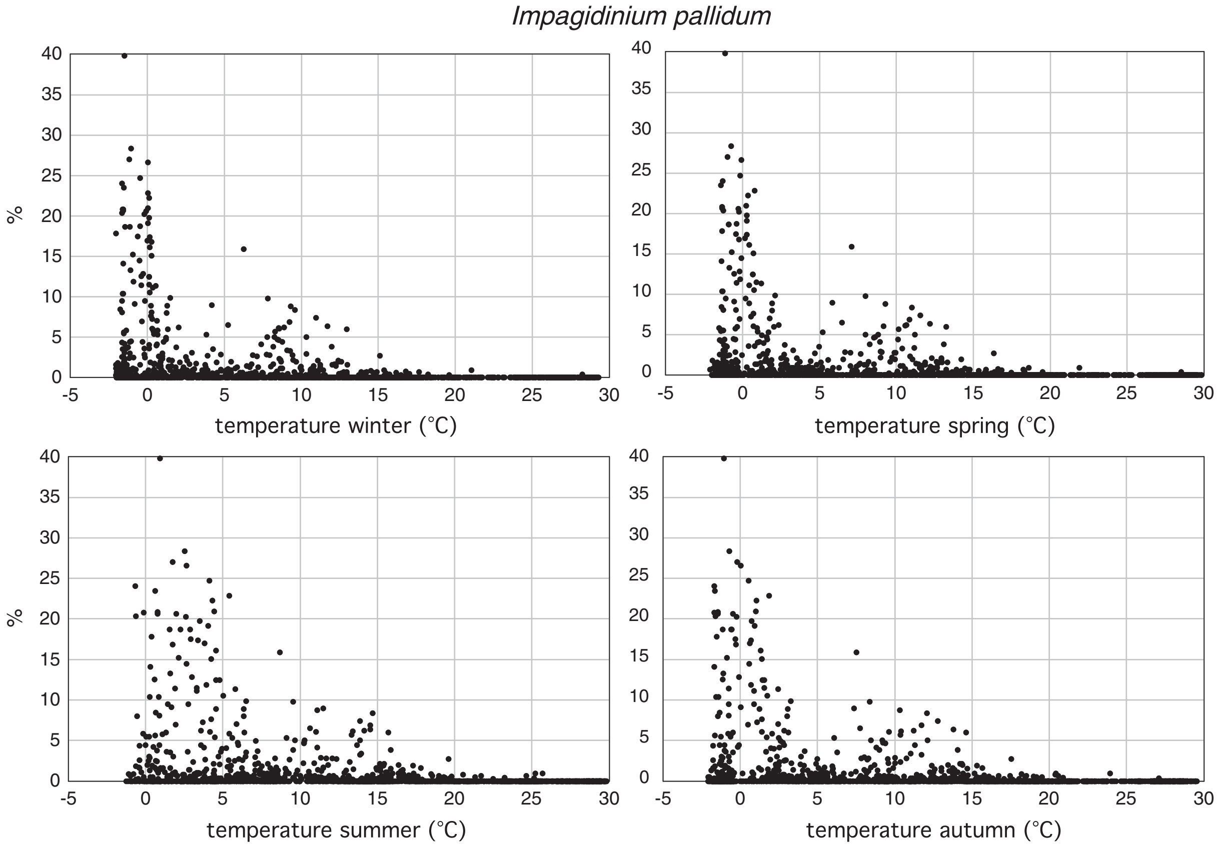

Fig. 87. Relative abundances of *Impagidinium pallidum* in relationship to seasonal temperature in surface waters.

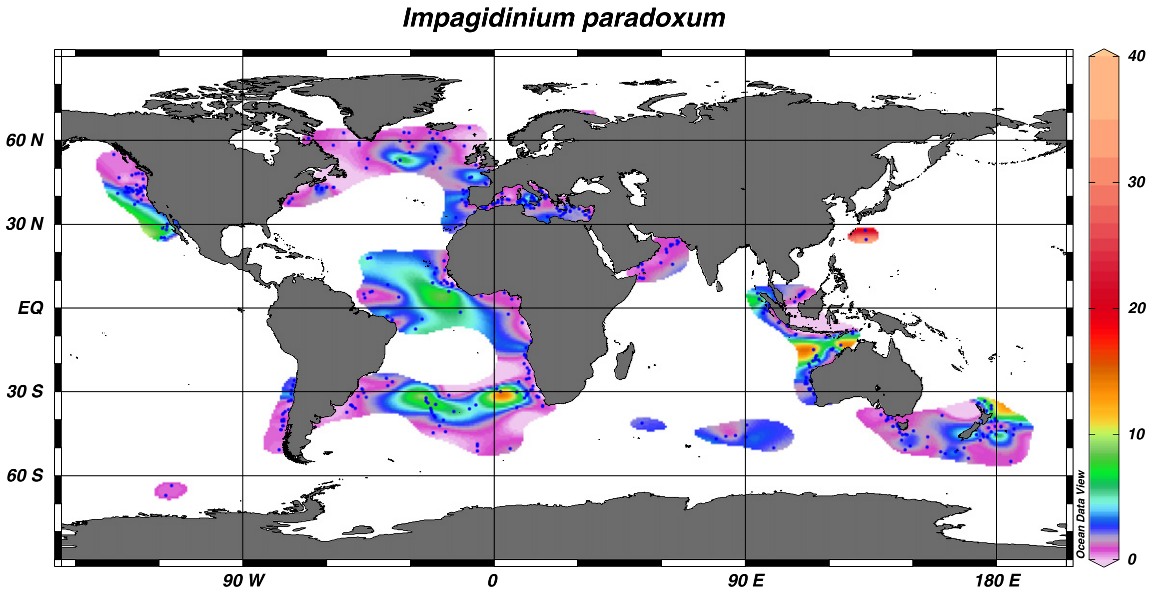

Fig. 88. Geographic distribution of *Impagidinium paradoxum*.

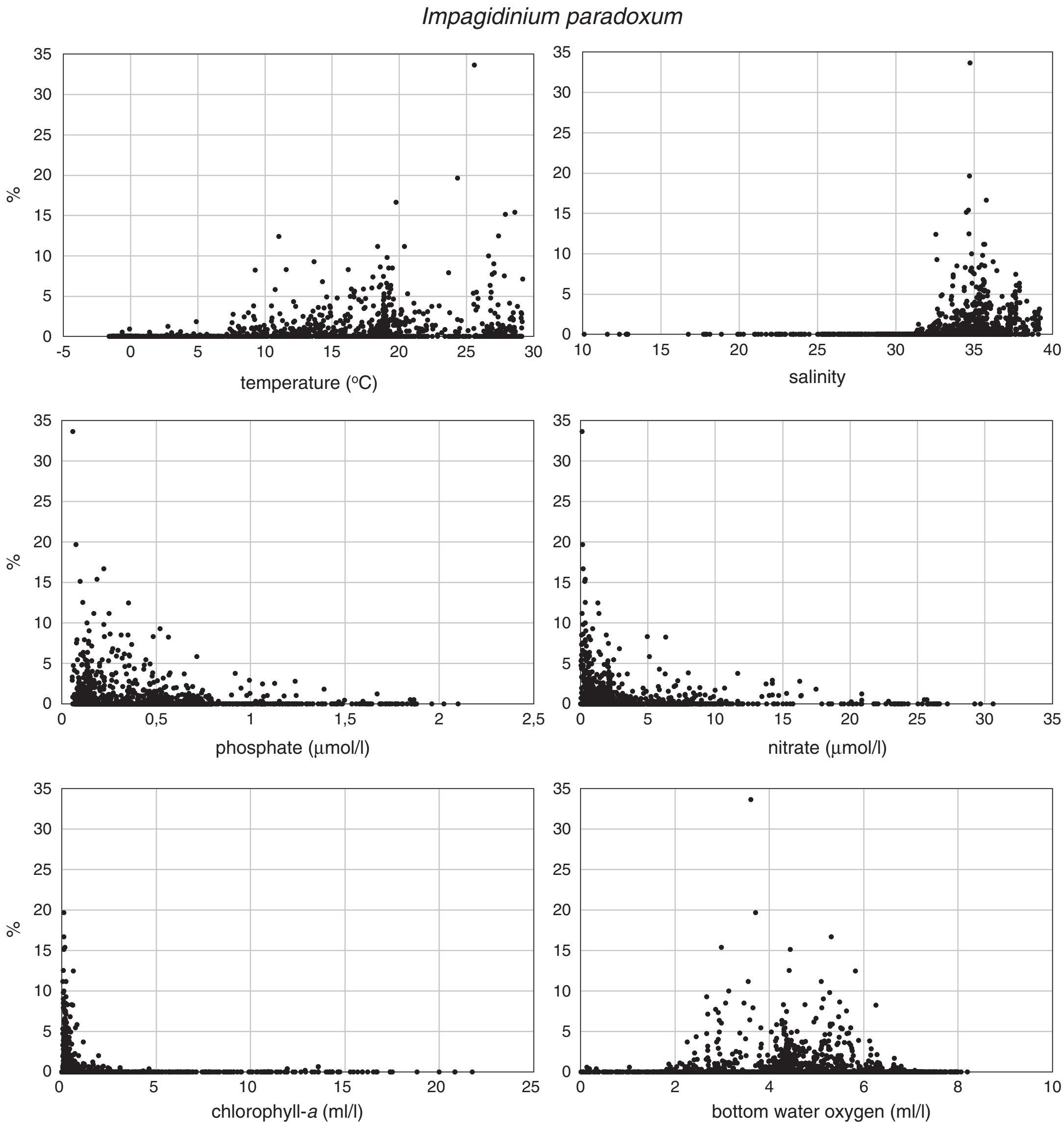

Fig. 89. Relative abundances of *Impagidinium paradoxum* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

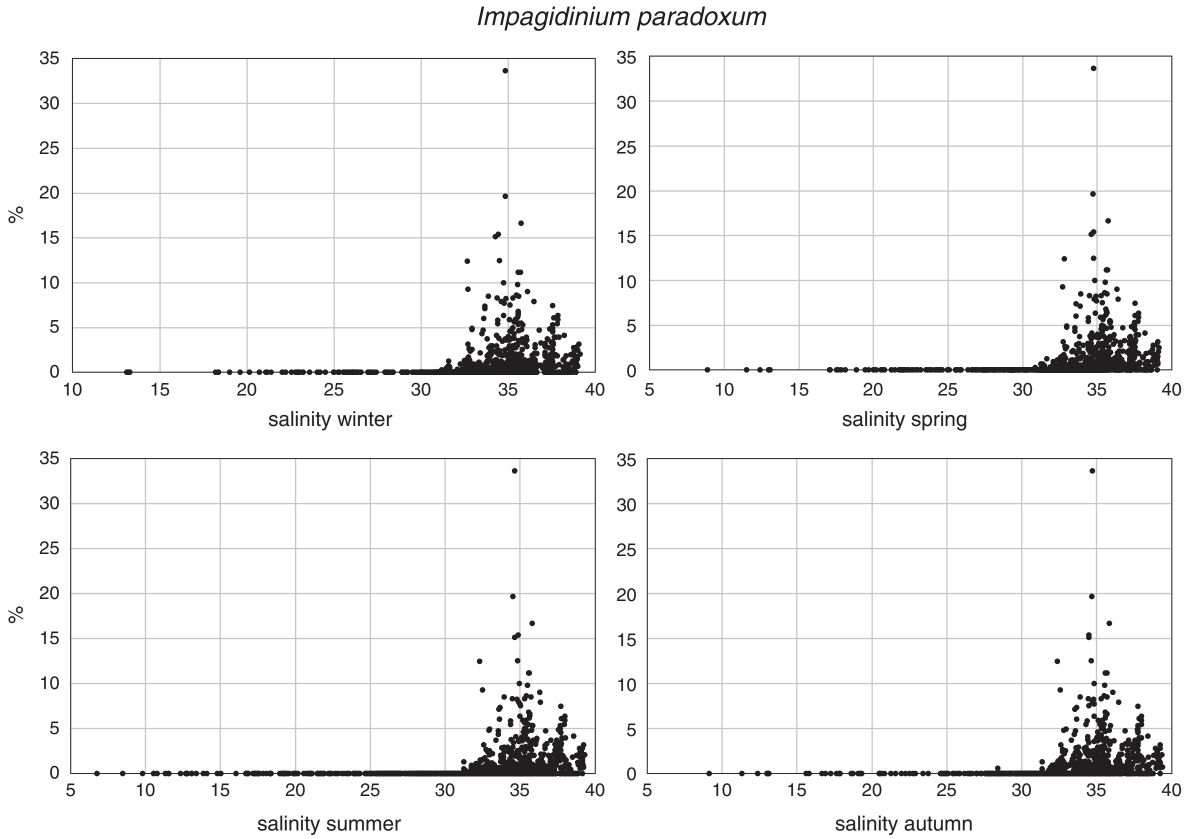

Fig. 90. Relative abundances of *Impagidinium paradoxum* in relationship to seasonal salinity in surface waters.

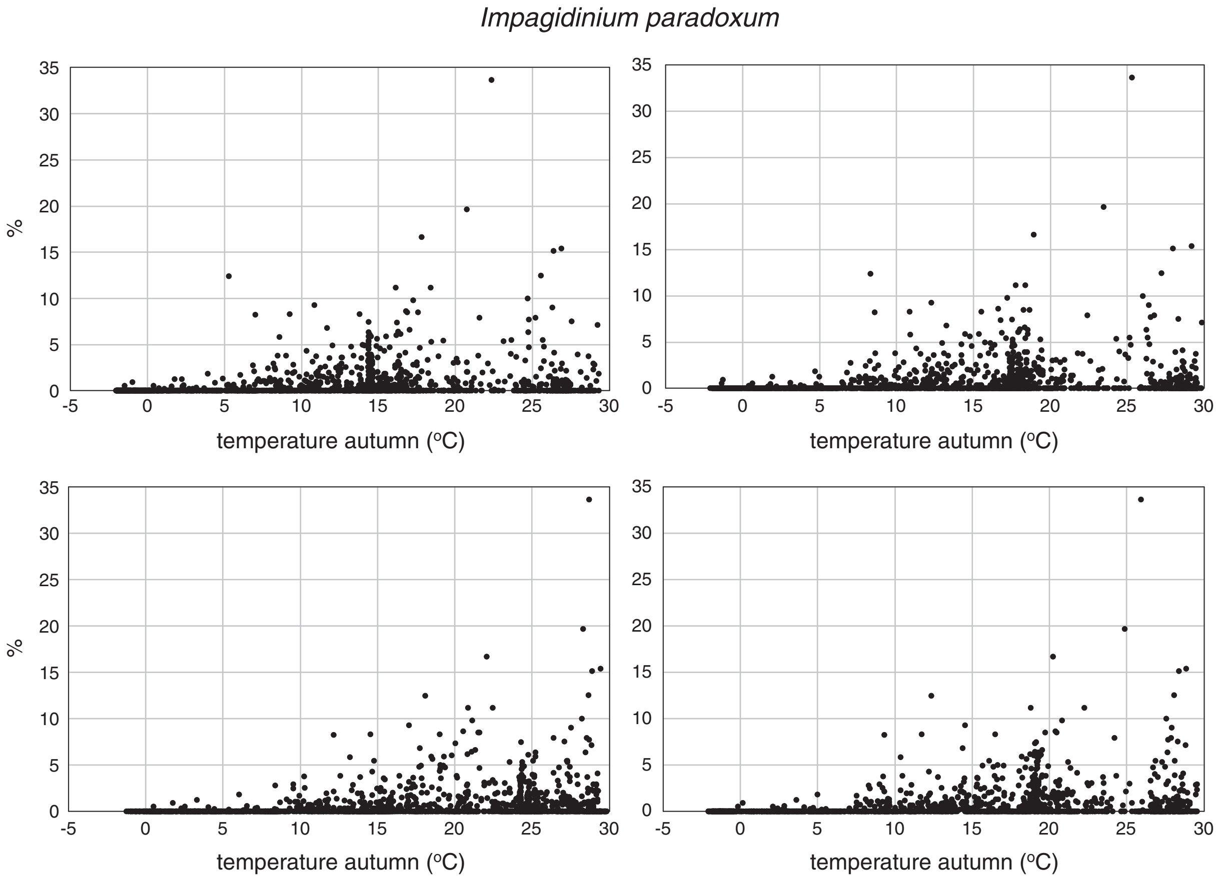

Fig. 91. Relative abundances of *Impagidinium paradoxum* in relationship to seasonal temperature in surface waters.

Environmental parameters:

SST: 0.3–29.8 °C (winter–spring) except for one site in the northern North Atlantic and one site in the southern South Pacific where winter and spring temperatures are below 0 °C. SSS: 30.8–39.4 (spring–summer), [P]: 0.06–1.87 μmol/l, [N]: 0.04–25.7 μmol/l, chlorophyll-*a*: 0.05–11.5 ml/l, bottom water [O_2]: > 1.0 ml/l except for two sites.

Highest relative abundances of more than 10% can be observed in regions with temperatures between 16.1–29.4 °C (winter–summer) in oligotrophic regions where Chlorophyll-*a* concentrations are low. With two exceptions its distribution is restricted to sites with well-ventilated bottom waters.

Comparison with other records:

So far *I. paradoxum* has not been documented from regions other than the ones covered in this Atlas. In records not included in this database, highest relative abundances can be observed in sites where oligotrophic conditions prevail although *I. paradoxum* does not avoid mesotrophic to eutrophic environments. So far only one sediment trap study reports the production of these cysts in the western Arabian Sea where it is found at times when stratified, oligotrophic conditions in the upper water column are present (Zonneveld and Brummer, 2000).

Concluding remarks:

I. paradoxum has a temperate to equatorial distribution, restricted to full-marine environments. Although it can be observed in both oligotrophic to eutrophic environments and sites that can be found in shallow-coastal to the open ocean regions, highest relative abundances of this species can be observed in the central oceans with low upper water productivity and well ventilated bottom waters.

23. *Impagidinium patulum* (Wall 1967) Stover et Evitt 1978

Figs. 92–95.

Distribution:

With a few exceptions of samples in the Beaufort Sea, the Bering Sea and near Antarctica, the distribution of *Impagidinium patulum* is restricted to temperate to equatorial full-marine regions between the sub-tropical frontal systems on both hemispheres. Although it can be observed in coastal sites, highest relative abundances up to 62% of the association can be observed in the central parts of the oceans such as the equatorial Atlantic and tropical western Pacific.

Environmental parameters:

SST: −2.0–29.6 °C (winter–spring). SSS: 25.6–39.4 (summer–autumn), [P]: 0.06–1.87 μmol/l, [N]: 0.04–25.8 μmol/l, chlorophyll-*a*: 0.05–4.6 ml/l, bottom water [O_2]: > 1.7 ml/l except for two recordings.

Highest relative abundances of more than 10% can be observed in regions with temperatures between 12.0–28.4 °C (winter–summer). *I. patulum* occurs in oligotrophic to eutrophic regions where chlorophyll-*a* concentrations are relatively low. The majority of the recordings and highest relative abundances are observed in oligotrophic environments of the central oceans.

Comparison with other records:

Apart from the recordings in this Atlas *I. patulum* has been documented from the South China Sea (see references in Marret and Zonneveld, 2003). In records other than those included in our dataset, highest relative abundances can be observed in sites where oligotrophic environments prevail although *I. patulum* does not avoid mesotrophic to eutrophic environments. So far only one sediment trap study reports the seasonal production of these cysts from the upwelling area off NW Africa. In this region cyst production increases when nutrient availability in upper waters is enhanced (Zonneveld et al., 2010).

Concluding remarks:

I. patulum has a temperate to equatorial distribution although it can be sporadically recorded in sub-polar and polar regions. It is restricted to full-marine environments. Although it can be observed in both oligotrophic to eutrophic environments and in shallow-coastal to the open ocean regions, highest relative abundances of this species occur in the central oceans with low upper water productivity and well ventilated bottom waters.

24. *Impagidinium plicatum* Versteegh et Zevenboom 1995

Figs. 96–99.

Distribution:

Impagidinium plicatum is restricted to temperate to equatorial full-marine regions between the sub-tropical frontal systems of both hemispheres although there are a few recordings from the Beaufort Sea, the Bering Sea and near Antarctica. Although it can be observed in coastal sites, highest abundances (up to 20%) occur in the offshore eastern Pacific.

Environmental parameters:

SST: 0–29.6 °C (winter–summer) and SST > 8.0 °C in summer. Exception is formed by few sites from the Beaufort Sea, the Bering Sea and Pacific Sector of the Antarctic Circumpolar Current where SST winter lies between −2.0–-0.3 °C. SSS: 30.3–39.3 (summer–autumn) with exception of the Antarctic site where SSS: 26.2 (summer), [P]: 0.06–1.07 μmol/l, [N]: 0.04–8.8 μmol/l, chlorophyll-*a*: 0.05–2.1 ml/l, bottom water [O_2]: > 0.8 ml/l.

Abundances of > 10% occur at temperatures between 12.0–25.2 °C (winter–summer). With exception of a Bering Sea site, *I. patulum* occurs in oligotrophic to mesotrophic regions with low upper water bioproductivity and well ventilated bottom waters.

Comparison with other records:

Impagidinium plicatum has not been recorded from regions not covered by this Atlas.

Concluding remarks:

I. plicatum has a temperate to equatorial distribution. Although it can be observed in shallow-coastal sites it is usually found in oligotrophic/mesotrophic environments with low upper water productivity such can be found in the central parts of the oceans. It distribution is restricted to full-marine environments that are characterised by well ventilated bottom waters.

25. *Impagidinium sphaericum* (Wall 1967) Lentin and Williams 1981

Figs. 100–103.

Distribution:

Impagidinium sphaericum has a cosmopolitan distribution and can be observed in all studied regions from the arctic/antarctic to the equator, and from the coast to the central oceans. However, its distribution is restricted to environments with low upper water chlorophyll-*a* concentrations and well ventilated bottom waters. Highest abundances (up to 65%) occur in the Atlantic sector of the southern Ocean and the northern North Atlantic Ocean in the vicinity of the sub-polar frontal systems as well as in the central South Atlantic Ocean.

Environmental parameters:

SST: −2.1–29.4 °C (spring–spring), SSS: 17.4–39.4 (summer–autumn), [P]: 0.06–1.88 μmol/l, [N]: 0.04–26.5 μmol/l, chlorophyll-*a*: 0.05–3.56 ml/l, bottom water [O_2]: > 1.7 ml/l except for one recording.

Impagidinium sphaericum can be observed in regions where salinities are seasonally reduced due to melting of ice.

Comparison with other records:

Apart from the distribution covered in this Atlas *I. sphaericum* has been documented from the South China Sea, Iberian upwelling area and the Peruvian upwelling area (Marret and Zonneveld, 2003; Sprangers et al., 2004). Relative abundances decrease with increasing duration of seasonal sea ice cover which may last several months (de Vernal et al., 1998; Radi and de Vernal, 2008; Solignac et al., 2009). The only sediment trap study reporting this species from the upwelling area off NW Africa records no seasonality in cyst production nor any relationship to characteristic upper water conditions (Zonneveld et al., 2010).

Concluding remarks:

I. spahericum has a cosmopolitan distribution and can be observed from coastal to open oceanic sites in all climatic zones. It

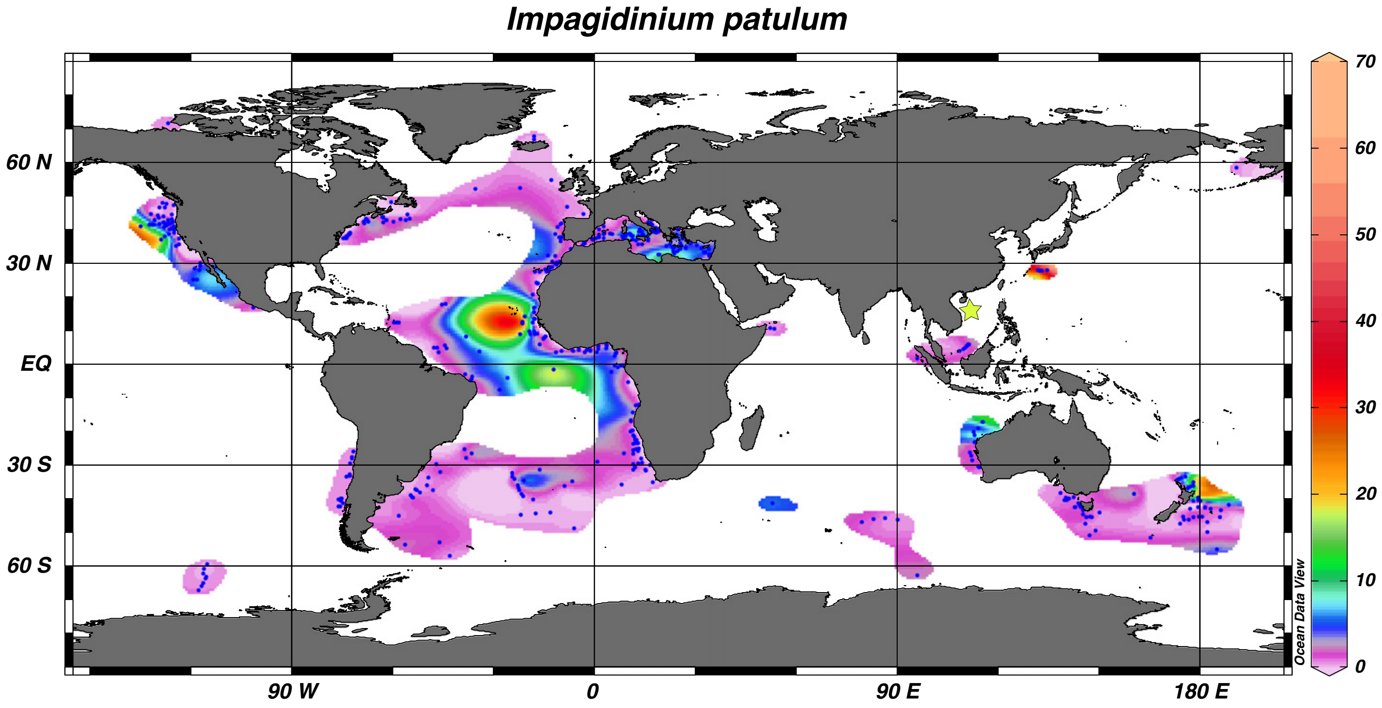

Fig. 92. Geographic distribution of *Impagidinium patulum*.

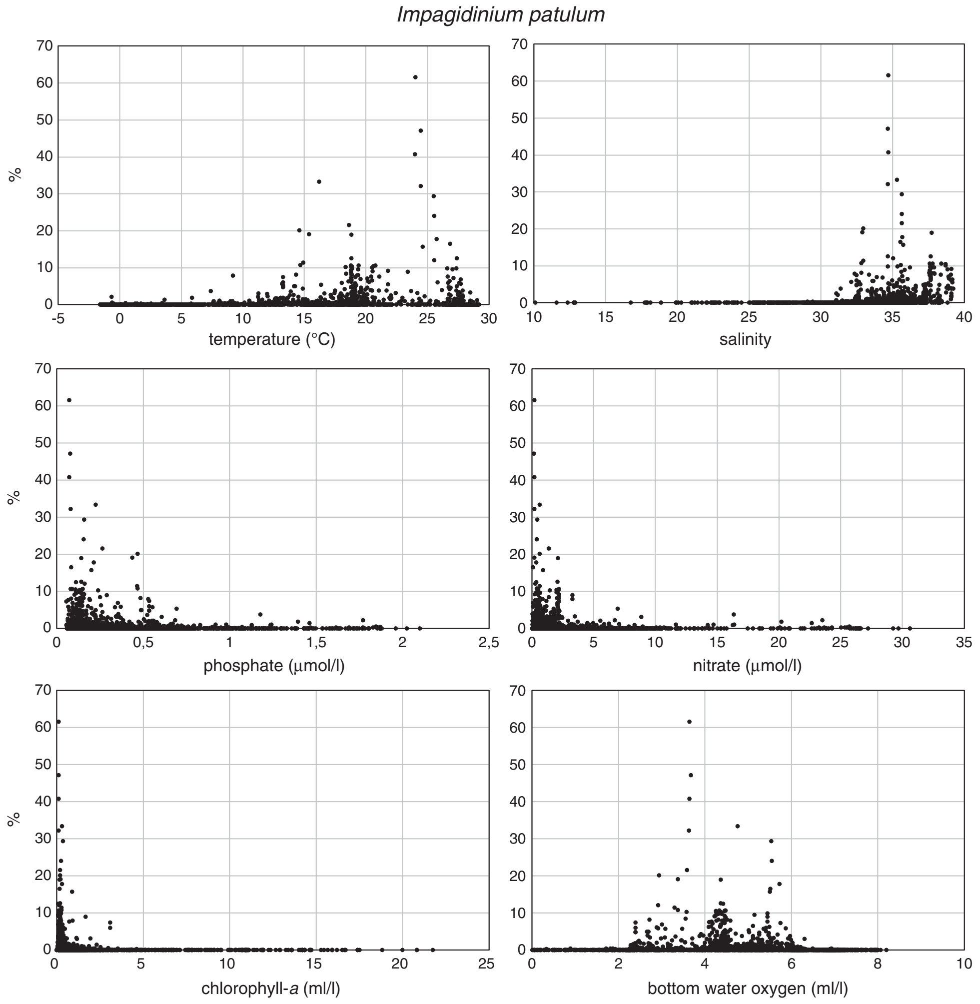

Fig. 93. Relative abundances of *Impagidinium patulum* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

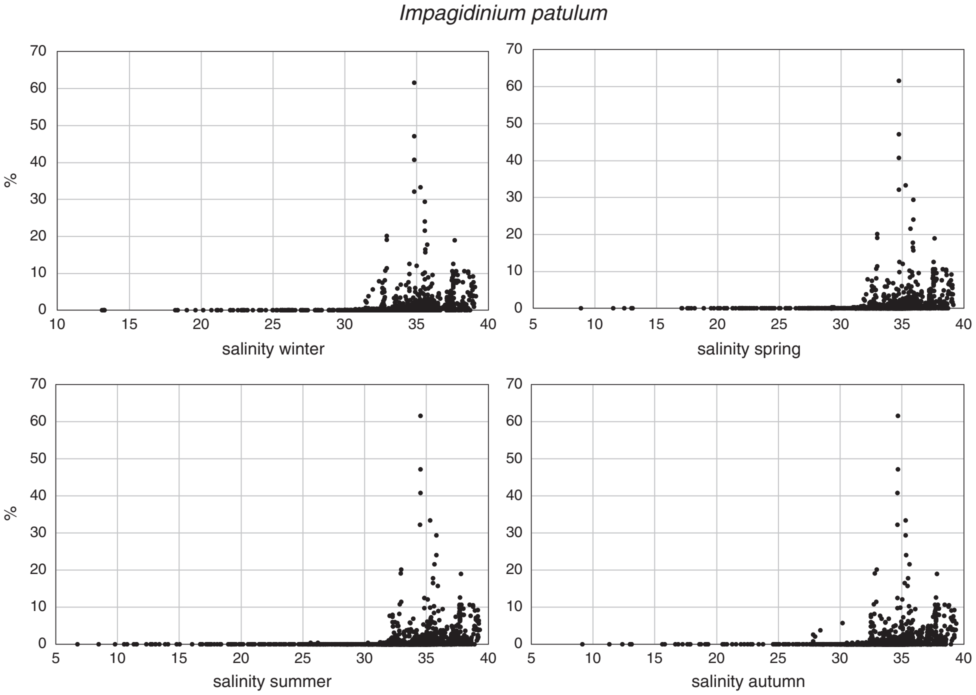

Fig. 94. Relative abundances of *Impagidinium patulum* in relationship to seasonal salinity in surface waters.

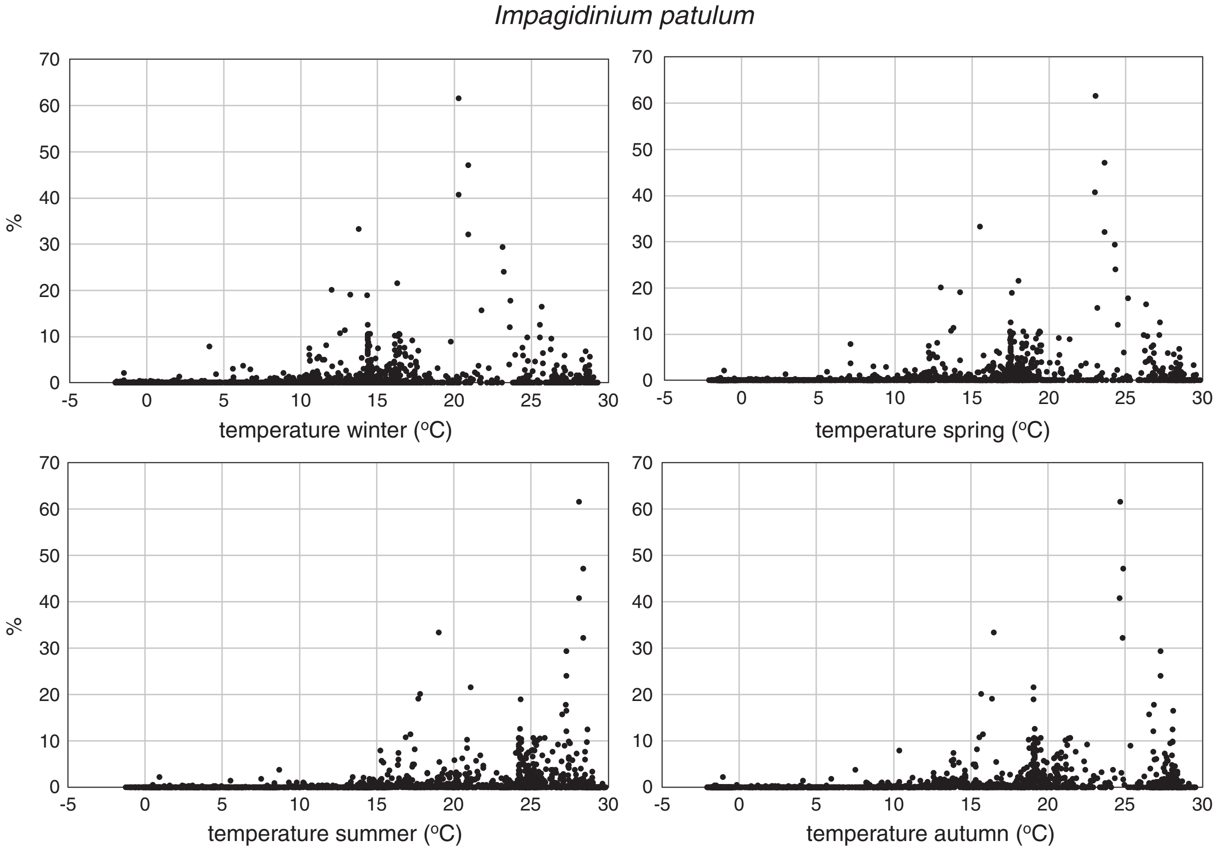

Fig. 95. Relative abundances of *Impagidinium patulum* in relationship to seasonal temperature in surface waters.

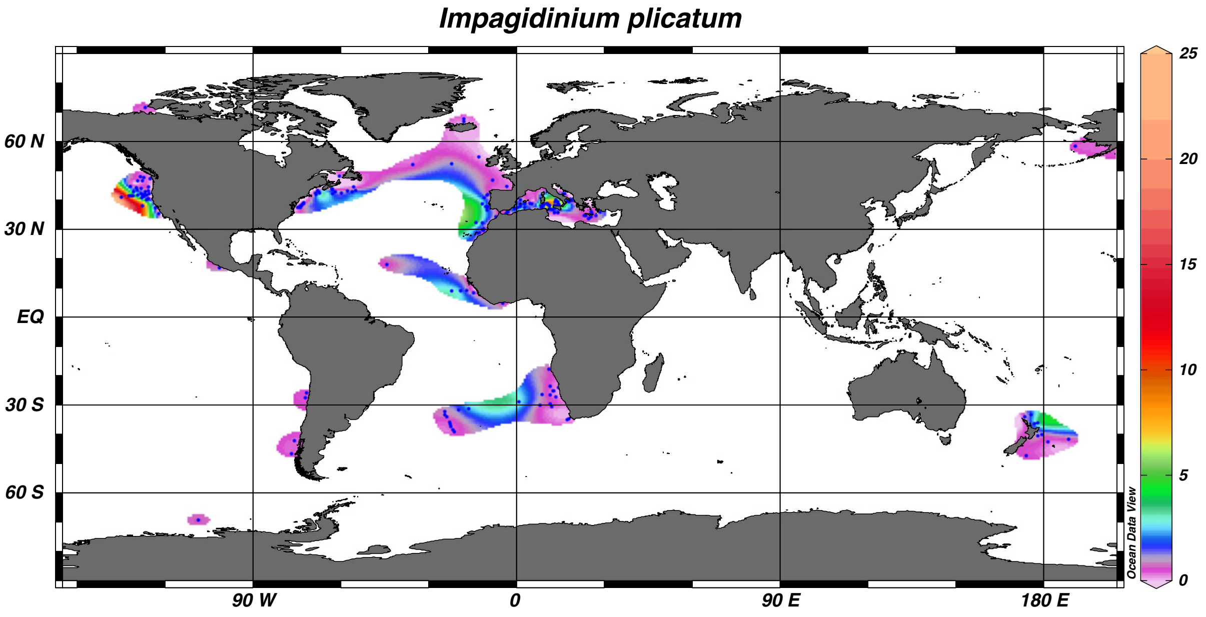

Fig. 96. Geographic distribution of *Impagidinium plicatum*.

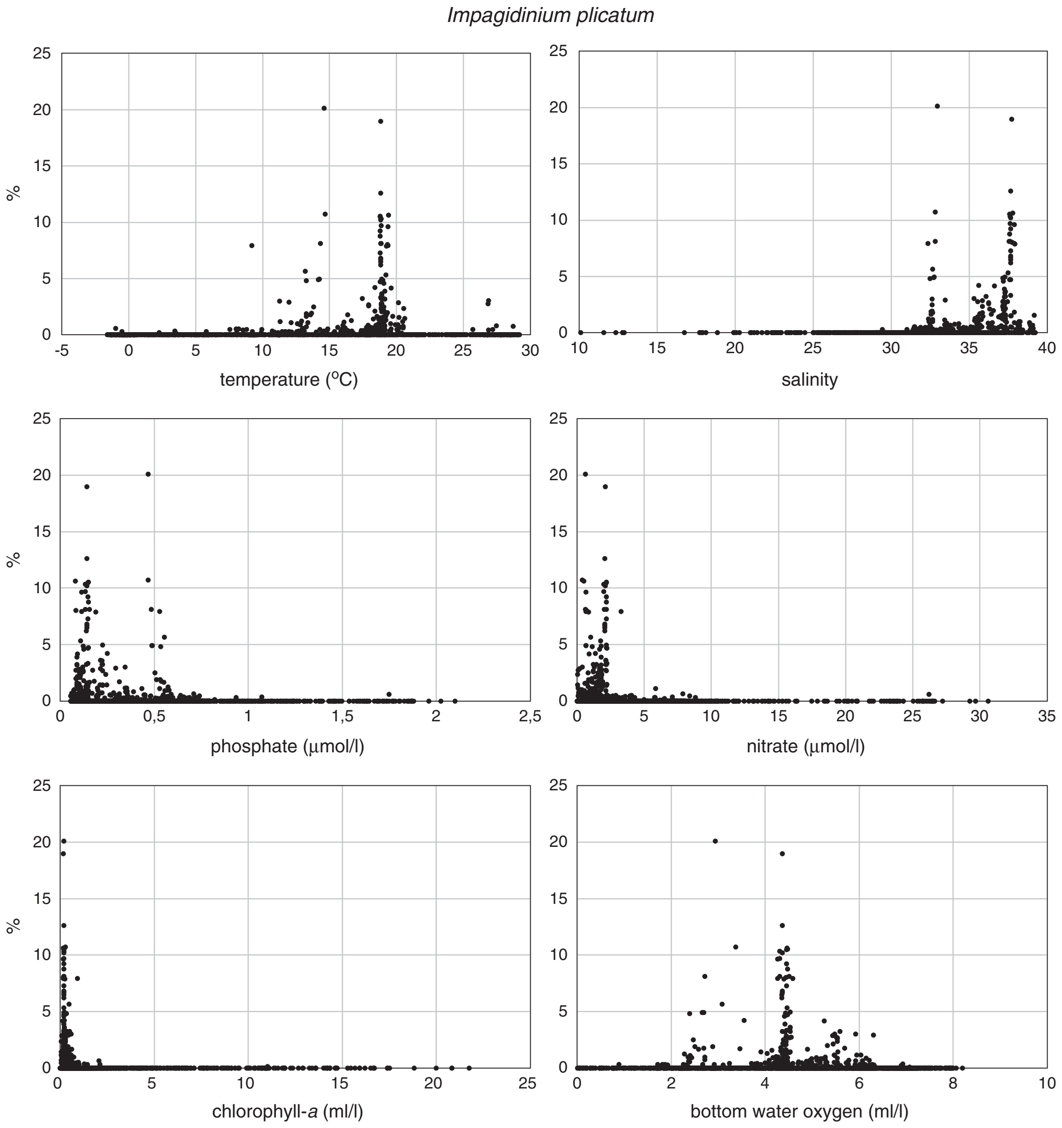

Fig. 97. Relative abundances of *Impagidinium plicatum* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

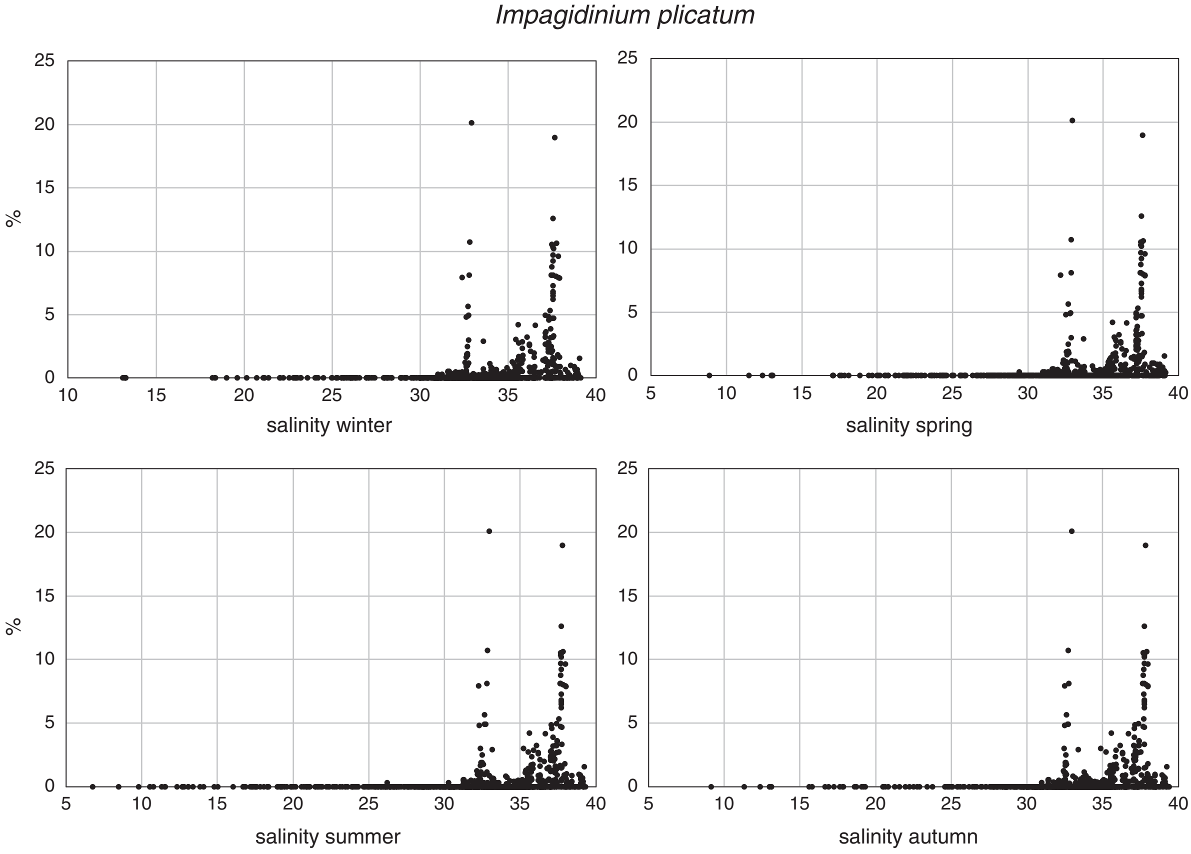

Fig. 98. Relative abundances of *Impagidinium plicatum* in relationship to seasonal salinity in surface waters.

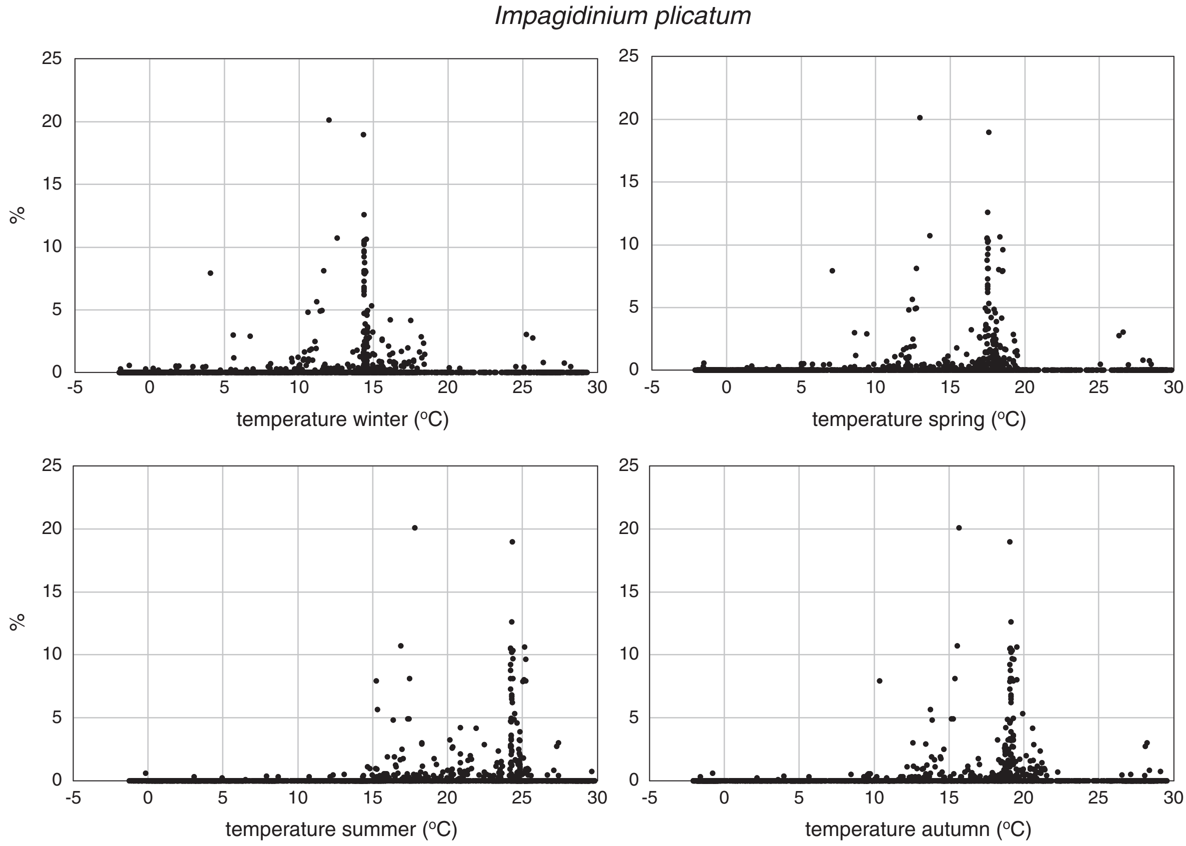

Fig. 99. Relative abundances of *Impagidinium plicatum* in relationship to seasonal temperature in surface waters.

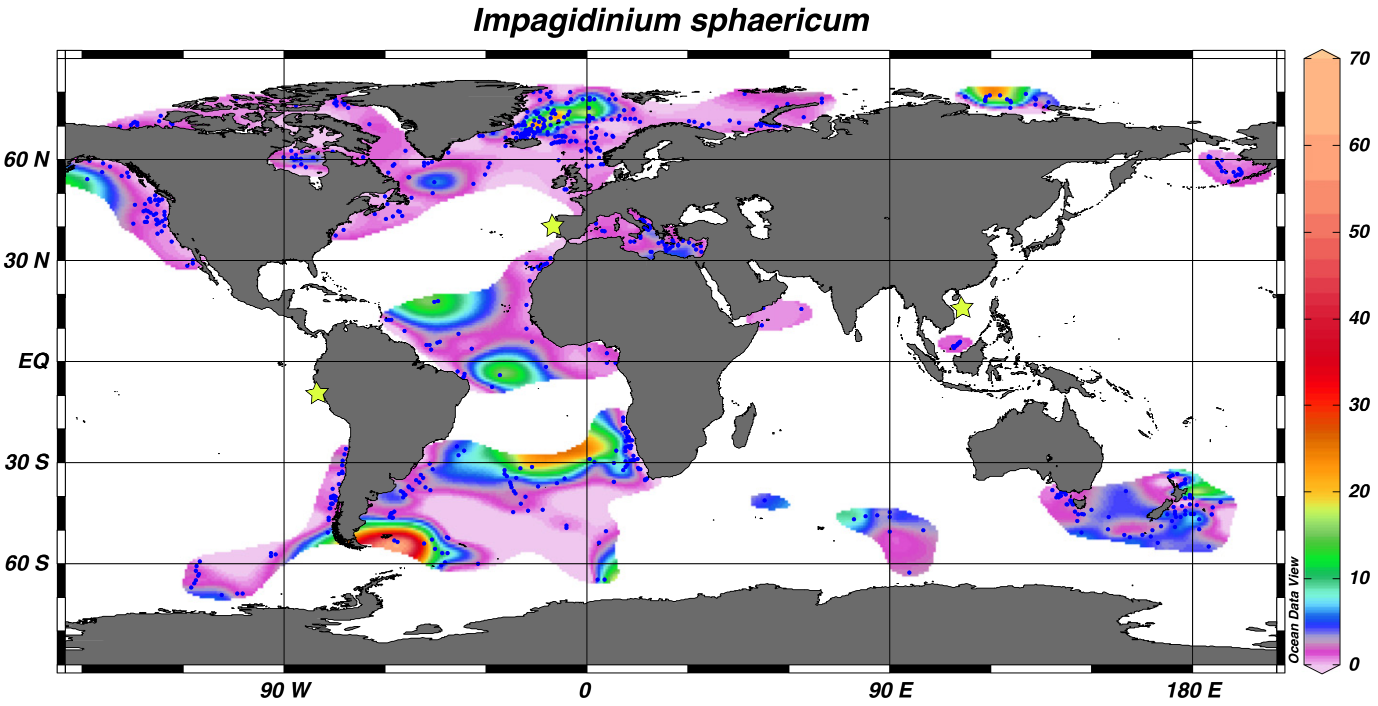

Fig. 100. Geographic distribution of *Impagidinium sphaericum*.

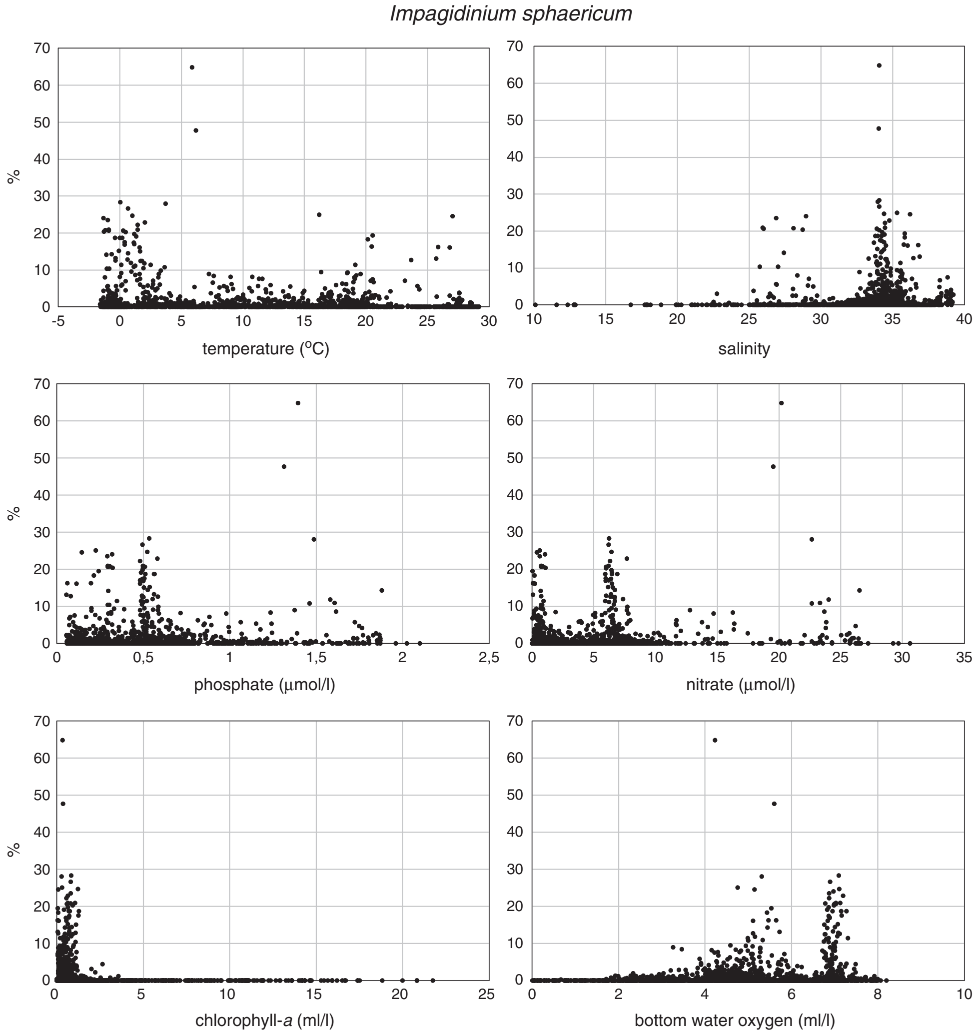

Fig. 101. Relative abundances of *Impagidinium sphaericum* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

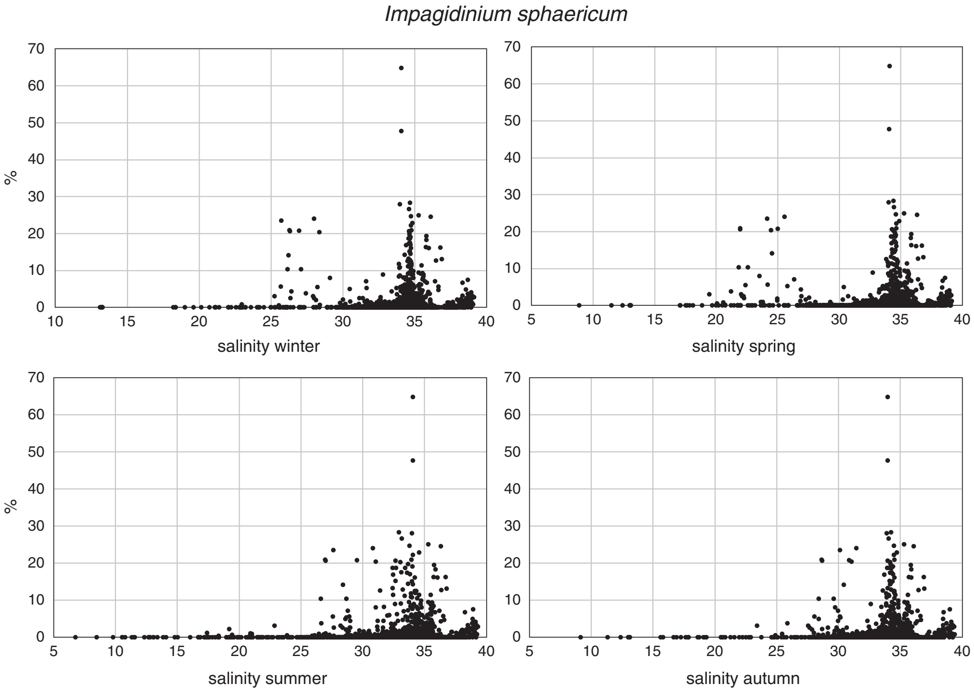

Fig. 102. Relative abundances of *Impagidinium sphaericum* in relationship to seasonal salinity in surface waters.

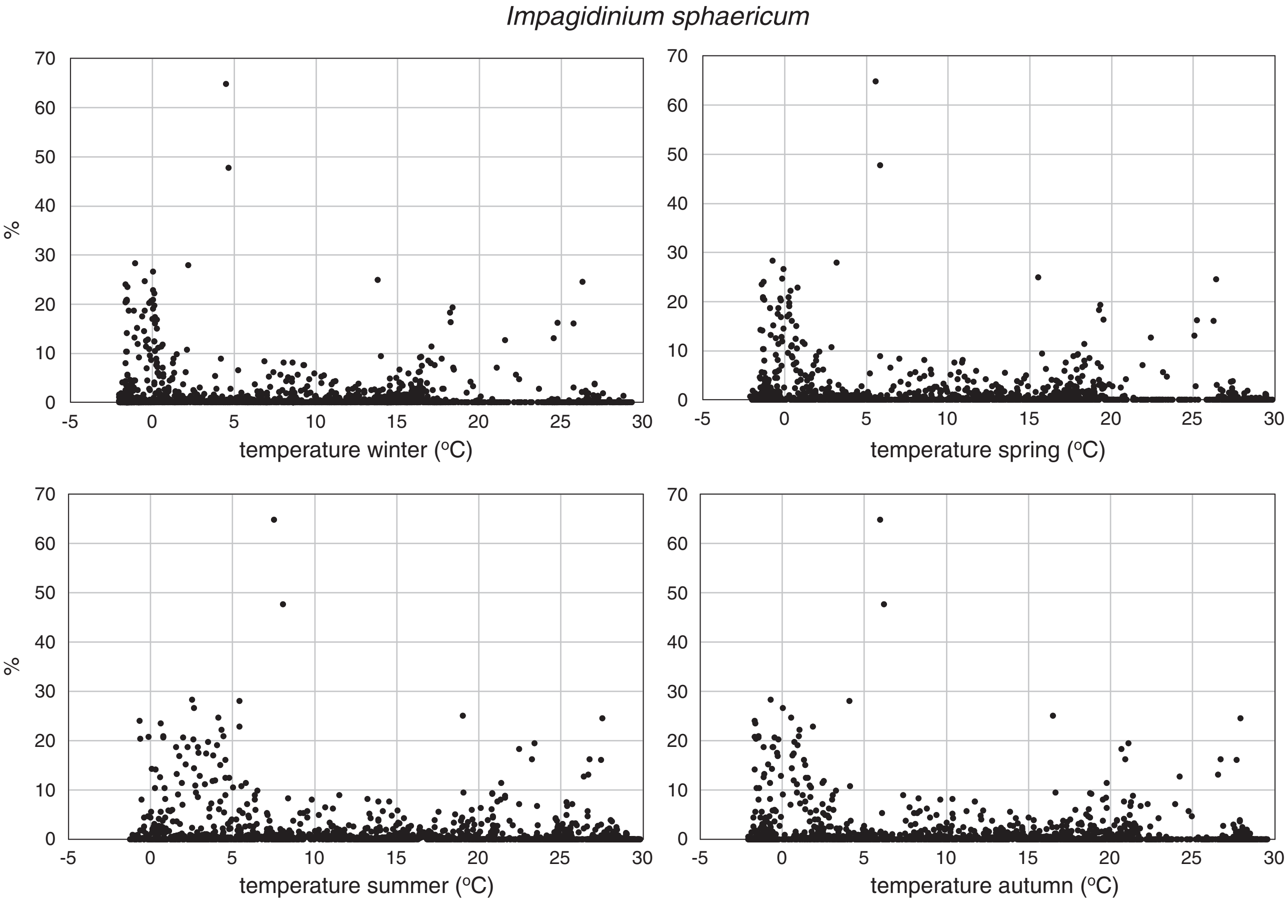

Fig. 103. Relative abundances of *Impagidinium sphaericum* in relationship to seasonal temperature in surface waters.

is restricted to regions with low upper water productivity, well ventilated bottom waters and high phosphate and nitrate concentrations. It can be observed in full-marine environments as well as regions where salinity can be seasonally reduced due to melting of ice.

26. *Impagidinium strialatum* (Wall 1967) Stover et Evitt 1978
Figs. 104–107.
Distribution:

Impagidinium strialatum is observed in sub-polar to equatorial regions bounded by the Arctic sub-tropical front in the north and the Antarctic Polar Front in the south. Exceptions are formed by four sites in the Pacific sector of the Southern Ocean where the species occurs between the polar and sub-tropical fronts. The species is not observed in coastal sites and highest abundances (up to 25%) occurs in the sub-tropical, tropical and equatorial central oceans.

Environmental parameters:

SST: 0–29.5 °C (winter–summer) except for the four Southern Ocean sites where SST: −1.5 °C (winter), SSS: 31.1–39.3 (spring–autumn) except for two sites in the Mediterranean where SSS: 27.8 (autumn), [P]: 0.06–1.87 μmol/l, [N]: 0.04–26.1 μmol/l, chlorophyll-*a*: 0.05–3.1 ml/l except for one Pacific site where chlorophyll-*a*: 12.9 ml/l, bottom water [O_2]: 1.8–7.1 ml/l.

Abundances > 10% are observed at sites where SST: > 5.2 in winter and 18.1–28.7 °C in summer. *I. strialatum* is restricted to full marine, oligotrophic to eutrophic environment with low upper water chlorophyll-*a* concentrations and well ventilated bottom waters.

Comparison with other records:

Apart from regions covered in this Atlas, *I. strialatum* occurs in the Congo deep-sea fan in samples outside the river plume (Dale et al., 2002). Although it can be present in some Southern Ocean sites where winter temperatures sink below 0 °C, it has not been recovered from sites with seasonal ice cover (de Vernal and Hillaire-Marcel, 2000; Radi and de Vernal, 2008). Highest abundances are found in oligotrophic environments. However, sediment trap studies have shown that cyst production of this species increases with nutrient availability and total bioproduction in the upper waters (Zonneveld and Brummer, 2000; Susek et al., 2005; Zonneveld et al., 2010).

Concluding remarks:

I. strialatum can be considered to be characteristic for open oceanic, full-marine, low productivity environments from temperate to equatorial regions where well ventilated bottom waters exist.

27. *Impagidinium variaseptum* Marret et de Vernal 1997
Figs. 108–111.
Distribution:

Impagidinium variaseptum is restricted to temperate regions of the Southern Hemisphere. Although it can be observed in coastal sites, highest abundances (up to 34%) occur in the open central part of the oceans.

Environmental parameters:

SST: 2.2–25.7 °C (winter–summer) except for two sites in the Pacific sector of the Southern Ocean where winter SST: −1.5 °C, SSS: 33.5–36.4 (summer–winter), [P]: 0.08–1.84 μmol/l, [N]: 0.04–25.8 μmol/l, chlorophyll-*a*: 0.06–2.2 ml/l, bottom water [O_2]: 0.04–5.6 ml/l.

Abundances > 10% occur in regions with temperatures between 12.6–21.6 °C (winter–summer).

Characteristically is abundant in oligotrophic settings although it is recorded from some sites where high nutrient concentrations but low productivity prevail.

Comparison with other records:

Impagidinium variaseptum has not been recorded from regions not covered by this Atlas.

Concluding remarks:

I. variaseptum is a species characteristic for full marine, low productivity environments from the Southern Hemisphere temperate regions.

28. *Impagidinium velorum* Bujak 1984
Figs. 112–115.
Distribution:

Impagidinium velorum is observed in sub-tropical to equatorial regions and one site in the Atlantic sector of the Southern Ocean at the sub-tropical front. The species is absent in coastal sites and highest abundances (up to 2%) are found in the central parts of the oceans and seas.

Environmental parameters:

SST: 12.0–29.1 °C (winter–spring) except for one site in the Atlantic Sector of Southern Ocean where SST: 2.6–4.5 °C (winter–autumn), SSS: 32.7–39.1 (winter–summer), [P]: 0.08–1.46 μmol/l, [N]: 0.04–20.1 μmol/l, chlorophyll-*a*: 0.06–0.68 ml/l, bottom water [O_2]: from 2.9–5.9 ml/l.

The distribution of *Impagidinium velorum* is restricted to oligotrophic environments in regions with well ventilated bottom waters.

Comparison with other records:

Impagidinium velorum has not been recorded from regions not covered by this Atlas.

Concluding remarks:

I. velorum is characteristic for open oceanic, full marine, low productivity environments of subtropical to equatorial regions where well ventilated bottom waters prevail.

29. *Islandinium minutum* (Harland et Reid in Harland et al., 1980) Head et al., 2001
Figs. 116–119.
Distribution:

Islandinium minutum has a bipolar distribution restricted to temperate to polar regions. Exception is given by two occurences of the species in the coastal eastern equatorial Atlantic Ocean. Abundances up to 97% can be observed in arctic polar waters. It has high relative abundances in regions where large seasonal contrasts exist. It can be observed in coastal sites as well as in the central oceans.

Environmental parameters:

SST: −2.1–29.3 °C (winter–summer), SSS: 6.7–38.1 (summer–autumn), [P]: 0.10–1.73 μmol/l, [N]: 0.01–26.2 μmol/l, chlorophyll-*a*: 0.01–20.8 ml/l, bottom water [O_2]: 0.3–8.2 ml/l.

Abundances > 10% occur where temperatures are <0 °C in winter and <5.0 °C in summer. A positive relationship between cyst abundance and decreasing SST can be observed. The species is present in regions where salinities can be seasonally strongly reduced as a result of melting of snow and ice. High relative abundances occur in high nutrient–low productivity regions.

Comparison with other records:

Apart from observations included in this atlas, *I. minutum* is documented off the northern part of the Iberian Peninsula and in Swedish fjords (Harland et al., 2004a, 2004b; Sprangers et al., 2004). In sediment trap records from the Weddell and Scotia Seas *I. minutum* forms a prominent part of the total cyst flux in sites that are located south of the maximal winter ice extension whereas it is absent in trap samples from sites north of this boundary (Harland and Pudsey, 1999). It occurs in offshore and inshore sediments of Svalbard (Grøsfjeld et al., 2009) In an arctic fjord of northern Svalbard production of this species occurs in late May, June when temperatures in the Fjord rise (Howe et al., 2010). Its occurence is associated with the presence of Arctic Water in this location.

In arctic regions the relative abundances of this species increase linearly with the duration of seasonal sea ice cover and it can be observed in high abundances in sites that can be covered by sea ice up to 12 months a year (de Vernal et al., 1998; Radi and de Vernal, 2008).

Concluding remarks:

Islandinium minutum is a temperate to polar species with a bipolar distribution. Highest relative abundances are found in polar regions where surface waters do not exceed 0 °C in winter and surface water salinity can be reduced due to melting of ice. It is present in

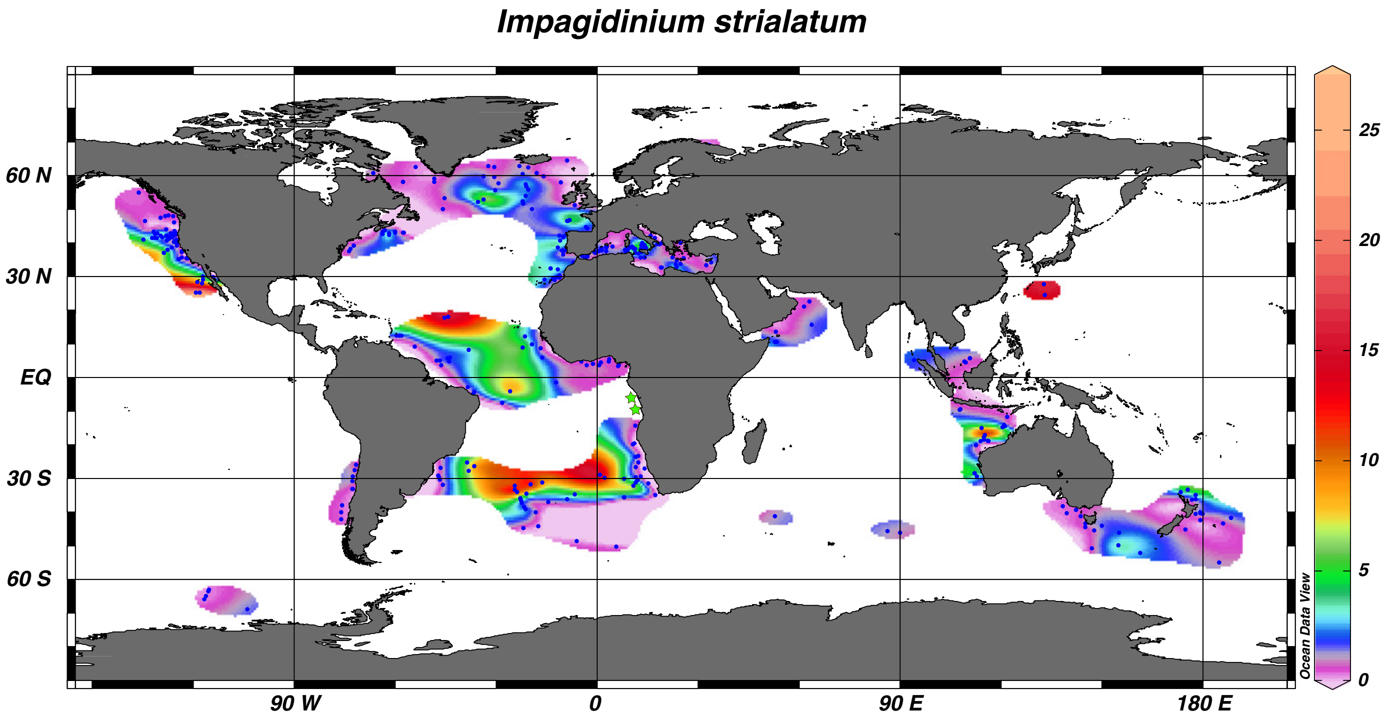

Fig. 104. Geographic distribution of *Impagidinium strialatum*.

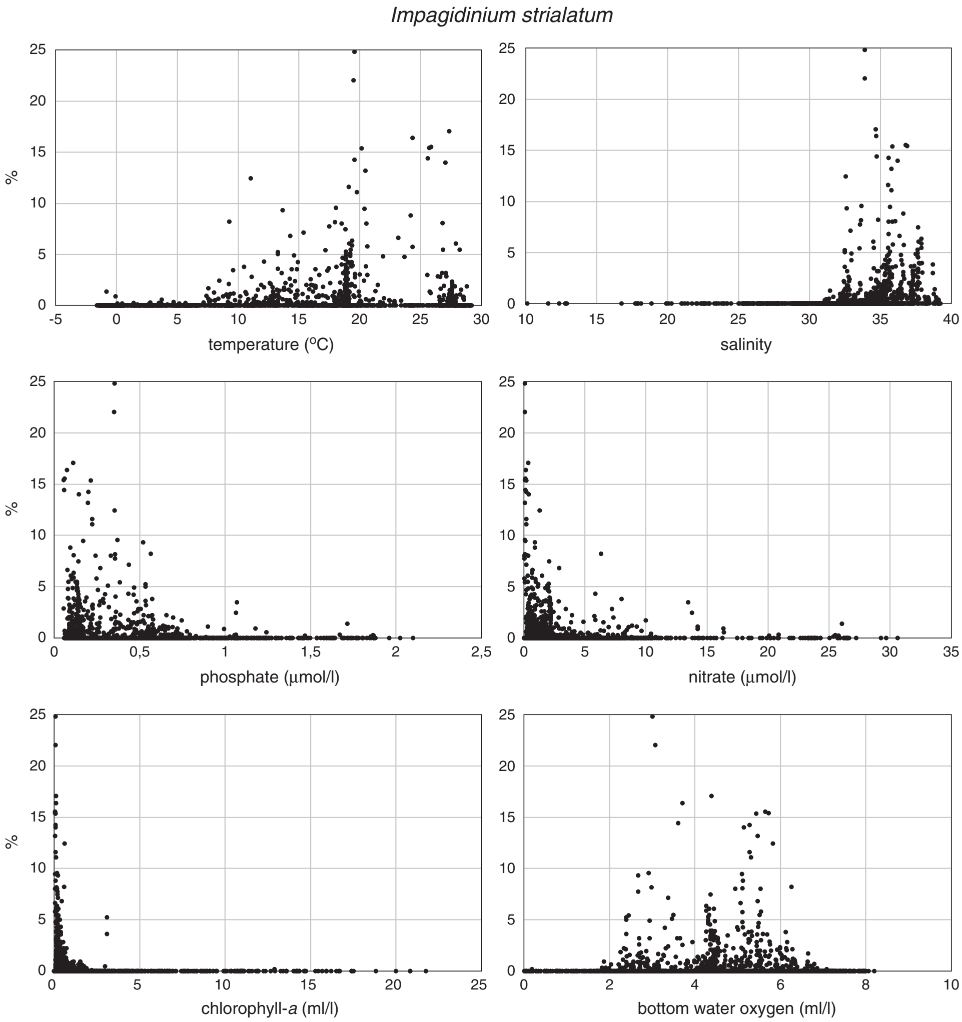

Fig. 105. Relative abundances of *Impagidinium strialatum* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

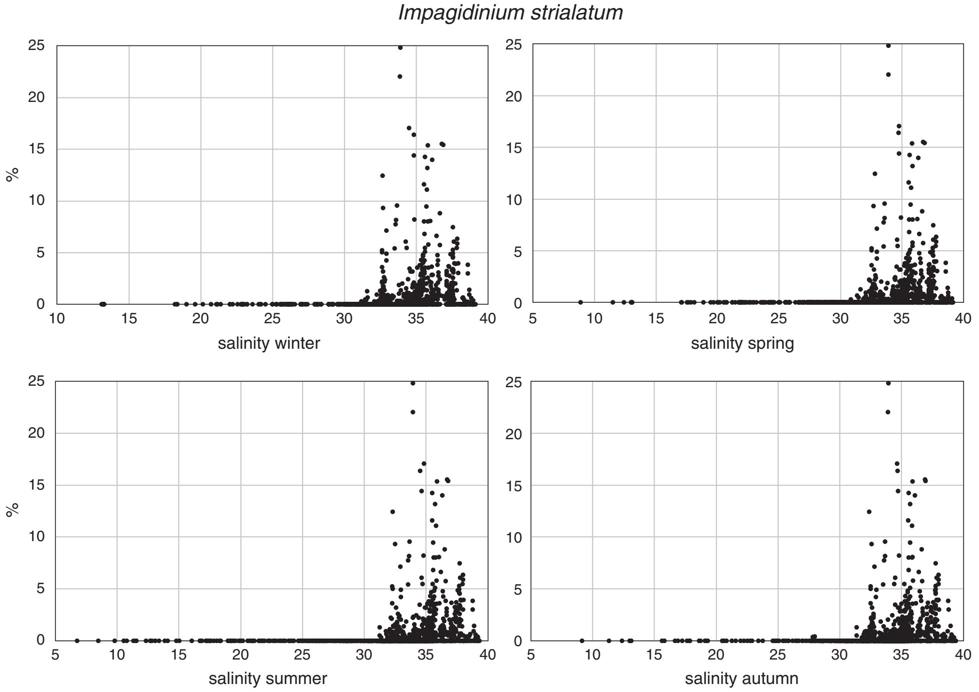

Fig. 106. Relative abundances of *Impagidinium strialatum* in relationship to seasonal salinity in surface waters.

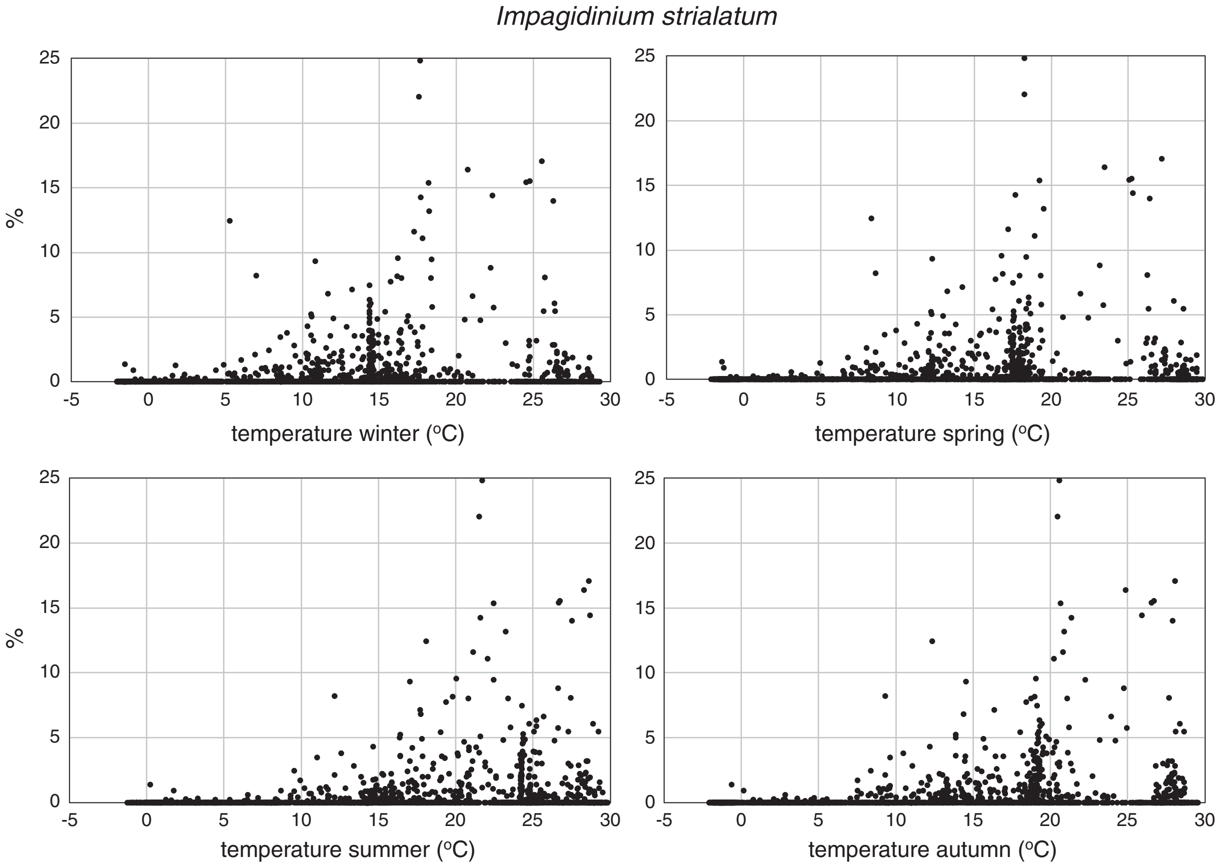

Fig. 107. Relative abundances of *Impagidinium strialatum* in relationship to seasonal temperature in surface waters.

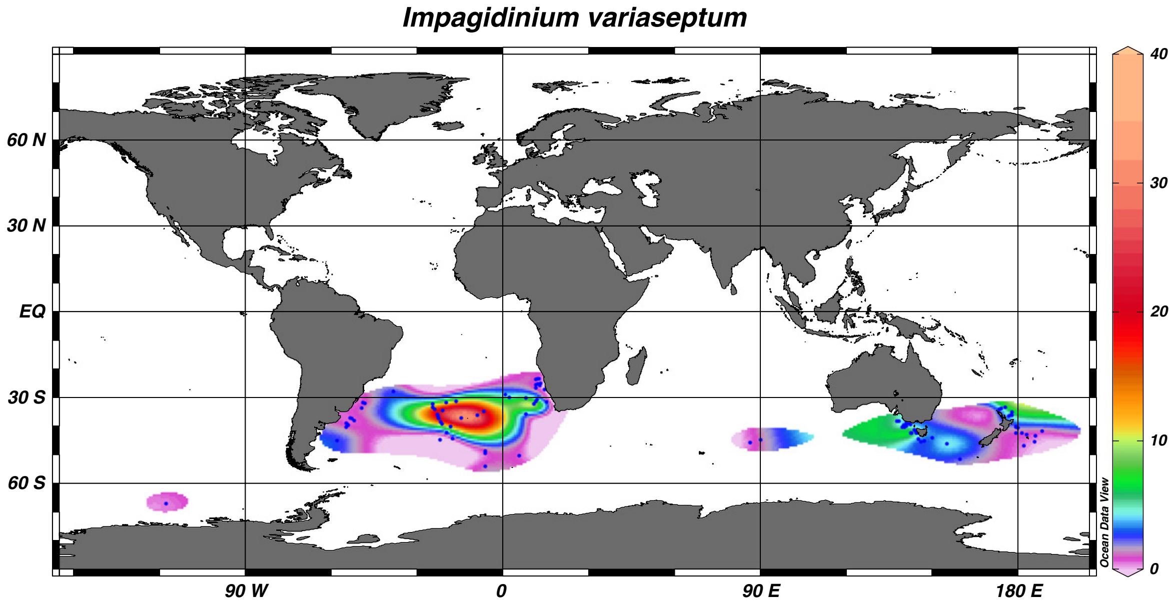

Fig. 108. Geographic distribution of *Impagidinium variaseptum*.

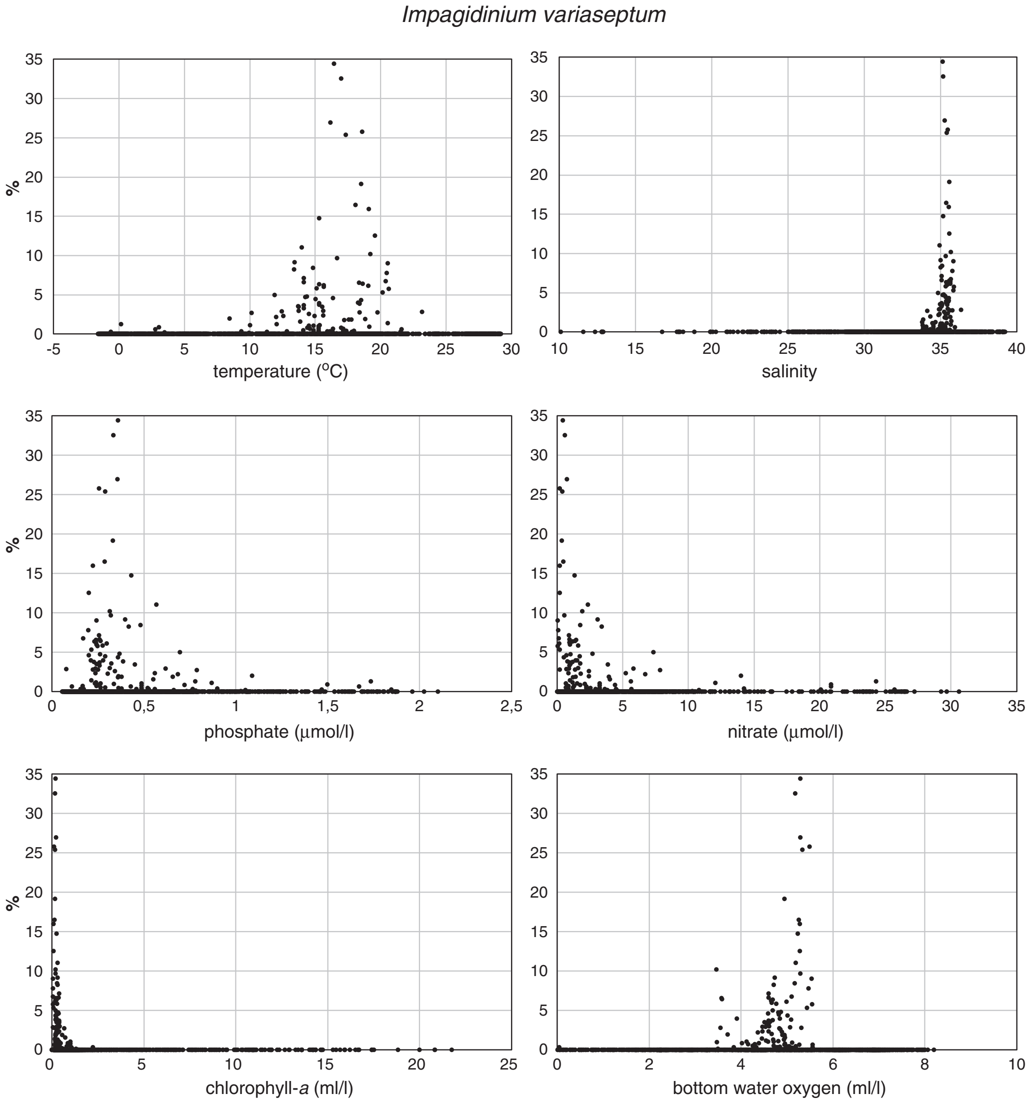

Fig. 109. Relative abundances of *Impagidinium variaseptum* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

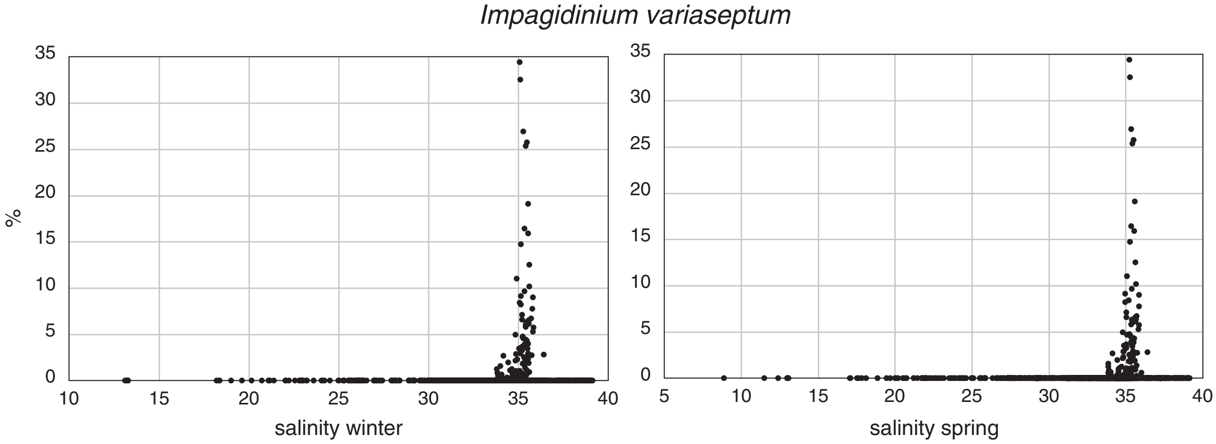

Fig. 110. Relative abundances of *Impagidinium variaseptum* in relationship to seasonal salinity in surface waters.

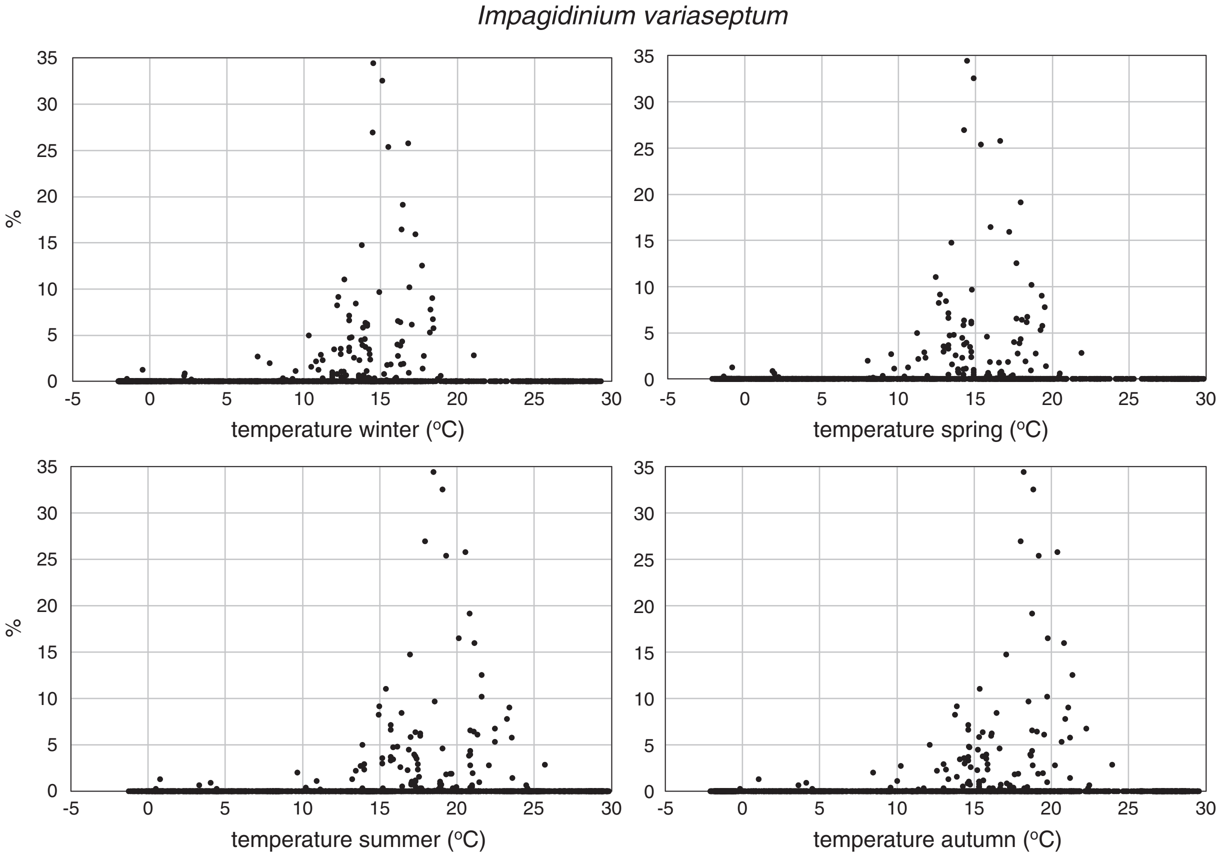

Fig. 111. Relative abundances of *Impagidinium variaseptum* in relationship to seasonal temperature in surface waters.

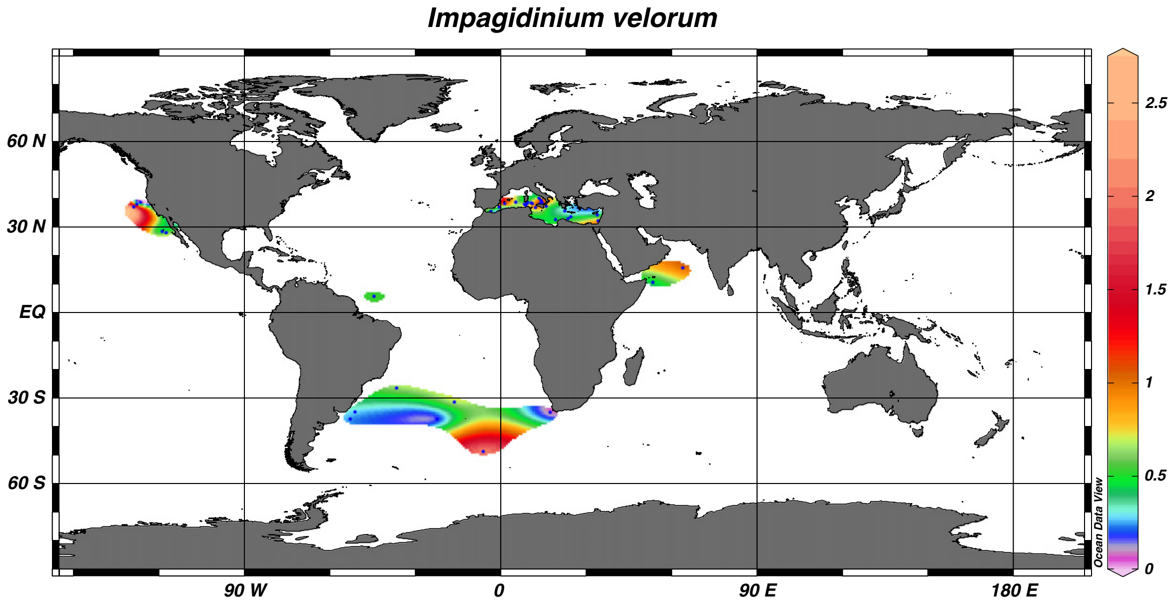

Fig. 112. Geographic distribution of *Impagidinium velorum*.

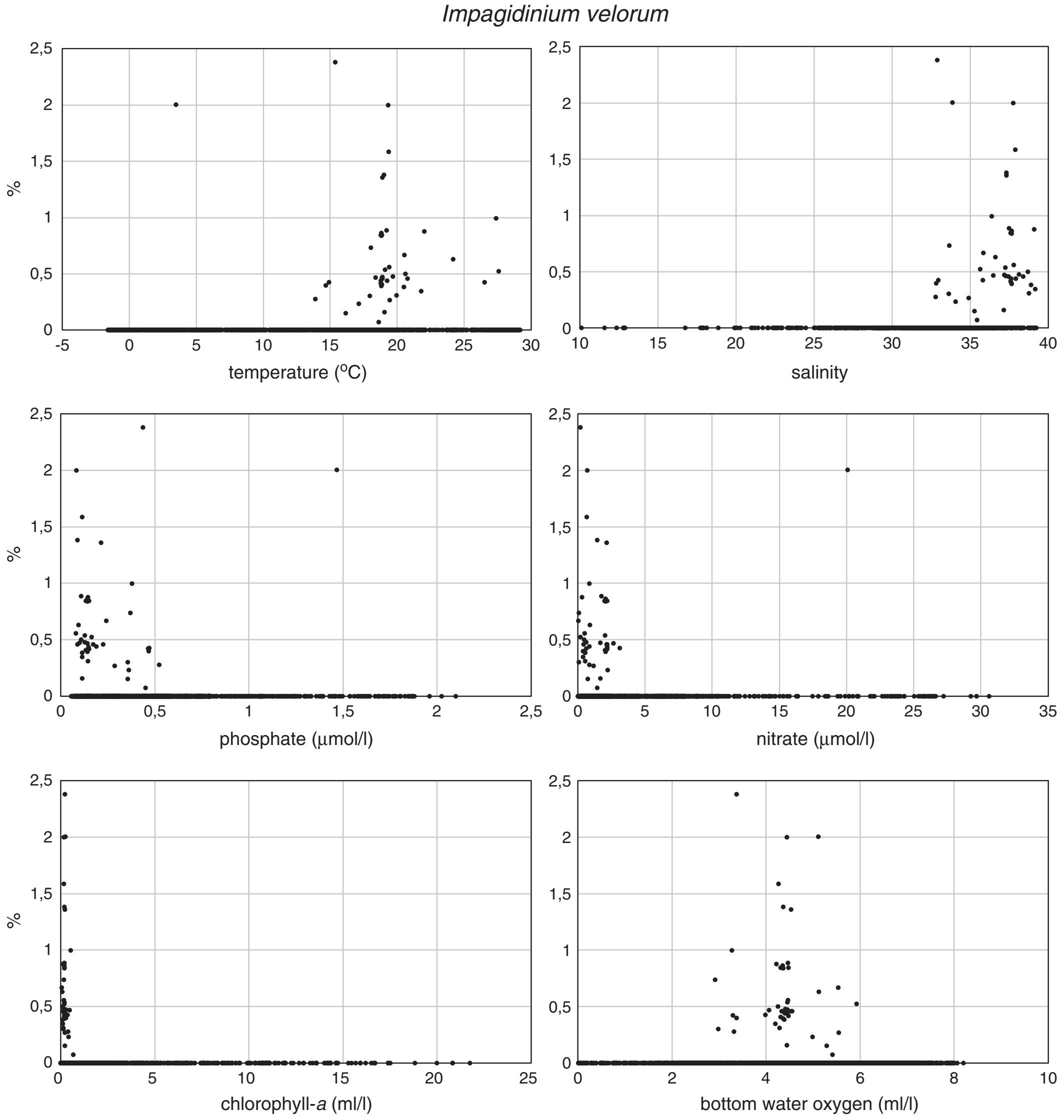

Fig. 113. Relative abundances of *Impagidinium velorum* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

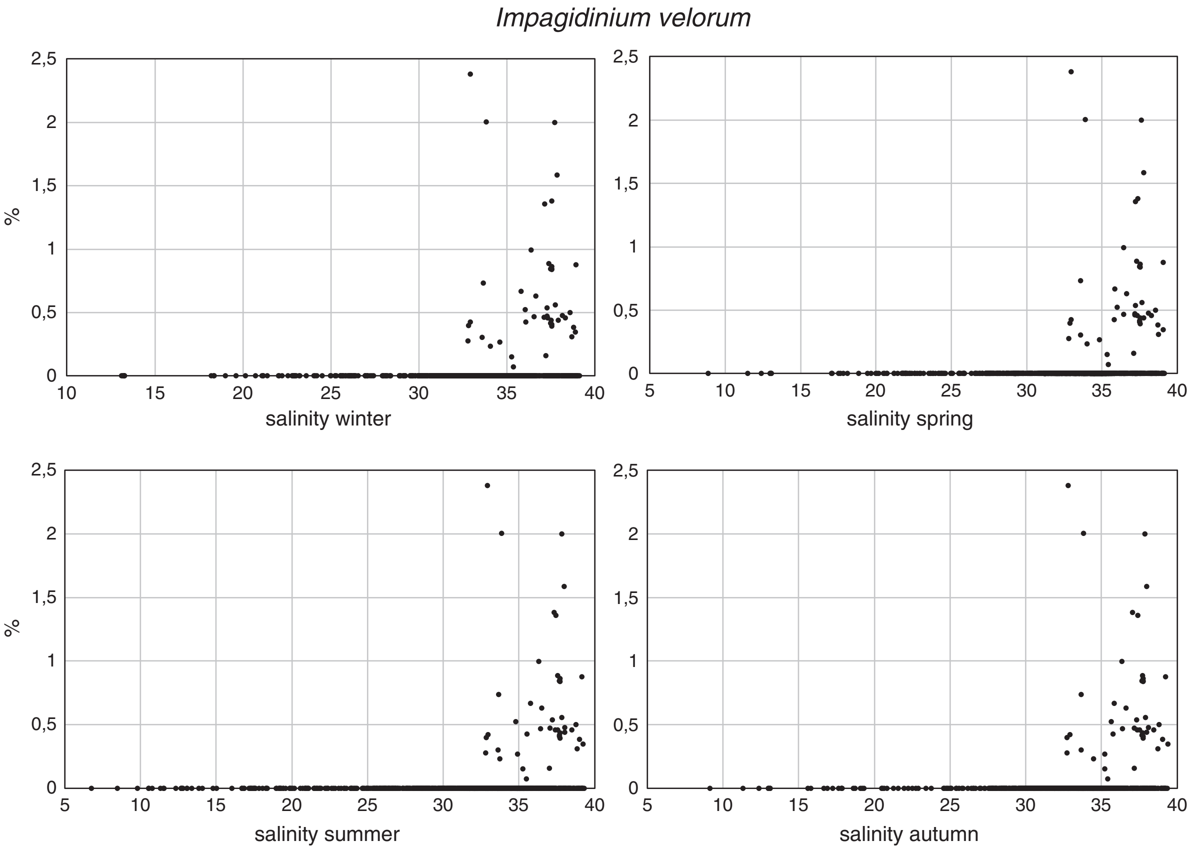

Fig. 114. Relative abundances of *Impagidinium velorum* in relationship to seasonal salinity in surface waters.

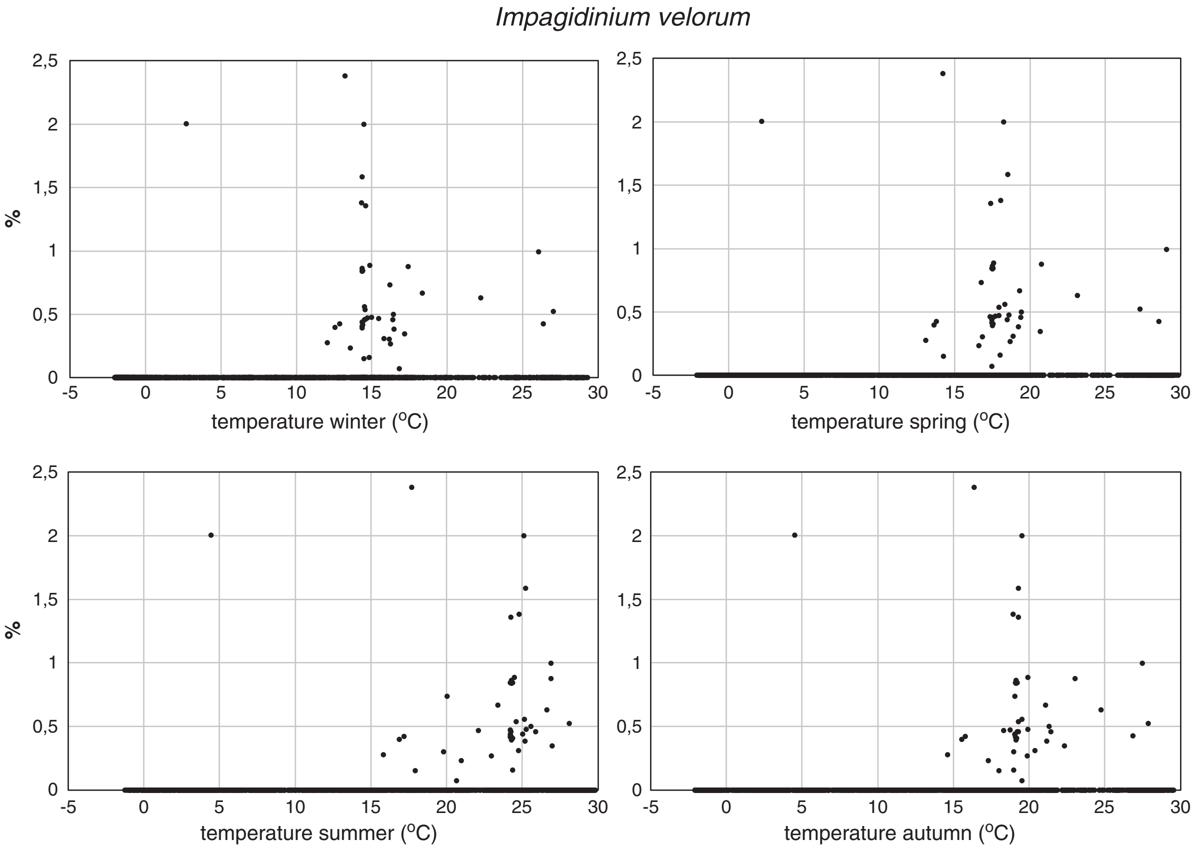

Fig. 115. Relative abundances of *Impagidinium velorum* in relationship to seasonal temperature in surface waters.

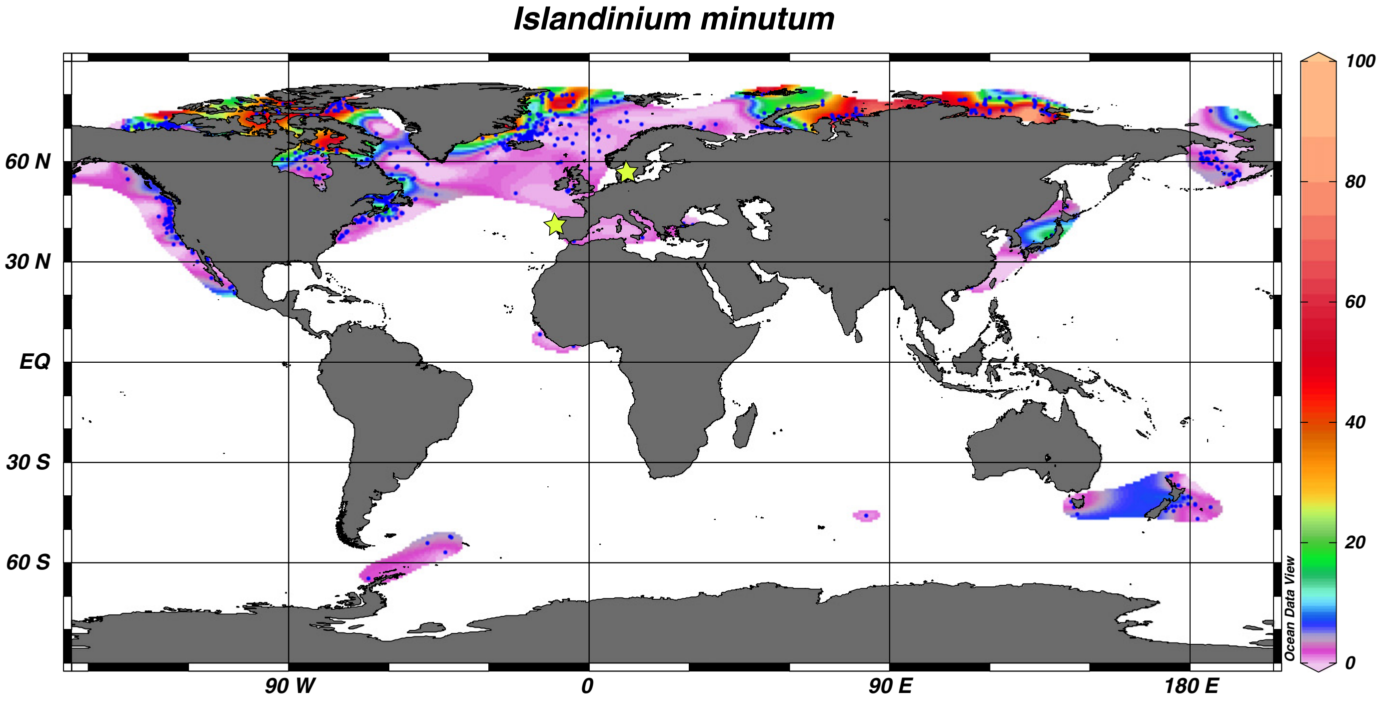

Fig. 116. Geographic distribution of *Islandinium minutum*.

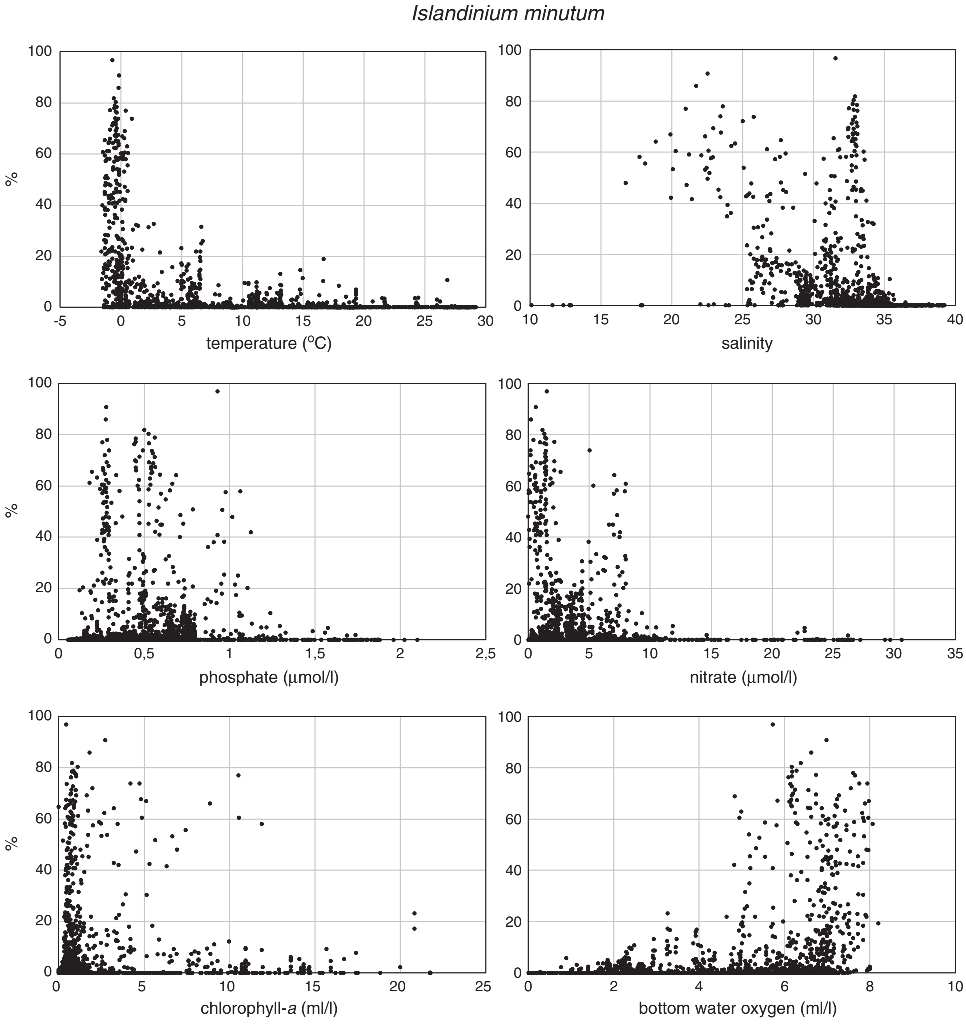

Fig. 117. Relative abundances of *Islandinium minutum* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

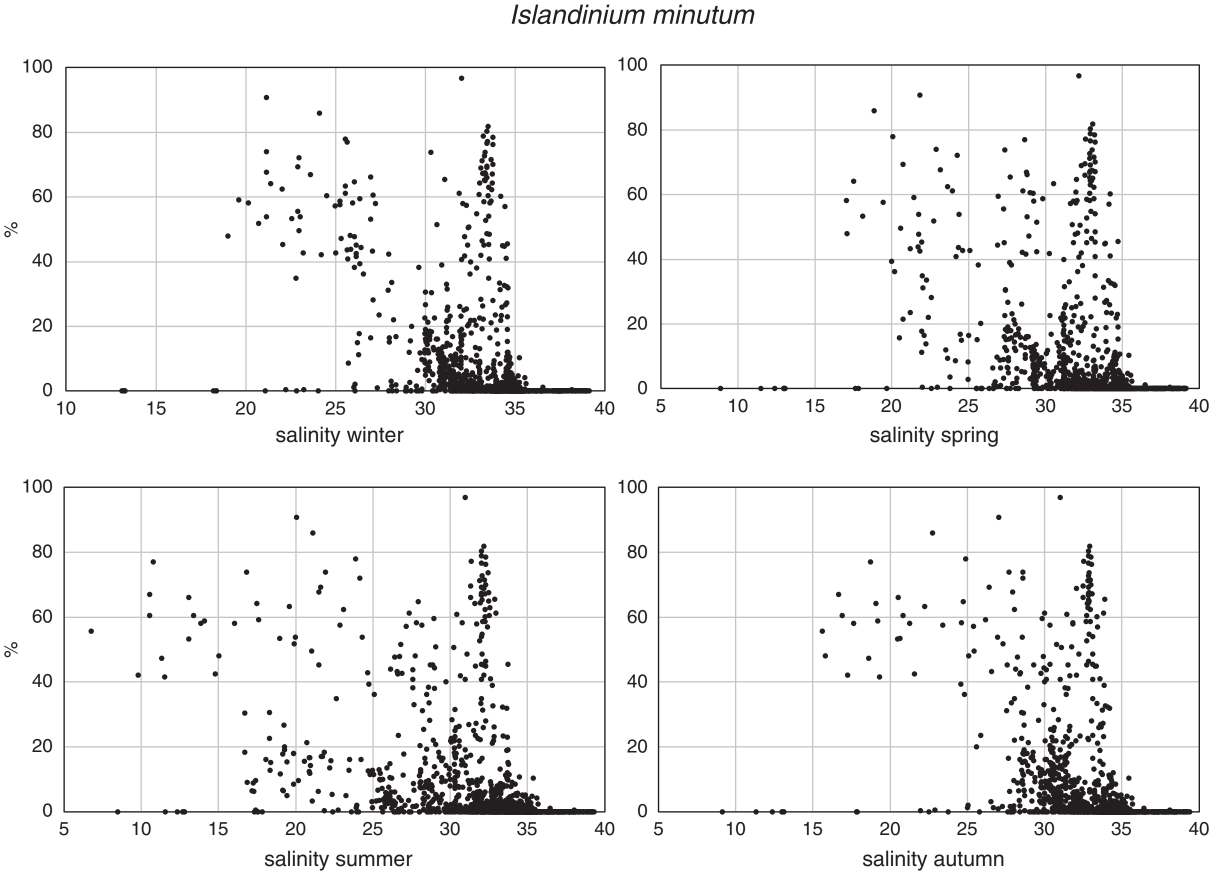

Fig. 118. Relative abundances of *Islandinium minutum* in relationship to seasonal salinity in surface waters.

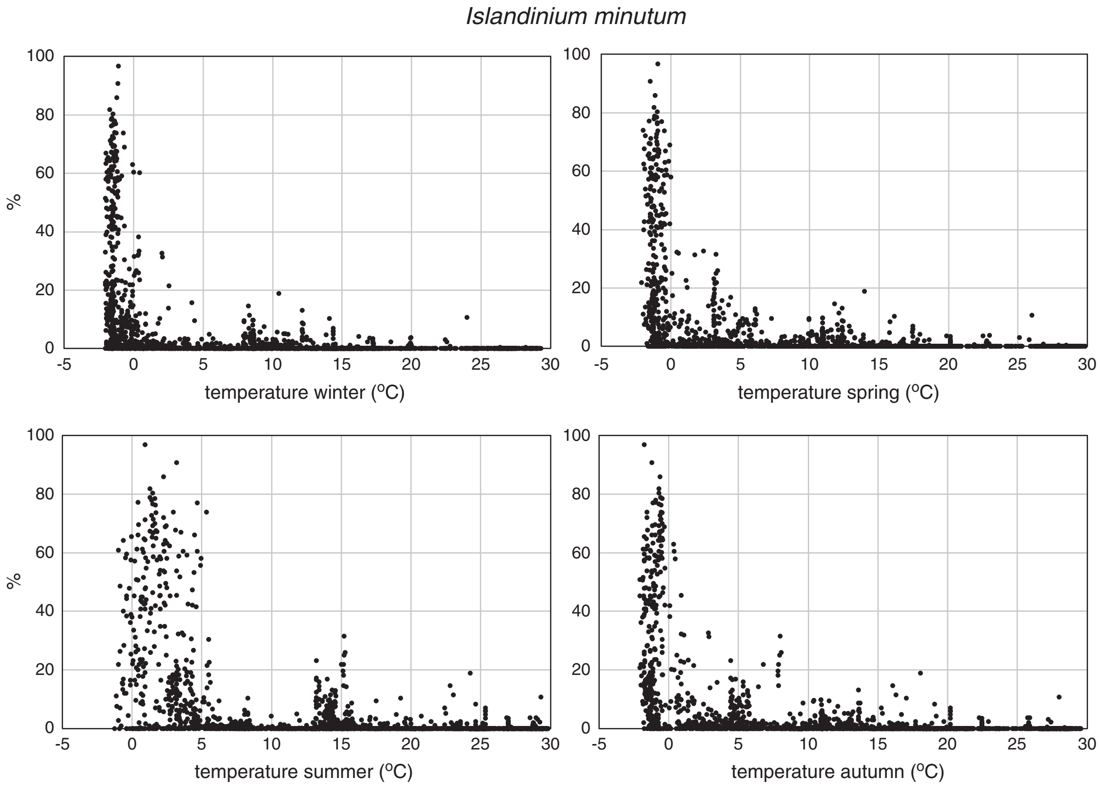

Fig. 119. Relative abundances of *Islandinium minutum* in relationship to seasonal temperature in surface waters.

oligotrophic to eutrophic environments where anoxic to well ventilated bottom water conditions can occur.

30. *Islandinium minutum* (Harland et Reid in Harland et al., 1980) var. *cezare* Head et al., 2001

Figs. 120–123.

Distribution:

Islandinium minutum var. *cezare* is observed in sub-polar to polar waters of the northern Hemisphere. Abundances up to 32% can be observed in the White Sea, Barents Sea and Laptev Sea. Relative abundances are high in regions with large seasonal contrasts are present. It can be found in coastal to central ocean environments.

Environmental parameters:

SST: −2.1–25.1 °C (winter–summer), SSS: 6.7–35.4 (summer–summer), [P]: 0.12–1.73 μmol/l, [N]: 0.01–10.4 μmol/l, chlorophyll-*a*: 0.24–16.7 ml/l, bottom water [O_2]: 0.3–8.2 ml/l.

Relative abundances are high when SST: < 0 °C during winter. *I. minutum* var. *cezare* is abundant in regions where SSS can be seasonally strongly reduced as a result of melting of snow and ice. High relative abundances occur in oligotrophic to eutrophic regions characterised by high productivity.

Comparison with other records:

In records other than those included in this Atlas, *I. minutum* var. *cezare* is registered from the Gullmar Fjord (Sweden, Harland et al., 2006). Sediment trap records from the central Strait of Georgia and the Saanich Inlet (BC. Canada) show that cysts are produced in early spring in this region (Pospelova et al., 2010; Price and Pospelova, 2011). In arctic regions the relative abundances increases linearly with the duration of seasonal sea ice cover and it can be observed in high abundances at sites that can be covered by sea ice up to 12 months a year (de Vernal et al., 1998; Radi and de Vernal, 2008).

Concluding remarks:

Islandinium minutum var. *cezare* is a sub-polar to polar arctic species that can be observed at sites where surface waters can be seasonally reduced due to melting of ice. Highest relative abundances are found in regions where surface water temperatures are<0 °C in winter. It is present in oligotrophic to eutrophic environments where anoxic to well ventilated bottom water conditions occur.

31. *Lejeunecysta oliva* (Reid 1977) Turon and Londeix 1988

Figs. 124–127.

Distribution:

Lejeunecysta oliva is restricted to the coastal environments of temperate to subtropical regions in the eastern North and South Atlantic Oceans, the eastern North Pacific Ocean and the eastern South Indian Ocean. Exceptions are formed by a few recordings in the tropical upwelling region off NW Africa. It is present in upwelling or river discharge environments. Highest abundances (>2% and up to 9%) occur in the vicinity of the active upwelling cells off Senegal (NW Africa) and South Africa (SW Africa).

Environmental parameter range:

SST: 0–29.7 °C (winter–summer) and summer SST: >8.2 °C. Exception is formed by a site in the northern Pacific Ocean where SST is below 0 °C in winter. SSS: 26.8–37.5(summer–winter), [P]: 0.1–1.3 μmol/l, [N]: 0.04–10.4 μmol/l, chlorophyll-*a*: 0.13–21.7 ml/l, bottom water [O_2]: 0–6.0 ml/l.. *Lejeunecysta oliva* is characteristically present in upwelling regions where large inter-annual variability in the trophic state of the upper waters can occur with eutrophic conditions during active upwelling or when upwelling filaments cross the site and oligotrophic conditions otherwise. Furthermore it is present in regions influenced by (anthropogenic and natural) nutrient input by river discharge waters. High relative abundances occur where bottom waters are poorly ventilated although it is not absent from well ventilated sites.

Comparison with other records:

Without providing details (Radi and de Vernal, 2008) note this species to be present in Arctic environments.

Concluding remarks:

L. oliva can be observed in temperate to subtropical coastal regions that are characterised by coastal upwelling and/or nutrient input by river discharge.

32. *Lejeunecysta sabrina* (Reid 1977) Bujak 1984

Figs. 128–131.

Distribution:

Lejeunecysta sabrina is sporadically observed in sediments of coastal areas from the temperate to tropical northern Hemisphere regions of the western North Atlantic Ocean, the western Mediterranean Sea, the Adriatic Sea, the South China Sea and the Bering Sea. Highest abundances up to 3% occur in the Irish Sea and in the South Adriatic Sea.

Environmental parameter range:

SST: 8.0 °C–29.7 °C (winter–summer) and summer SST> 14 °C. Exception is formed by three samples where SST is as low as 1.7 °C in winter and 8.2 °C in summer. SSS: 29.7–38.9 (spring–summer), [P]: 0.1–1.7 μmol/l, [N]: 0.04–14.6 μmol/l, chlorophyll-*a*: 0.11–2.7 ml/l, bottom water [O2]: 0–6.8 ml/l. This species has its highest abundances in sites where anoxic bottom waters prevail.

Comparison with other records:

Apart from the observations included into this Atlas *L. sabrina* has been observed in New england estuaries (Pospelova et al., 2004, 2005) and coastal bays of southern Korea that are characterised by high nutrient concentrations and an unstratified water column (Pospelova and Kim, 2010).

Concluding remarks:

L. sabrina can be observed in temperate to tropical coastal regions of the western North Atlantic Ocean, the western Mediterranean Sea and adjacent basins, the South China Sea and the Bering Sea.

33. *Lingulodinium machaerophorum* (Deflandre et Cookson 1955) Wall 1967

Figs. 132–135.

Distribution:

Lingulodinium machaerophorum is restricted to temperate to equatorial regions of the northern hemisphere and subtropical–equatorial regions of the Southern Hemisphere with the arctic and antarctic subtropical fronts forming its northern and southern distribution boundary, respectively. With a few exceptions, it is restricted to coastal regions and regions in the vicinity of continental margins. High relative abundances can be observed in sediments near upwelling cells or below river discharge plumes e.g. those of the Congo-river, Amazon, Po and Volga or in highly stratified waters (for instance in the Black Sea and Marmara Sea). Highest relative abundance values (up to 90%) are observed in sediments of the upwelling areas off NW Africa and the Iberian peninsula in close vicinity to the active upwelling cells as well as near river mouths.

Environmental parameters:

SST: 0–29.8 °C (winter–summer) with summer SST> 10.1 °C. Exception are formed by 4 recordings where winter SST<0 °C and can go down to −1.3 °C. SSS: 8.5–39.4 (summer–autumn), [P]: 0.06–1.1 μmol/l, [N]: 0.04–12.0 μmol/l, chlorophyll-*a*: 0.01–16.7 ml/l, [O_2]: 0.3–7.2 ml/l.

High relative abundances of *L. machaerophorum* occur where high as well as low sea surface salinities exist, the latter as a result of river discharge. It is abundant in regions with strong (seasonal) variability in the trophic state of the upper waters such as upwelling areas where eutrophic conditions prevail only at times of active upwelling, upwelling relaxation or when upwelling filaments cross the sampling site and where oligotrophic conditions exist during time intervals when upwelling is reduced or absent.

Comparison with other records:

Apart from the observations included in this atlas *L. machaerophorum* is registered from a few coastal sites in the Benguela upwelling region off

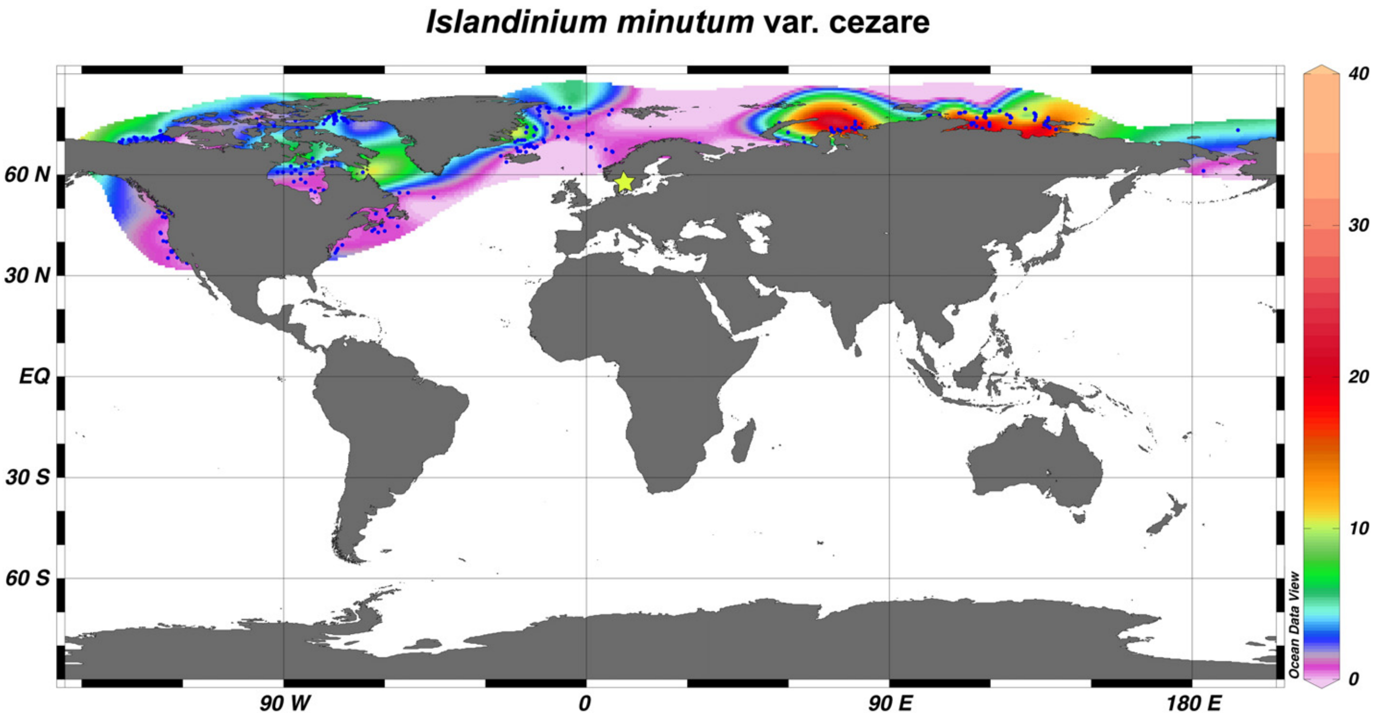

Fig. 120. Geographic distribution of *Islandinium minutum* var. *cezare*.

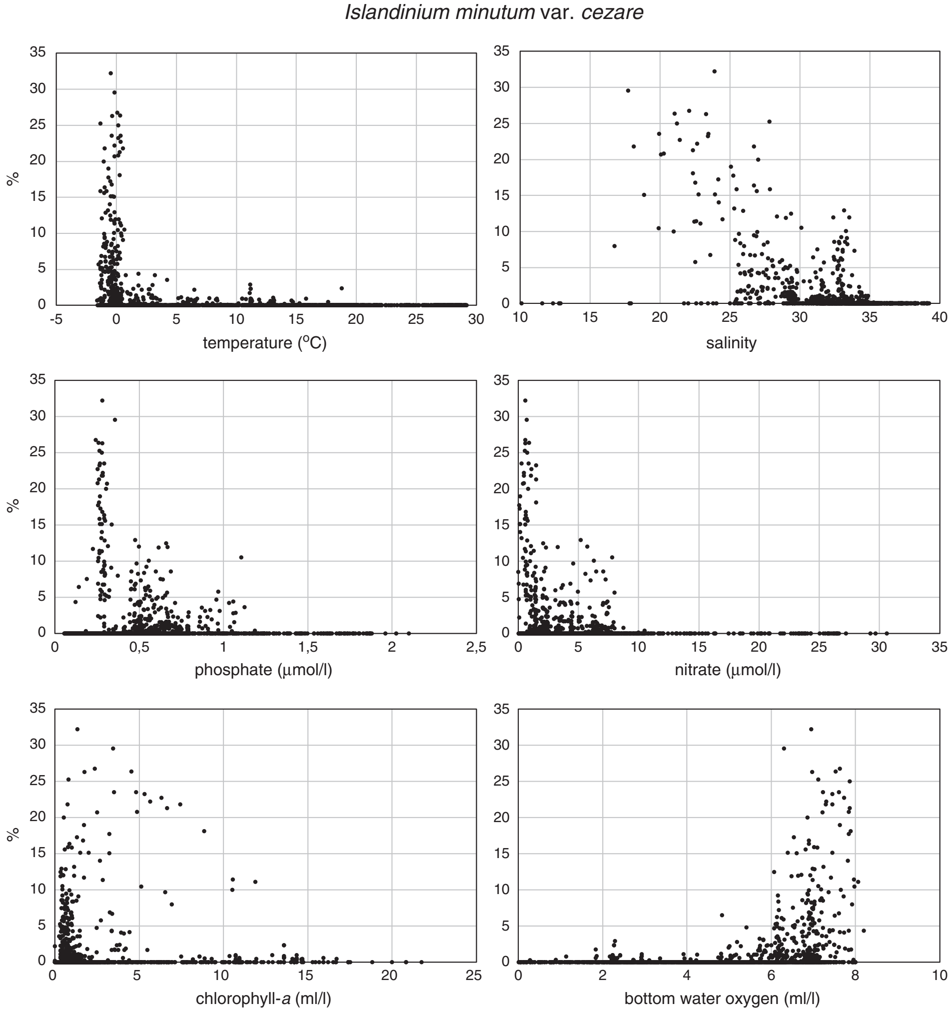

Fig. 121. Relative abundances of *Islandinium minutum* var. *cezare* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

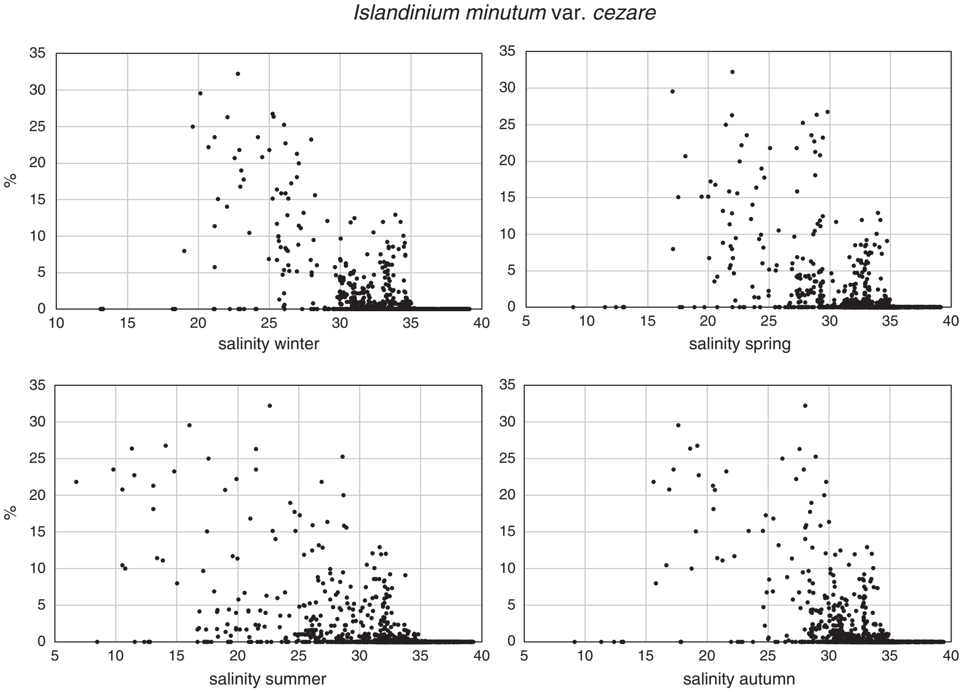

Fig. 122. Relative abundances of *Islandinium minutum* var. *cezare* in relationship to seasonal salinity in surface waters.

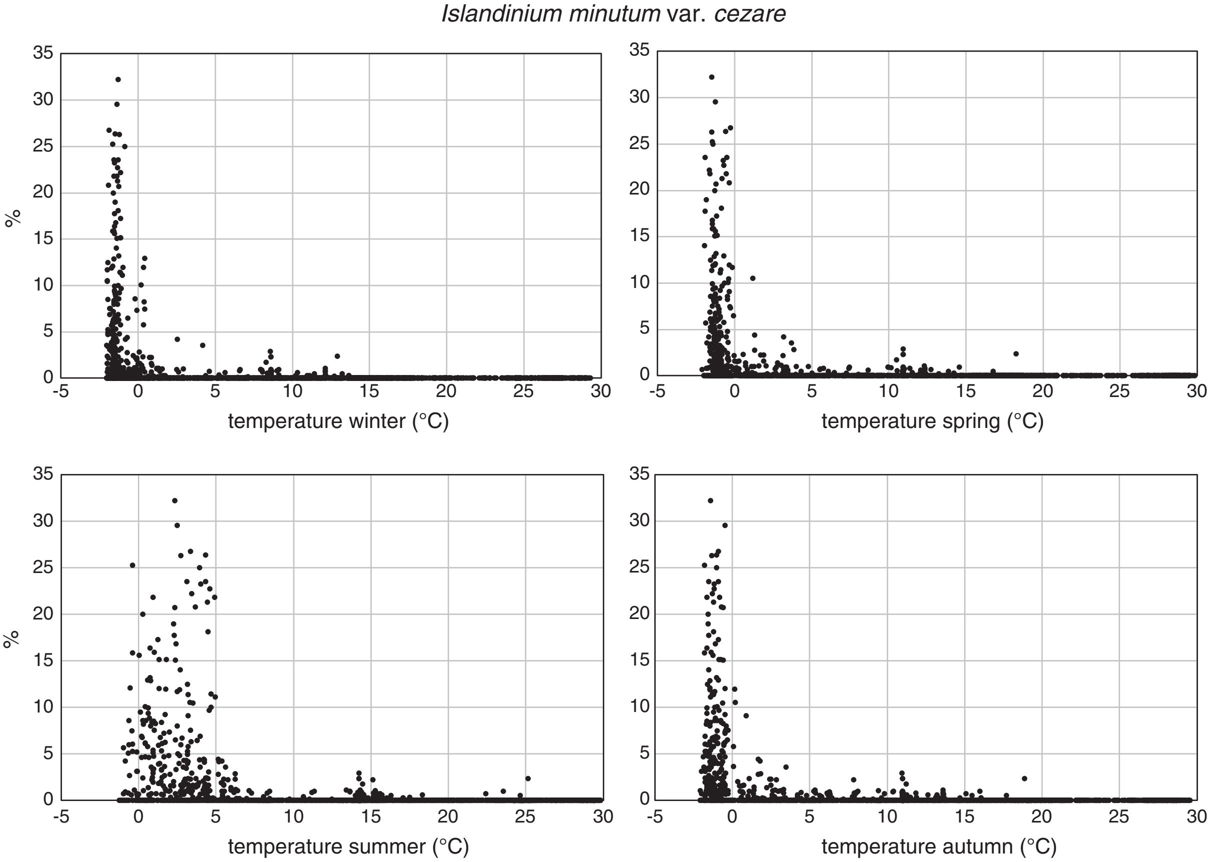

Fig. 123. Relative abundances of *Islandinium minutum* var. *cezare* in relationship to seasonal temperature in surface waters.

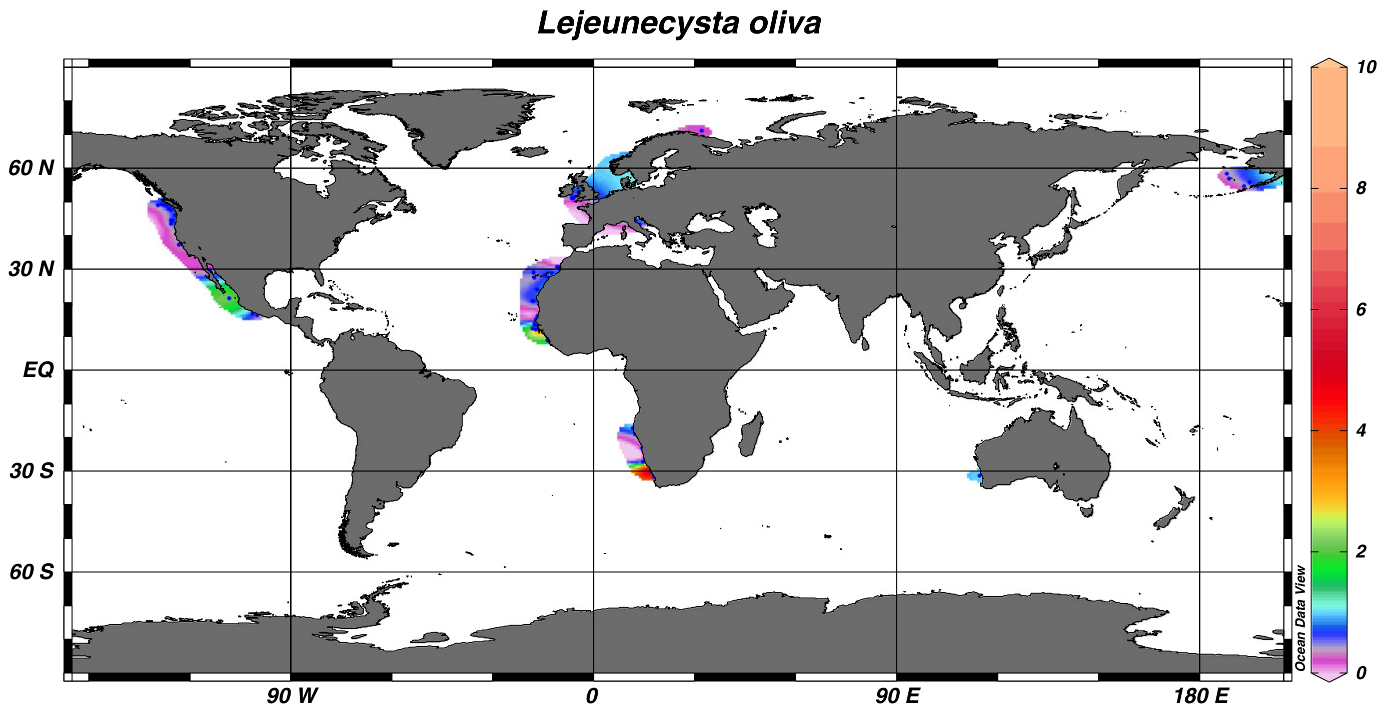

Fig. 124. Geographic distribution of *Lejeunecysta oliva*.

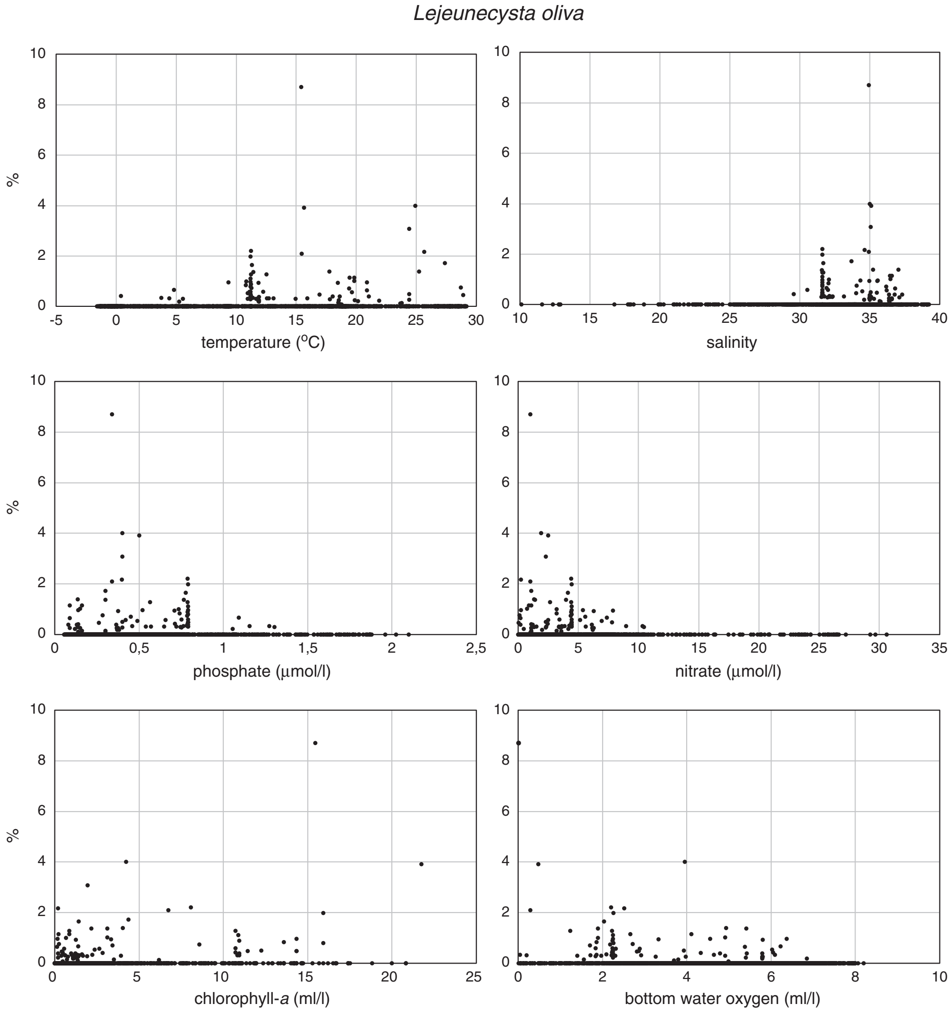

Fig. 125. Relative abundances of *Lejeunecysta oliva* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

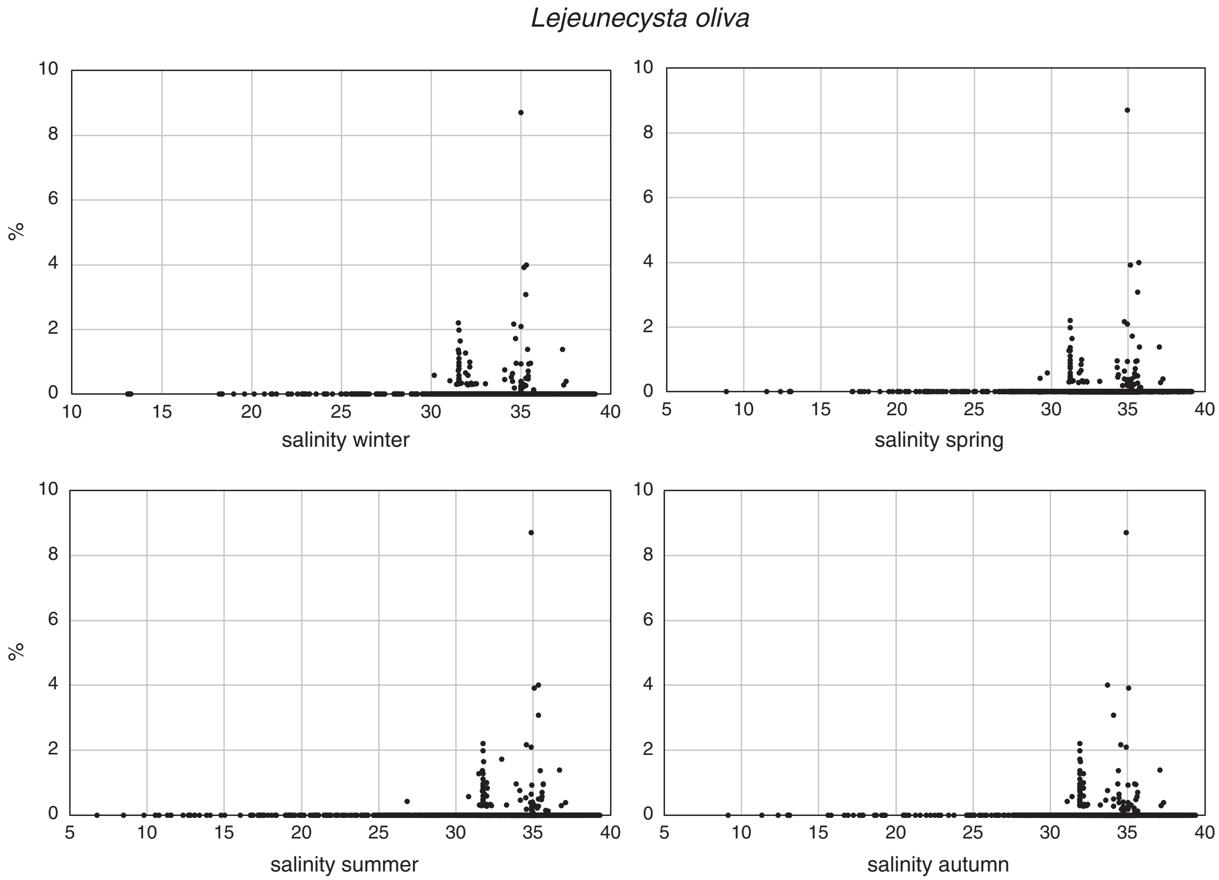

Fig. 126. Relative abundances of *Lejeunecysta oliva* in relationship to seasonal salinity in surface waters.

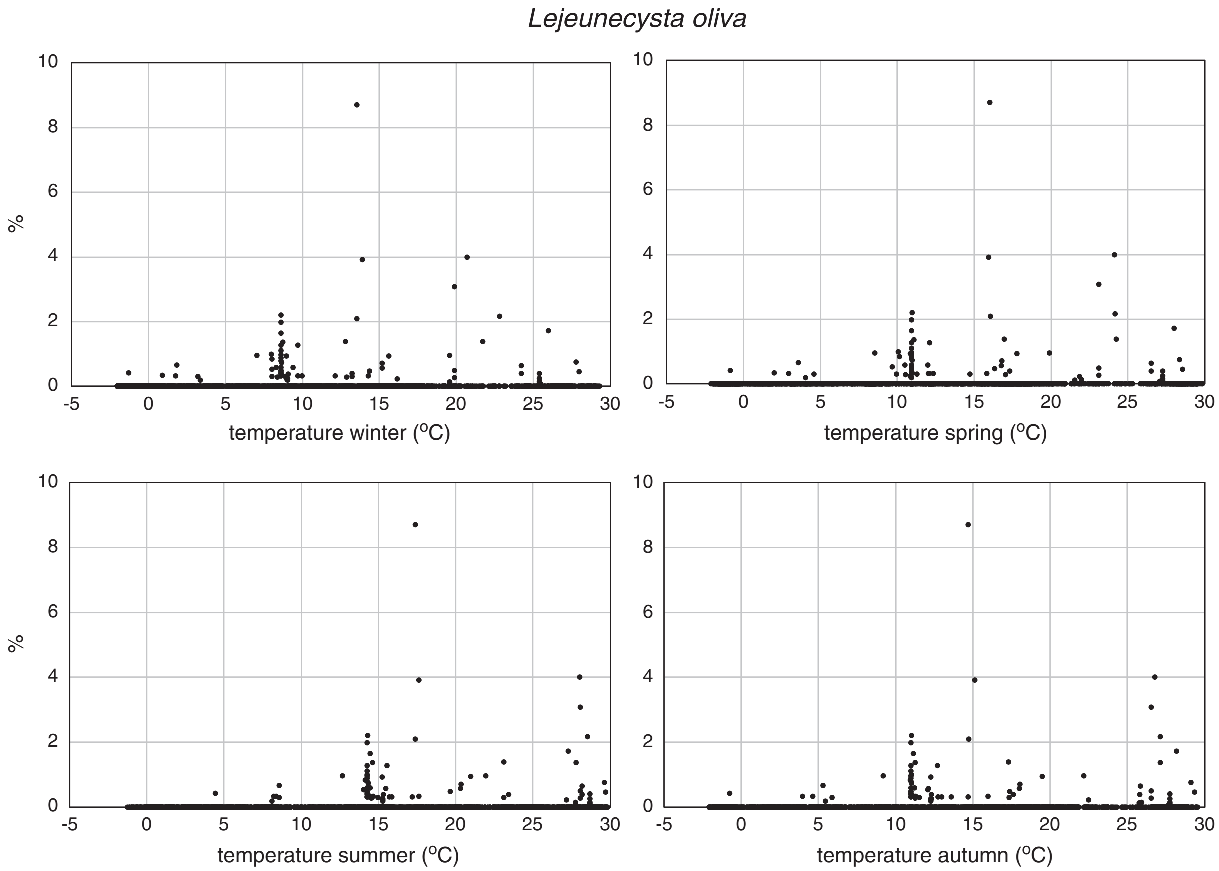

Fig. 127. Relative abundances of *Lejeunecysta oliva* in relationship to seasonal temperature in surface waters.

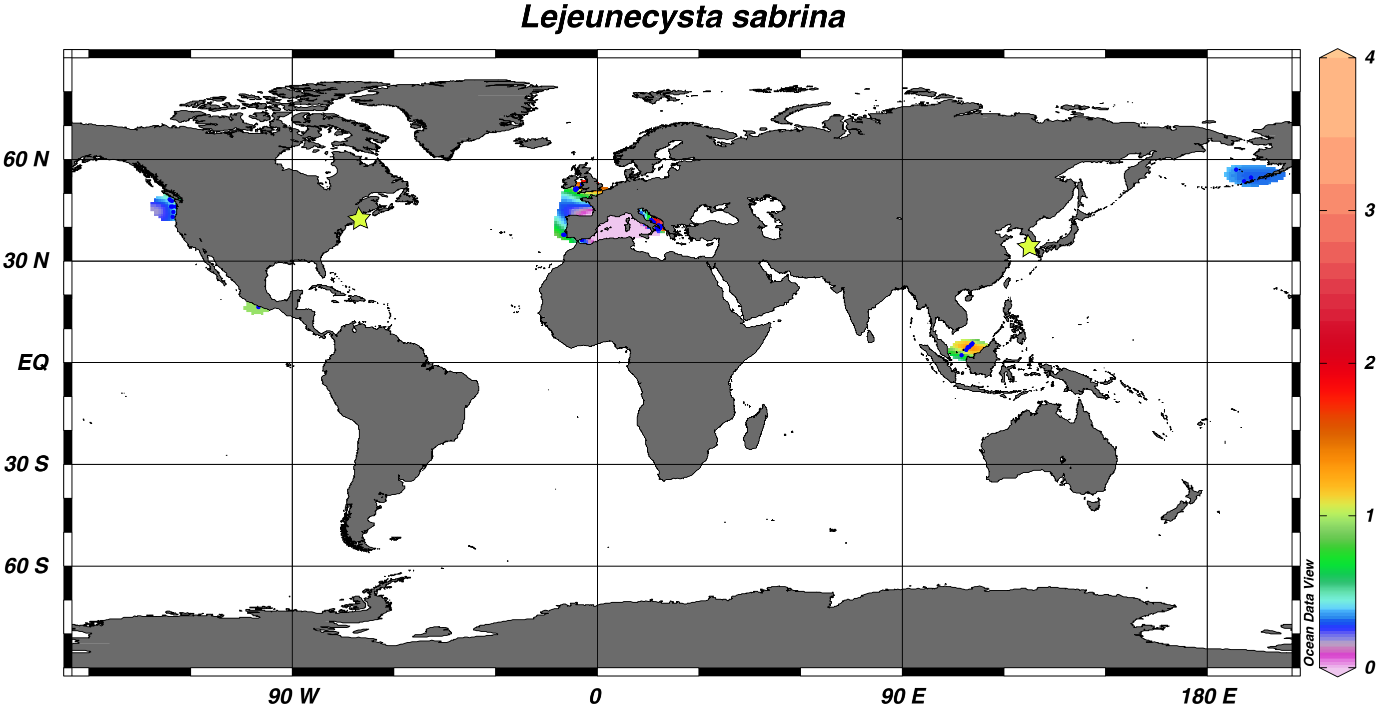

Fig. 128. Geographic distribution of *Lejeunecysta sabrina*.

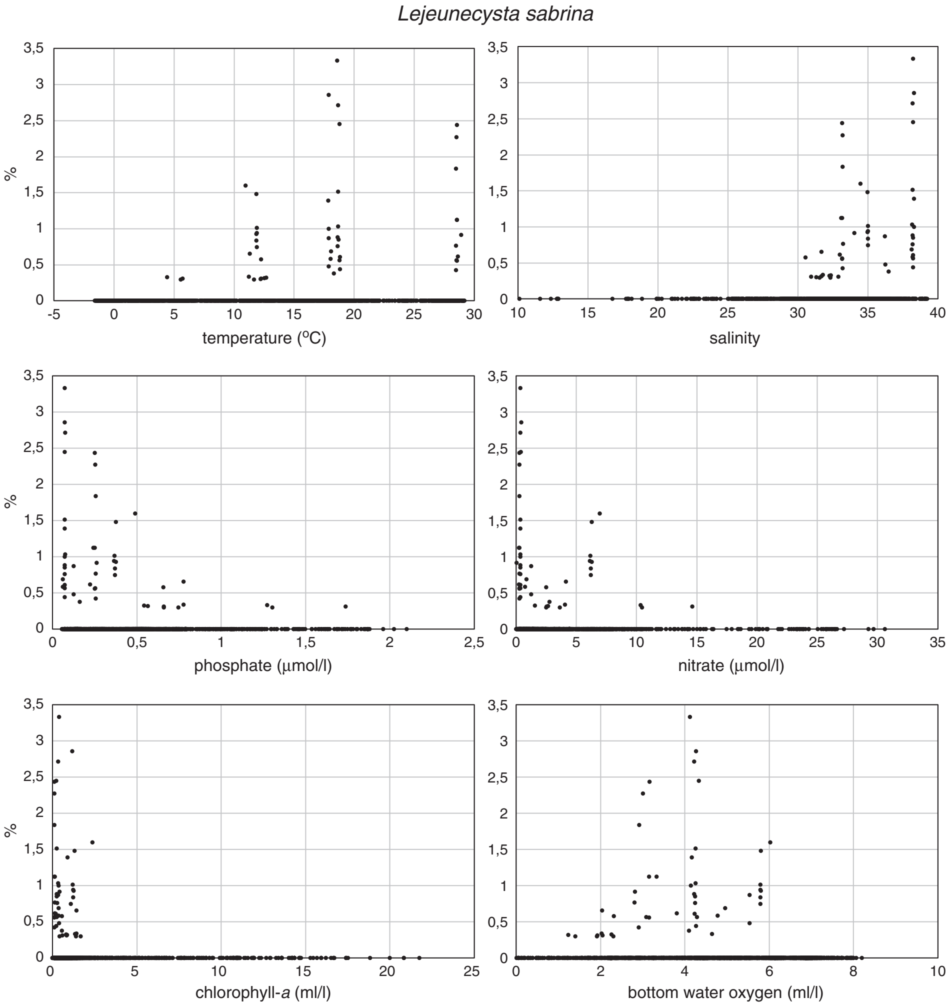

Fig. 129. Relative abundances of *Lejeunecysta sabrina* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

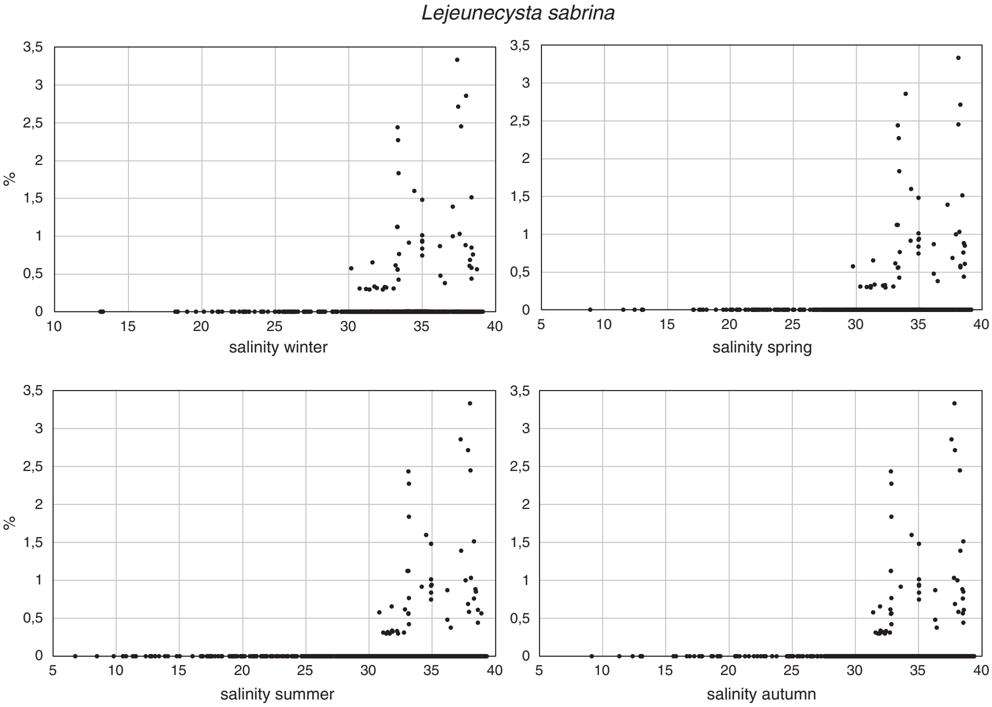

Fig. 130. Relative abundances of *Lejeunecysta sabrina* in relationship to seasonal salinity in surface waters.

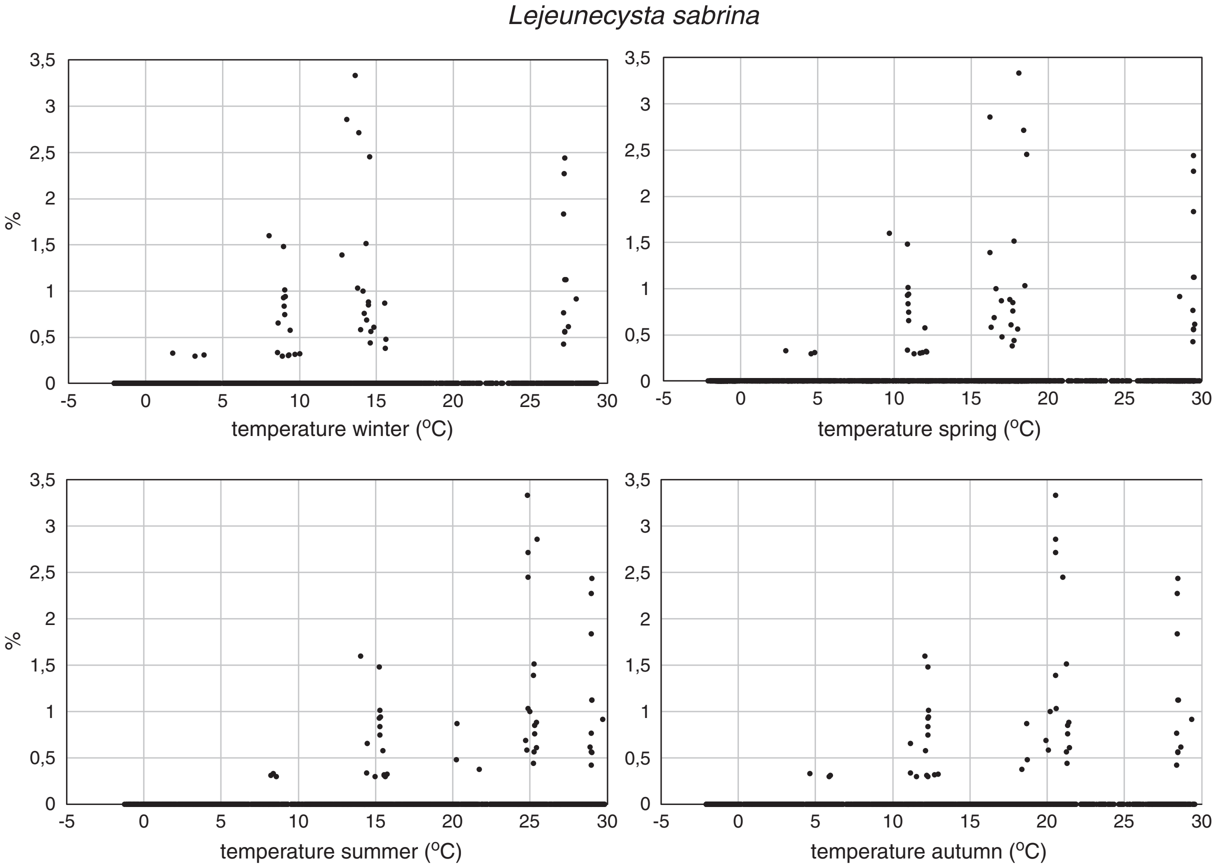

Fig. 131. Relative abundances of *Lejeunecysta sabrina* in relationship to seasonal temperature in surface waters.

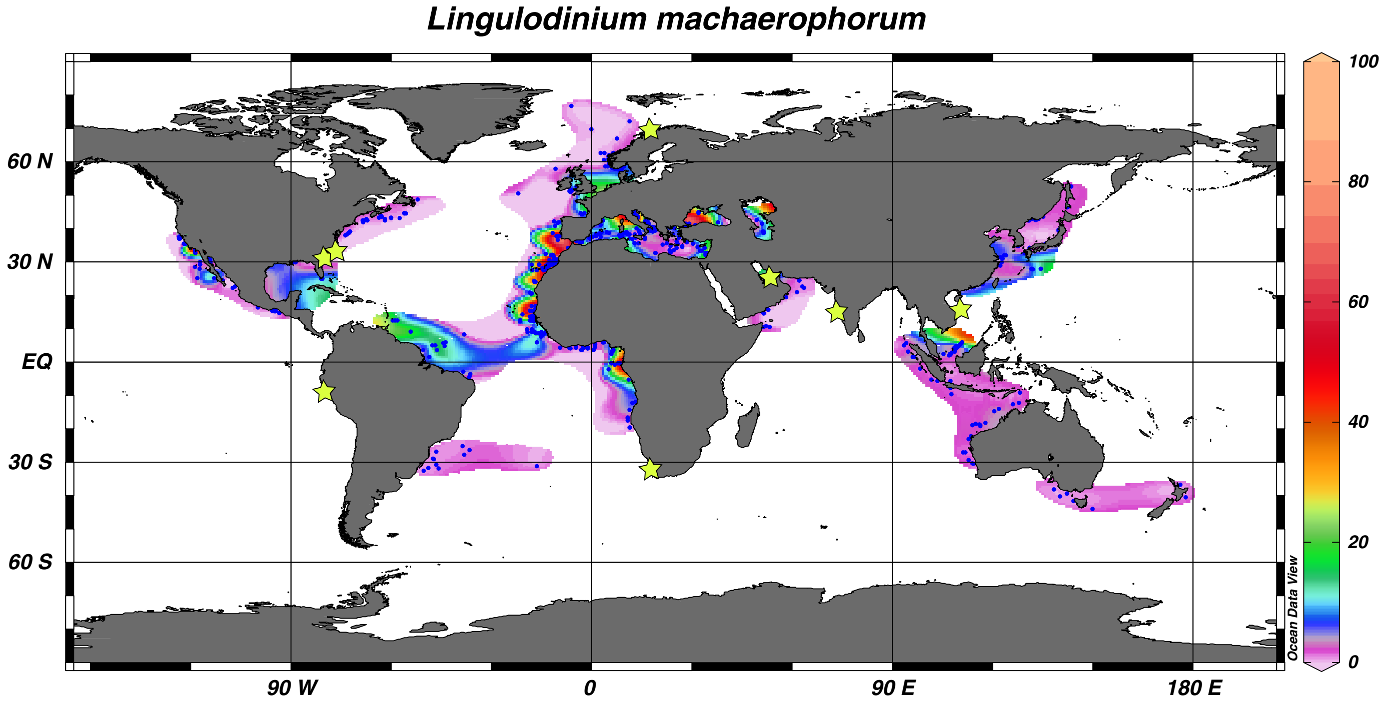

Fig. 132. Geographic distribution of *Lingulodinium machaerophorum*.

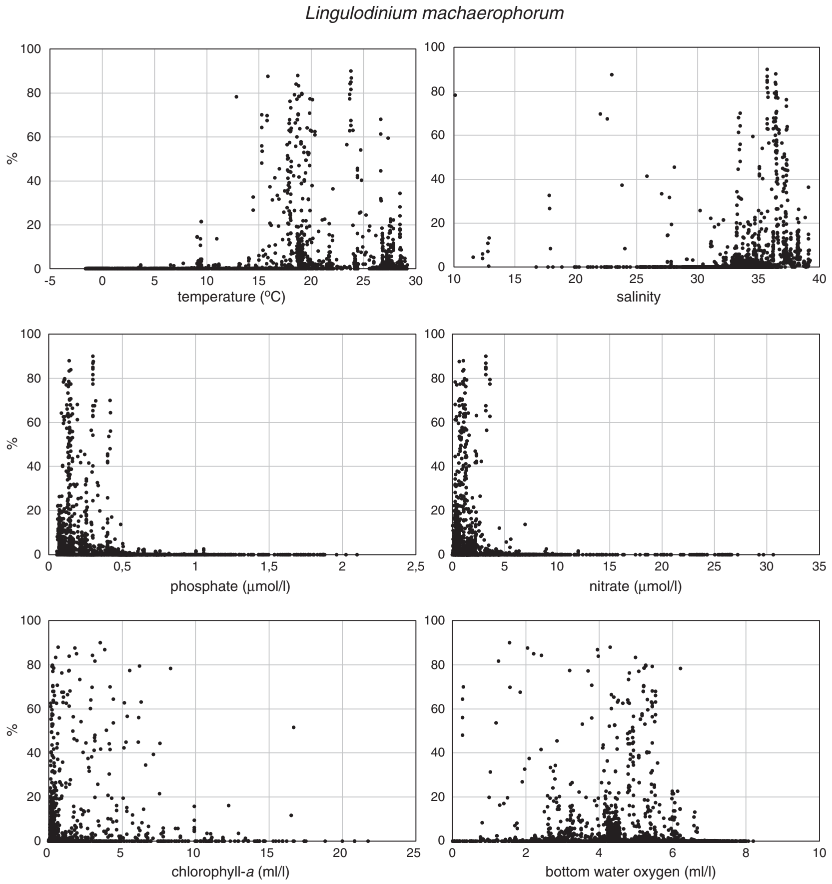

Fig. 133. Relative abundances of *Lingulodinium machaerophorum* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

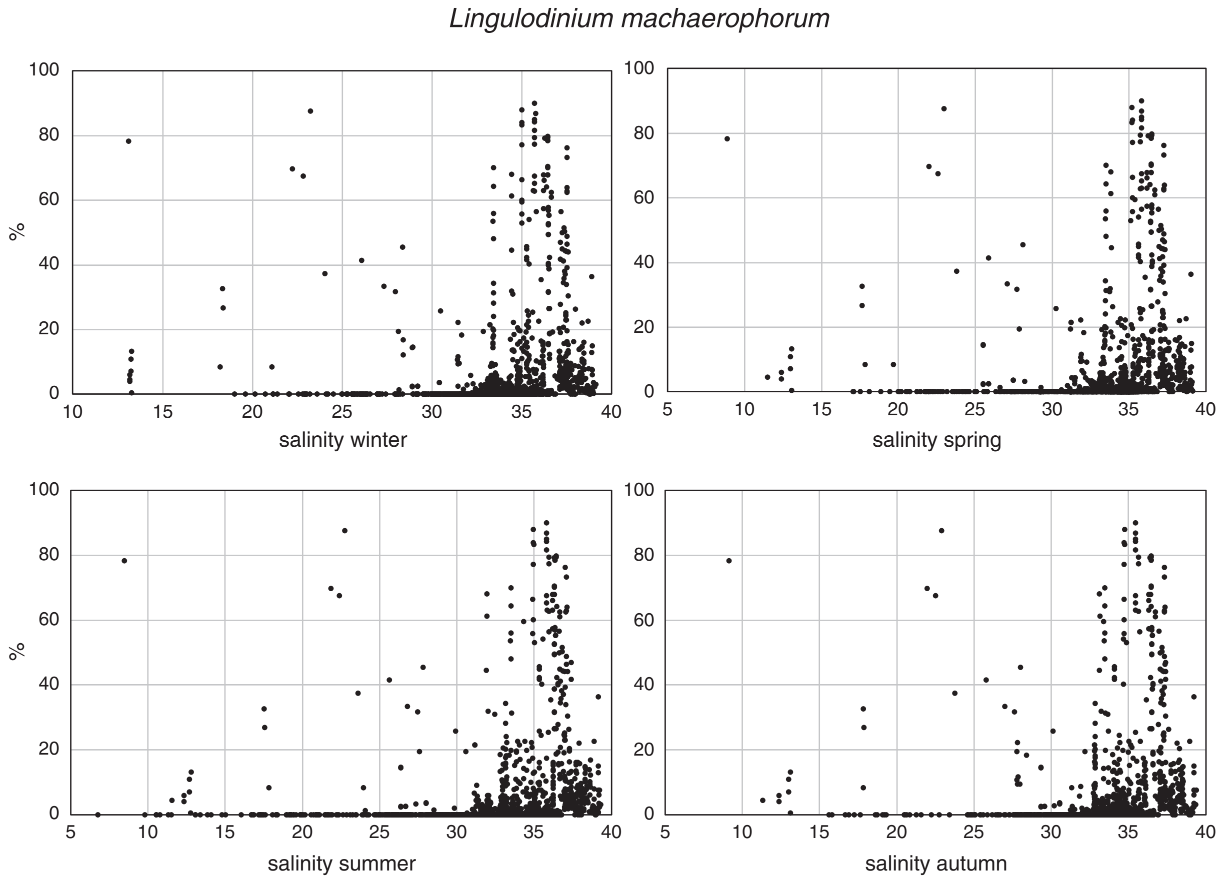

Fig. 134. Relative abundances of *Lingulodinium machaerophorum* in relationship to seasonal salinity in surface waters.

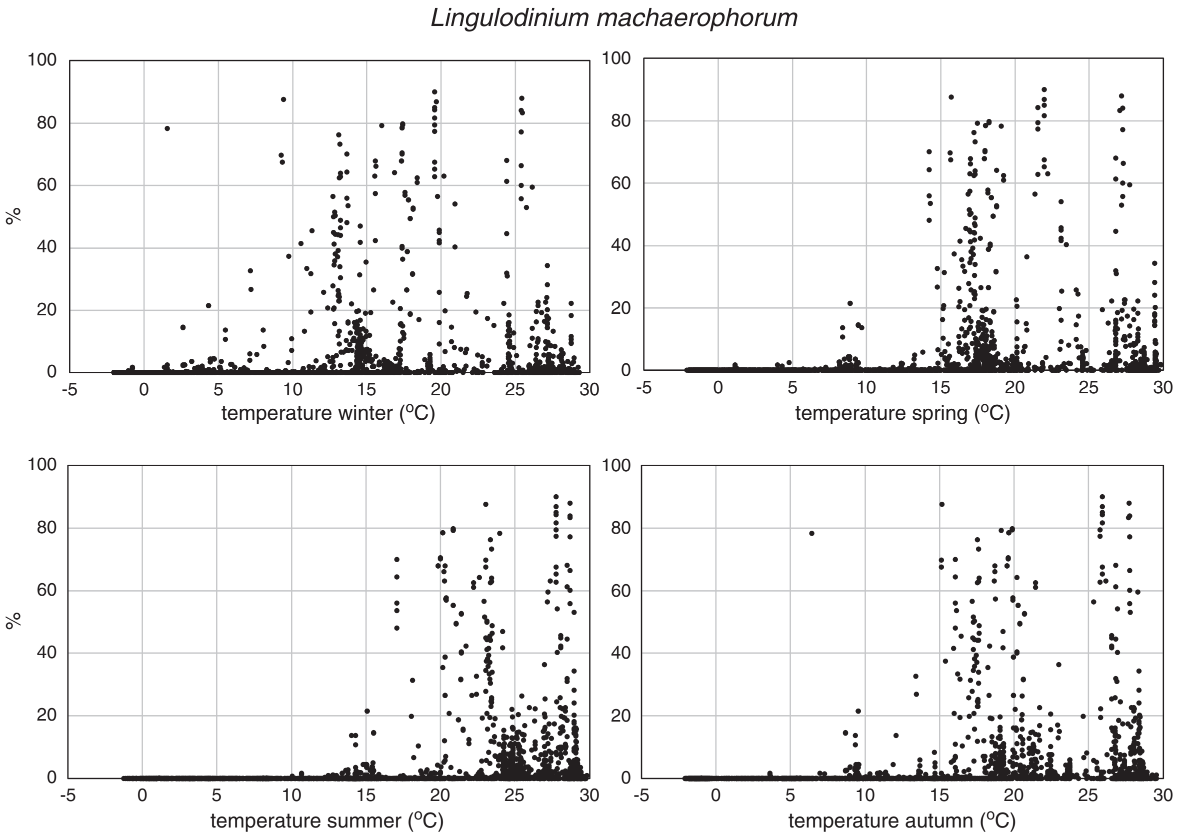

Fig. 135. Relative abundances of *Lingulodinium machaerophorum* in relationship to seasonal temperature in surface waters.

South Africa, the Peruvian upwelling area, the Gulf of Oman, along the South Atlantic coast of the eastern USA, in a fjord in northern Norway and in waters off western India (Godhe et al., 2000; Marret and Zonneveld, 2003; Joyce et al., 2005; Pitcher and Joyce, 2009; Rørvik et al., 2009 and references therein). In sediment trap and seasonal distribution studies of upwelling areas, cyst production of *L. machaerophorum* is typically observed during upwelling relaxation when upper waters still contain high nutrient/trace element concentrations but have become stratified (Marret and Zonneveld, 2003; Susek et al., 2005; Ribeiro and Amorim, 2008; Zonneveld et al., 2010 and references therein). In Bahía Concepción (Gulf of California), cyst production of *L. machaerophorum* occurs when upper waters become more stratified (Morquecho and Lechuga-Devéze, 2004). In the meso/eutrophic Omura Bay (Japan) *L. machaerophorum* is produced sporadically throughout the year independent of seasonal variations (Fujii and Matsuoka, 2006).

Recently, Smayda and Trainer (2010) suggested in an overview on dinoflagellate bloom developments in upwelling areas that the successful occurrence of *L. machaerophorum* in the highly variable upwelling environment might be the result of its multiple seeding behaviour. Apart from the sexual resting cysts, *L. machaerophorum* can produce asexual ecdysal cysts of which the production can be induced by turbulence (Figueroa and Bravo, 2005). These asexual cysts appear to protect the specimens against turbulence during upwelling and allow a fast re-colonisation of the water column upon upwelling relaxation. Comparable changes in upper water conditions can be observed in several river-plume environments as a result of varying river outflow. When river discharge increases a wedge of nutrient-rich fresh water can move off the river mouth. Turbidity is highest at the edge of such a wedge. After the edge of a wedge has passed, upper waters consist of relative fresh, nutrient-rich river plume waters that force the upper water column to become stratified.

A relationship between a reduction of process length and reduced salinities (see references in Marret and Zonneveld, 2003). Culture experiments by Hallett (1999) revealed a strong relationship between processes length and salinity as well as temperature with reduced processes at high temperatures and low as well as high salinities. This relationship with both temperature and salinity has been confirmed from field observations and has proven to be a useful tool to reconstruct downcore salinity (Mertens et al., 2009, 2012, and references therein).

Concluding remarks:

L. machaerophorum can be found in temperate to equatorial environments with temperatures above 10 °C in summer and 0 °C in winter. It is observed in regions with a broad salinity range. Reduced process length can be observed in relationship to reduced salinity and enhanced salinities and temperatures. Highest relative abundances occur in the vicinity of the active upwelling cells and near river mouths. Seasonal production occurs when stratified upper waters develop after a time of turbulence for instance at times of upwelling relaxation.

34. *Nematosphaeropsis labyrinthus* (Ostenfeld 1903) Reid 1974
Figs. 136–139.

Distribution:

Nematosphaeropsis labyrinthus occurs world-wide from the arctic to the equator in full-marine eutrophic to oligotrophic environments. Abundances >50% (up to 78%) are observed in eutrophic environments that are characterised by well ventilated bottom waters in the North Atlantic Ocean off Greenland, the Southern Ocean off New Zealand and the Southeastern Pacific off Chilli. The species is not registered from sediments of the northwestern Pacific (Sea of Japan, Sea of Okhotsk, Bering Sea), the majority of the Arctic Ocean and western Passages, the Black Sea, the low salinity Baltic Sea and Caspian Sea as well as the high salinity Gulf of Oman and Red Sea.

Environmental parameters:

SST: −2.1–29.8 °C (spring–summer), SSS: 25.8–39.4 (summer–autumn) except for two sites in the North Atlantic Ocean and in the Beaufort Sea where SSS: 17.4 and 20.2 respectively. [P]: 0.06–1.9 μmol/l, [N]: 0.01–26.5 μmol/l, chlorophyll-*a*: 0.05–20.9 ml/l, bottom water [O_2]: 0–8.2 ml/l.

It has a broad temperature tolerance and can be abundant both in regions where temperatures remain <0 °C throughout the year as well as regions where upper water temperatures are >25 °C in all seasons. High relative abundances are observed in eutrophic as well as oligotrophic regions. Although it is present in regions with anoxic/hypoxic bottom waters, highest relative abundances can be observed in regions where bottom waters are well ventilated.

Comparison with other records:

Apart from the observations included in this atlas *N. labyrinthus* is registered from a few coastal sites of the White Sea where upper water salinity can be seasonally reduced due to enhanced river discharge related to ice melting (Golovnina and Polyakova, 2004; Novichkova and Polyakova, 2007). It has also been registered from the Peruvian upwelling area (Biebow et al., 1993). In the North Atlantic and Arctic Seas *N. labyrinthus* occurs in regions that can be ice covered throughout the year but its relative abundance anti-correlates with the duration of annual ice cover (de Vernal et al., 1998; Radi and de Vernal, 2008). In sediment trap studies of the upwelling region off Somalia, *N. labyrinthus* is produced in higher amounts at times of active upwelling at the sampling site (Zonneveld and Brummer, 2000). In the upwelling areas off NW Africa and off NW Iberia, it is present in such low abundances that no relationship with upper water conditions could be drawn (Ribeiro and Amorim, 2008; Zonneveld et al., 2010). This holds as well for sediment trap studies of the coastal Saanich Inlet and the central Strait of Georgia (BC, Canada, Pospelova et al., 2010; Price and Pospelova, 2011). In the Southern Ocean (Atlantic Sector) N. labyrinthus has been registered from two traps that are located just north of the maximal sea ice extension (Harland and Pudsey, 1999).

Concluding remarks:

N. labyrinthus is a cosmopolitan species that can be present in high relative abundances in sediments of eutrophic as well as oligotrophic environments. With a very few exceptions only it is found to be restricted to full-marine settings.

35. *Operculodinium centrocarpum* (Deflandre et Cookson 1955) Wall 1967 var. *arctica* sensu Radi and De Vernal 2008
Figs. 140–143.

Distribution:

Operculodinium centrocarpum var. *arctica* is restricted to the temperate, subarctic and Arctic regions of the northern Hemisphere. Its southern boundary is the subtropical front. Abundances >10% (and up to 54%) are registered from the cold water regions of the Beaufort and Chuckchi Seas as well as the Northern Labrador Sea and eastern North Pacific Ocean that are characterised by high upper water phosphate concentrations.

Environmental parameters:

SST: −2.0–24.7 °C (winter–summer) with winter SST: <12.4 °C, SSS: 16.6–35.5 (summer–summer), [P]: 0.22-1,3 μmol/l, [N]: 0.6–12.0 μmol/l, chlorophyll-*a*: 0.2–13.5 ml/l, bottom water [O_2]: 0.9–8.0 ml/l.

Comparison with other records:

Operculodinium centrocarpum var. *arctica* is not recorded from sites other than included in this Atlas. Radi and de Vernal (2008) observe a strong positive relationship between the duration of ice cover and the relative abundance of *Operculodinium centrocarpum* var. *arctica*.

Concluding remarks:

Operculodinium centrocarpum var. *arctica* can be regarded as a cold-water species of mesotrophic to eutrophic environments that are characterised by well-ventilated bottom waters and where upper water salinities can be seasonally reduced as a result of melting of snow and ice. Its relative abundance in surface sediments increases with the duration of seasonal ice cover in the arctic.

36. *Operculodinium centrocarpum* (Deflandre et Cookson 1955) Wall 1967.

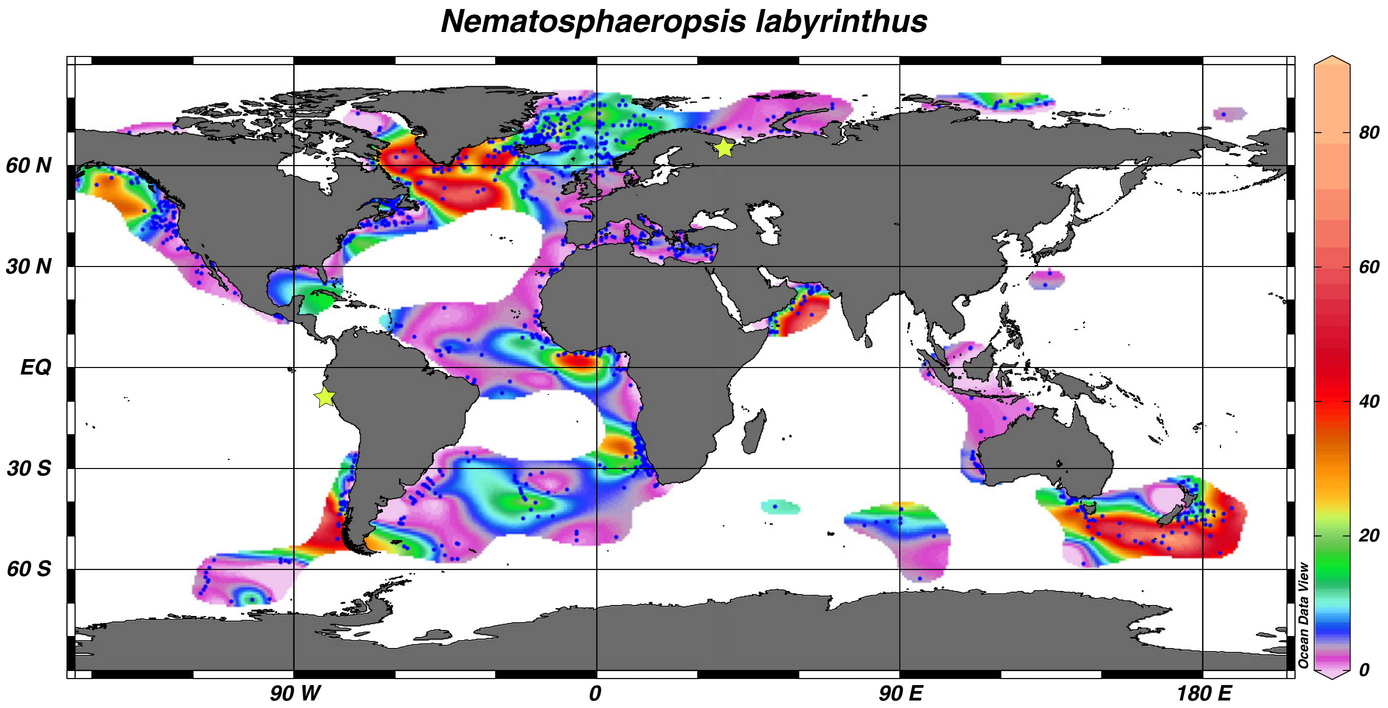

Fig. 136. Geographic distribution of *Nematosphaeropsis labyrinthus*.

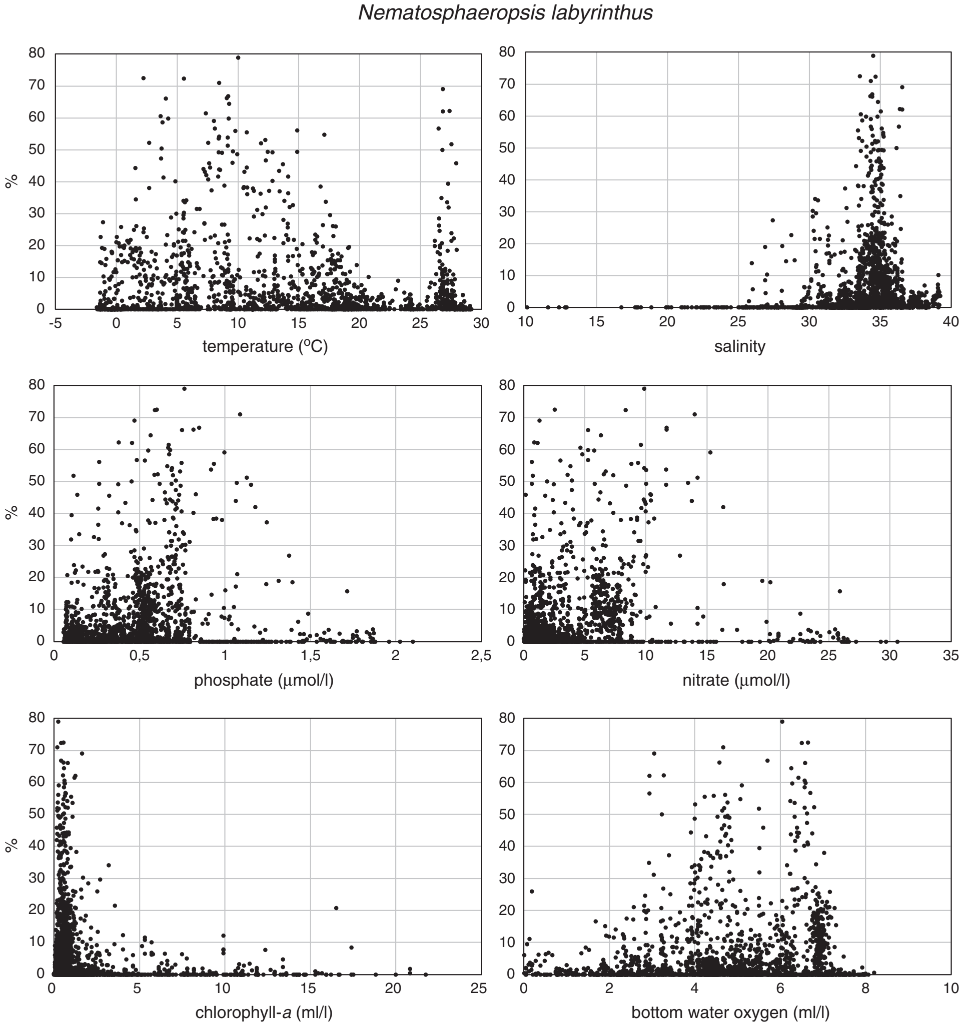

Fig. 137. Relative abundances of *Nematosphaeropsis labyrinthus* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

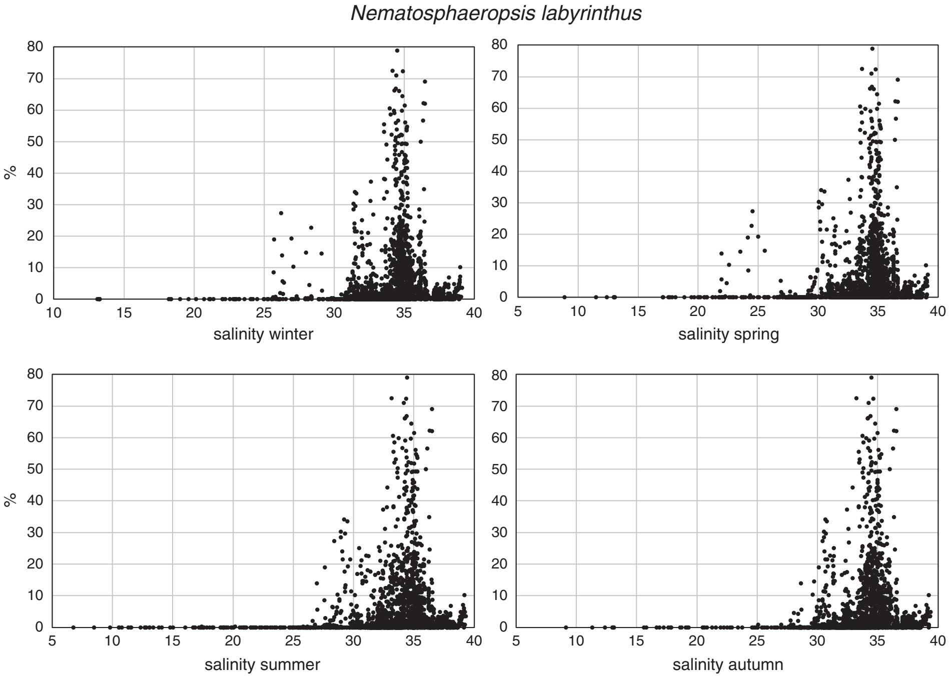

Fig. 138. Relative abundances of *Nematosphaeropsis labyrinthus* in relationship to seasonal salinity in surface waters.

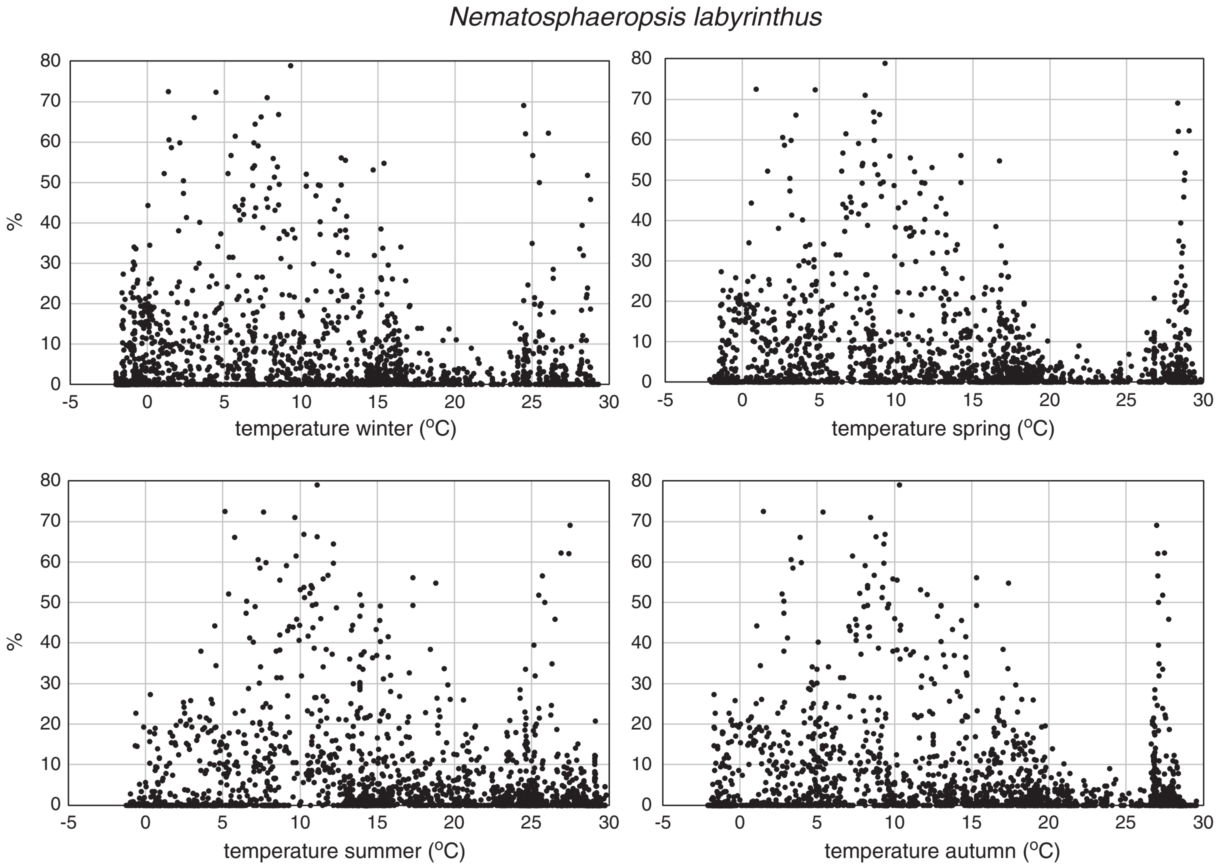

Fig. 139. Relative abundances of *Nematosphaeropsis labyrinthus* in relationship to seasonal temperature in surface waters.

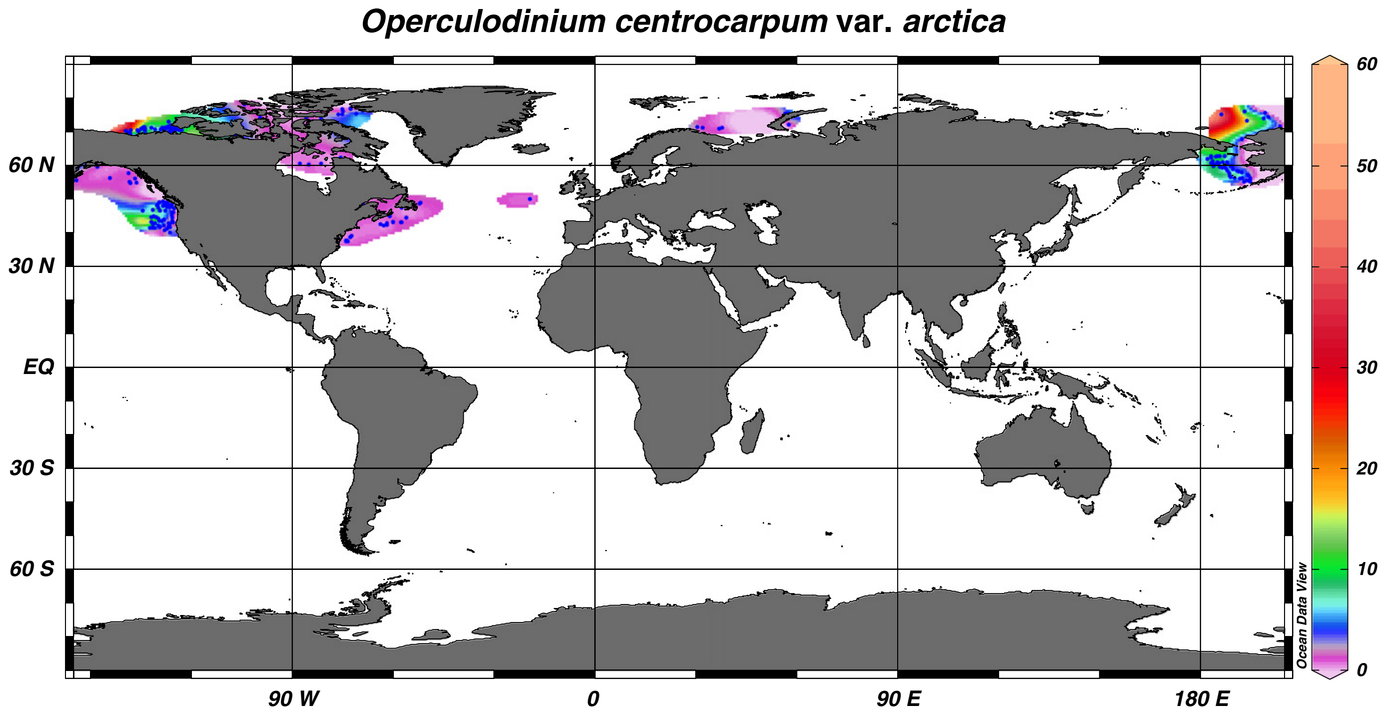

Fig. 140. Geographic distribution of *Operculodinium centrocarpum* var. *arctica*.

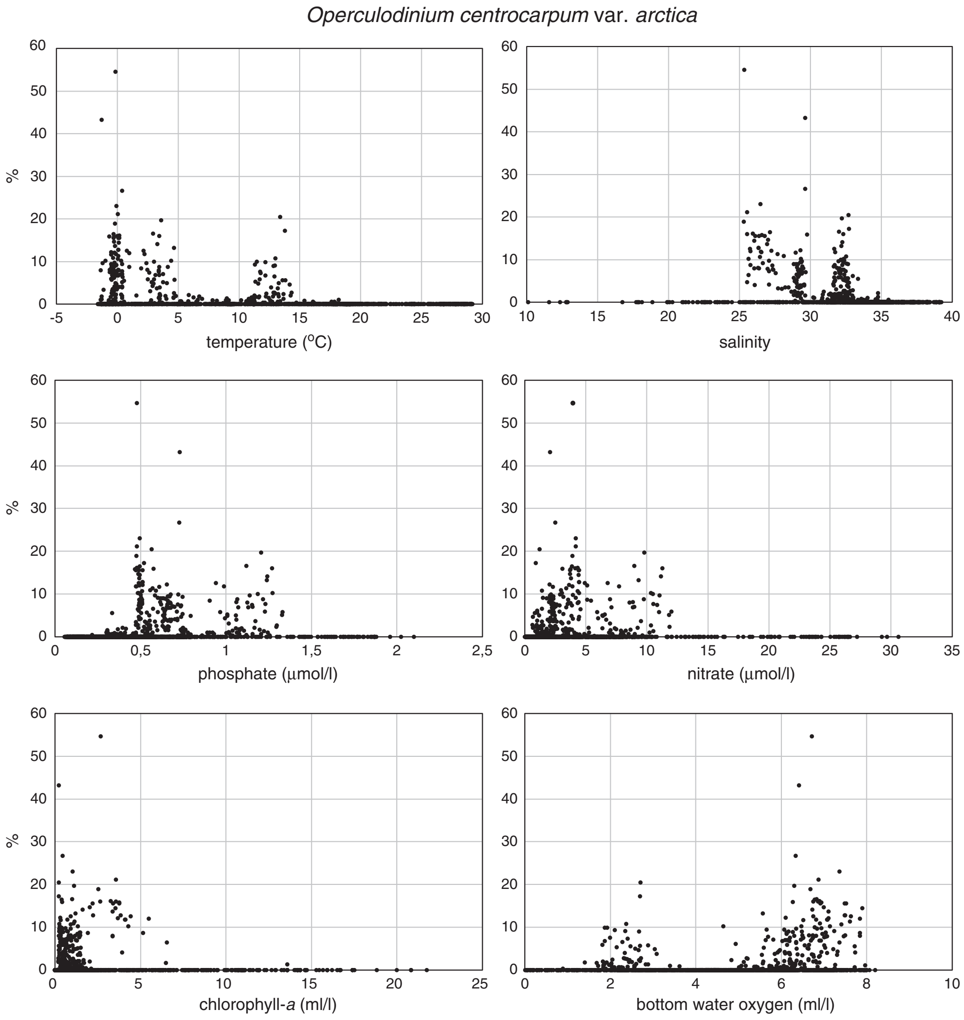

Fig. 141. Relative abundances of *Operculodinium centrocarpum* var. *arctica* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

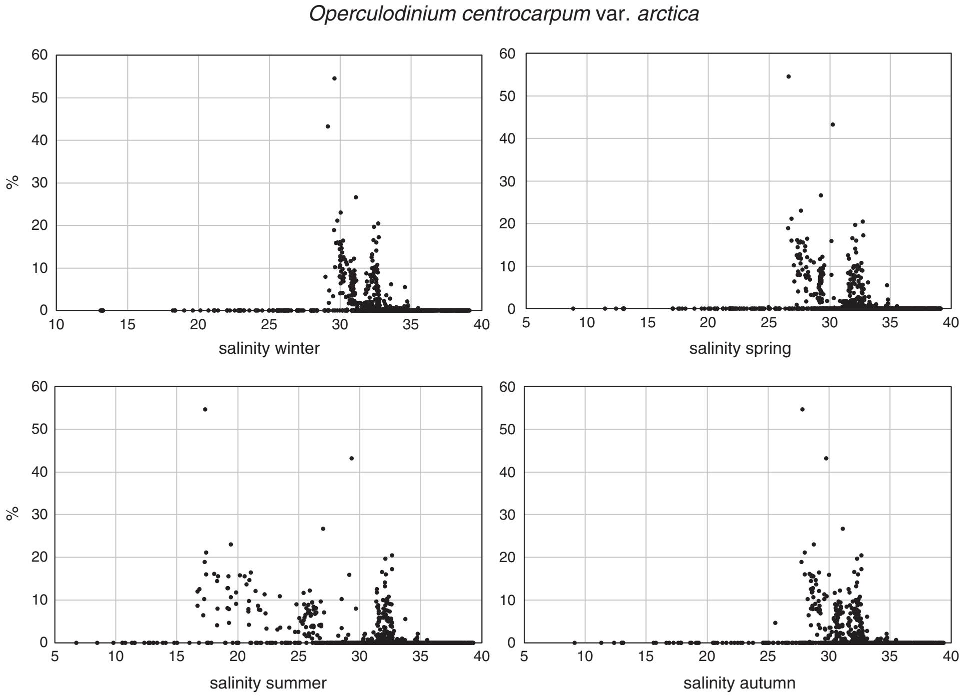

Fig. 142. Relative abundances of *Operculodinium centrocarpum* var. *arctica* in relationship to seasonal salinity in surface waters.

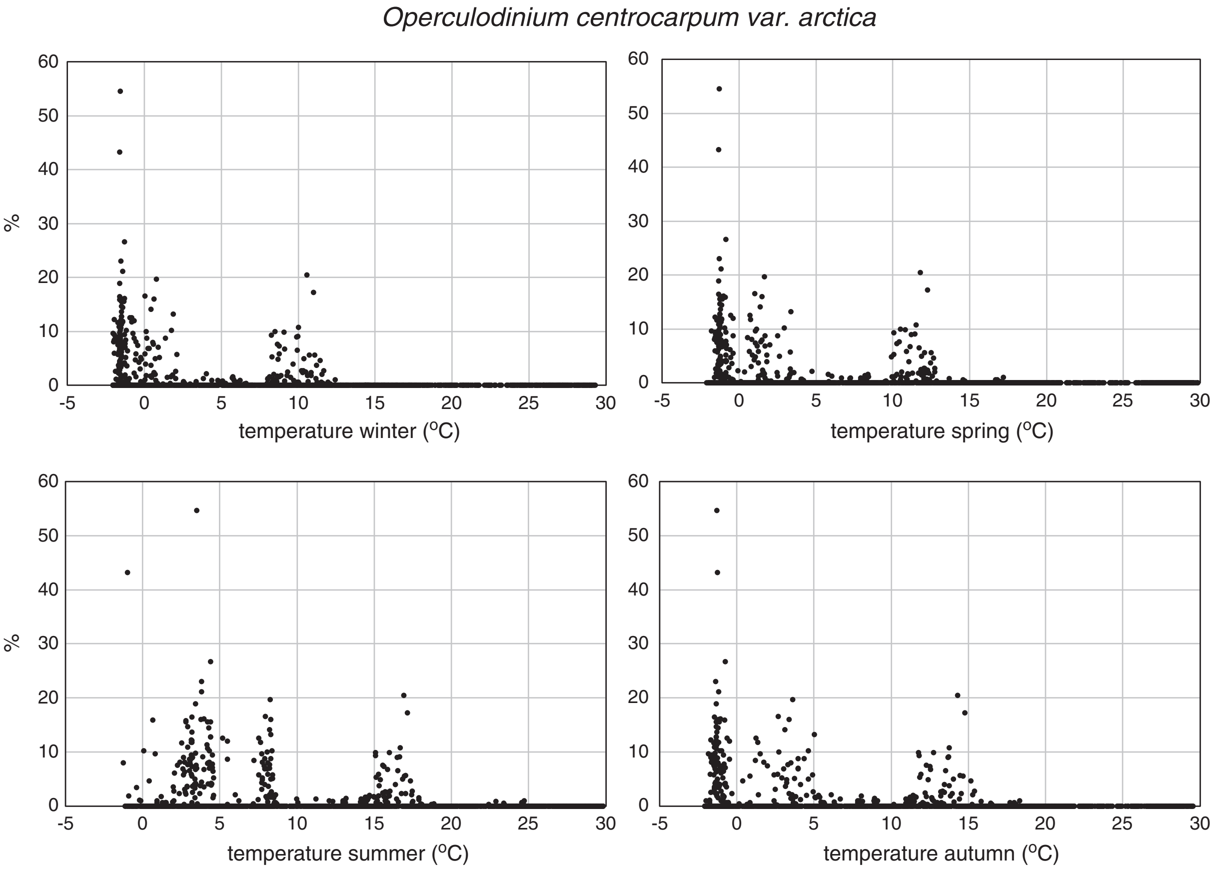

Fig. 143. Relative abundances of *Operculodinium centrocarpum* var. *arctica* in relationship to seasonal temperature in surface waters.

Figs. 144–147.

Distribution:

Operculodinium centrocarpum is observed in all studied environments from the polar to equatorial regions and coastal to open oceanic sites. Highest abundances (up to 91%) occur in the temperate to subpolar North Atlantic Ocean.

Environmental parameters:

SST: −2.1–29.8 °C (spring–summer), SSS: 9.8–39.4 (summer–summer), [P]: 0.06–1.87 μmol/l, [N]:, 0.01–25.99 μmol/l, chlorophyll-*a*:, 0.001–21.8 ml/l, $[O_2]$: between 0.01–8.2 ml/l.

Operculodinium centrocarpum can be abundant in sites where upper water temperatures are<0 °C throughout the year. High relative abundances can be observed in regions where salinities are reduced as result of meltwater input during the summer season or due to river discharge. This species is not restricted to regions with specific trophic conditions in the upper waters.

Comparison with other records:

Apart from the sites included in this atlas *Operculodinium centrocarpum* is recorded from the SW Indian margin, the White Sea, a fjord in northern Norway (North Atlantic Ocean), the South China Sea, Chinese coastal waters, the Peruvian upwelling area and the Gulf of Oman (Godhe et al., 2000; Marret and Zonneveld, 2003; Golovnina and Polyakova, 2004; Wang et al., 2004c; Novichkova and Polyakova, 2007; Rørvik et al., 2009 and references therein). In the Arctic *O. centrocarpum* occurs in areas that can be covered by sea ice for up to 12 months a year whereby a negative relationship exists between its relative abundance annual ice cover (de Vernal et al., 1998; Radi and de Vernal, 2008).

Sediment trap and seasonal distribution studies do not reveal a clear seasonal pattern in the cyst production, although in the Mediterranean Sea cyst production is restricted to the summer-early autumn seasons (June-October, Montresor et al., 1998). Furthermore it is observed in suspendet matter of the Marmara Sea in summer (Mudie pers. comm 2012). No seasonal trend or relationship with upper water characteristics could be documented in the upwelling areas off Somalia (Arabian Sea), off NW Africa and the Iberian peninsula, as well as in the North Pacific regions Omura Bay (Japan), central Strait of Georgia and Saanich Inlet (BC, Canada, Zonneveld and Brummer, 2000; Ribeiro and Amorim, 2008; Susek et al., 2005; Fujii and Matsuoka, 2006; Pospelova et al., 2010; Zonneveld et al., 2010; Price and Pospelova, 2011). In the British Columbia studies, *O. centrocarpum* is observed throughout the year and often forms the most abundant cyst species. This is in contrast to the other studies cited above, where it is only recorded sporadically in trap or surface sediments.

Concluding remarks:

Operculodinium centrocarpum can be regarded as a cosmopolitan species that can be observed in high relative abundances in all environments covered by this Atlas.

37. *Operculodinium centrocarpum* (Deflandre et Cookson 1955) Wall 1967 reduced process form

Figs. 148–151.

Distribution:

A separation between morphotypes of *Operculodinium centrocarpum* with and without reduced processes has been made for only a part of the datasets included in this Atlas. For those datasets that contain this separation the distribution of *O. centrocarpum* reduced processes is not restricted to a certain region and/or environment. The form with reduced processes is observed from temperate regions to the tropics and from coastal to open oceanic settings. Highest abundances (up to 29%) occur SE of the northern Island of New Zealand and in the Rio de la Plata discharge plume (South America).

Environmental parameters:

SST: −1.7–28.5 °C (winter–spring), SSS: 19.8 to 37.5 (summer–winter), [P]:, 0.1–1.05 μmol/l, [N]:, 0.05–10.81 μmol/l, chlorophyll-*a*: 0.08–15.9 ml/l, $[O_2]$: from 0.02–7.1 ml/l.

Operculodinium centrocarpum reduced processes can be abundant in regions where upper water temperatures are below 0 °C in autumn, winter and spring but with summer temperatures > 2.2 °C. No correlation is observed between the relative abundance of *Operculodinium centrocarpum* with reduced processes and the temperature or salinity gradients. The morphotype is not restricted to regions with specific trophic conditions in the upper waters.

Comparison with other records:

Relative abundances of *Operculodinium centrocarpum* with reduced processes have been semi-quantitatively related to (past) changes in upper water salinity (Dale, 1996; de Vernal et al., 1998; Ellegaard, 2000; Brenner, 2005; Head, 2007). In the Baltic Sea the average process length of *O. centrocarpum* is significantly correlated to both salinity and temperature (Mertens et al., 2011a). *Operculodinium centrocarpum* with reduced processes are observed in a fjord in northern Norway where salinities can be seasonally reduced (varying between 11–34.6, Rørvik et al., 2009).

Concluding remarks:

Operculodinium centrocarpum with reduced processes can be regarded as a cosmopolitan species. No relationship between relative abundances and variation in any of the investigated environmental gradients can be observed although there is strong evidence provided in the literature, that the average process length can be influenced by environmental conditions in the upper waters such as temperature and salinity.

38. *Operculodinium israelianum* (Rossignol 1962) Wall 1967

Figs. 152–155.

Distribution:

Operculodinium israelianum is restricted to subtropical, tropical and equatorial regions. It is abundant in coastal and open oceanic sites. Highest abundances (up to 20.3%) occur in the Eastern Mediterranean Sea notably off the Nile-river delta, in nearshore sites off northern Argentina/southern Brazil and in the nearshore central eastern Atlantic.

Environmental parameters:

SST: 1.8–29.8 °C (winter–spring) with summer SST > 10 °C except for three sites located south of South Africa. SSS: 30.3–39.4 (summer–autumn) except for one site near the coast of Argentina where SSS: 19.6–21.1–23.9–31.34 (spring–winter–summer–autumn). [P]: 0.06–1.67 μmol/l, [N]: 0.04–20.86 μmol/l, chlorophyll-*a*: 0.05–18.8 ml/l, $[O_2]$: from 0.01–6.6 ml/l.

Operculodinium israelianum can be abundant in regions where SST > 28.8 °C throughout the year. Abundances (> 10%) occur where SST: exceed 14.3 °C in winter and 24.2 °C in summer.

O. israelianum is restricted to full-marine regions. Highest relative abundances can be observed in regions where bottom waters are well ventilated.

Comparison with other records:

Apart from the sites included in this atlas *Operculodinium israelianum* is recorded from the SW Iberian margin (Sprangers et al., 2004), the Gulf of Oman and several sites from the southern coastal waters of Korea, the Yellow Sea and the East China Sea (Cho and Matsuoka, 2000; Cho et al., 2003; Marret and Zonneveld, 2003; Shin et al., 2007; Pospelova and Kim, 2010 and references therein). It can dominate assemblages in high salinity environments such as shallow lagoons in sub-tropical–tropical regions (Bradford and Wall, 1984; Morzadec-Kerfourn et al., 1990) Sediment trap and seasonal distribution studies do not reveal a seasonal pattern in the cyst production of *O. israelianum* (Susek et al., 2005; Ribeiro and Amorim, 2008; Zonneveld et al., 2010).

Concluding remarks:

Operculodinium israelianum can be regarded as a subtropical to equatorial species that can be observed in high relative abundances in nearshore sites and sites where high upper water salinities prevail.

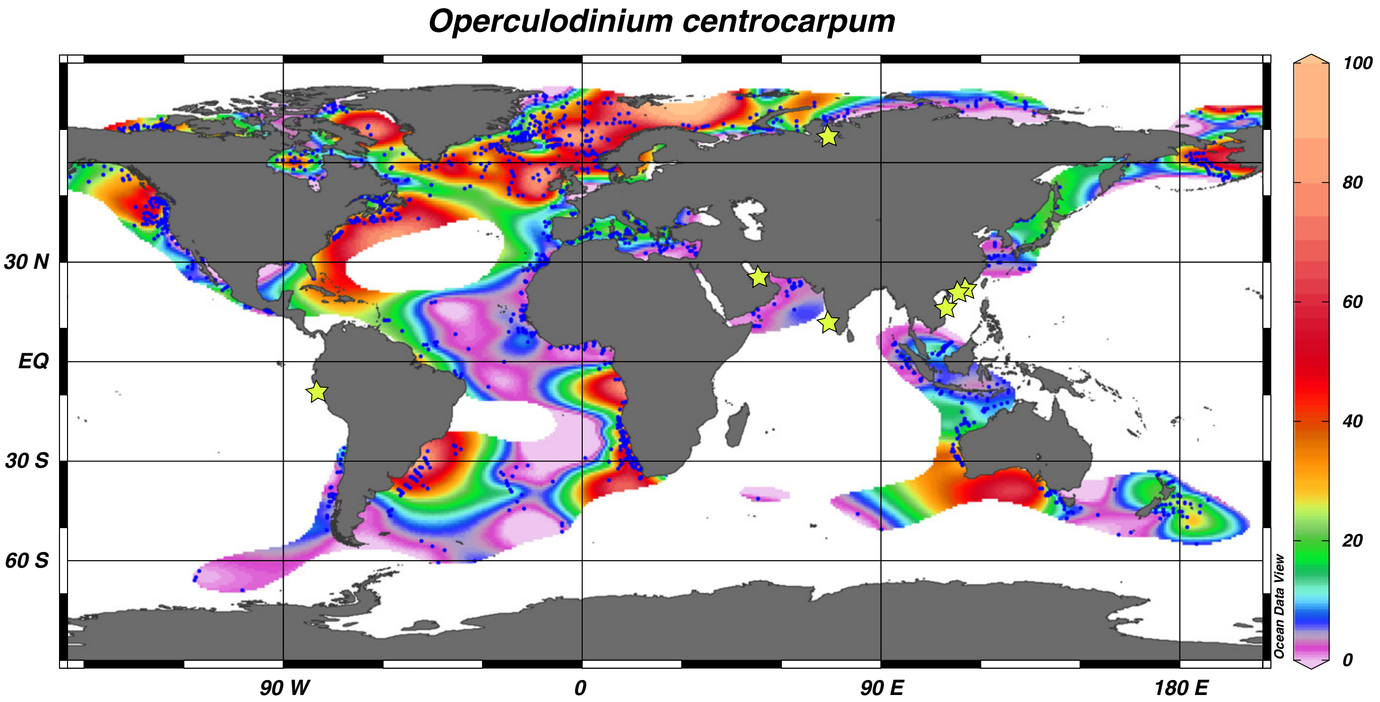

Fig. 144. Geographic distribution of *Operculodinium centrocarpum*.

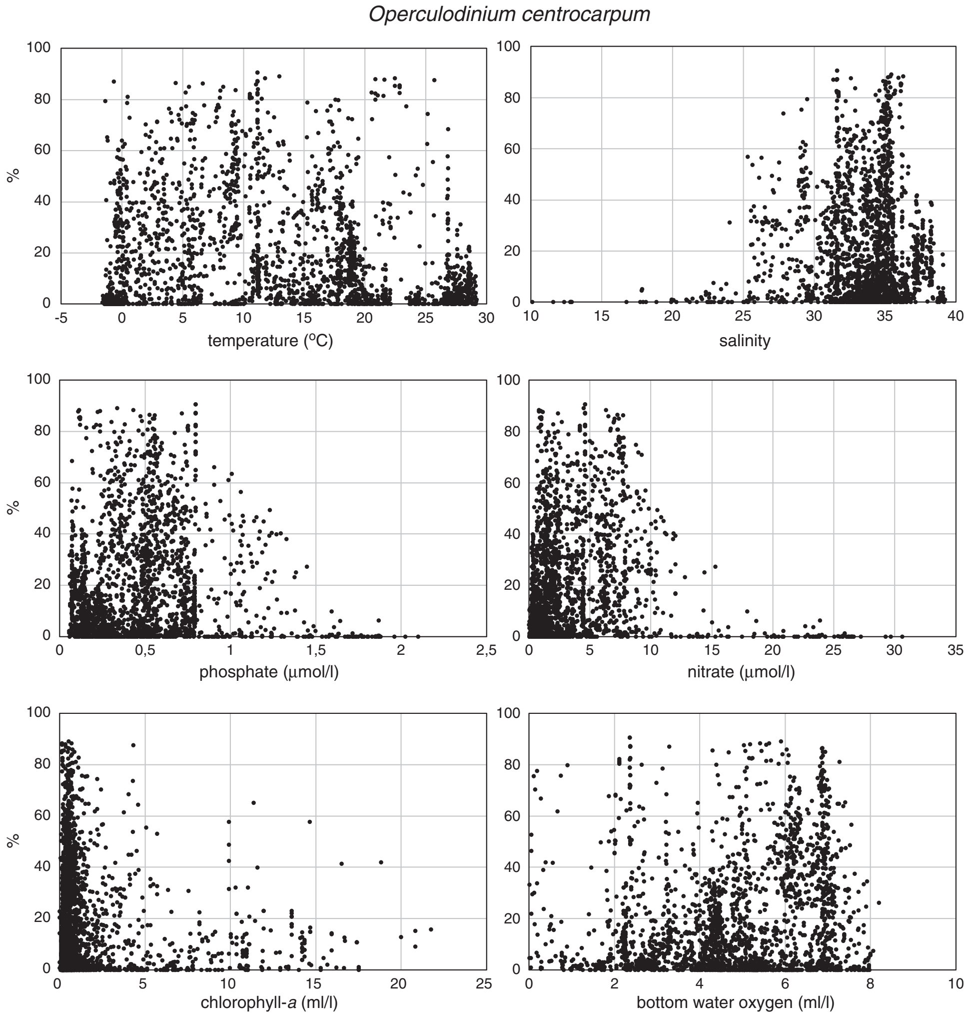

Fig. 145. Relative abundances of *Operculodinium centrocarpum* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

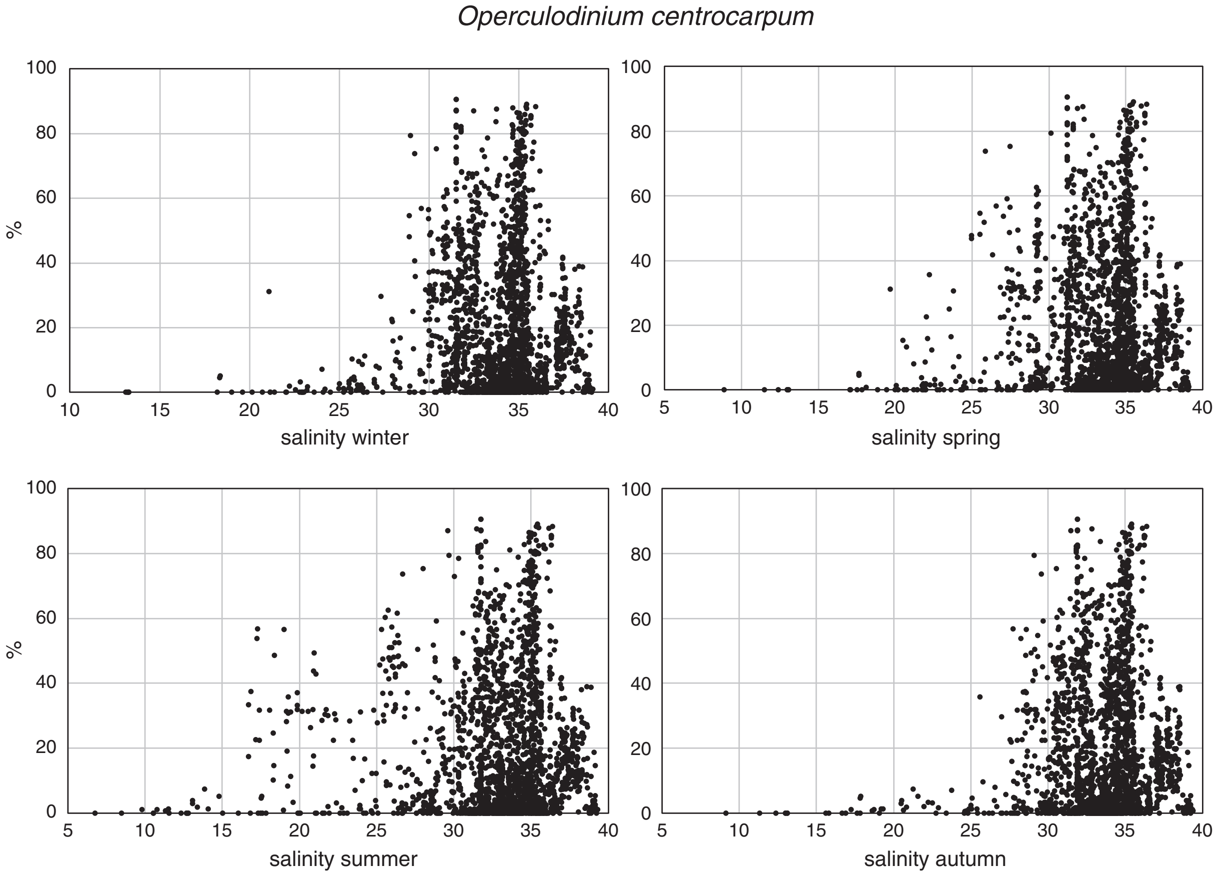

Fig. 146. Relative abundances of *Operculodinium centrocarpum* in relationship to seasonal salinity in surface waters.

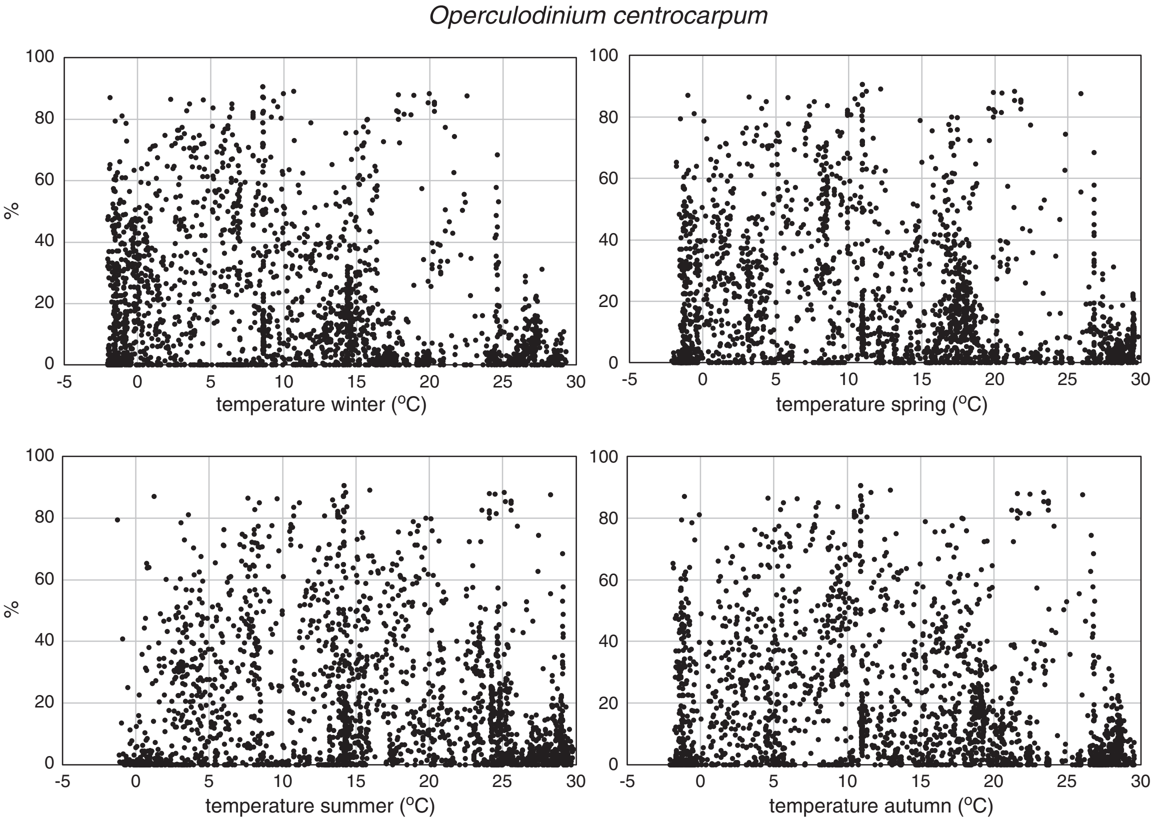

Fig. 147. Relative abundances of *Operculodinium centrocarpum* in relationship to seasonal temperature in surface waters.

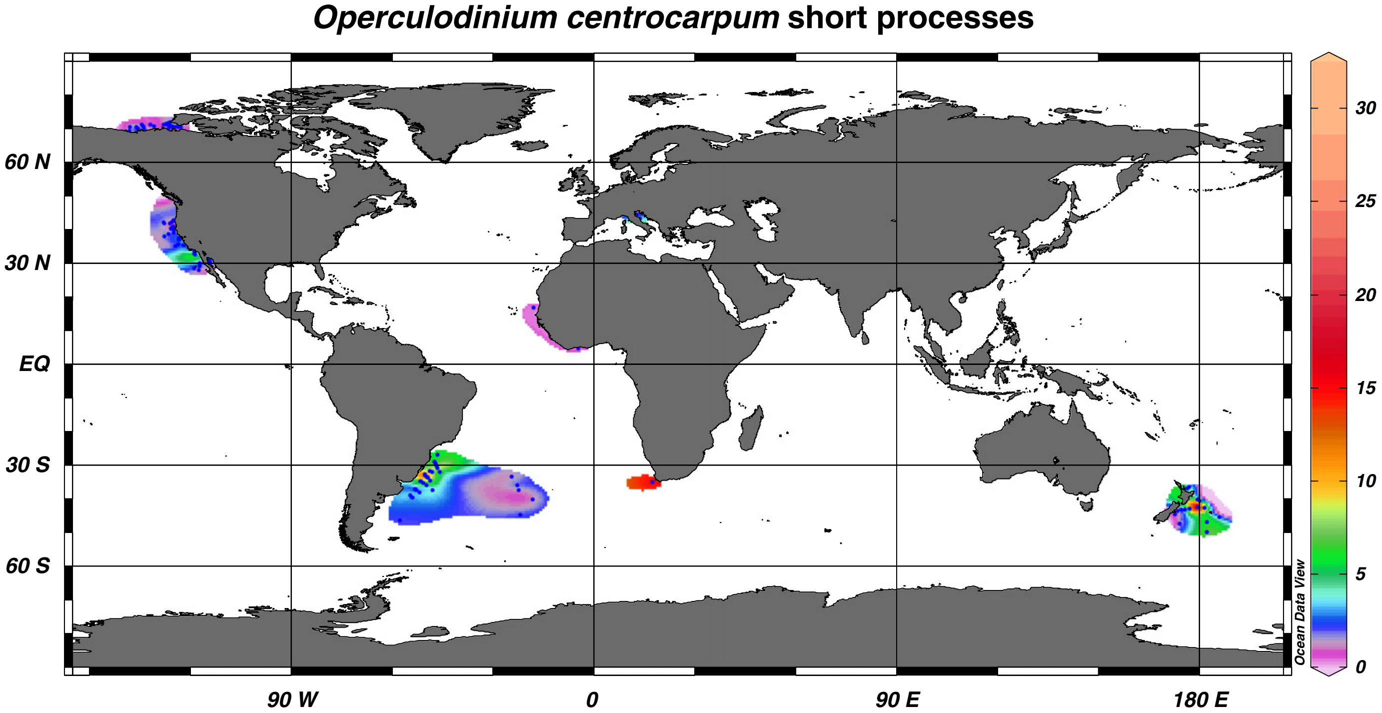

Fig. 148. Geographic distribution of *Operculodinium centrocarpum* reduced processes.

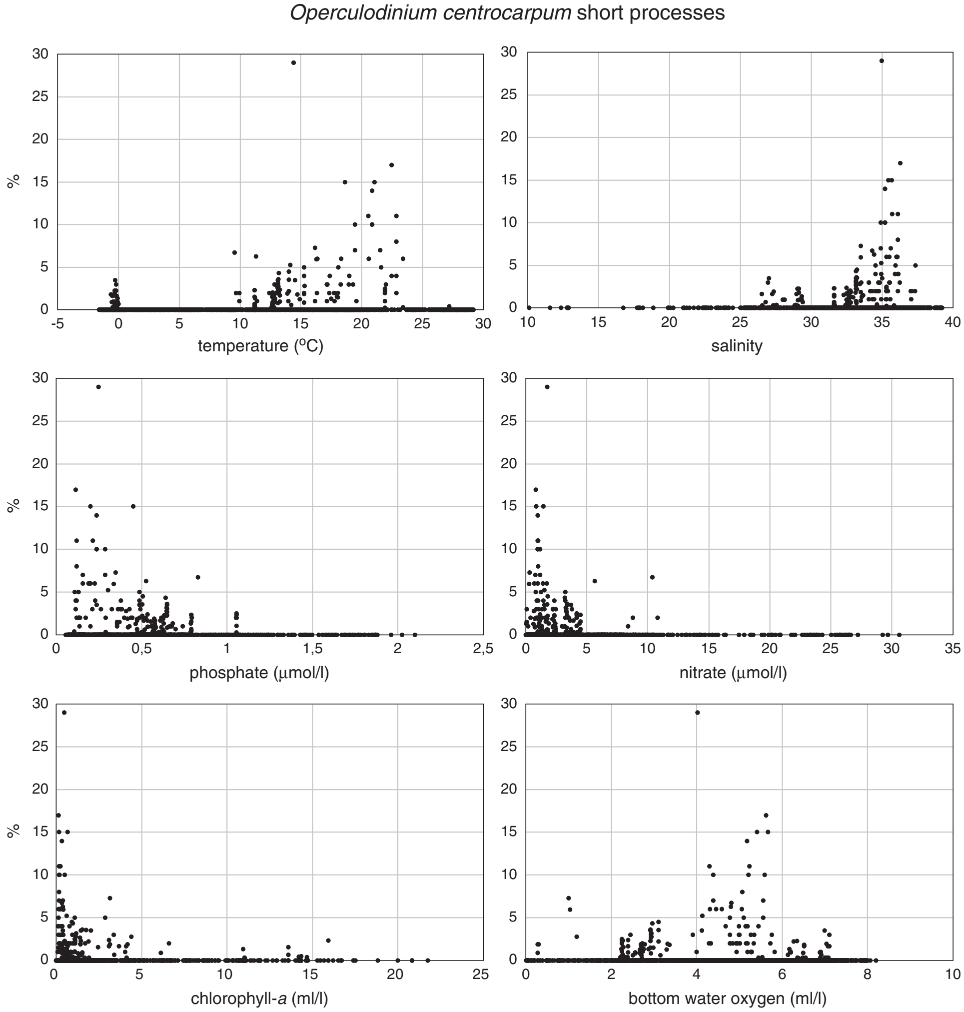

Fig. 149. Relative abundances of *Operculodinium centrocarpum* reduced processes in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

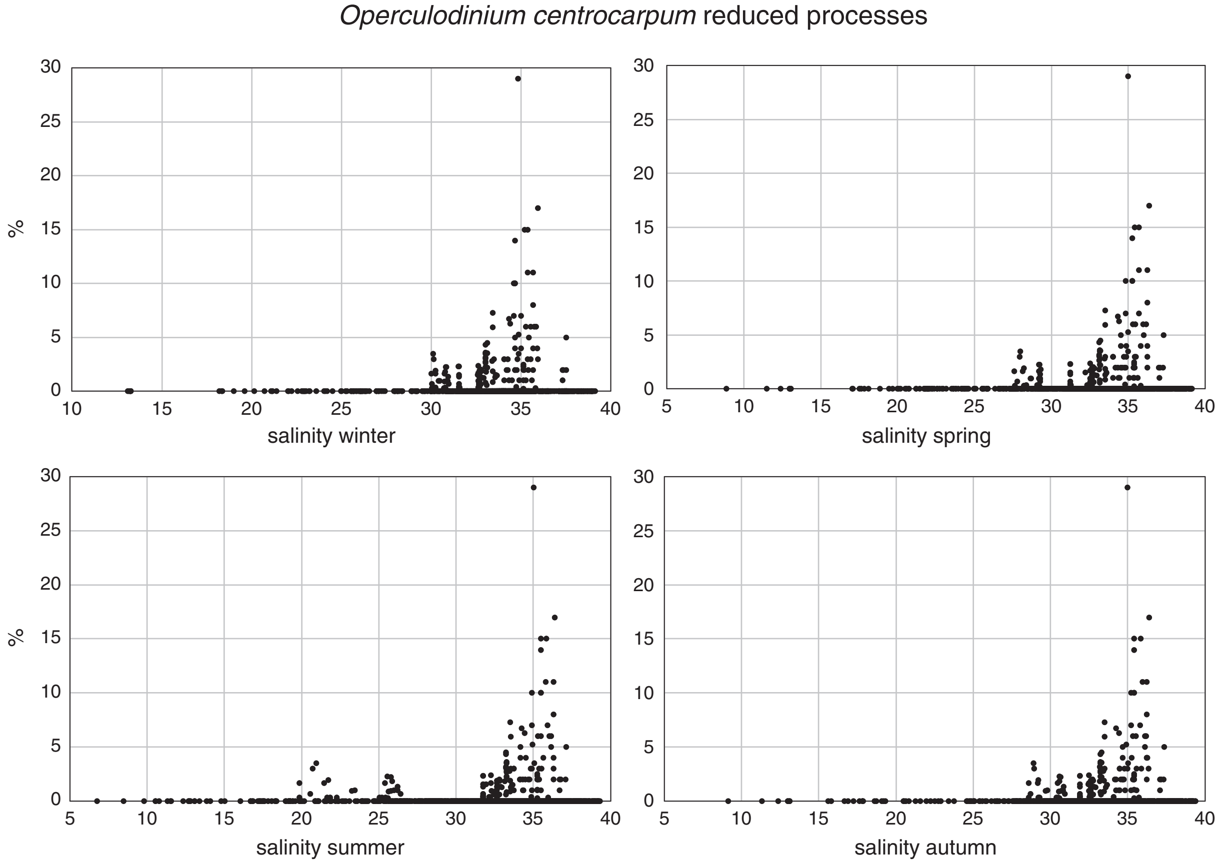

Fig. 150. Relative abundances of *Operculodinium centrocarpum* reduced processes in relationship to seasonal salinity in surface waters.

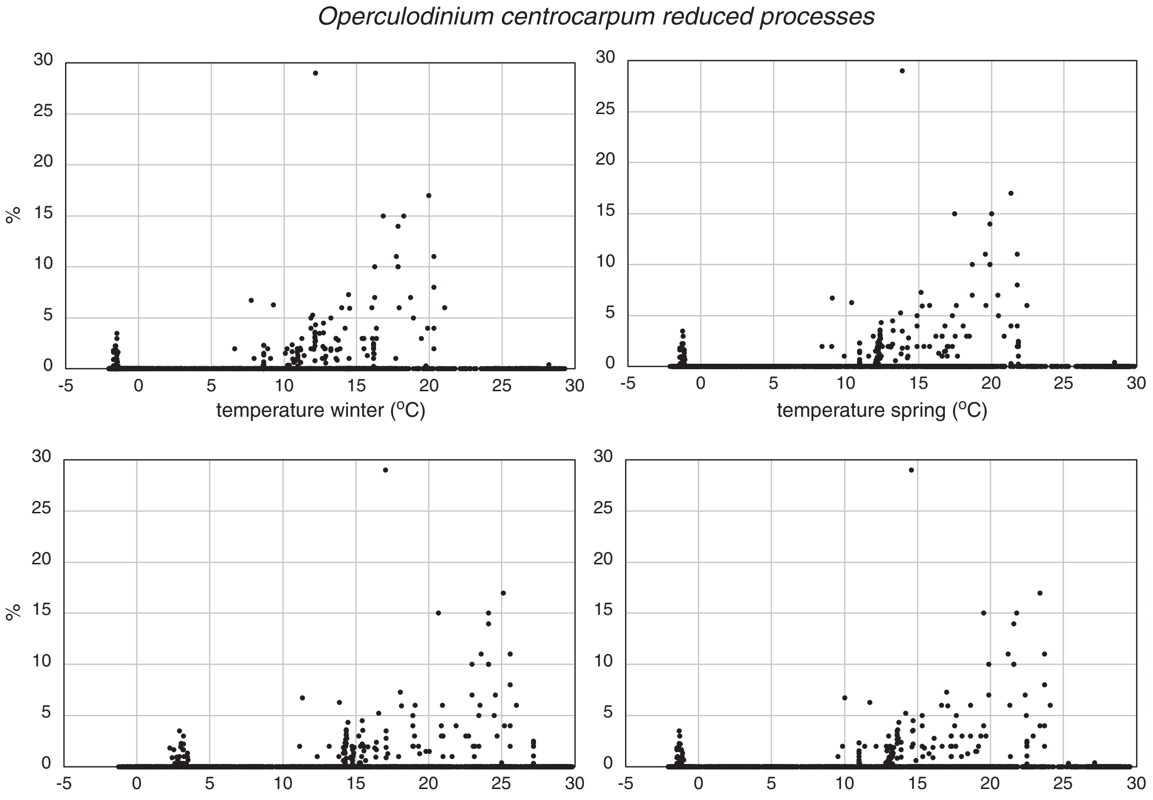

Fig. 151. Relative abundances of *Operculodinium centrocarpum* reduced processes in relationship to seasonal temperature in surface waters.

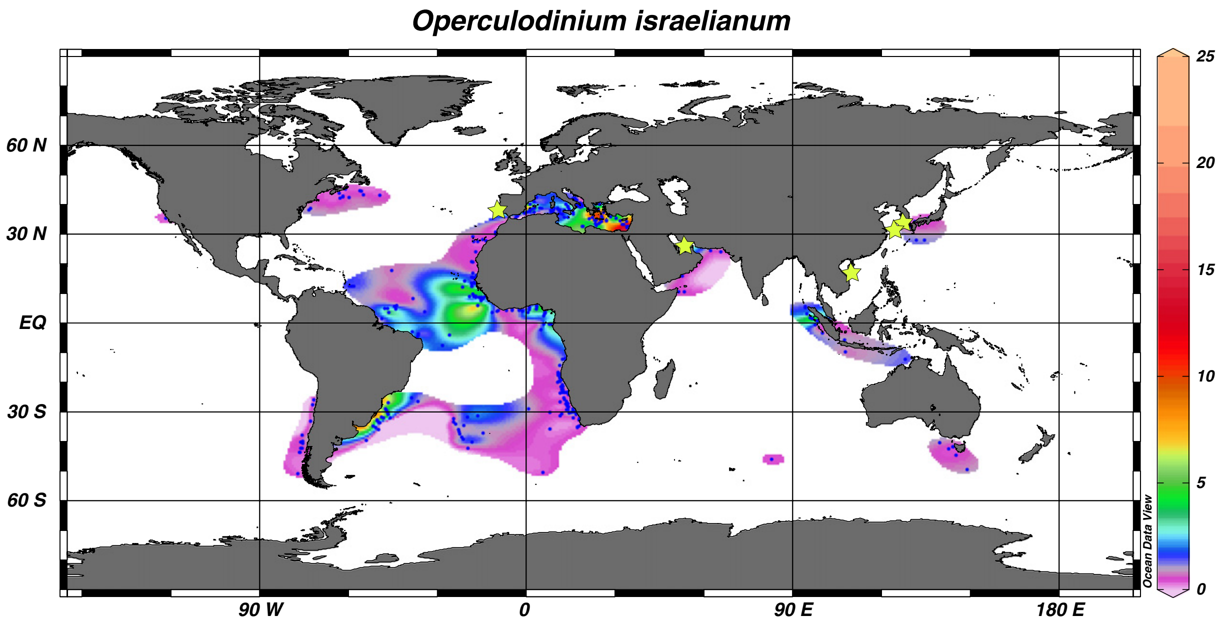

Fig. 152. Geographic distribution of *Operculodinium israelianum*.

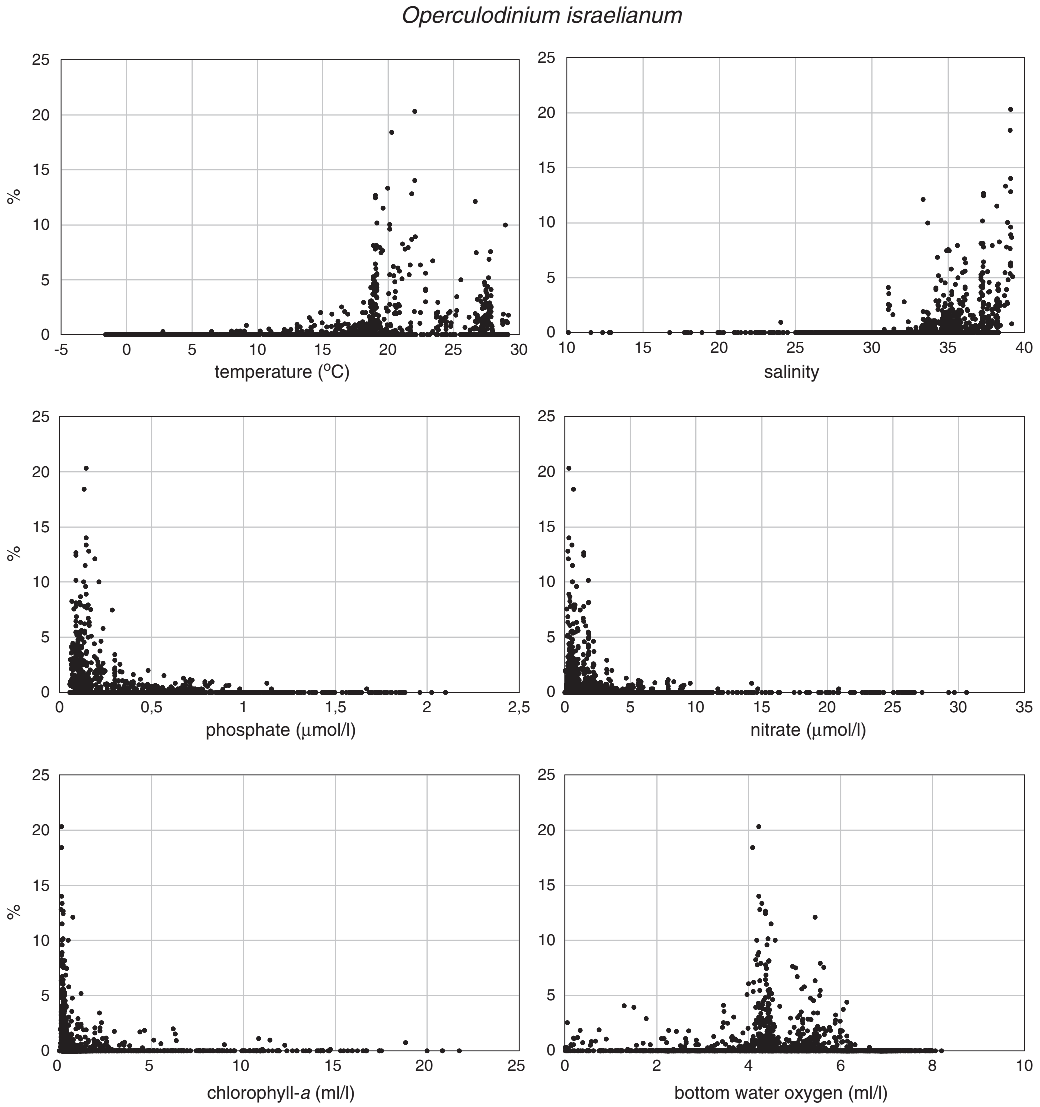

Fig. 153. Relative abundances of *Operculodinium israelianum* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

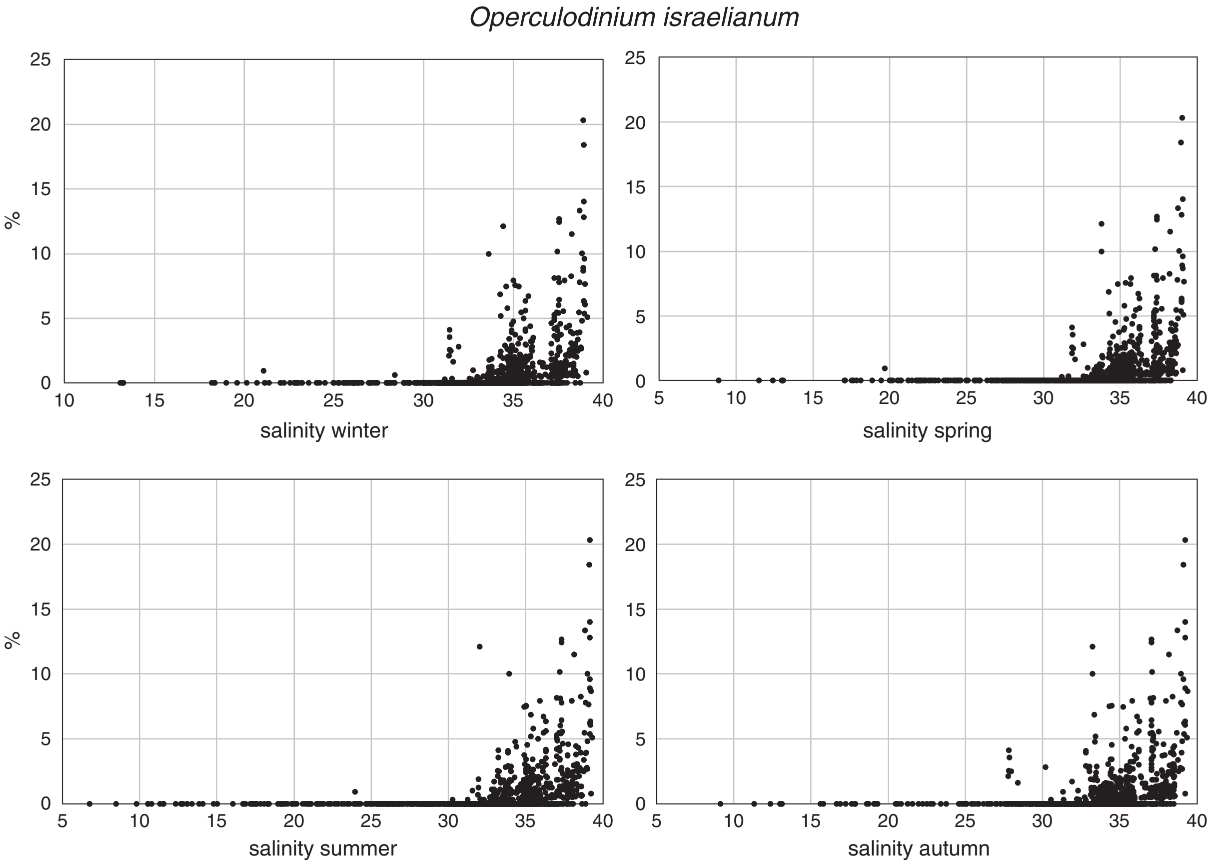

Fig. 154. Relative abundances of *Operculodinium israelianum* in relationship to seasonal salinity in surface waters.

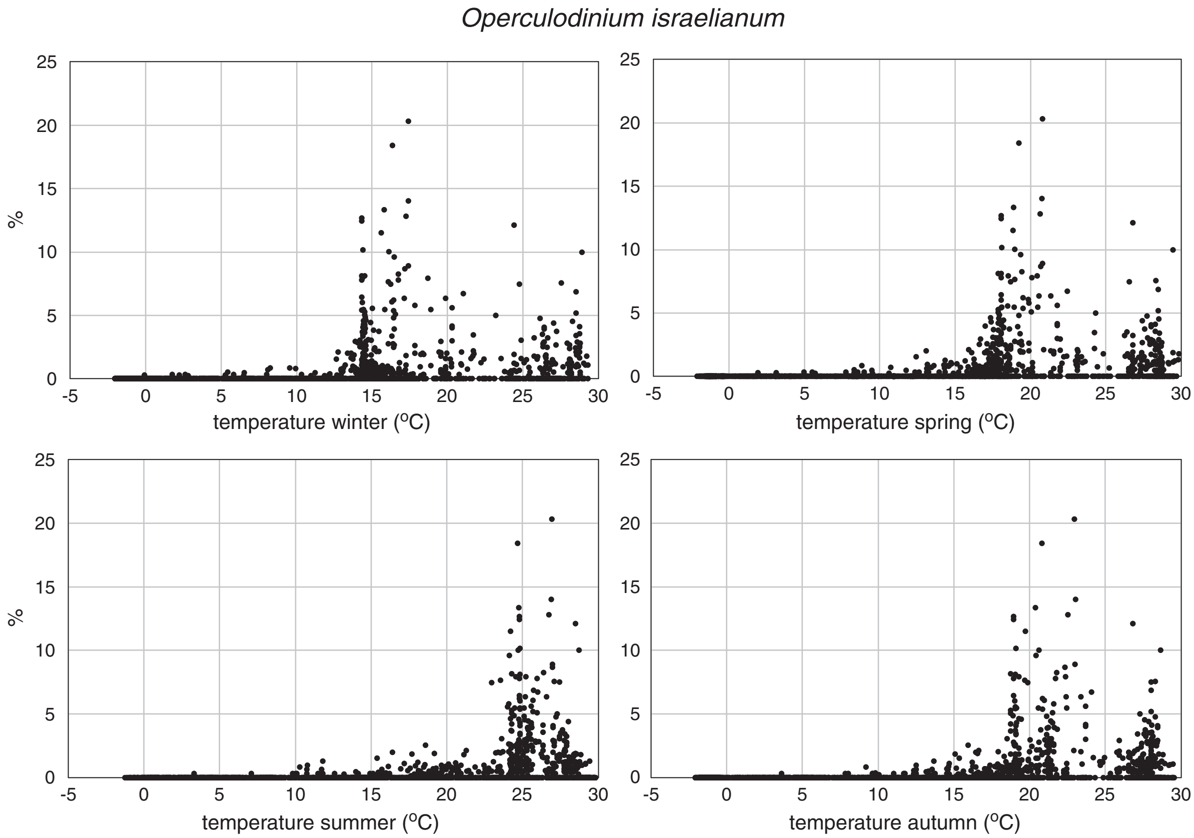

Fig. 155. Relative abundances of *Operculodinium israelianum* in relationship to seasonal temperature in surface waters.

39. *Operculodinium janduchenei* Head et al. 1989

Figs. 156–159.

Distribution:

Operculodinium janduchenei is restricted to temperate to equatorial regions. With exception of the temperate North Atlantic and Antarctic Ocean (Indian Sector) where it is found in the central part of the oceans, its distribution restricted to the continental margins. Highest abundances (up to 14.3%) occur in the eastern Indian Ocean off Indonesia.

Environmental parameters:

SST: −1.7–27.9 °C (winter–summer) with summer SST > 2.5 °C. SSS: 17.5–38.3 (summer–winter), [P]: 0.06–1.24 μmol/l, [N]: 0.2–16.27 μmol/l, chlorophyll-*a*: 0.08–18.8 ml/l, bottom water [O_2]: between 0.19–6.8 ml/l.

O. janduchenei characteristically occurs in regions where salinity is reduced throughout the year by river discharge but it is not restricted to these areas and can occur in high relative abundances in full-marine environments as well. O. *janduchenei* can be found in oligotrophic to eutrophic environments but is absent in regions where anoxic bottom waters prevail. Highest relative abundances can be observed in regions where bottom waters are well ventilated.

Comparison with other records:

It is not registered from regions other than covered by this Atlas.

Concluding remarks:

Operculodinium janduchenei can be regarded as a temperate to equatorial species that occurs where salinity is reduced throughout the year as well as in full-marine environments. It can be found in oligotrophic to eutrophic environments. Its distribution is restricted to regions where hypoxic to well-ventilated bottom waters prevail.

40. *Operculodinium longispinigerum* Matsuoka 1983

Figs. 160–163.

Distribution:

Operculodinium longispinigerum occurs in tropical to equatorial regions of the eastern equatorial Indian Ocean and adjacent seas. Highest abundances (up to 22.7%) occur south of the Indonesian island Java.

Environmental parameters:

SST: 20.6–29.8 °C (winter–spring). SSS: 31.6–35.7 (summer–summer), [P]: 0.09–0.36 μmol/l, [N]: 0.23–0.68 μmol/l, chlorophyll-*a*: 0.11–0.39 ml/l, bottom water [O_2]: 2.2–4.6 ml/l.

The distribution of O. *longispinigerum* is restricted to full-marine oligotrophic environments with well ventilated bottom waters.

Comparison with other records:

So far *O. longispinigerum* has not been recorded from other regions than those recorded in this Atlas. However, the species has been described from Late Cainozoic sediments of the Niigata district in central Japan suggesting that it could have a wider distribution than as documented in this Atlas.

Concluding remarks:

Operculodinium longispinigerum occurs in tropical to equatorial, full-marine, oligotrophic environments with well ventilated bottom waters.

41. Cysts of *Pentapharsodinium dalei* Indelicato et Loeblich III 1986 and *Ensiqulifera imariense*

Figs. 164–167.

Distribution:

Cysts of *Pentapharsodinium dalei*/*Ensiculifera imariense* are observed in polar to equatorial regions. The arctic front (Northern Hemisphere) and the subtropical front (Southern Hemisphere) form the northern and southern boundaries of its distribution. *Pentapharsodinium dalei*/*Ensiculifera imariense* can dominate (>50%) in the Hudson Bay, off Iceland (North Atlantic Ocean), the North Sea, the Barents Sea, the Chukchi Sea and the Bering Sea. It can form up to 96% of the association in these regions. It is abundant in the open ocean as well as in sediments of coastal sites.

Environmental parameters:

SST: −2.1–29.5 °C (spring–summer) with summer SST > 0 °C. SSS: 11.3–39.3 (autumn–autumn), [P]: 0.06–1.87 μmol/l, [N]: 0.01–26.5 μmol/l, chlorophyll-*a*: 0.08–20.9 ml/l, bottom water [O_2]: 0.01–8.2 ml/l.

Cysts can be abundant in sites where upper water temperatures < 0 °C throughout the year except during summer. Cysts of *Pentapharsodinium dalei*/*Ensiculifera imariense* occur in full marine environments where upper water salinities are reduced throughout the year as a result of meltwater or river input. This species complex is not restricted to regions with specific trophic conditions in the upper waters. Although cysts of *Pentapharsodinium dalei*/*Ensiculiefera imariense* occur in sediments where anoxic and hypoxic conditions prevail in bottom waters, relative abundances increase with bottom water oxygen concentrations.

Comparison with other records:

Apart from the sites included in this Atlas cysts of *Pentapharsodinium dalei*/*Ensiculifera imariense* are recorded from the Indian Ocean (Godhe et al., 2000), the Peruvian upwelling area (Biebow et al., 1993), Imari Bay, southwestern Japan (Kobayashi and Matsuoka, 1995) and coastal sediments of southern South Korea (Pospelova and Kim, 2010).

In the Arctic, cysts of *Pentapharsodinium dalei*/*Ensiculifera imariense* are observed in areas that can be covered by sea ice for up to 9 to 12 months a year although a slight negative relationship between its relative abundance and annual ice cover can be distinguished (de Vernal et al., 1998; Radi and de Vernal, 2008; Howe et al., 2010). It is observed in Svalbard fjords with much less sea ice (Grøsfjeld et al., 2009).

Sediment trap and seasonal distribution studies do generally not reveal a clear seasonal pattern in the cyst production of *Pentapharsodinium dalei*/*Ensiculifera imariense*. Cysts of *Pentapharsodinium dalei* /*Ensiculifera imariense*are produced throughout the year in the North Atlantic Ocean. In the Somali Basin, highest cyst production occurs at times of active upwelling during the southwest Monsoon (Zonneveld and Brummer, 2000). In the Georgia Strait (British Columbia) cysts of *Pentapharsodinium dalei*/*Ensiculifera imariense* have been observed in one of the studied years only without showing a seasonal production pattern. In the Saanich Inlet (British Columbia) its production is negatively related to the amount of Fraser River output, upper water temperature, biogenic silica concentrations in the trap sediments and solar insolation. Its production is however positively correlated to precipitation in the area, wind speed and cloud cover (Pospelova et al., 2010; Price and Pospelova, 2011). In an arctic in a fjord north of Svalbard, high production of this species is observed in a short periods in summer/ to late autumn related to full arctic conditions with stratified high productivity conditions (Howe et al., 2010).

A recent study on eutrophication trends in the Mediterranean Sea reveals that cyst production of *Pentapharsodinium dalei*/*Ensiculifera imariense* increases when upper water phosphate concentrations increase (Zonneveld et al., 2012).

Note, so far no morphological difference between cysts of *Pentapharsodinium dalei* and *Esiculifera imariense* have been described and it is therefore not possible to date to differenciate their geographic distribution.

Concluding remarks:

Cysts of *Pentapharsodinium dalei*/*Ensiculifera imariense* can be regarded to represent a polar to equatorial, euryhaline cosmopolitan species complex that can be observed in high relative abundances in all environments covered by this Atlas with exception of the arctic regions.

42. *Peridinium ponticum* Wall et Dale 1973

Figs. 168–171.

Distribution:

The distribution of *Peridinium ponticum* is restricted to the Black Sea and Marmara Sea. Here it can form up to 7% of the association. It is restricted to brackish environments.

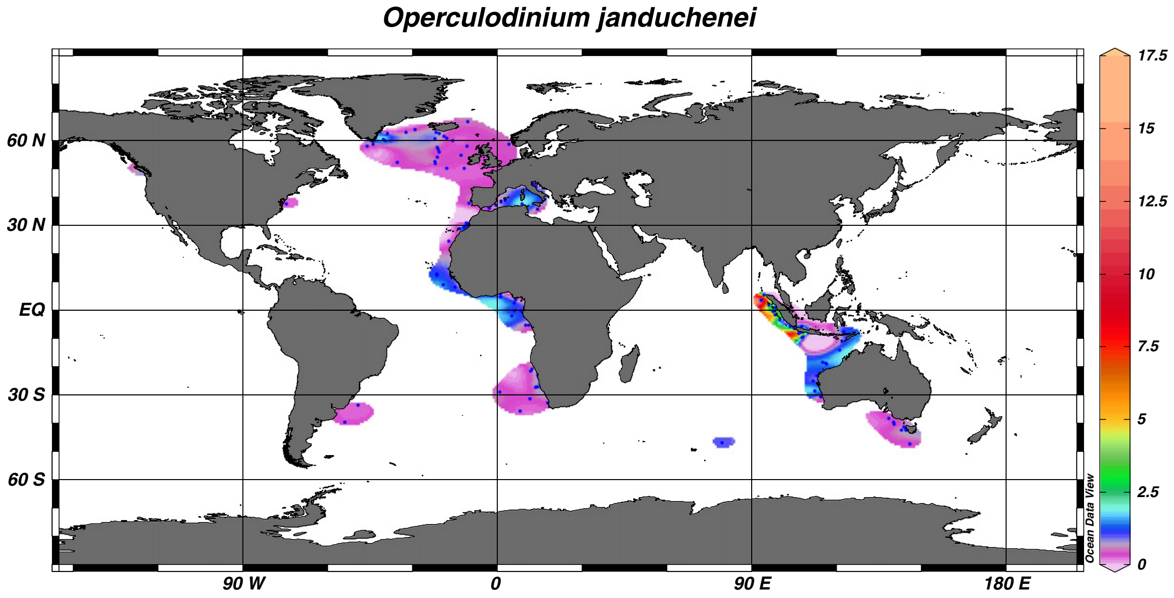

Fig. 156. Geographic distribution of *Operculodinium janduchenei*.

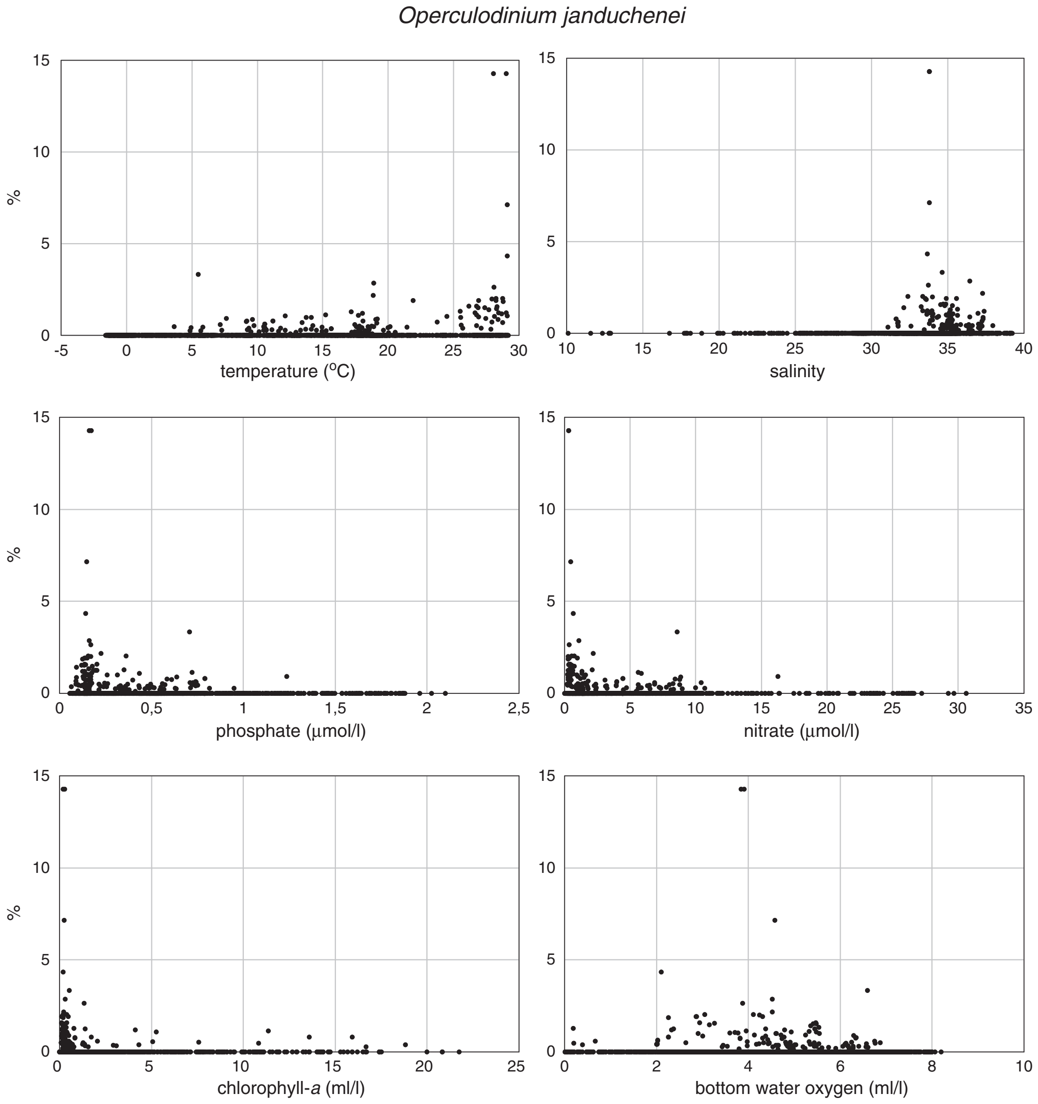

Fig. 157. Relative abundances of *Operculodinium janduchenei* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

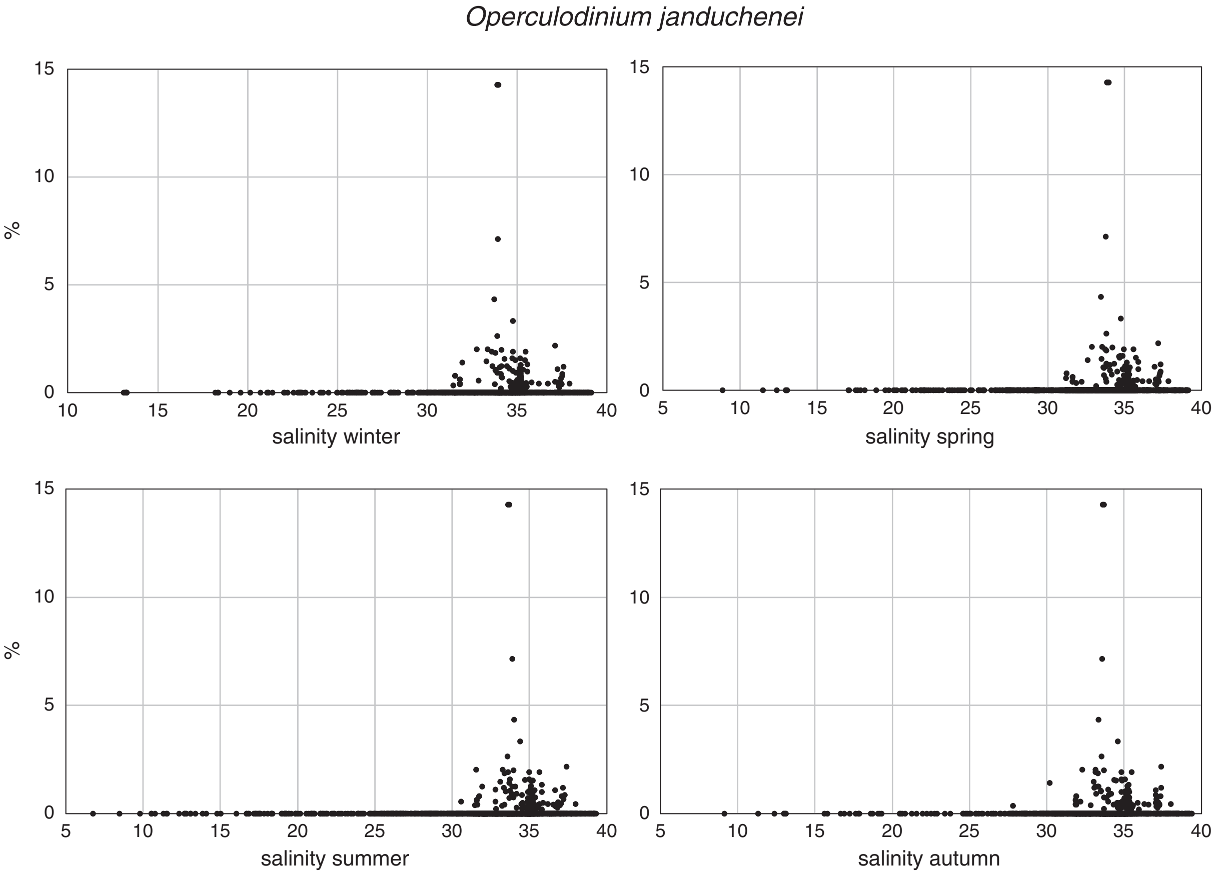

Fig. 158. Relative abundances of *Operculodinium janduchenei* in relationship to seasonal salinity in surface waters.

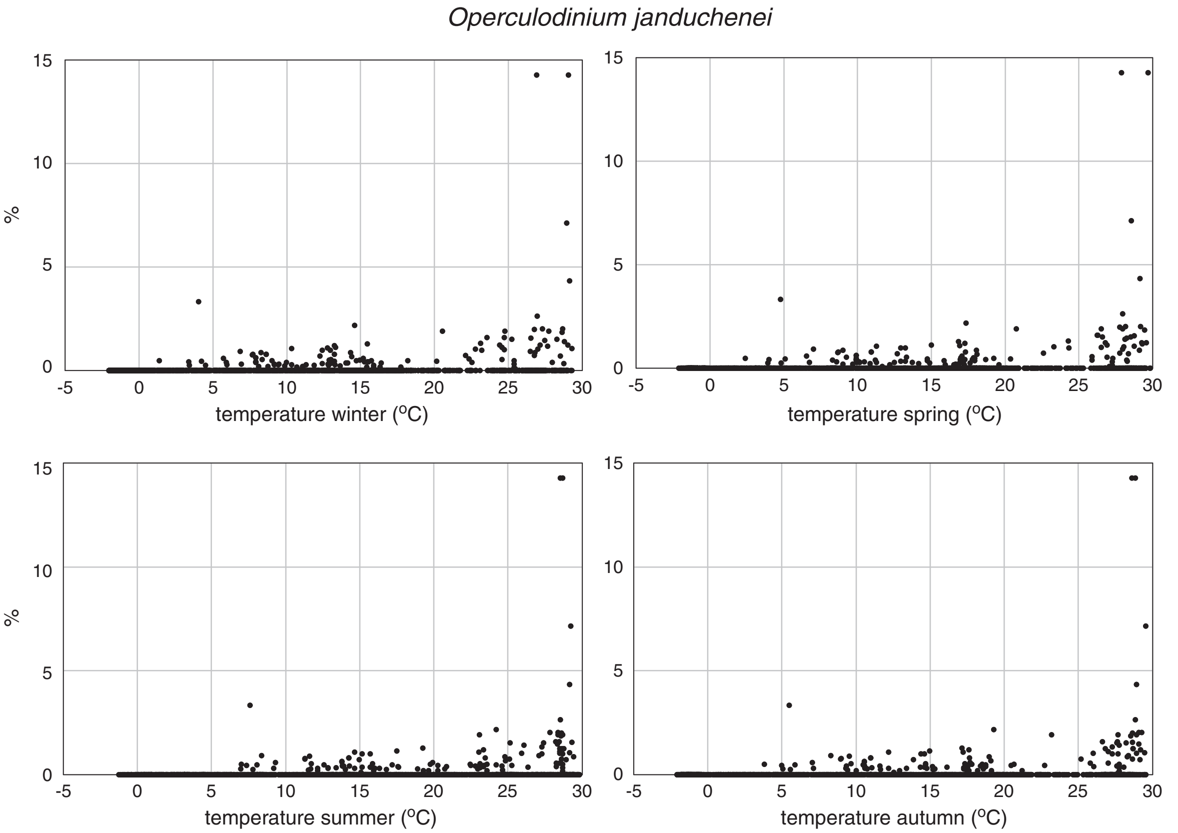

Fig. 159. Relative abundances of *Operculodinium janduchenei* in relationship to seasonal temperature in surface waters.

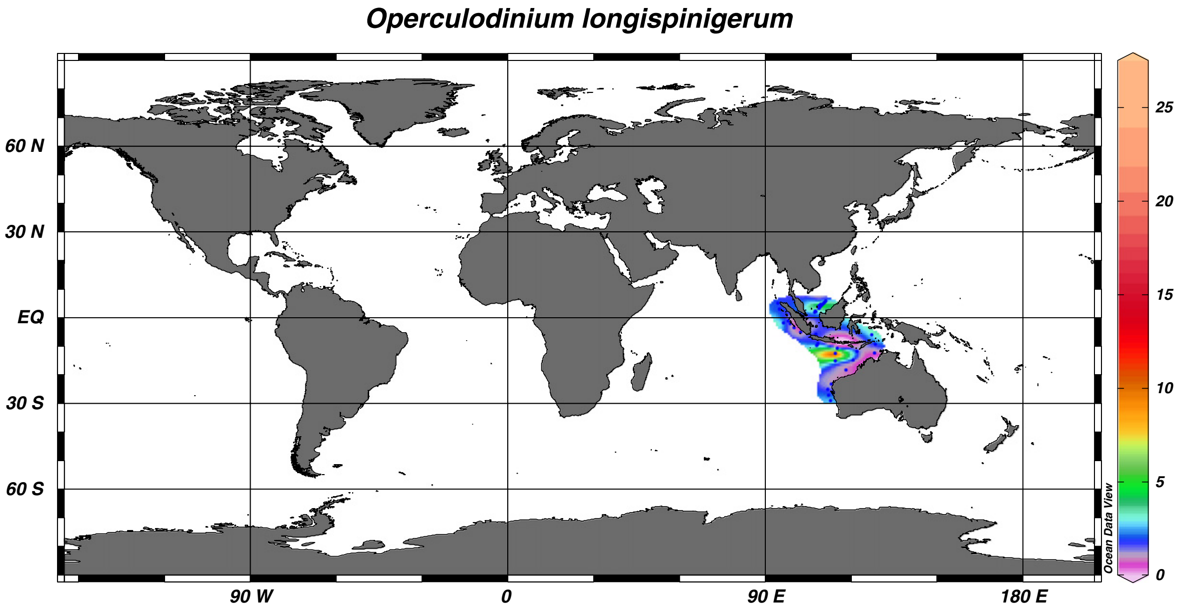

Fig. 160. Geographic distribution of *Operculodinium longispinigerum*.

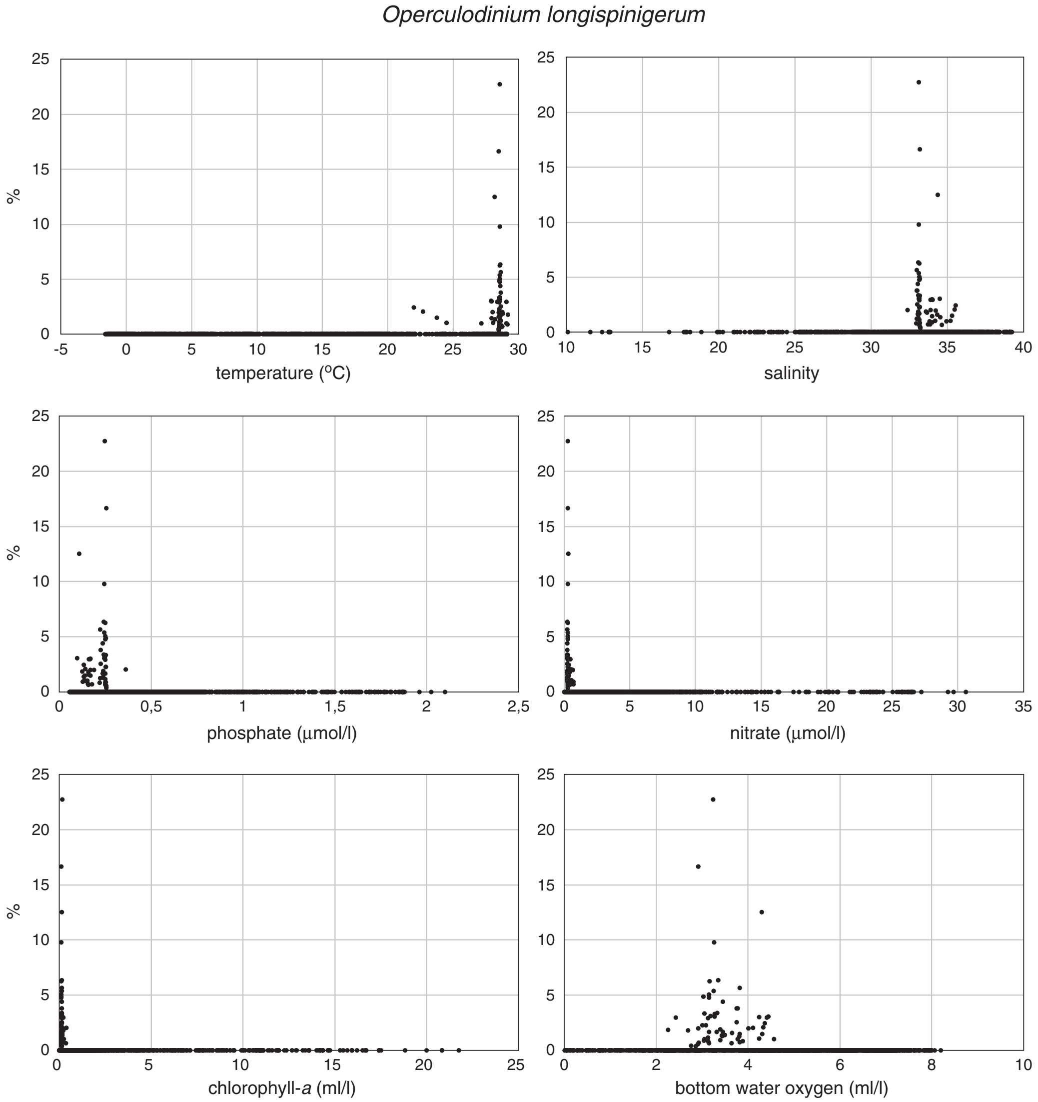

Fig. 161. Relative abundances of *Peridinium ponticum* in relationship to seasonal temperature in surface waters.

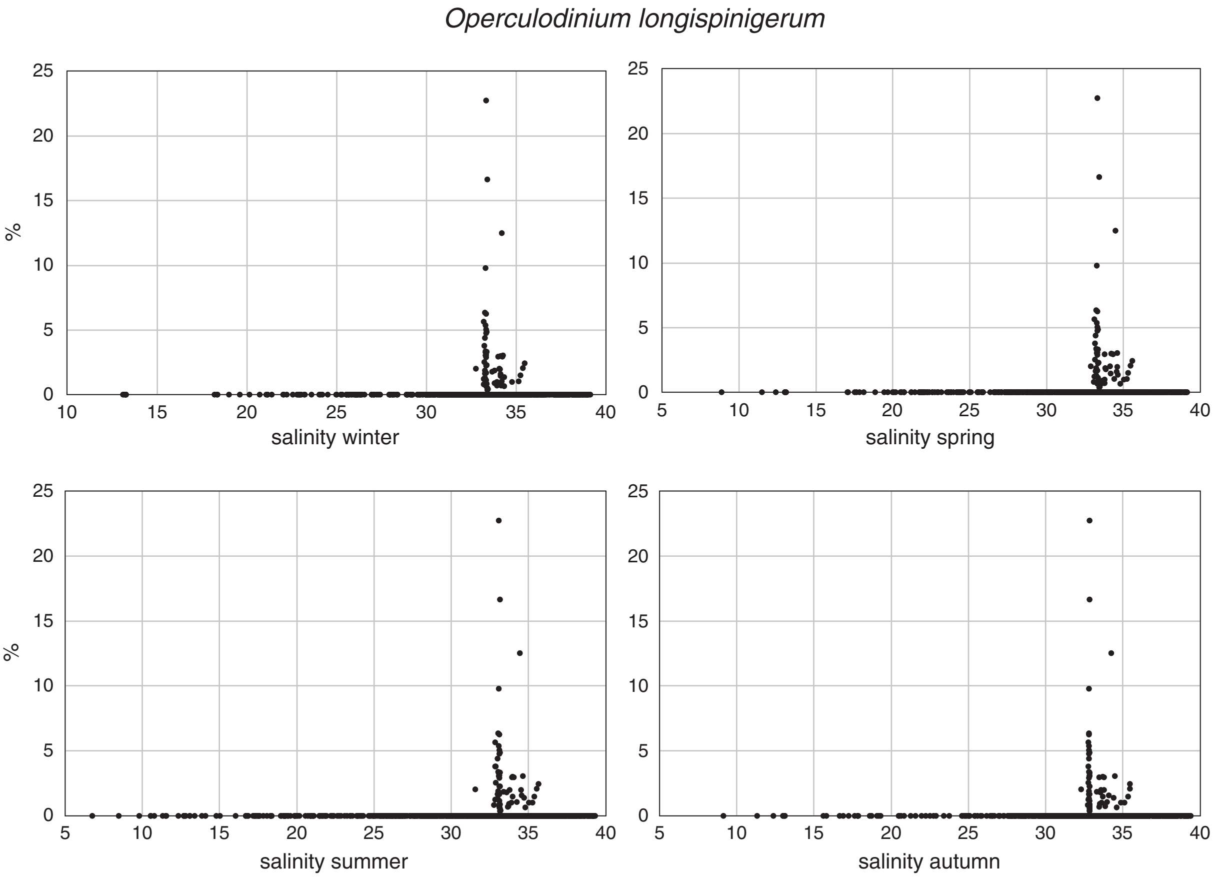

Fig. 162. Relative abundances of *Operculodinium longispinigerum* in relationship to seasonal salinity in surface waters.

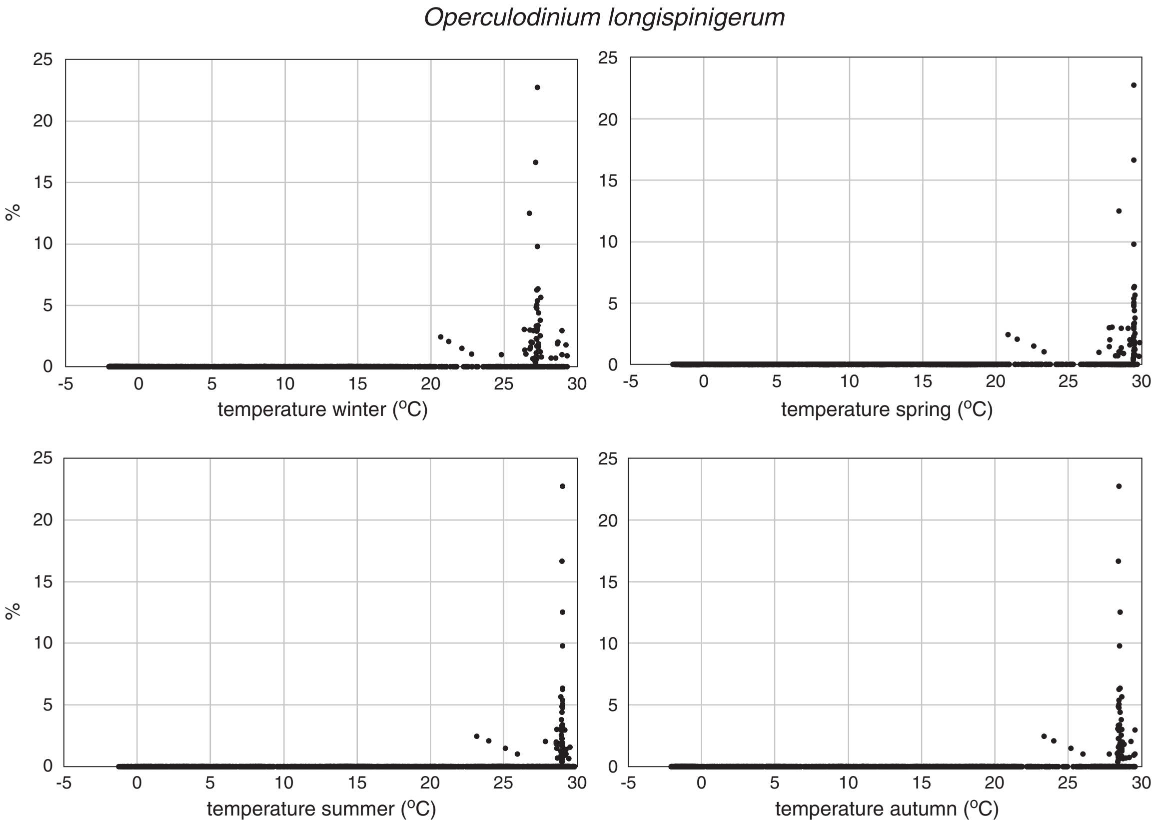

Fig. 163. Relative abundances of *Operculodinium longispinigerum* in relationship to seasonal temperature in surface waters.

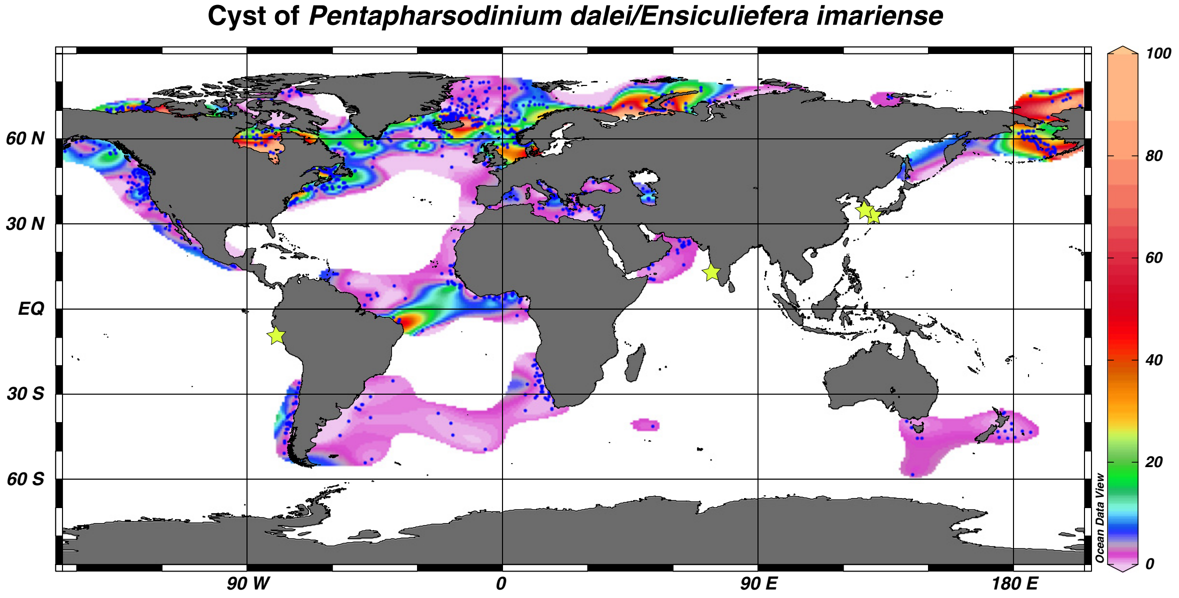

Fig. 164. Geographic distribution of cysts of *Pentapharsodinium dalei*.

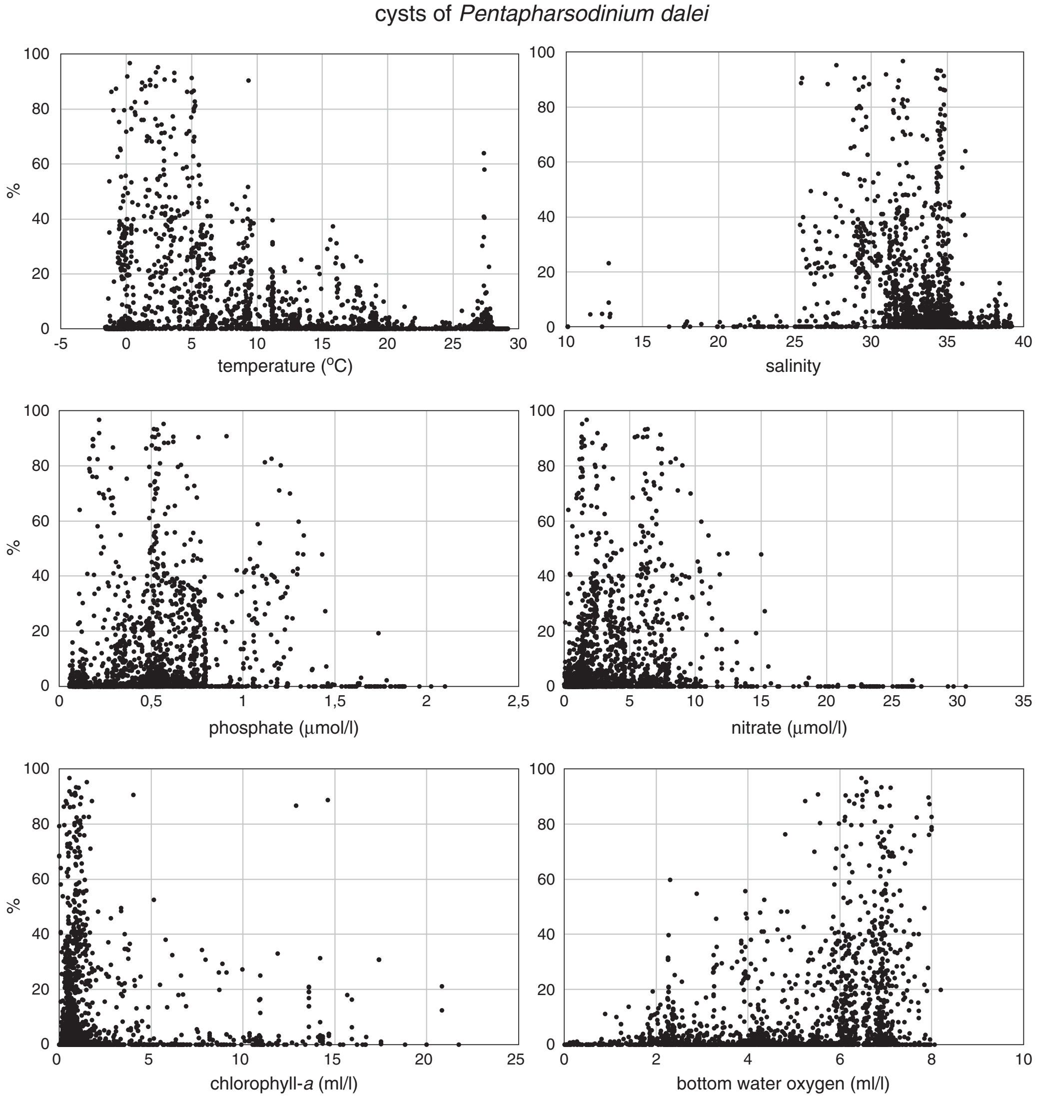

Fig. 165. Relative abundances of cysts of *Pentapharsodinium dalei* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

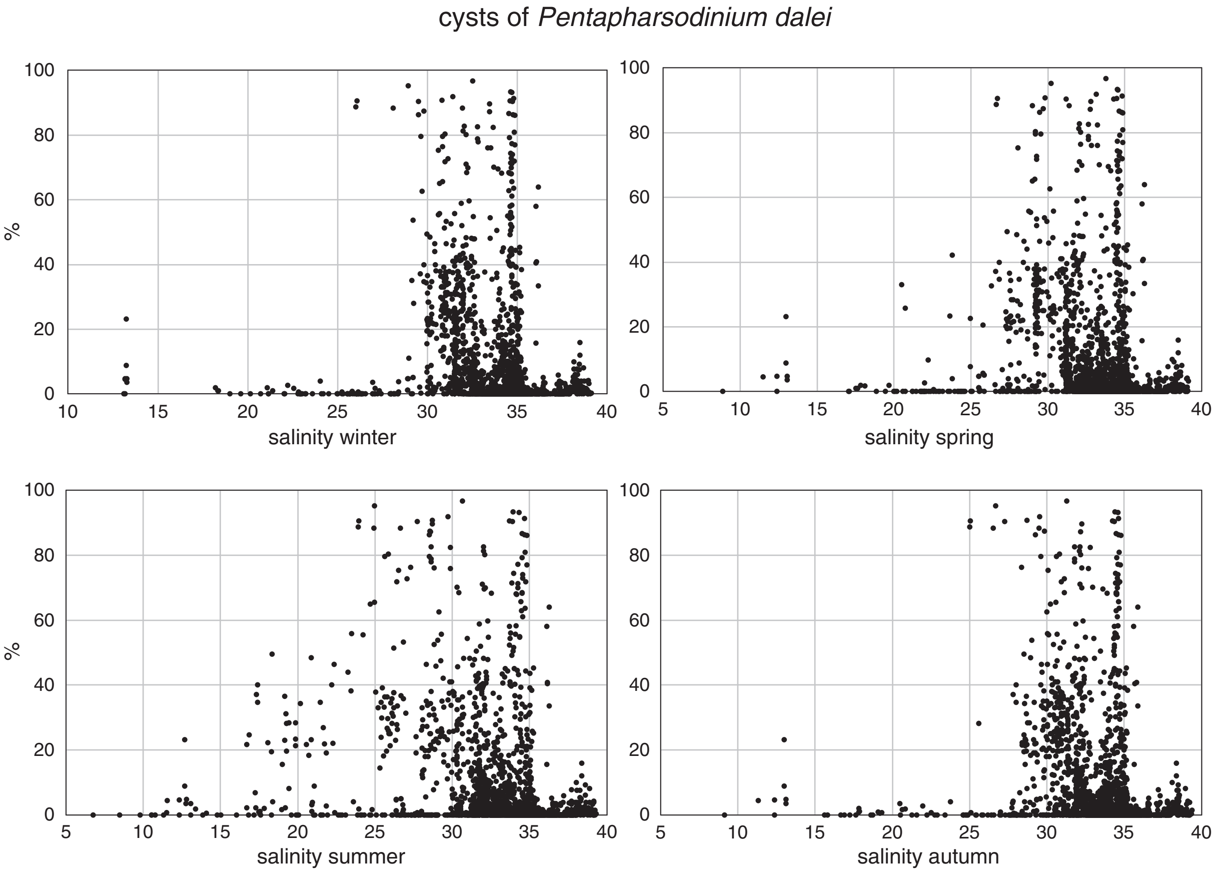

Fig. 166. Relative abundances of cysts of *Pentapharsodinium dalei* in relationship to seasonal salinity in surface waters.

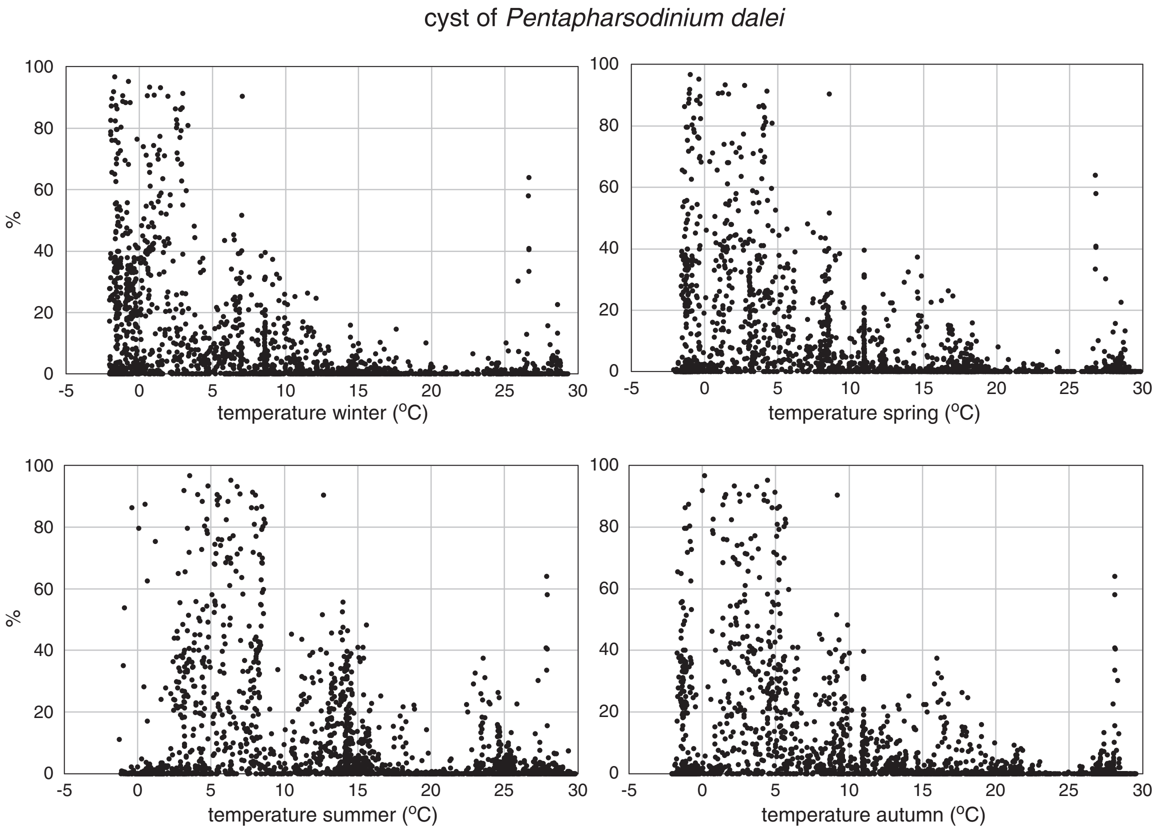

Fig. 167. Relative abundances of cysts of *Pentapharsodinium dalei* in relationship to seasonal temperature in surface waters.

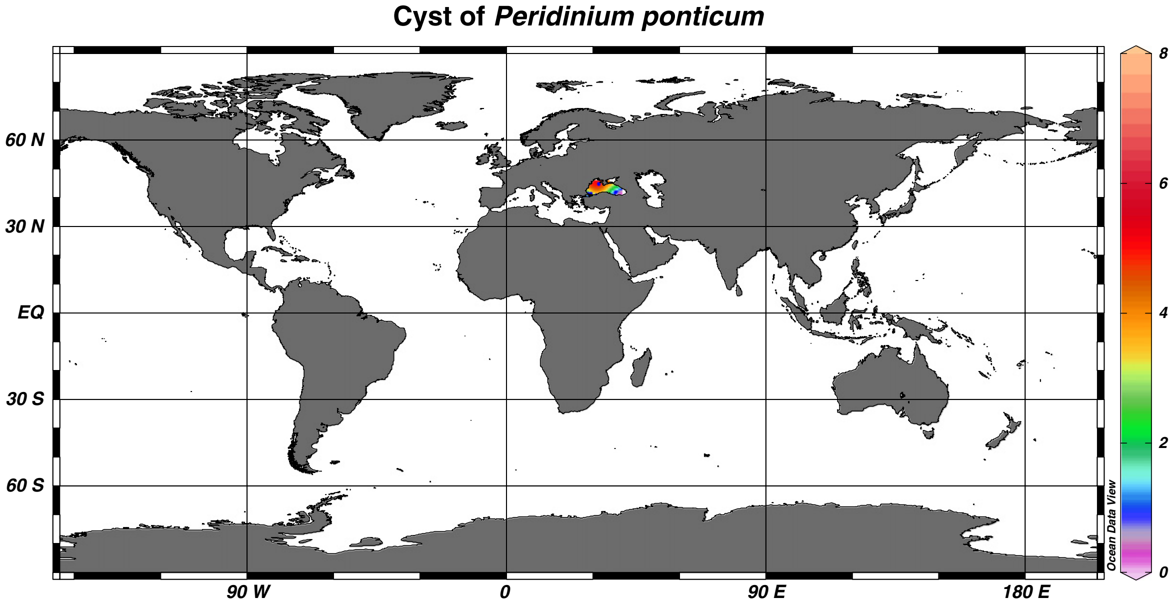

Fig. 168. Geographic distribution of *Peridinium ponticum*.

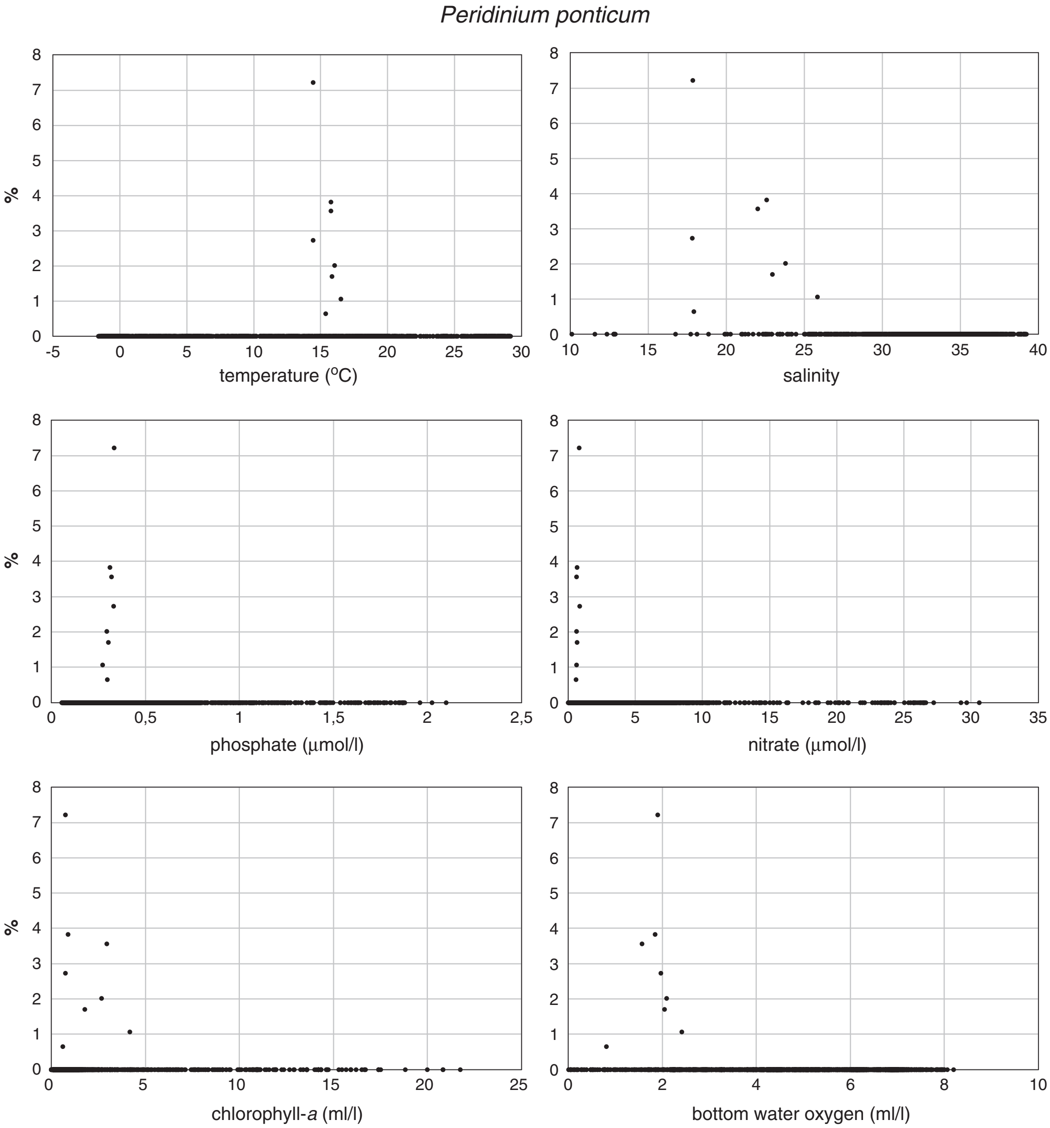

Fig. 169. Relative abundances of *Operculodinium longispinigerum* in relationship to seasonal temperature in surface waters.

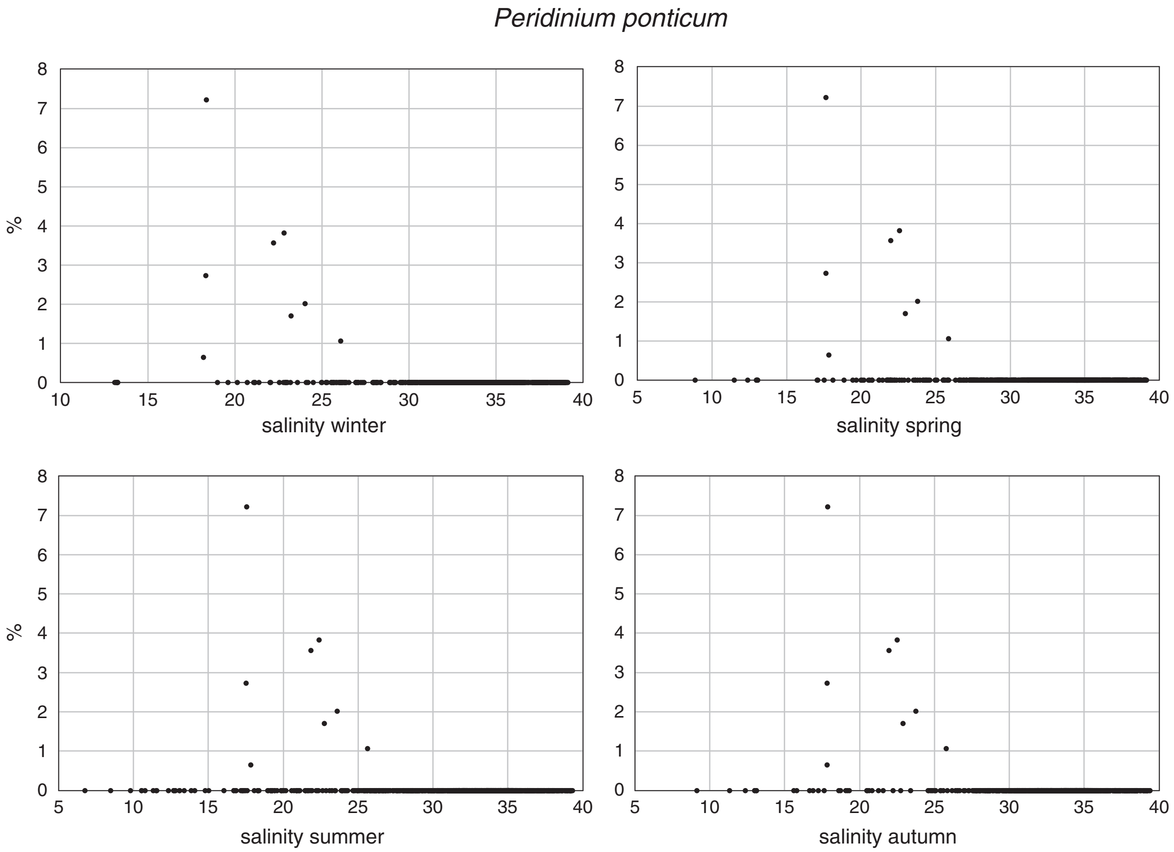

Fig. 170. Relative abundances of *Peridinium ponticum* in relationship to seasonal salinity in surface waters.

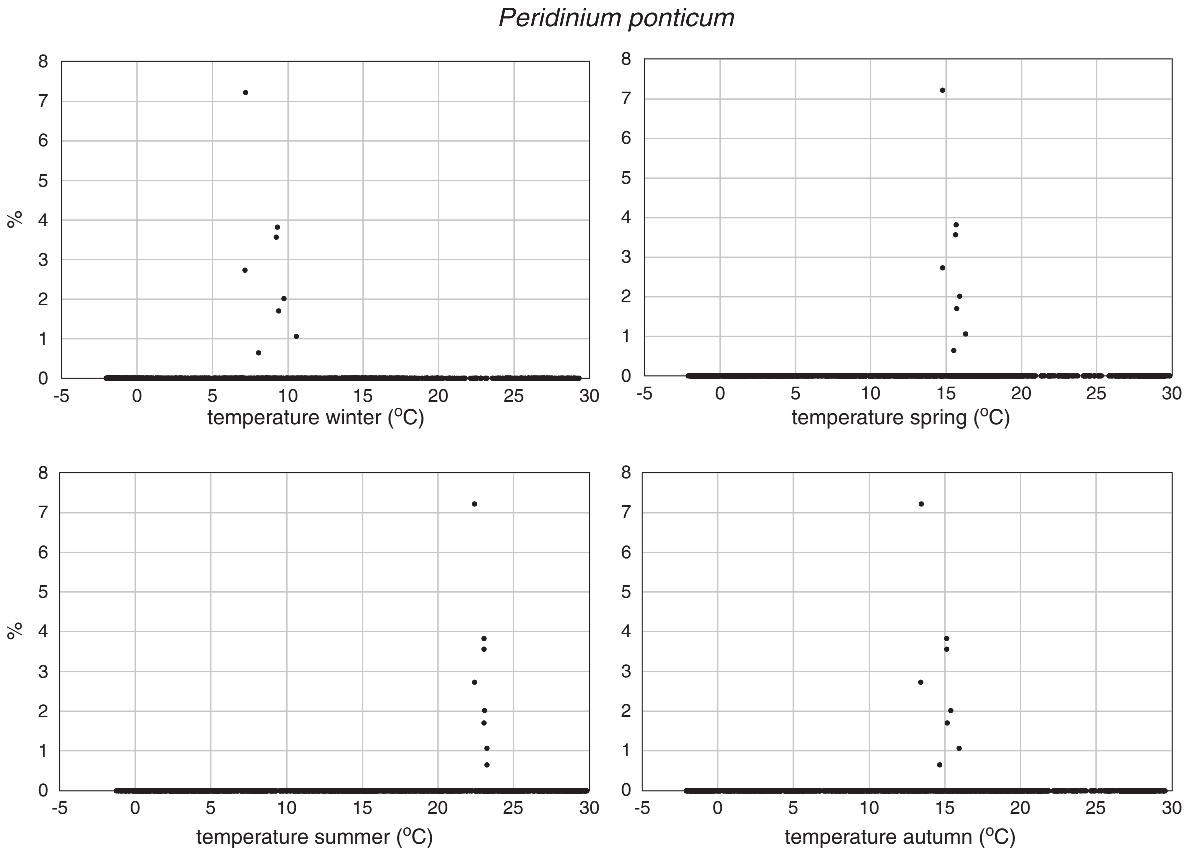

Fig. 171. Relative abundances of *Peridinium ponticum* in relationship to seasonal temperature in surface waters.

Environmental parameters:

SST: 7.1–23.2 °C (winter–summer), iSSS: 17.5–26.0 (summer–winter), [P]: 0.22–0.33 μmol/l, [N]: 0.59–0.83 μmol/l, chlorophyll-*a*: 0.61–4.16 ml/l, bottom water [O_2]: 0.8–2.4 ml/l.

The distribution of *Peridinium ponticum* is restricted to brackish water environments with mesotrophic to eutrophic upper waters conditions.

Comparison with other records:

Peridinium ponticum has not been recorded from regions not covered by this Atlas.

Concluding remarks:

Peridinium ponticum is endemic to the brackish Black Sea and Marmara Sea.

43. Cysts of *Polykrikos* sp. var. *arctica* Kunz-Pirrung 1998

Figs. 172–175.

Distribution:

Cysts of *Polykrikos* spp. var. *arctica* occur in arctic polar and sub-polar regions where it can form up to 15% of the association. Highest relative abundances are observed in the Northwestern Passages and Laptev Sea. It is mainly restricted to coastal sites where surface water salinities can be seasonally reduced as a result of melting of snow and ice.

Environmental parameters:

SST: −2.1–6.8 °C (autumn–summer), SSS: 6.7–34.7 (summer–winter), [P]: 0.12–1.12 μmol/l, [N]: 0.01–7.5 μmol/l, chlorophyll-*a*: 0.24–11.9 ml/l, bottom water [O_2]: ranging between 4.8–8.2 ml/l.

Cysts of *Polykrikos* spp. var. *arctica* can be observed in regions where temperatures are below 0 °C throughout the year. Seasonal contrast in upper water salinity can be large as a result of seasonal meltwater input (maximal seasonal variability at one site ranges between 27.3 in spring and 6.7 in summer). However, although the species is abundant in regions where salinity is seasonally reduced its distribution is not restricted to these areas and it can be abundant in full-marine areas as well.

Cysts of *Polykrikos* spp. var. *arctica* are exclusively observed in regions where bottom waters are well ventilated.

Comparison with other records:

So far cysts of *Polykrikos* spp. var. *arctica* have not been registered in other regions than covered by this Atlas. In the arctic relative abundances increase with the duration of seasonal ice cover (Radi and de Vernal, 2008).

Concluding remarks:

Polykrikos spp. var. *arctica* is an arctic species restricted to regions with cold upper waters and well ventilated bottom waters. These regions are generally mesotrophic to eutrophic. It can be abundant where salinity contrast is large due to seasonal input of meltwater. Its relative abundances increase with the duration of seasonal ice cover.

44. Cysts of *Polykrikos kofoidii* (Chatton 1914) sensu Matsuoka et al., 2009

Figs. 176–179.

Distribution:

Polykrikos kofoidii has a bipolar distribution. On the Northern Hemisphere it is mainly observed in the sub-polar and temperate coastal as well as open oceanic sites. On the Southern Hemisphere it occurs mainly in coastal sites in temperate regions. Highest abundances (up to 51%) occur in the Western Mediterranean Sea and the East China Sea. Although it is mainly registered from coastal areas it is observed in relatively high relative abundances in some parts of the central oceans as well.

Environmental parameters:

SST: −1.6–29.8 °C (winter–summer) with summer SST > 0 °C, SSS: 17.5–38.7 (summer–summer), [P]: 0.06–1.73 μmol/l, [N]: 0.04–18.5 μmol/l, chlorophyll-*a*: 0.08–21.7 ml/l, bottom water [O_2]: 0.01–7.3 ml/l.

Comparison with other records:

Apart from the distribution recorded in this Atlas, *Polykrikos kofoidii* has been documented from several sites along the western Indian coast (Indian Ocean), in the upwelling area of Peru and along the western Mexican coast (central Eastern Pacific, Biebow et al., 1993; Godhe et al., 2000; D'Costa et al., 2008; Limoges et al., 2010).

Sediment trap and seasonal distribution studies do not reveal a clear seasonal pattern in the cyst production of *Polykrikos kofoidii* (Fujii and Matsuoka, 2006; Ribeiro and Amorim, 2008; Pospelova et al., 2010; Price and Pospelova, 2011). In the Saanich Inlet (BC, Canada) slightly enhanced flux rates occurred when upper water salinity and temperatures were reduced due to Cowichan River discharge (Price and Pospelova, 2011). *Polykrikos kofoidii* occurs generally in ice-free environments although it has sporadically been found in arctic sites where seasonal ice cover can last for 4 months (de Vernal et al., 1998). However, ice cover duration correlates negatively with relative abundances of this species in the arctic (Radi and de Vernal, 2008).

Polykrikos kofoidii/*schwartzii* are often characteristically present in highly polluted coastal waters and are thought to be typical for areas where human-induced eutrophication occurs (Pospelova et al., 2002; Pospelova et al., 2004; Pospelova et al., 2005; Dale, 2009; Kim et al., 2009; Pospelova and Kim, 2010; Zonneveld et al., 2012). Unfortunately it is not always clear which of the two species (*P. kofoidii* or *P. schwartzii*) has been recorded or if they have been separated at all. In general cysts of *Polykrikos schwartzyii* are more common in the Pacific coastal waters whereas cysts of *P. kofoidii* are more common in the Atlantic.

Concluding remarks:

Cysts of *Polykrikos kofoidii* can be observed in sub-tropical to sub-polar Northern Hemisphere and in the temperate southern Hemisphere. Although it occurs generally in coastal regions where full-marine conditions prevail although it is not restricted to that. It occurs also in the open ocean and at sites where upper water salinities are reduced throughout the year. The species has a broad distribution with respect to the upper water trophic state and bottom water oxygen concentrations.

45. Cysts of *Polykrikos schwartzii* (Bütschli 1873) sensu Matsuoka et al., 2009

Figs. 180–183.

Distribution:

Cysts of *Polykrikos schwartzii* are observed in coastal regions of the equatorial and sub-tropical north Atlantic, the Eastern Mediterranean Sea, Black Sea and Marmara Sea as well as the temperate South Atlantic, the sub-tropical Arabian Sea and the equatorial to sub-polar Pacific Ocean. It is not observed in the central parts of the oceans but can be very abundant in the vicinity of active upwelling cells for instance off NW Africa, the Benguela upwelling area off SW Africa and off central western America. Abundances >20% (up to 77%) occur in the tropical/equatorial parts off the Mexican coast (eastern equatorial Pacific), off NW Africa (eastern equatorial Atlantic), the Yellow Sea, East China Sea and Sea of Japan.

Environmental parameters:

SST: −1.6–29.4 °C (winter–summer), SSS: 16.7–38.7 (summer–summer), [P]: 0.07–1.63 μmol/l, [N]: 0.18–18.5 μmol/l, chlorophyll-*a*: 0.01–20.0 ml/l, bottom water [O_2]: 0.8–8.2 ml/l.

Although the majority of the recordings are from full-marine settings, cysts of *P. schwartzii* can be observed in areas with reduced salinities occur during summer. The species can be very abundant in eutrophic environments but it is occasionally recorded from oligotrophic environments. Low cysts concentrations occur where phosphate concentrations are lowest. Cysts of *Polykrikos schwartzii* are not recorded from sites with anoxic bottom waters.

Comparison with other records:

Apart from the distribution recorded in this Atlas, cysts of *Polykrikos schwartzii* are observed along the western Indian margin, in the Congo

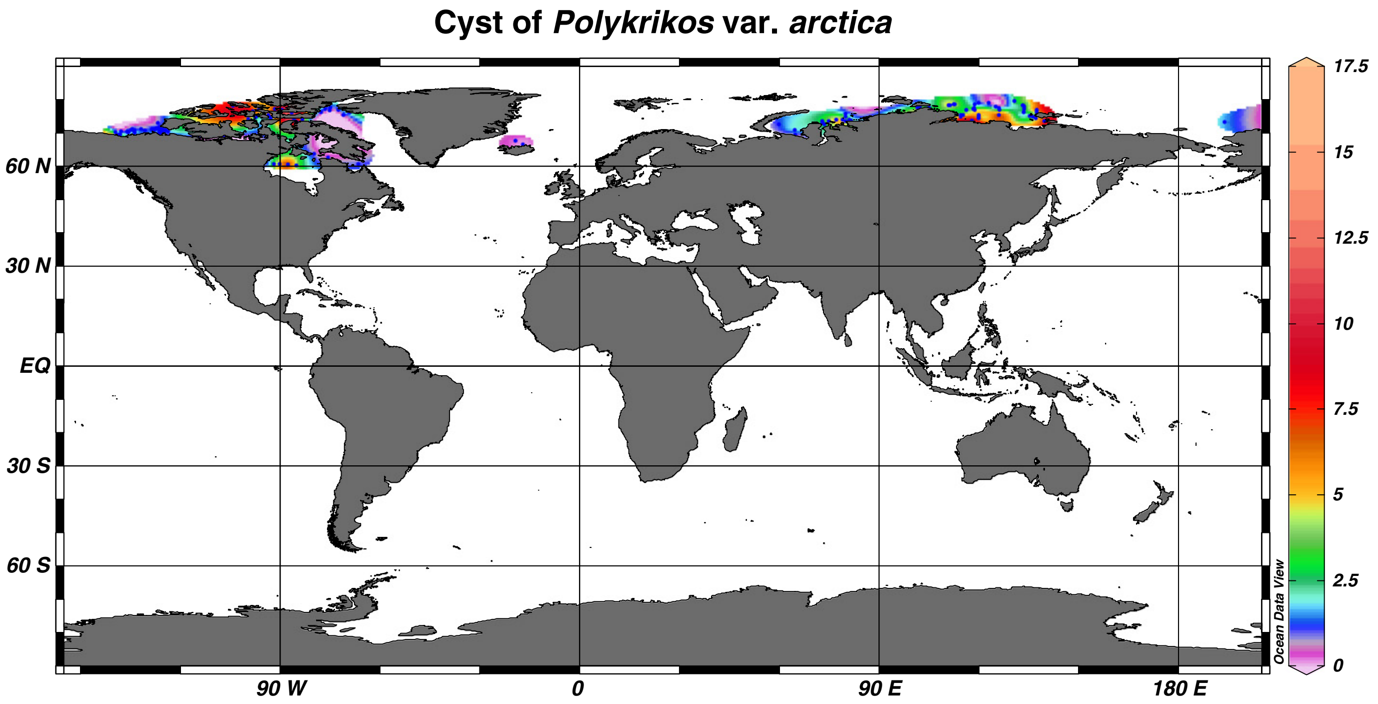

Fig. 172. Geographic distribution of cysts of *Polykrikos* spp. var. *arctica*.

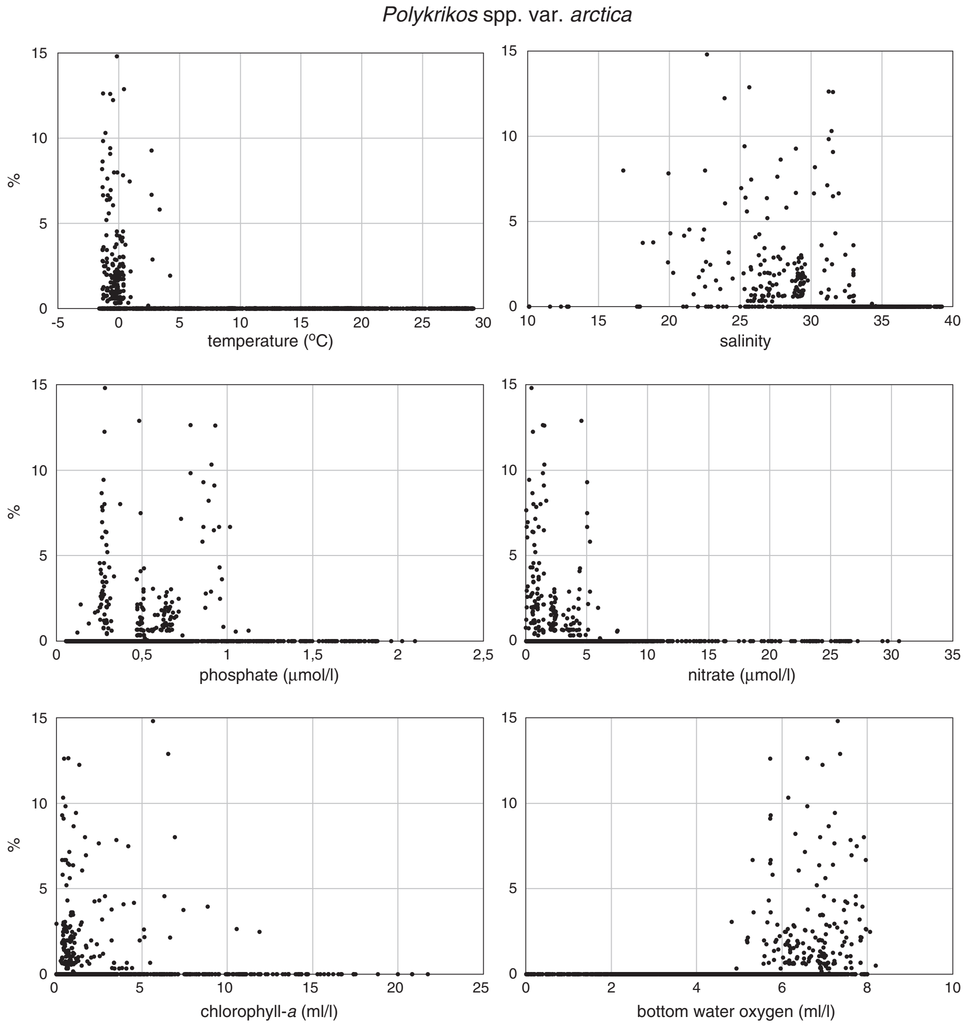

Fig. 173. Relative abundances of cysts of *Polykrikos* spp. var. *arctica* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

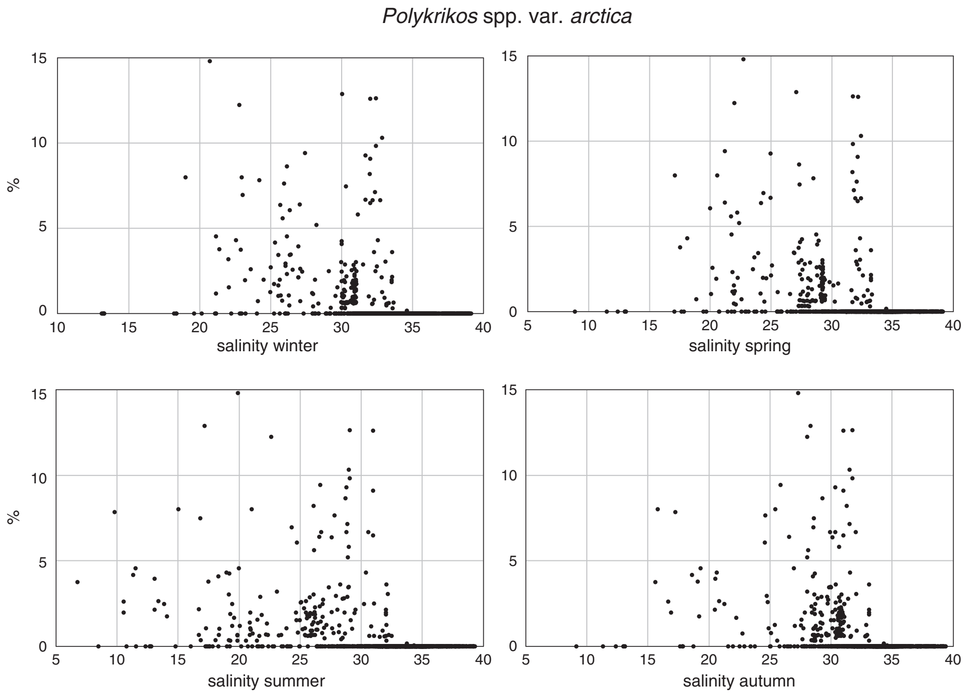

Fig. 174. Relative abundances of cysts of *Polykrikos* spp. var. *arctica* in relationship to seasonal salinity in surface waters.

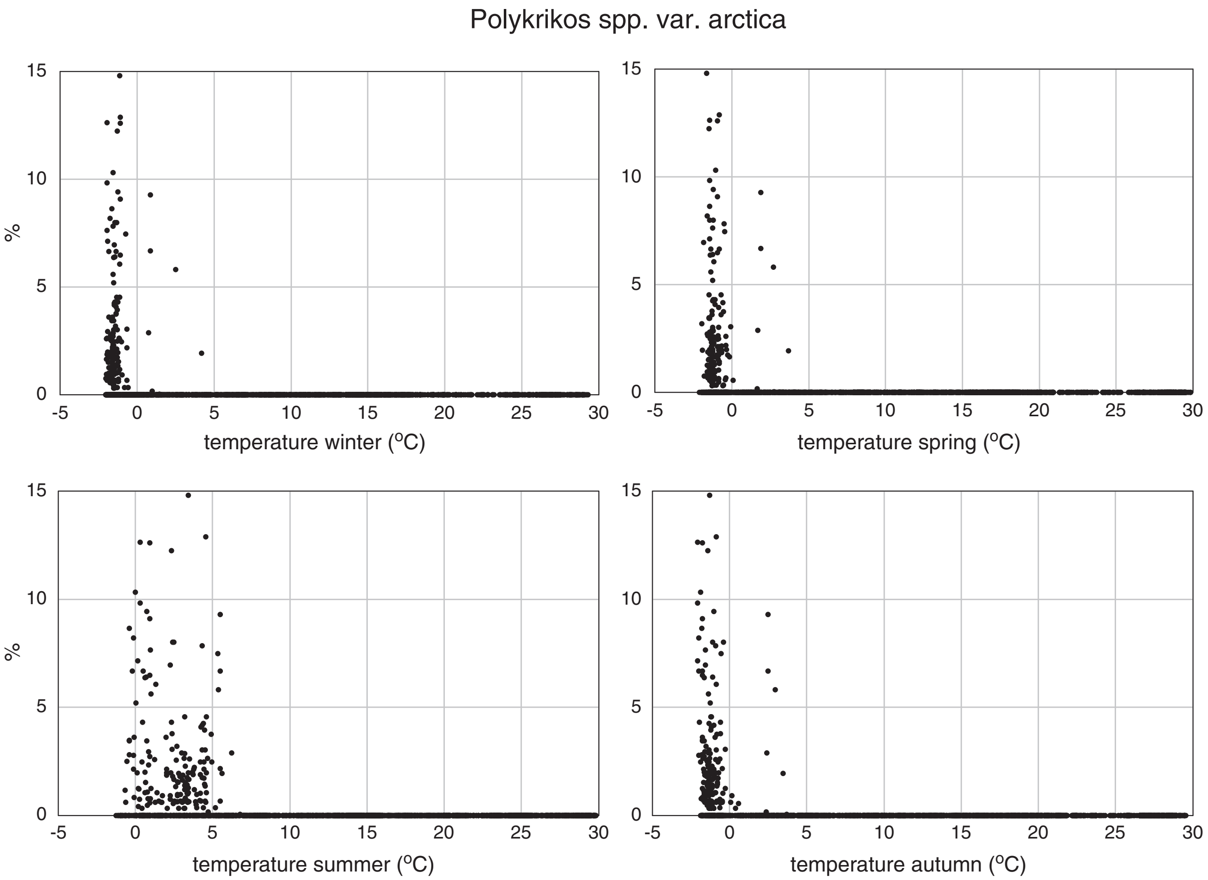

Fig. 175. Relative abundances of cysts of *Polykrikos* spp. var. *arctica* in relationship to seasonal temperature in surface waters.

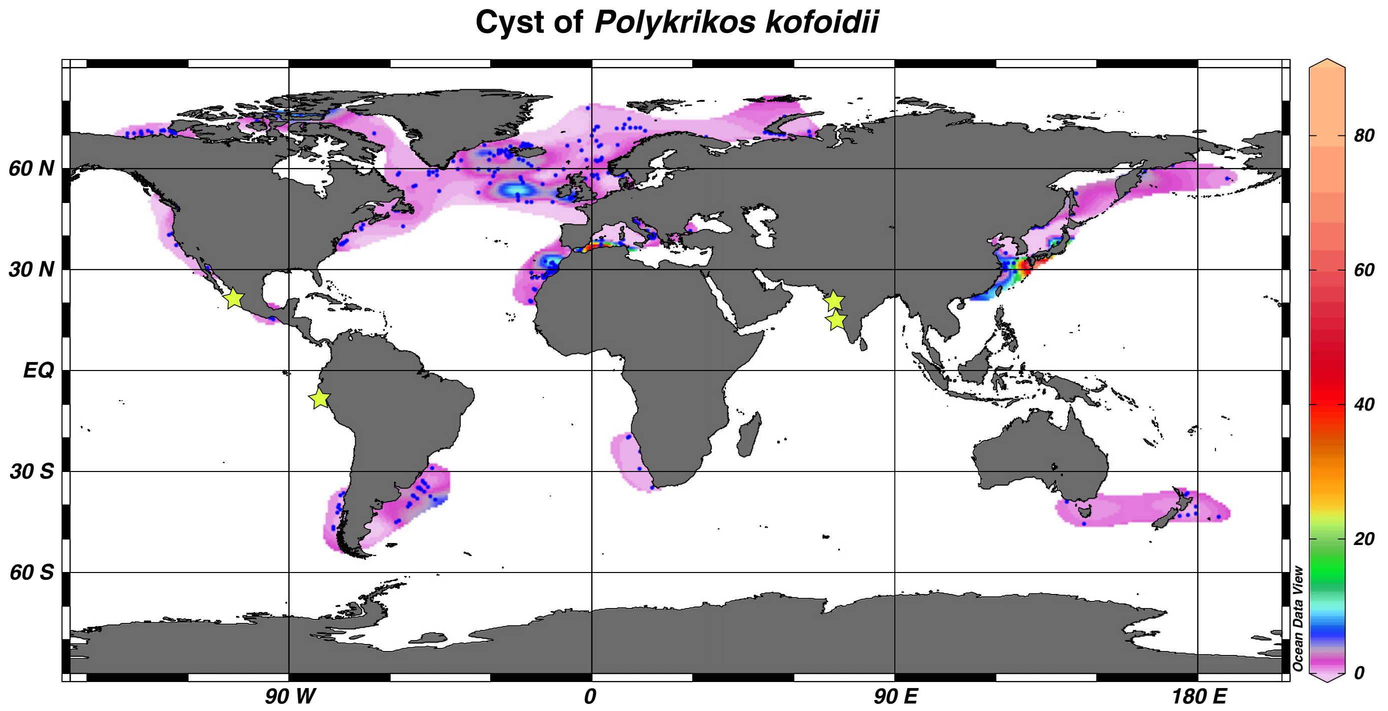

Fig. 176. Geographic distribution of cysts of *Polykrikos kofoidii*.

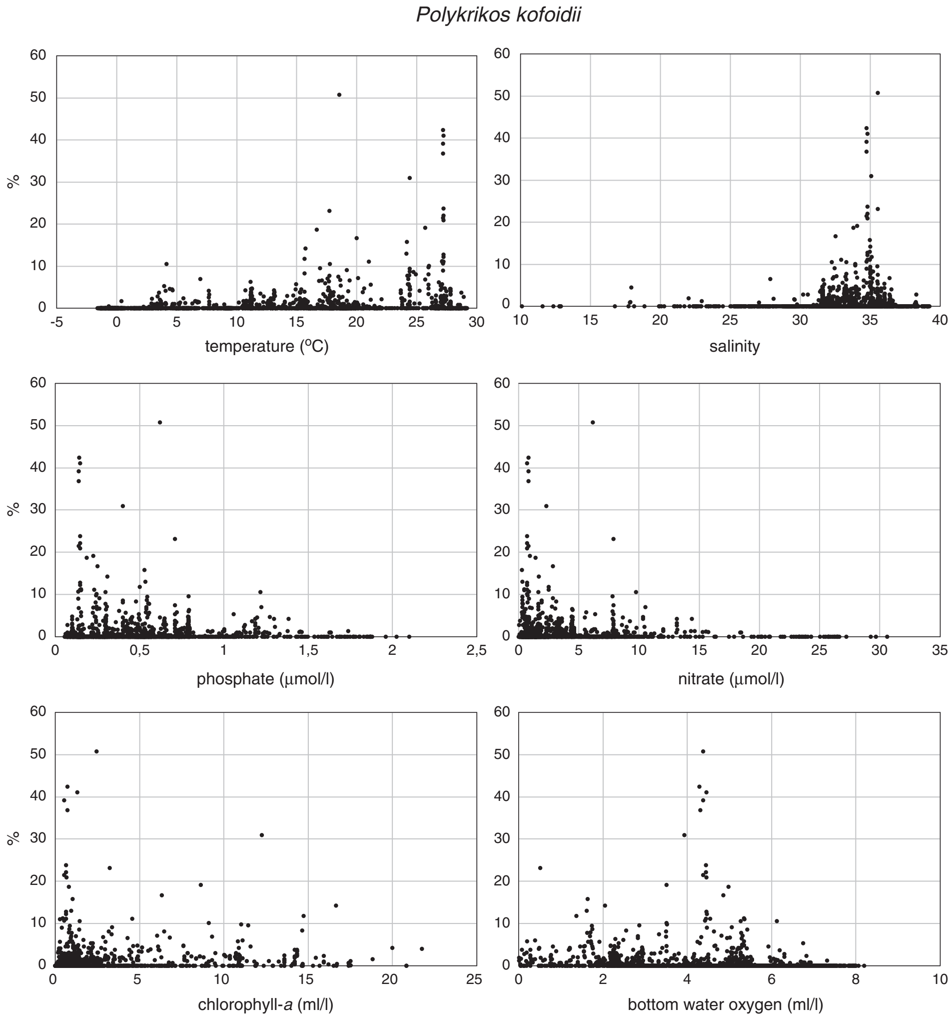

Fig. 177. Relative abundances of cysts of *Polykrikos kofoidii* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

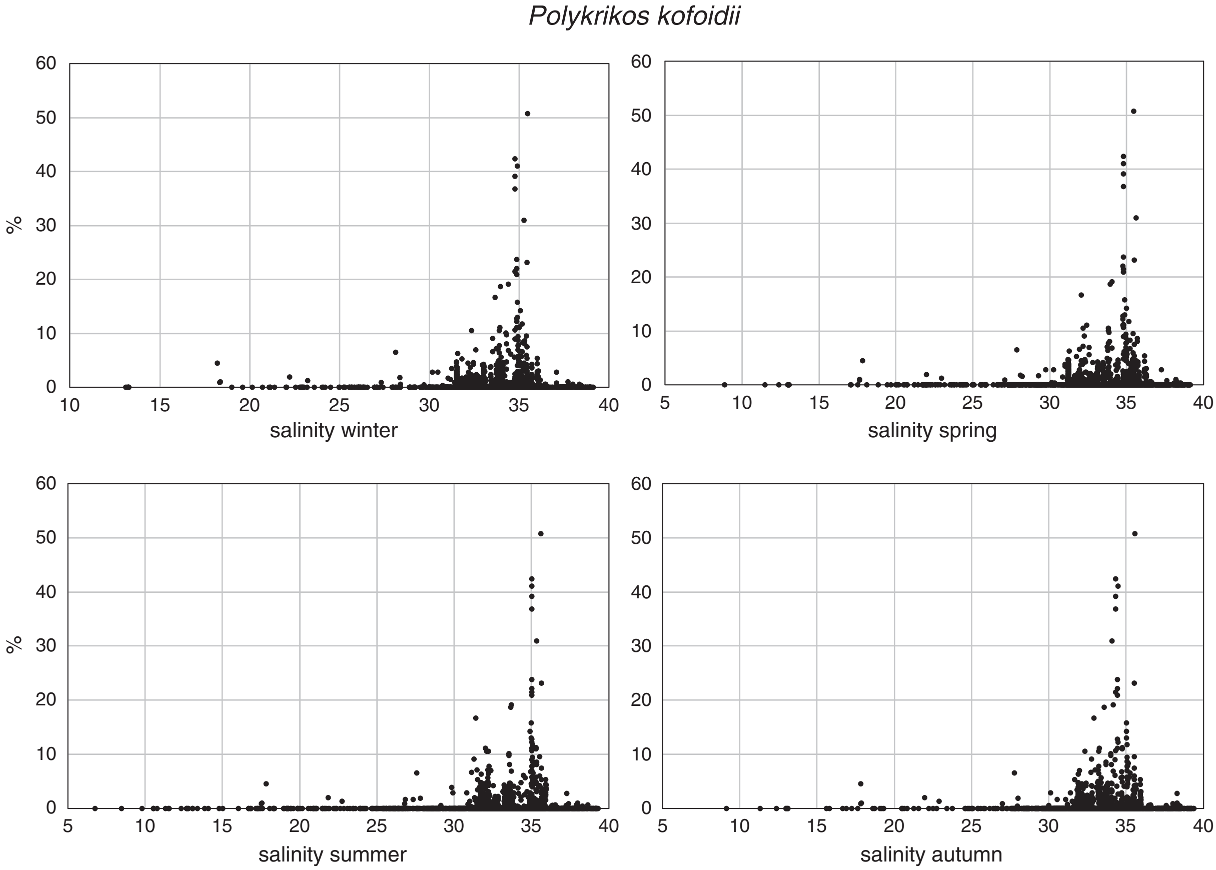

Fig. 178. Relative abundances of cysts of *Polykrikos kofoidii* in relationship to seasonal salinity in surface waters.

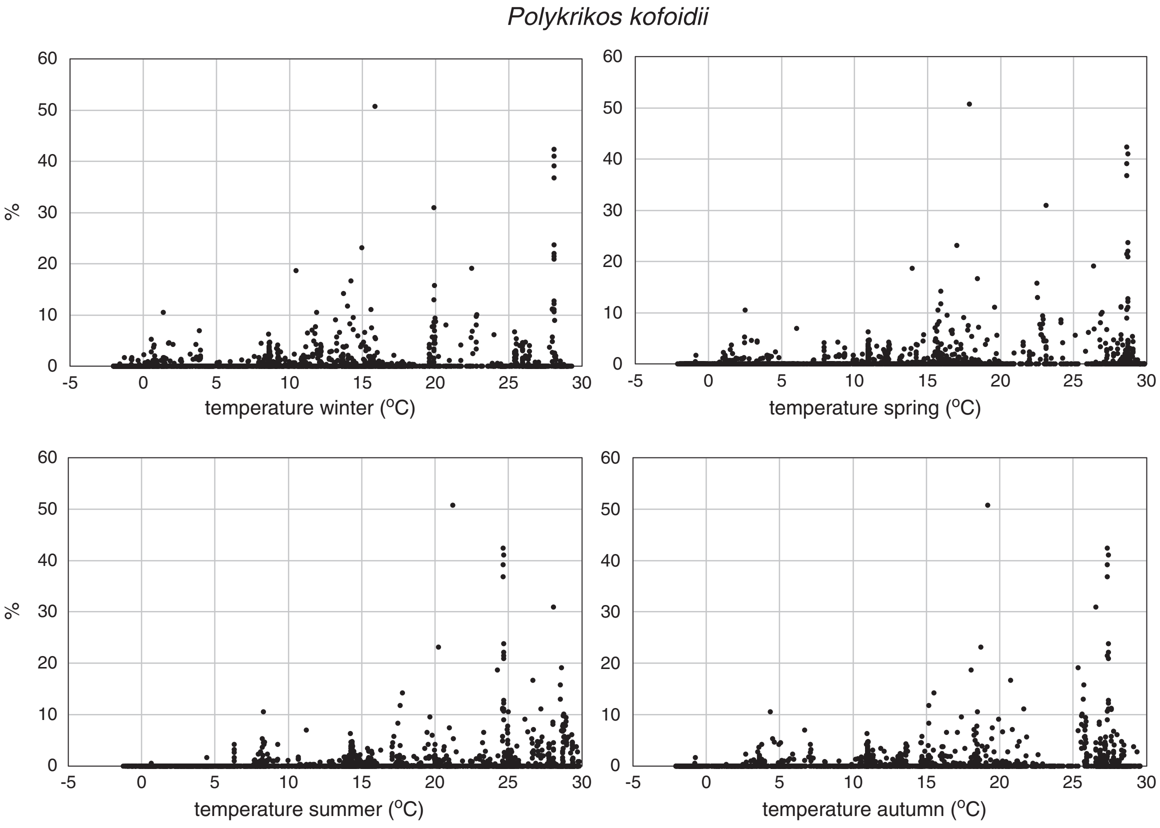

Fig. 179. Relative abundances of cysts of *Polykrikos kofoidii* in relationship to seasonal temperature in surface waters.

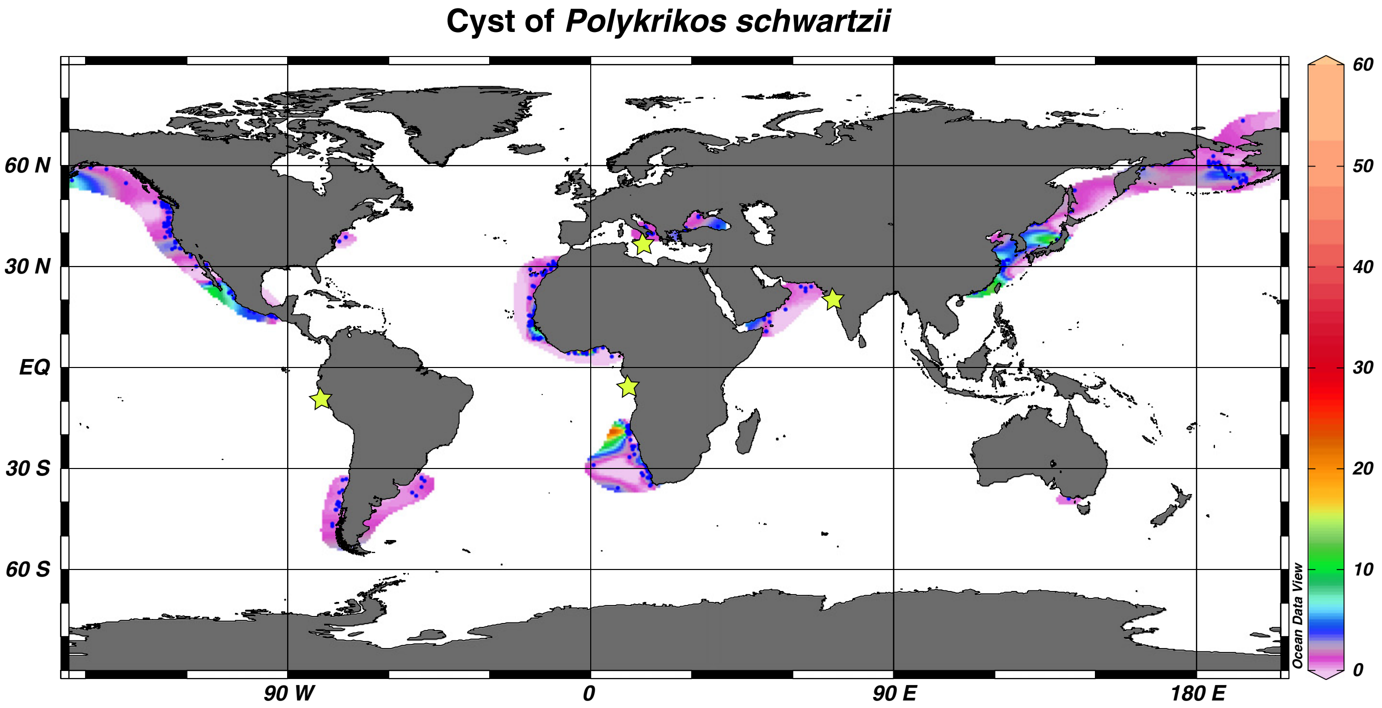

Fig. 180. Geographic distribution of cysts of *Polykrikos schwartzii*.

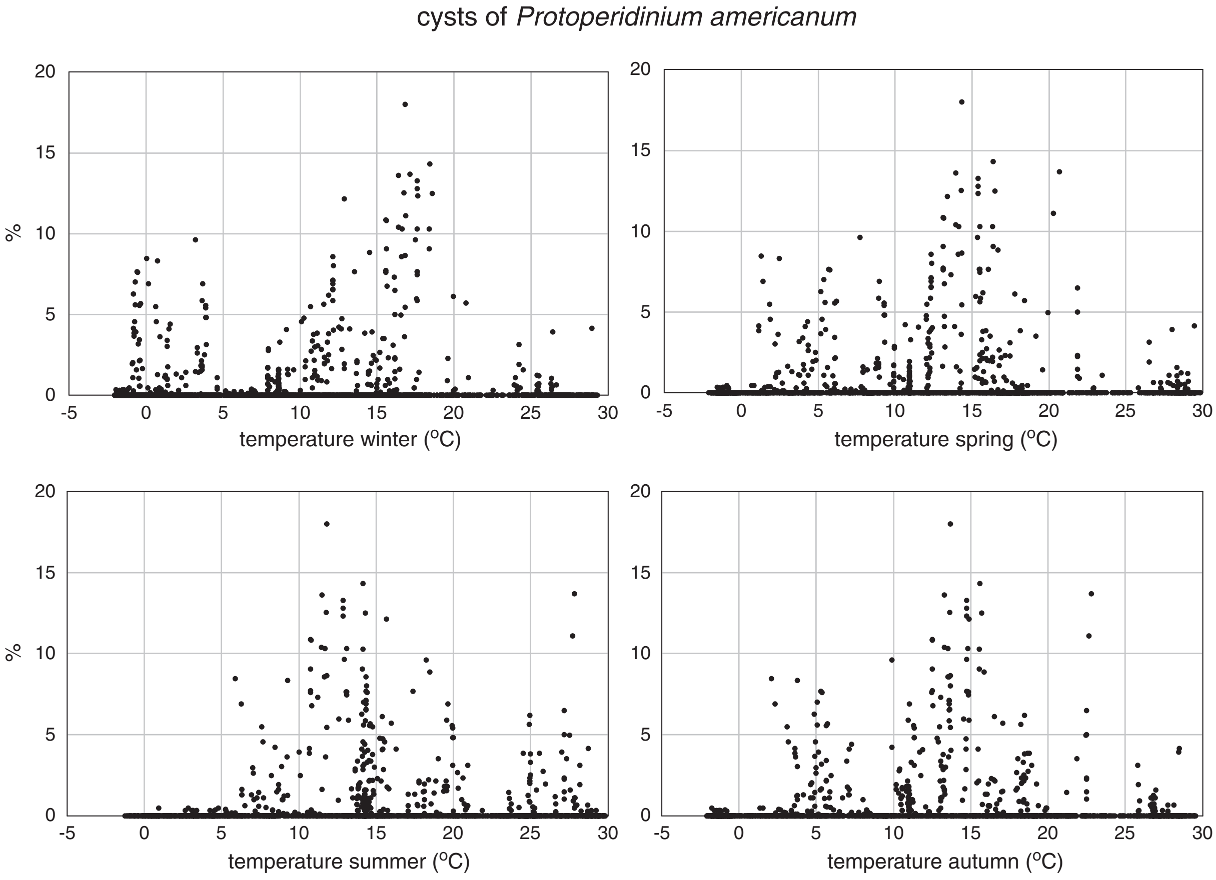

Fig. 181. Relative abundances of cysts of *Polykrikos schwartzii* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

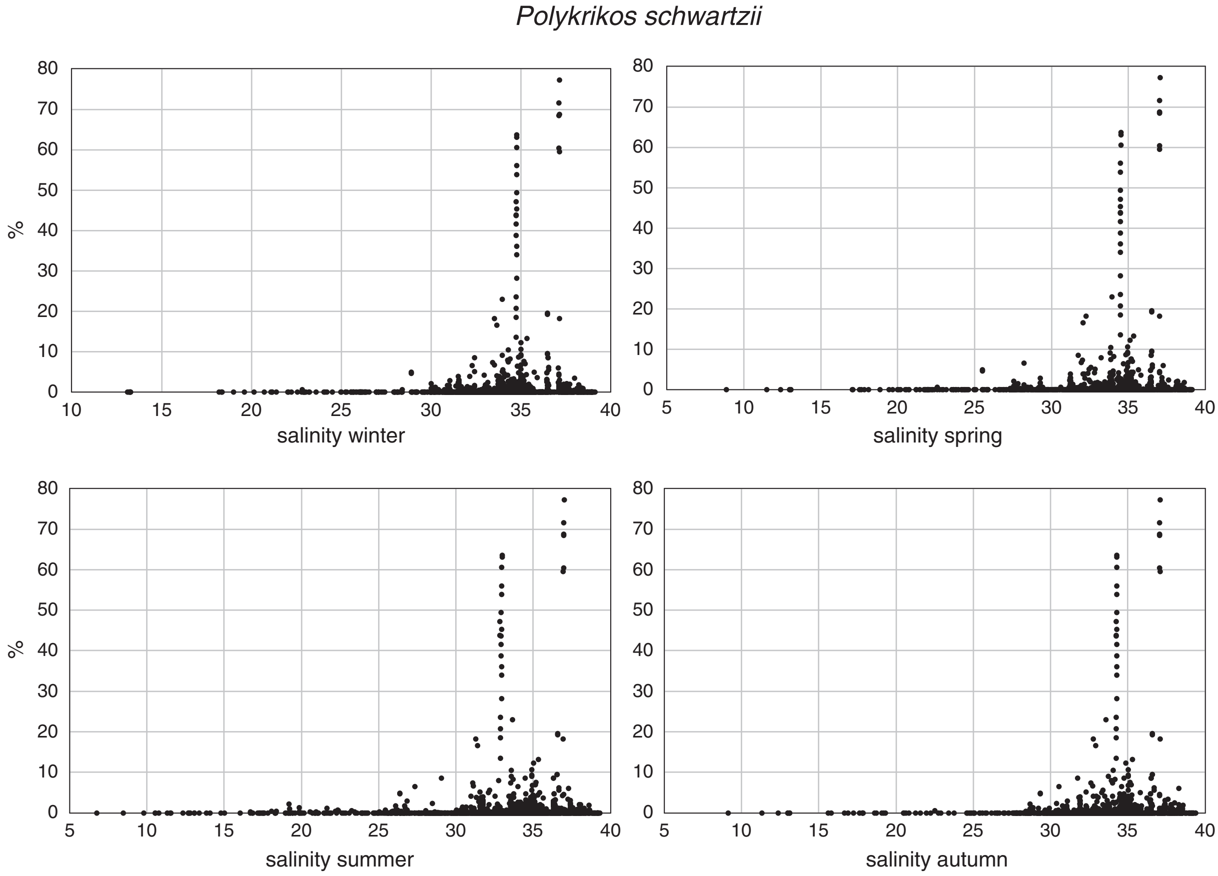

Fig. 182. Relative abundances of cysts of *Polykrikos schwartzii* in relationship to seasonal salinity in surface waters.

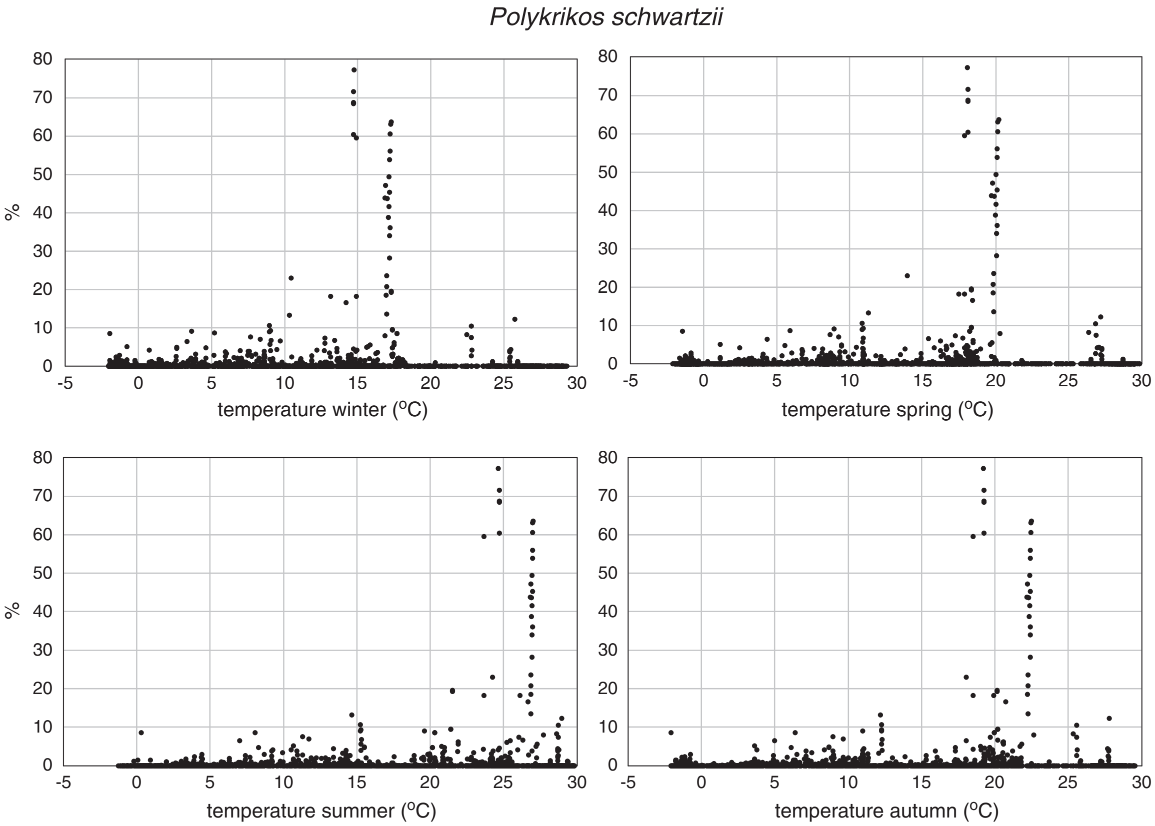

Fig. 183. Relative abundances of cysts of *Polykrikos schwartzii* in relationship to seasonal temperature in surface waters.

discharge plume off western central Africa, the Peruvian upwelling area and off Sicily (Italy, central Mediterranean sea, Biebow et al., 1993; Dale et al., 2002; D'Costa et al., 2008; Rubino et al., 2010). Sediment trap studies show no seasonal pattern in the cyst production of *Polykrikos schwartzii* (Montresor et al., 1998; Zonneveld and Brummer, 2000; Fujii and Matsuoka, 2006; Price and Pospelova, 2011). In the Saanich Inlet (BC, Canada) enhanced cyst fluxes were registered when biogenic silica flux was enhanced (Price and Pospelova, 2011). In the western Arabian Sea off Somalia, cysts of *Polykrikos schwartzii* are observed in high abundances for the most coastal trap site only. There they reach extremely high numbers in sediments that had been transported from the shelf into the deeper ocean during a mass transport flux (Zonneveld and Brummer, 2000).

Polykrikos schwartzii is often observed in the tropics and subtropics. An exception is formed by the Pacific Ocean where it can be found in high latitudes as well. In the Pacific Arctic a positive correlation occurs between seasonal ice cover duration and the abundance of *Polykrikos schwartzii* cysts (Radi and de Vernal, 2008). Radi and de Vernal (2008) note however that there are slight morphological differences between the cysts of *Polykrikos schwartzii* in the North Pacific and those in other parts of the world although this is not confirmed by Radi et al. (2007) and Pospelova et al. (2008) who observed cysts with a morphotype comparable to that of the Atlantic Ocean along the coast of British Columbia (Canada) and Washington State (USA) in the North Pacific. A species with a different morphology marked in previous literature as "*Polykrikos* cf. *kofoidii*" can be observed in the warmer waters of the coastal eastern Pacific (Pospelova et al., 2008). This morphotype seems to be endemic for the Pacific Ocean. The above discussion documents that several "cryptic species" have been included into the morphotype "cysts of *Polykrikos schwartzii*" in this Atlas and future studies are needed to separate these forms on species level.

Polykrikos kofoidii/*schwartzii* are often characteristically present in highly polluted coastal waters and are thought to be typical for areas where human-induced eutrophication occurs (Pospelova et al., 2002; Matsuoka et al., 2003; Pospelova et al., 2004; Pospelova et al., 2005; Dale, 2009; Kim et al., 2009; Pospelova and Kim, 2010; Zonneveld et al., 2012). Unfortunately it is not always clear which of the two species (*P. kofoidii* or *P. schwartzii*) has been recorded or if they have been separated at all.

Concluding remarks:

Cysts of *Polykrikos schwartzii* typically occur in coastal temperate to equatorial environments. Only in the Pacific Ocean is occurs also in high latitudes. It can be abundant in regions with seasonally reduced salinities. it also occurs in but is not restricted to eutrophic areas and is not observed in regions where anoxic bottom waters occur.

46. *Polysphaeridium zoharyi* (Rossignol 1962) Bujak et al., 1980

Figs. 184–189.

Distribution:

Polysphaeridium zoharyi is observed in coastal sub-tropical to equatorial regions. Abundances >50% (up to 98%) occur in the Gulf of Mexico and the Banda Sea (off Indonesia) where high upper water salinities and temperatures exist. It also is found in the South Atlantic and Pacific Oceans at large distances from the shore. With exception of the Mediterranean Sea it is not recorded north of 30°N and south of 40°S.

Environmental parameters:

SST: 8.9–29.8 °C (winter–summer) with summer SST > 14 °C. SSS: 28.4–39.4 (autumn–autumn), [P]: 0.06–1.1 μmol/l, [N]: 0.04–8.9 μmol/l, chlorophyll-*a*: 0.06–18.8 ml/l, bottom water [O_2]: 0.05–6.0 ml/l.

Abundances >50% occur where upper temperatures are > 29.1 °C in summer and >19.1 °C in winter. High relative abundances are observed in regions with low phosphate and nitrate concentrations.

Phosphate concentrations in the upper waters are low to intermediate (0.06–1.1 μmol/l) and nitrate concentrations.

Comparison with other records:

Apart from the distribution recorded in this Atlas, *Polysphaeridium zoharyi* is registered from coastal sediments off southern Korea, the South China Sea, the Gulf off Oman, coastal areas off North Australia and off the NW Iberian peninsula (Marret and Zonneveld, 2003; Ribeiro and Amorim, 2008; Pospelova and Kim, 2010; Usup et al., 2012 and references therein). Sediment trap and seasonal distribution studies do not reveal a clear seasonal pattern in its cyst production (Ribeiro and Amorim, 2008; Zonneveld et al., 2010). In the past *P. zoharyi* has often been characterised as a species characteristic for elevated upper water salinities such as shallow lagoons (see discussion in Marret and Zonneveld, 2003). Although it is abundant to dominant in these environments, it is not restricted to them and in our dataset no positive correlation between salinity and its relative abundance can be observed.

Concluding remarks:

Polysphaeridium zoharyi is characteristic for coastal fully-marine subtropical to tropical regions which may have a high productivity. Although it is not restricted to areas with high upper water salinities it can form a major part of the association in regions where this condition occurs.

47. Cysts of *Protoperidinium americanum* (Paulsen 1907) Zonneveld et Dale 1994

Figs. 188–191.

Distribution:

Cysts of *Protoperidinium americanum* have only been reported from coastal sub-polar to tropical regions except for a few sites in the open North Atlantic Ocean and equatorial Indian Ocean. The cysts of this species are recorded only twice in equatorial sites. Abundances >5% and up to 18% occur in the vicinity of upwelling cells off western North America (Eastern Pacific), on the margins of the NW Pacific, off Chilli (southeastern Pacific), off NW Africa and off SW Africa. It is not observed where surface waters are influenced by river discharge.

Environmental parameter range:

SST: −2.9–29.4 °C (winter–spring) with summer SST: >2.6 °C except for one site where summer SST: 0.9 °C. SSS: 25–38.2 (summer–autumn) except for two sites where SSS drops in summer to 18.3 and 20.9. [P]: 0.08–1.7 μmol/l, [N]: 0.09–18.6 μmol/l, chlorophyll-*a*: 0.08–20.0 ml/l, bottom water [O_2]: 0–7.9 ml/l.

Although cysts of *Protoperidinium americanum* have their highest relative abundance in eutrophic environments, they are observed in oligotrophic environments as well. The species is abundant in upwelling areas where large inter-annual variability in the trophic state of the upper waters can occur with eutrophic conditions during active upwelling or when upwelling filaments cross the sampling site and oligotrophic conditions otherwise. Highest relative abundances are observed in regions with anoxic and hypoxic bottom water concentrations.

Comparison with other records:

Apart from the records in the dataset of this Atlas, cysts of *Protoperidinium americanum* have been documented from coastal embayments of the South China Sea, coastal sites off South Australia, the western Indian coast and off the Iberian margin (Godhe et al., 2000; Marret and Zonneveld, 2003; Wang et al., 2004c; Ribeiro and Amorim, 2008 and references therein).

Sediment trap studies of the Arabian Sea (off Somalia) and off NW Africa document enhanced cyst production of *Protoperidinium americanum* during active upwelling in the vicinity of the trap sites when upper waters at the trap sites are unstratified (Zonneveld and Brummer, 2000; Susek et al., 2005; Zonneveld et al., 2010). In the Saanich Inlet (BC, Canada) a positive correlation occurs between cyst production and biogenic silica flux combined with enhanced wind speed and relatively low SST (Price and Pospelova, 2011). In the central Northern Atlantic Ocean cysts of this

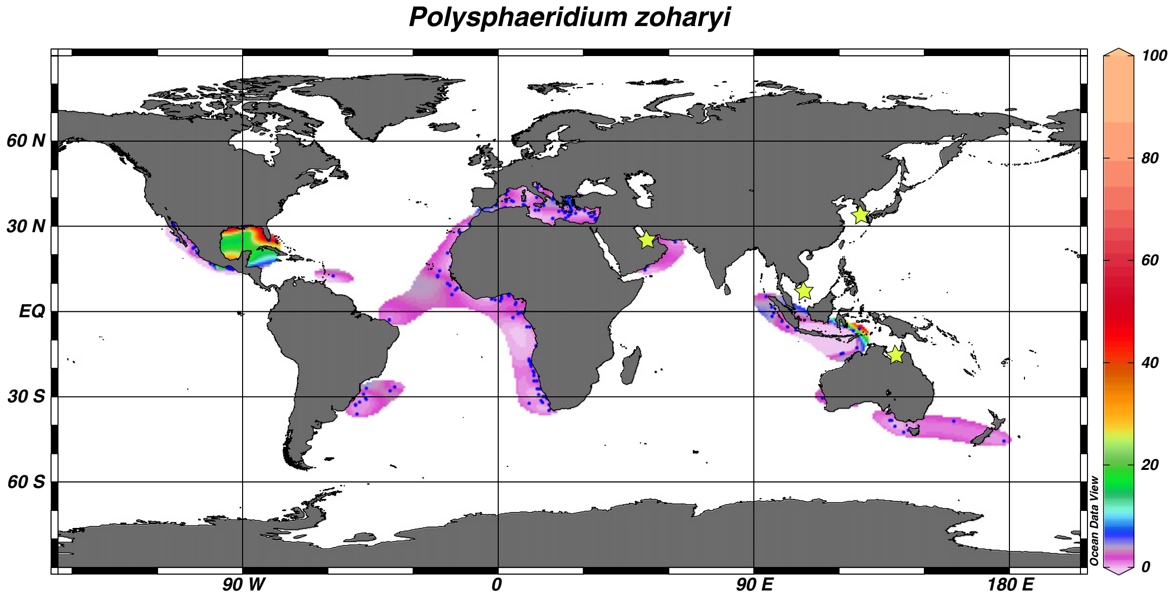

Fig. 184. Geographic distribution of *Polysphaeridium zoharyi*.

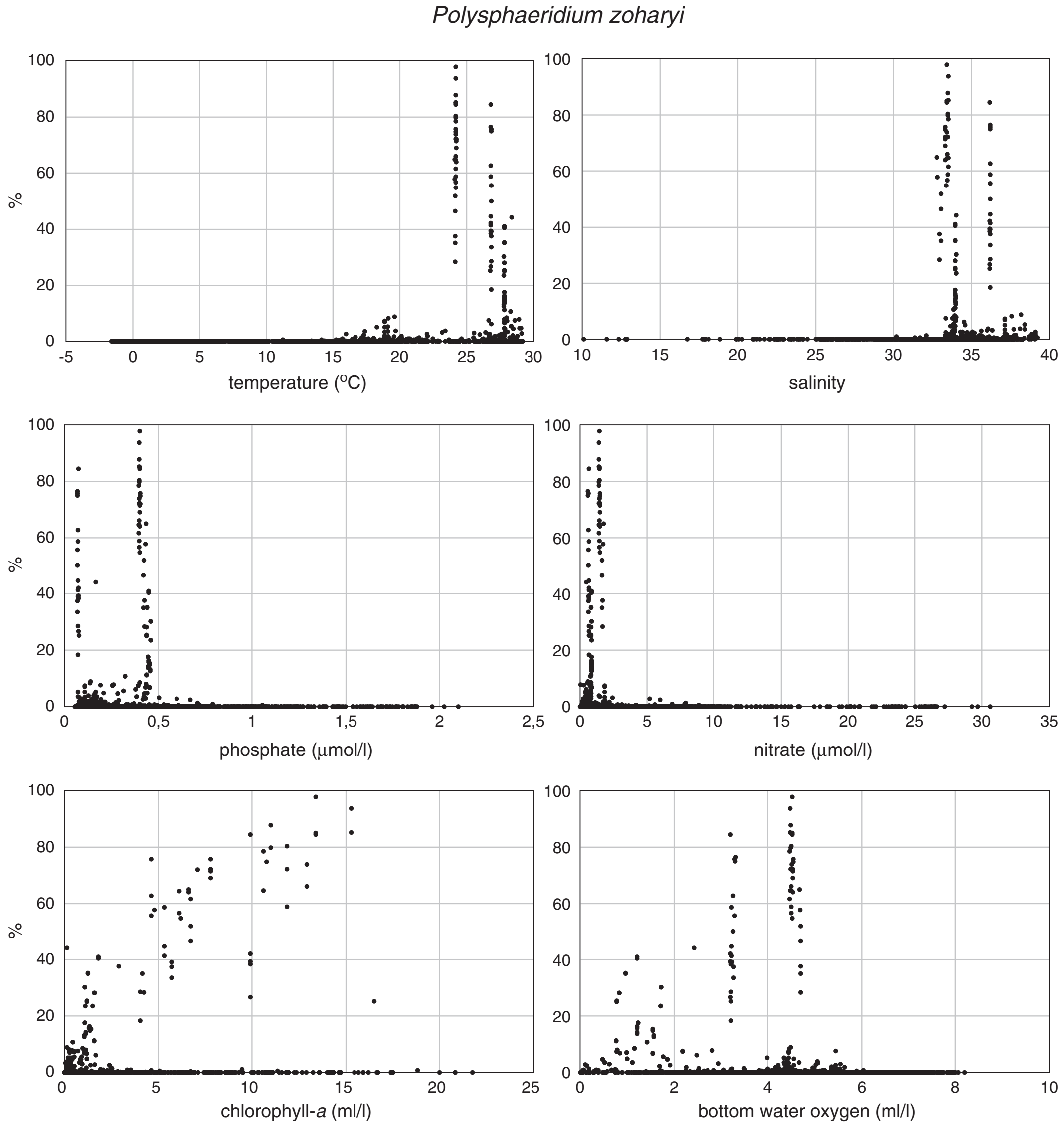

Fig. 185. Relative abundances of *Polysphaeridium zoharyi* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

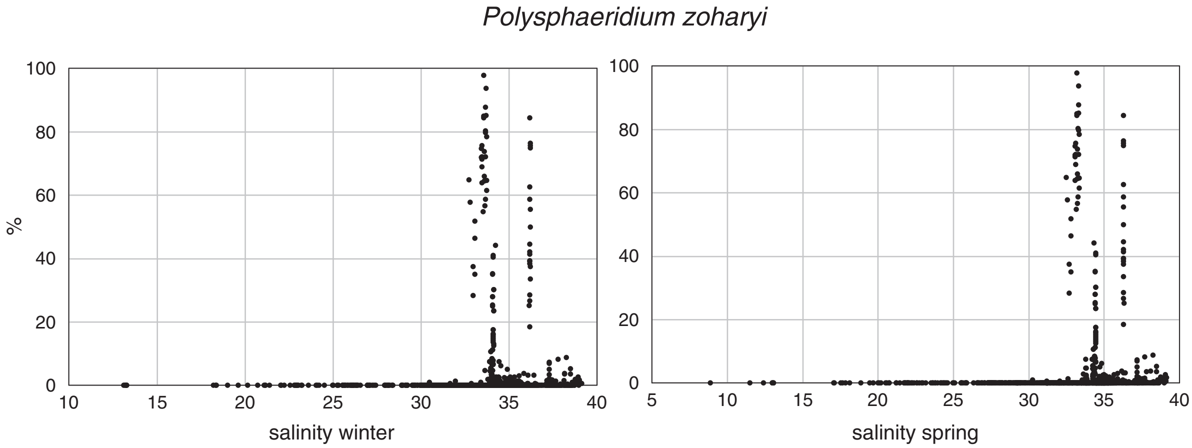

Fig. 186. Relative abundances of *Polysphaeridium zoharyi* in relationship to seasonal salinity in surface waters.

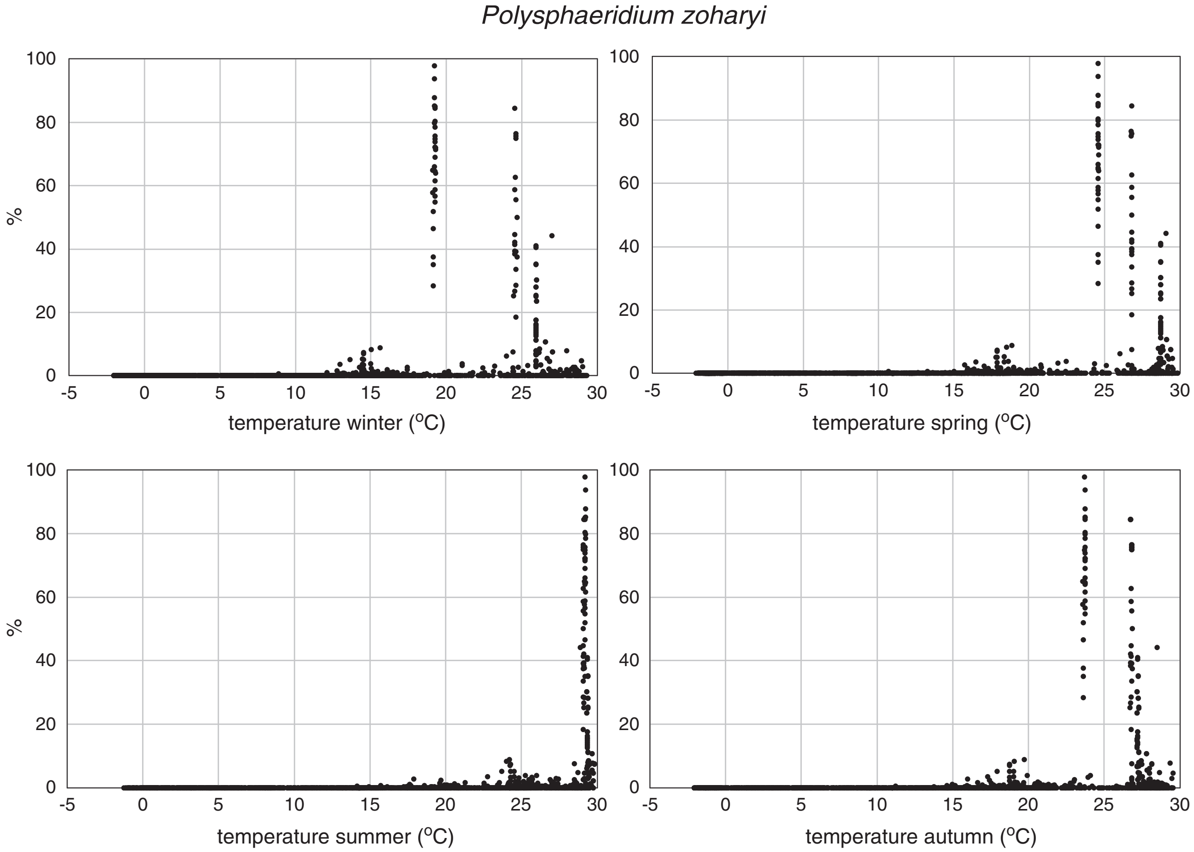

Fig. 187. Relative abundances of *Polysphaeridium zoharyi* in relationship to seasonal temperature in surface waters.

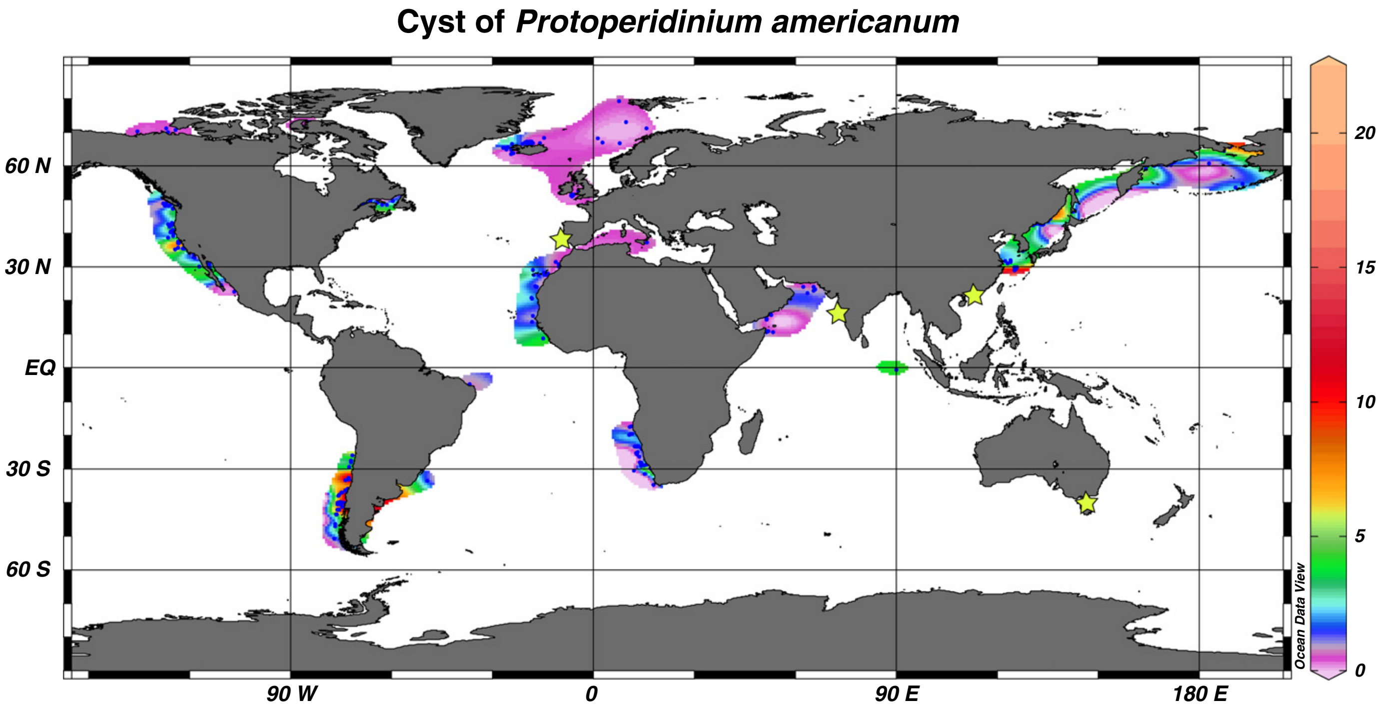

Fig. 188. Geographic distribution of cysts of *Protoperidinium americanum*.

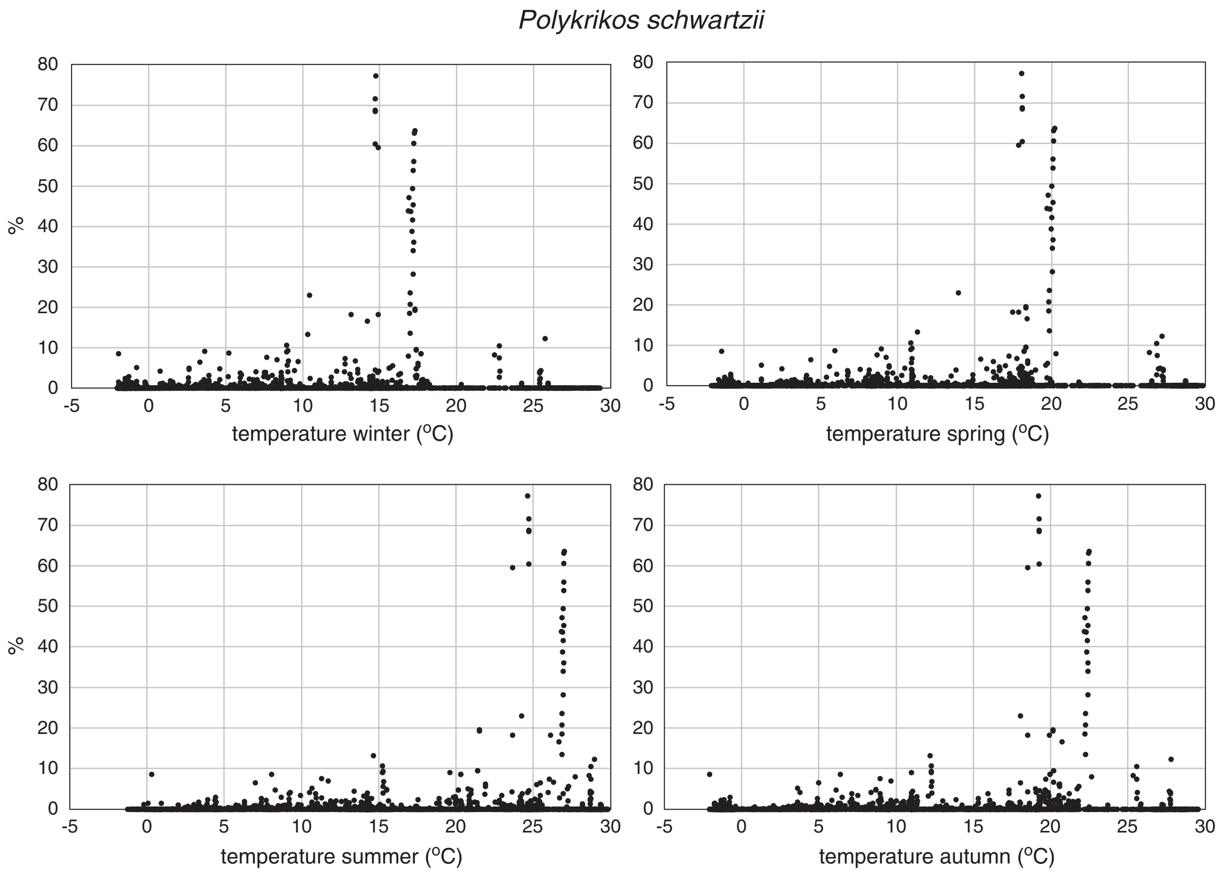

Fig. 189. Relative abundances of cysts of *Protoperidinium americanum* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

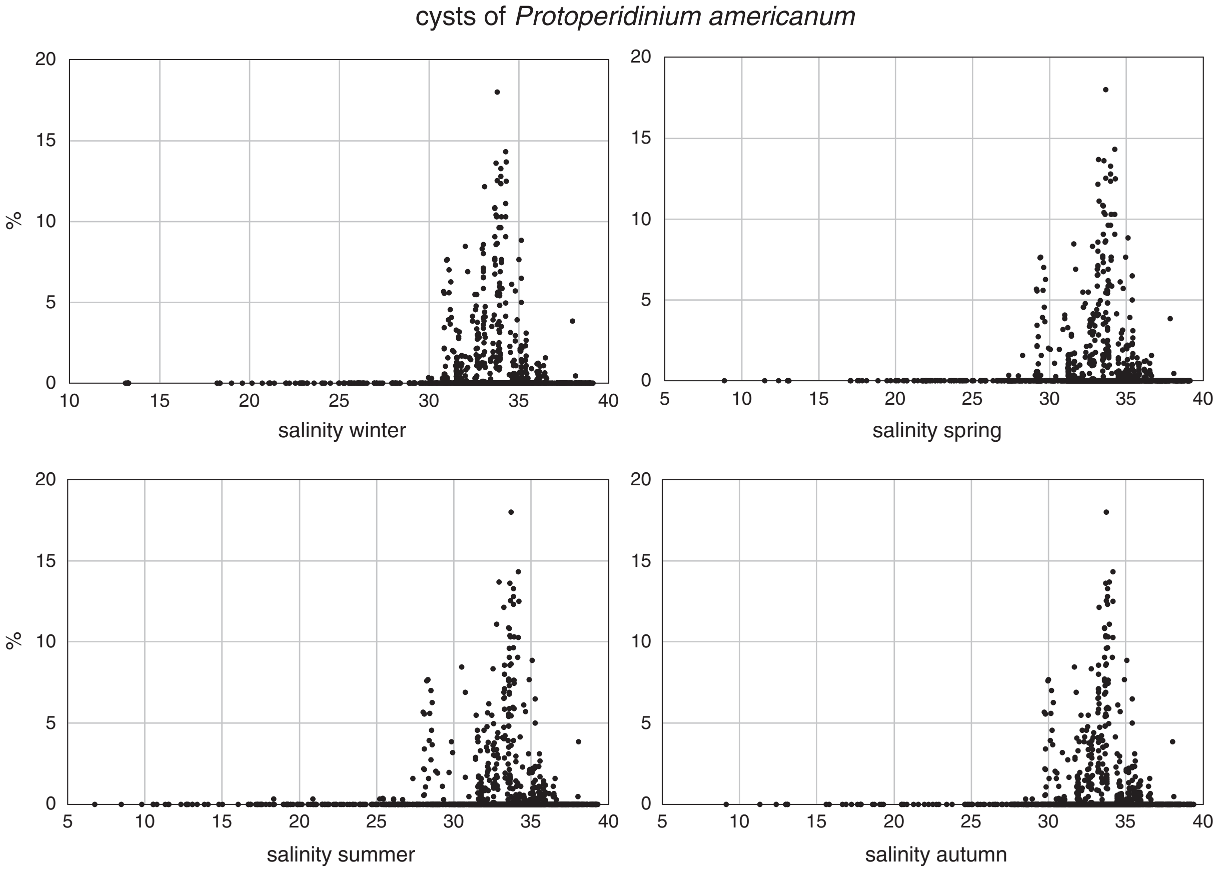

Fig. 190. Relative abundances of cysts of *Protoperidinium americanum* in relationship to seasonal salinity in surface waters.

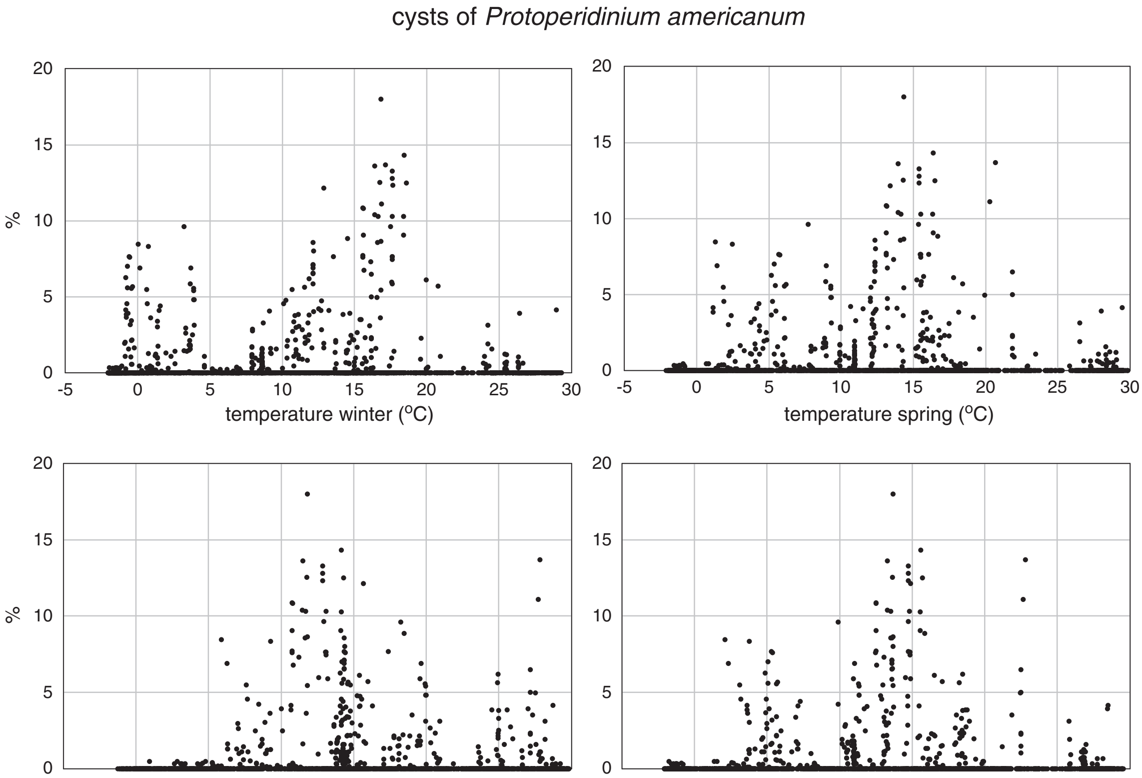

Fig. 191. Relative abundances of cysts of *Protoperidinium americanum* in relationship to seasonal temperature in surface waters.

species are observed in several trap sediments that are located far from the shore at sites where upwelling is absent (Dale and Dale, 1992). Unfortunately no information about the seasonal production is available from these sites. Off the Iberian margin cyst production is registered in sediment traps to occur throughout the year (Ribeiro and Amorim, 2008).

This species can be observed in areas with <0 °C during several seasons but a negative correlation exists between its relative abundance in the sediment and sea ice cover duration in the arctic (de Vernal et al., 1998; Radi and de Vernal, 2008).

Concluding remarks:

The distribution of cysts of *Protoperidinium americanum* is coastal sub-polar to tropical in regions where eutrophic conditions can prevail during parts of the year, for instance as the result of upwelling. So far it is not observed in regions that are influenced by river discharge. In the upwelling regions of NW Africa and the Arabian Sea highest cyst production occurs during upwelling.

48. Cysts of *Protoperidinium monospinum* (Gran et Braarud 1930) Balech 1974

Figs. 192–195.

Distribution:

Cysts of *Protoperidinium monospinum* is exclusively observed in coastal sites of the subtropical to equatorial upwelling areas off NW Africa (eastern equatorial Atlantic Ocean) except for one coastal site off SW Africa. Highest abundances (up to 12%) occur in the vicinity of upwelling cells off NW Africa.

Environmental parameter range:

SST: 16.0–29.1 °C (winter–summer), SSS: 32.8–36.0 (autumn–summer), [P]: 0.1–0.7 μmol/l, [N]: 0.5–7.9 μmol/l, chlorophyll-*a*: 0.2–12.2 ml/l, bottom water [O_2]: 0–5.5 ml/l.

Highest abundances of cysts of *Protoperidinium monospinum* are observed in upwelling areas where large inter-annual variability in the trophic state of the upper waters can occur with eutrophic conditions during active upwelling or when upwelling filaments cross the sampling site and oligotrophic conditions otherwise.

Comparison with other records:

Apart from the records in the dataset of this Atlas, cysts of *Protoperidinium monospinum* have been isolated and cultured from sediments of the Oslo Fjord (Zonneveld and Dale, 1994). Furthermore, they have been documented from sediment trap samples from the Gulf of Napels (Mediterranean Sea (Montresor et al., 1998). This suggests that the distribution documented by this Atlas might be a severe underestimate.

In sediment trap studies off NW Africa cysts of *P. monospinum* are produced when active upwelling occurs in the vicinity of the trap sites or when upwelling filaments cross the trap position (Susek et al., 2005; Zonneveld et al., 2010). In the Gulf of Napels cysts were recovered in spring and autumn (Montresor et al., 1998).

Concluding remarks:

Cysts of *Protoperidinium monospinum* are characteristically present in full marine, tropical to equatorial upwelling areas off NW Africa. Seasonally, cysts are produced when active upwelling occurs in the vicinity of the sampling sites.

49. *Pyxidinopsis psilata* Wall et Dale 1973

Figs. 196–199.

Distribution:

Pyxidinopsis psilata has a scattered distribution as it is observed in subtropical sediments off central western North America and along the western and eastern margins of the South Atlantic Ocean around 30°S, in the Black Sea and in the Marmara Sea. Although most recordings are from coastal sites, it is not restricted to coastal areas. Highest abundances (up to 11.7%) occur in shallow tropical sites of the Gulf of Mexico.

Environmental parameter range:

SST: 7.1–29.0 °C (winter–summer), SSS: 12.7–37.8 (summer–winter), [P]: 0.1–0.8 μmol/l, [N]: 0.05–4.6 μmol/l, chlorophyll-*a*: 0.2–5.2 ml/l, bottom water [O_2]: 0.8–6.6 ml/l.

Pyxidinopsis psilata has a euryhaline distribution with high relative abundances either with reduced salinities throughout the year or with high salinities.

Comparison with other records:

Apart from the records in the dataset of this Atlas, *Pyxidinopsis psilata* has been observed in coastal sites from the German Bight in the North Sea (Nehring, 1994a, 1994b, 1994c) and in the Baltic Sea (Sangiorgi pers. comm. 2012).

Concluding remarks:

Pyxidinopsis psilata can be considered as an euryhaline, temperal/sub-tropical to tropical species.

50. Pyxidinopsis reticulata (McMinn et sun 1994) Marret et de Vernal 1997

Figs. 200–203.

Distribution:

Pyxidinopsis reticulata is observed in all studied regions included in this Atlas exception for the Arabian Sea and the Arctic north of the arctic front. Abundances >50% (up to 84%) occur in the North Sea.

Environmental parameters:

SST: −2.0–28.8 °C (autumn–spring). SSS: 17.2–39.4 (summer–autumn), [P]: 0.06–1.9 μmol/l, [N]: 0.04–26.5 μmol/l, chlorophyll-*a*: 0.05–13.6 ml/l, [O_2]: 0.05–7.7 ml/l.

Generally SSS: >30 throughout the year but in some cases SSS can be seasonally reduced. *Pyxidinopsis reticulata* almost exclusively occurs in mesotrophic and eutrophic environments.

Comparison with other records:

Pyxidinopsis reticulata is not registered from regions not covered by this Atlas. In sediment trap studies of the upwelling region off NW Africa slightly enhanced cyst production could be observed when Sahara dust input is high and when active upwelling occurs in the vicinity of the trap site (Zonneveld et al., 2010). In the arctic a slight positive correlation is present between its relative abundances and sea ice cover duration (de Vernal et al., 1998; Radi and de Vernal, 2008).

Concluding remarks:

Pyxidinopsis reticulata is a cosmopolitan species, which is not observed in the arctic north of the arctic front. Its relative abundances are higherin mesotrophic to eutrophic environments.

51. *Quinquecuspis concreta* (Reid 1977) Harland 1977

Figs. 204–207.

Distribution:

Quinquecuspis concreta is observed in temperate to equatorial regions and a single registration in the Barents Sea. It is mainly observed coastal or in upwelling regions. Highest abundances (up to 30%) occur in the East China Sea.

Environmental parameter range:

SST: 0.2–29.7 °C (winter–summer), with summer SST>7.9 °C exception for two recordings in the Barents Sea and northern west Pacific where SST: −1.7–4 °C (winter–summer). SSS: 17.8–38.6 (winter–autumn), [P]: 0.06–1.7 μmol/l, [N]: 0.04–18.5 μmol/l, chlorophyll-*a*: 0.08–19.9 ml/l, bottom water [O_2]: 0–7.1 ml/l.

Abundances >20% occur when SST: 8.6–14.4 °C (winter–summer). High relative abundances can be found in environments that are eutrophic and have high chlorophyll-*a*: concentrations. The species is most abundant where low oxygen concentrations prevail.

Comparison with other records:

Apart from the records in the dataset of this Atlas, *Q. concreta* has been documented from coastal embayments of the western Indian coast (D'Costa et al., 2008), Chinese coastal waters (Wang et al., 2004c), Tokyo Bay (Matsuoka et al., 2003), the Benguela and South African coasts (Joyce et al., 2005; Pitcher and Joyce, 2009), the

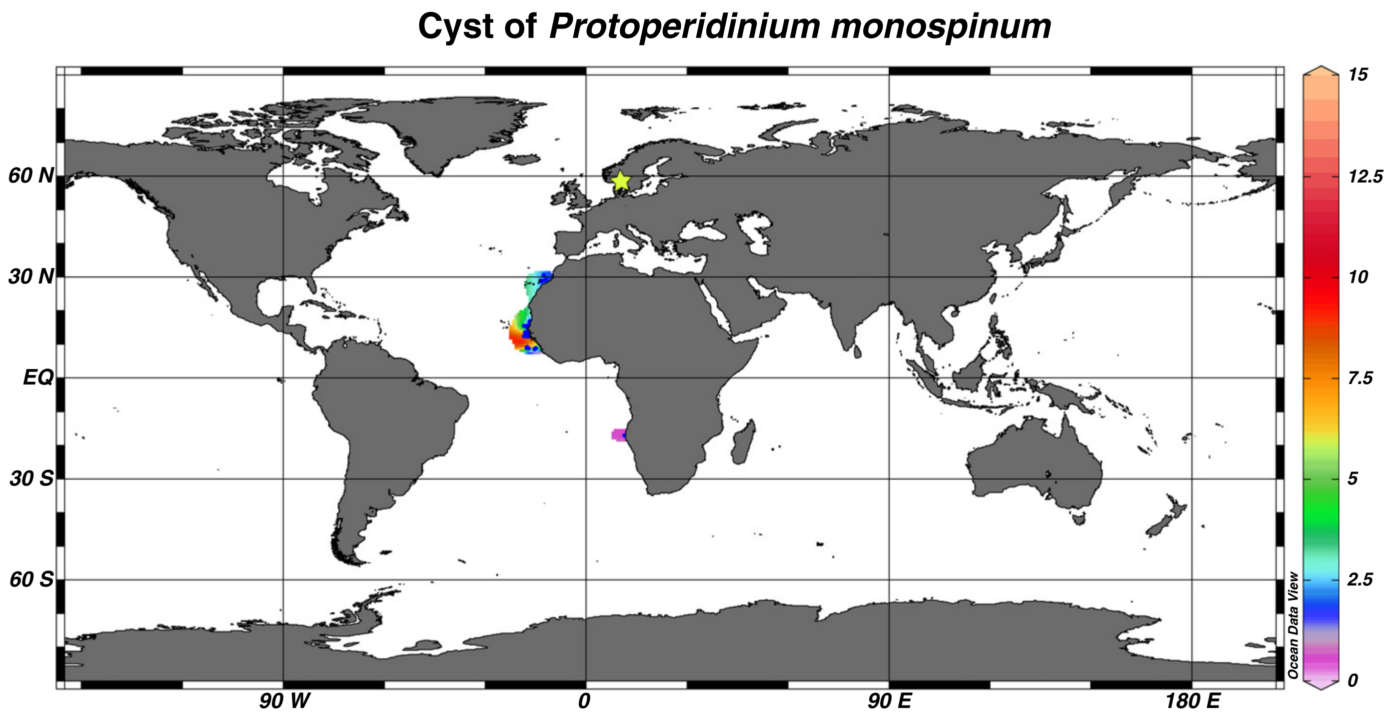

Fig. 192. Geographic distribution of cysts of *Protoperidinium monospinum*.

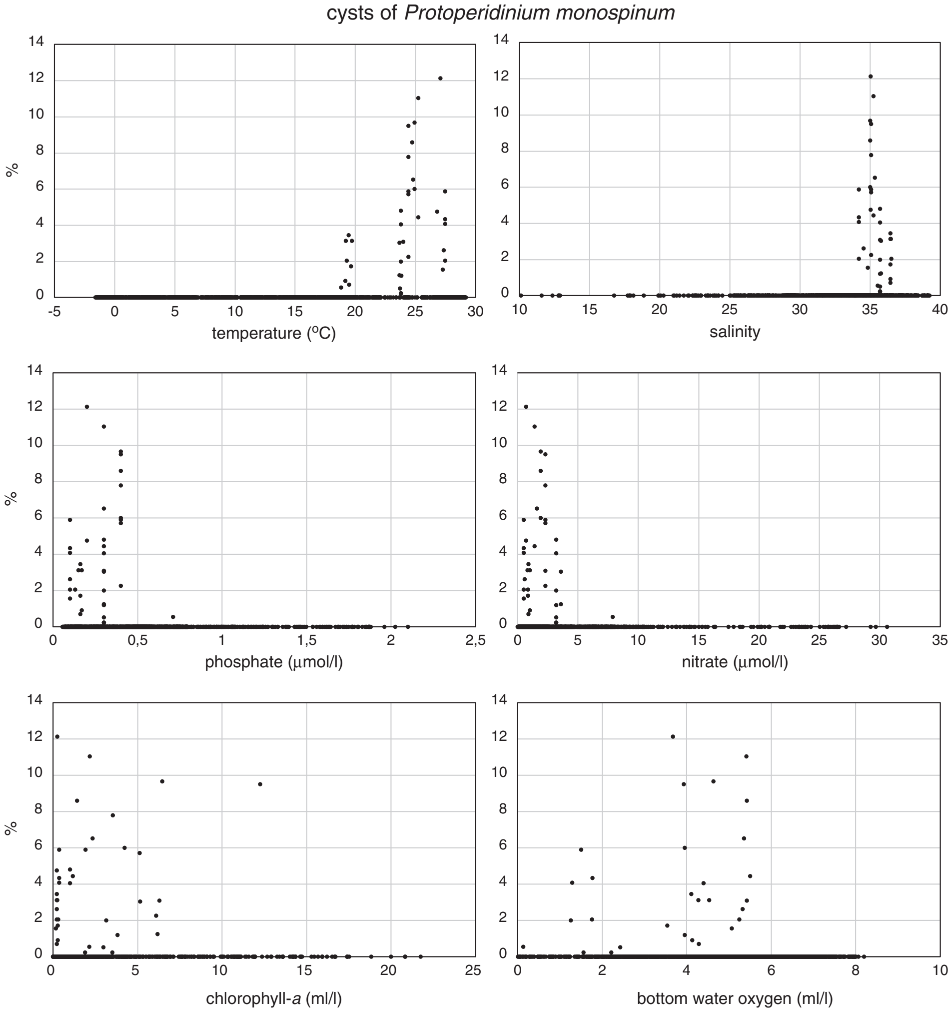

Fig. 193. Relative abundances of cysts of *Protoperidinium monospinum* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

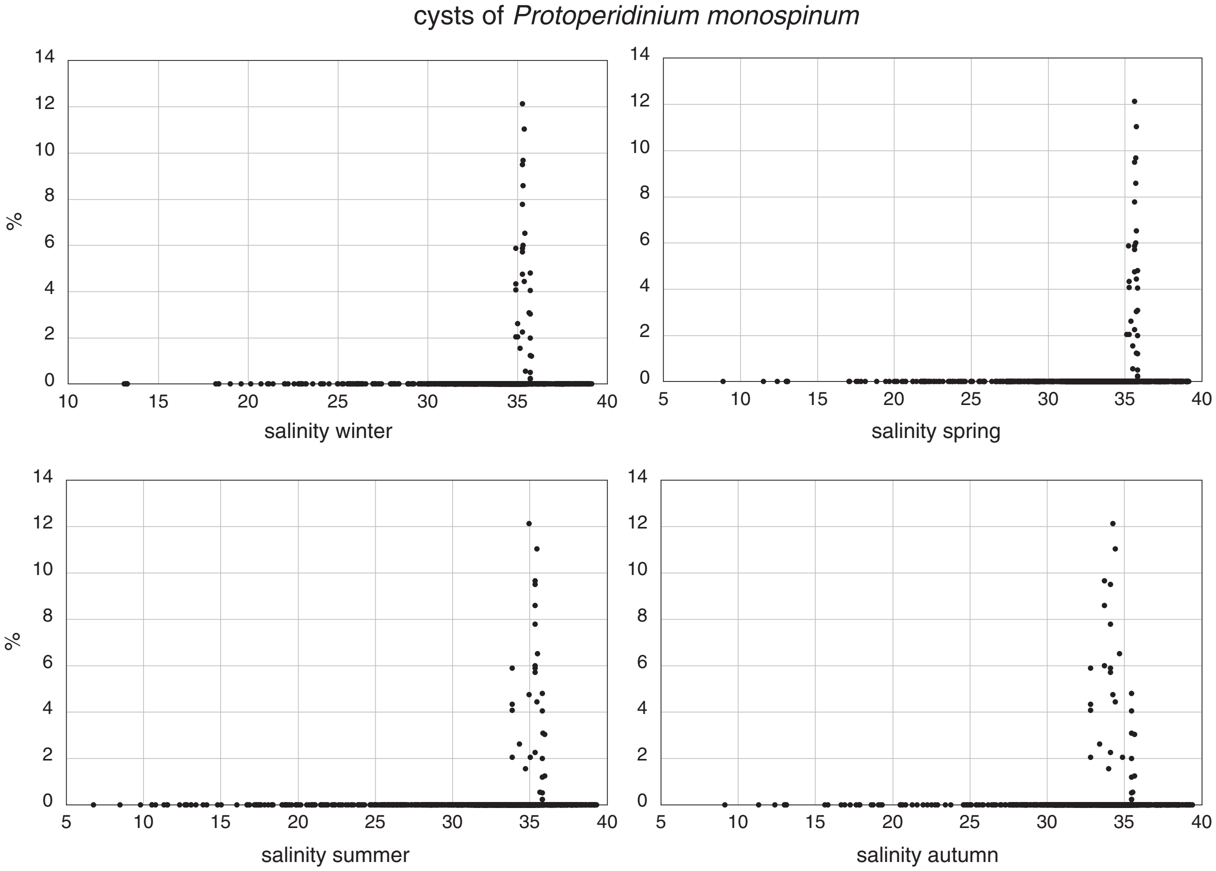

Fig. 194. Relative abundances of cysts of *Protoperidinium monospinum* in relationship to seasonal salinity in surface waters.

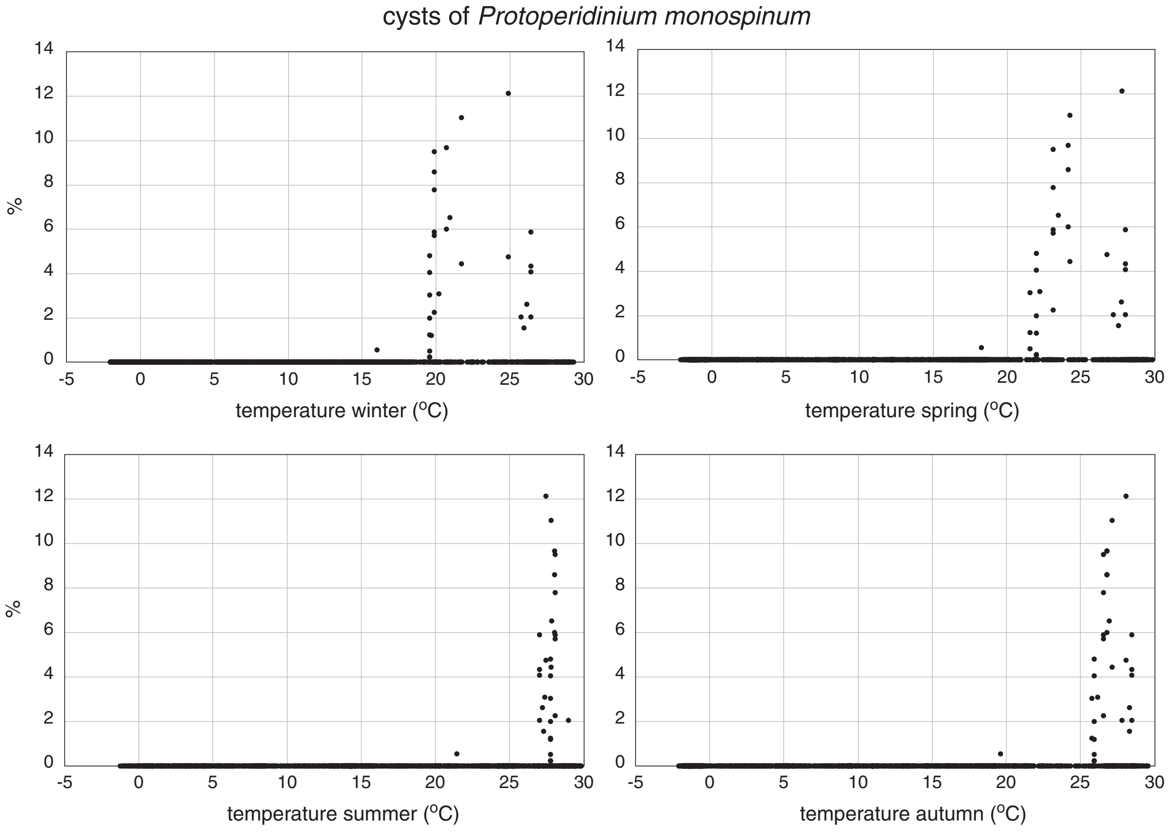

Fig. 195. Relative abundances of cysts of *Protoperidinium monospinum* in relationship to seasonal temperature in surface waters.

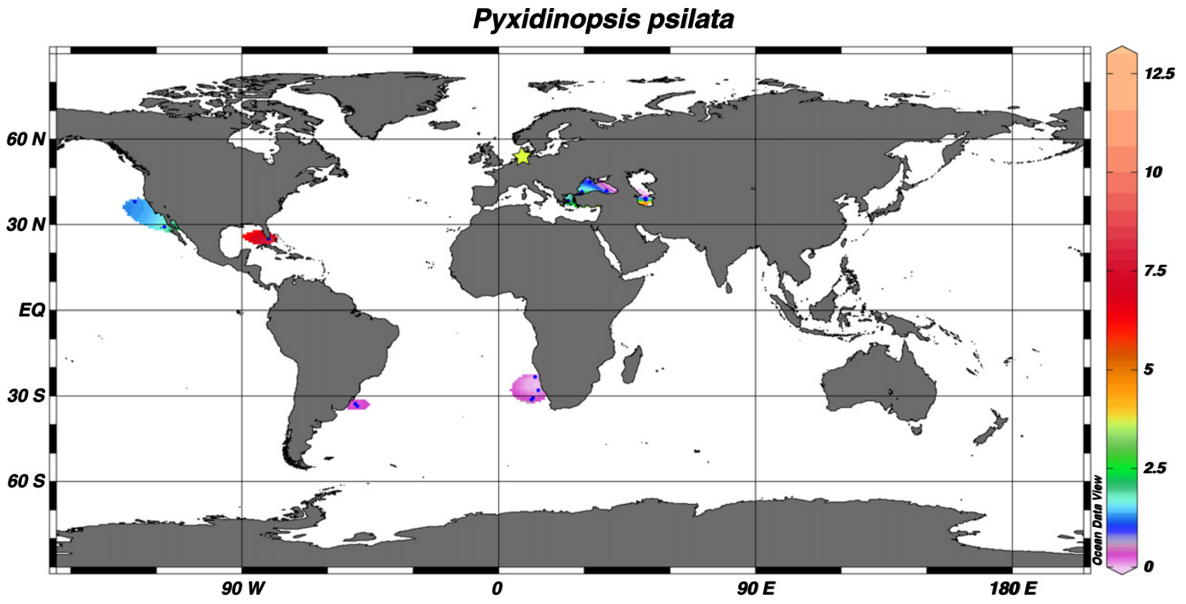

Fig. 196. Geographic distribution of *Pyxidinopsis psilata*.

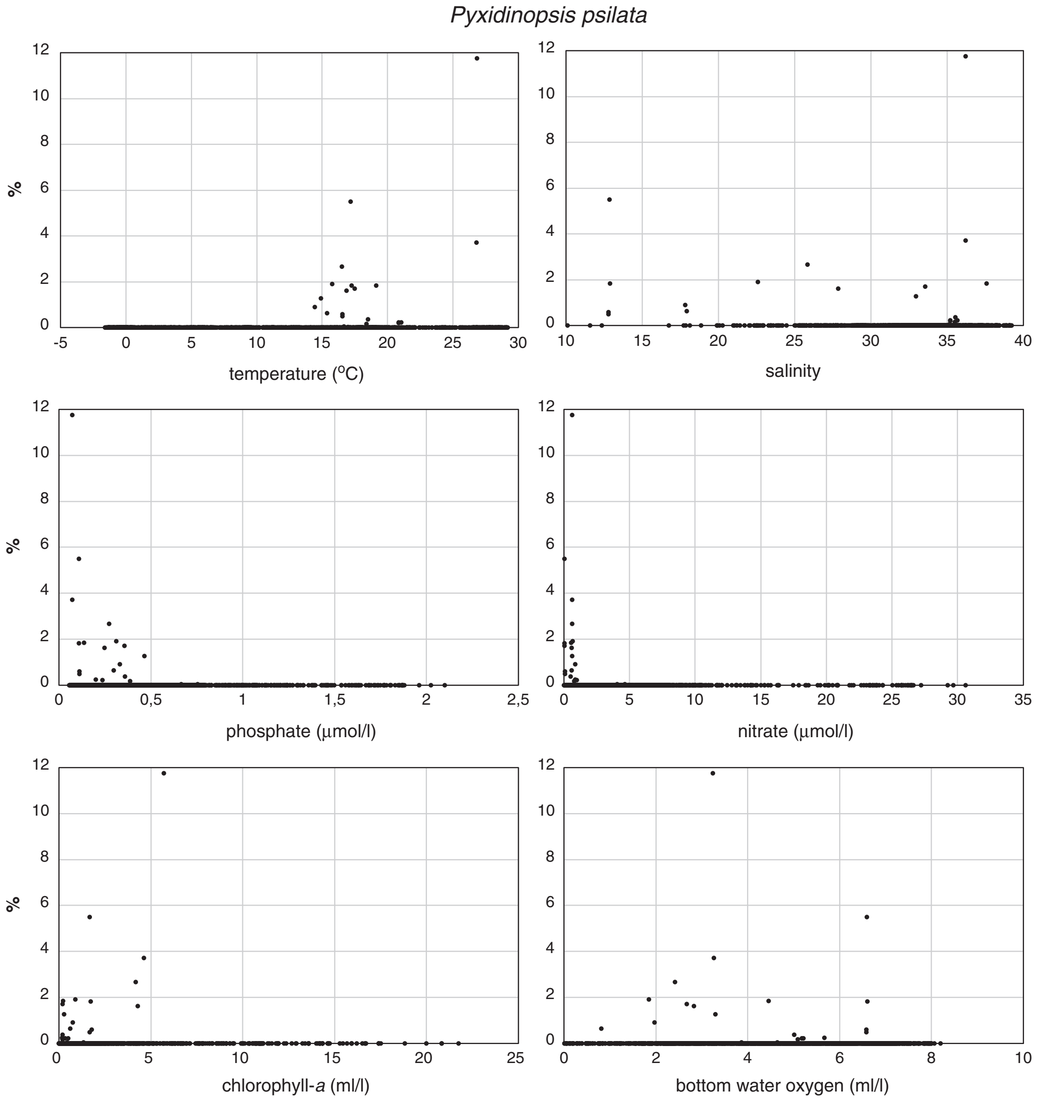

Fig. 197. Relative abundances of *Pyxidinopsis psilata* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

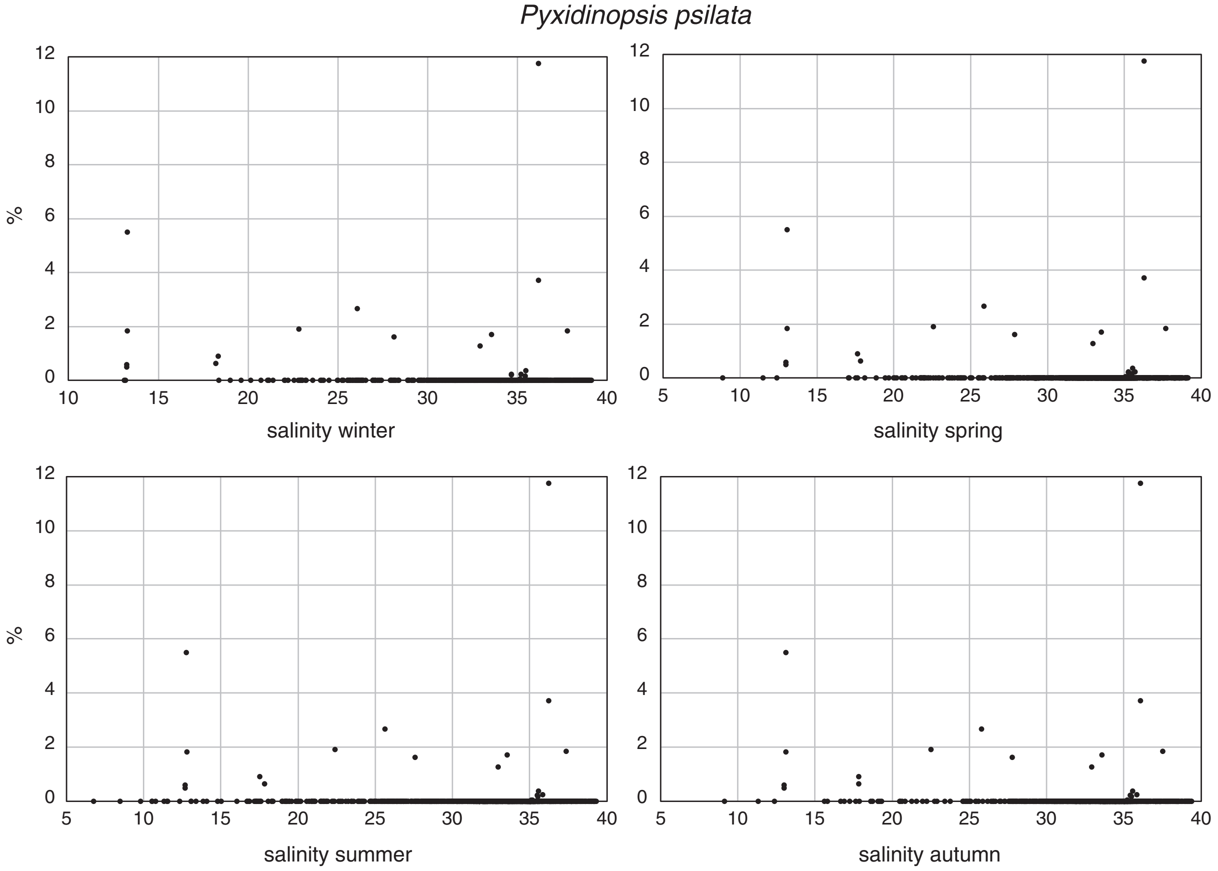

Fig. 198. Relative abundances of *Pyxidinopsis psilata* in relationship to seasonal salinity in surface waters.

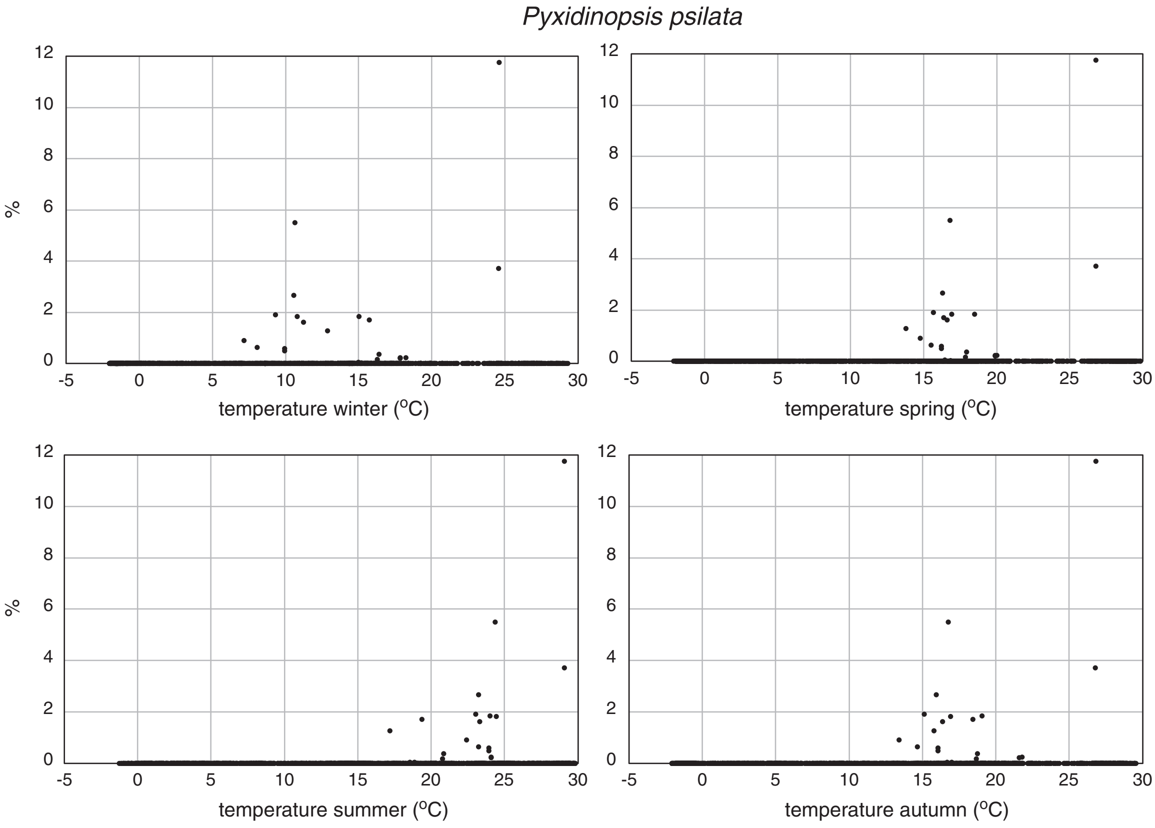

Fig. 199. Relative abundances of *Pyxidinopsis psilata* in relationship to seasonal temperature in surface waters.

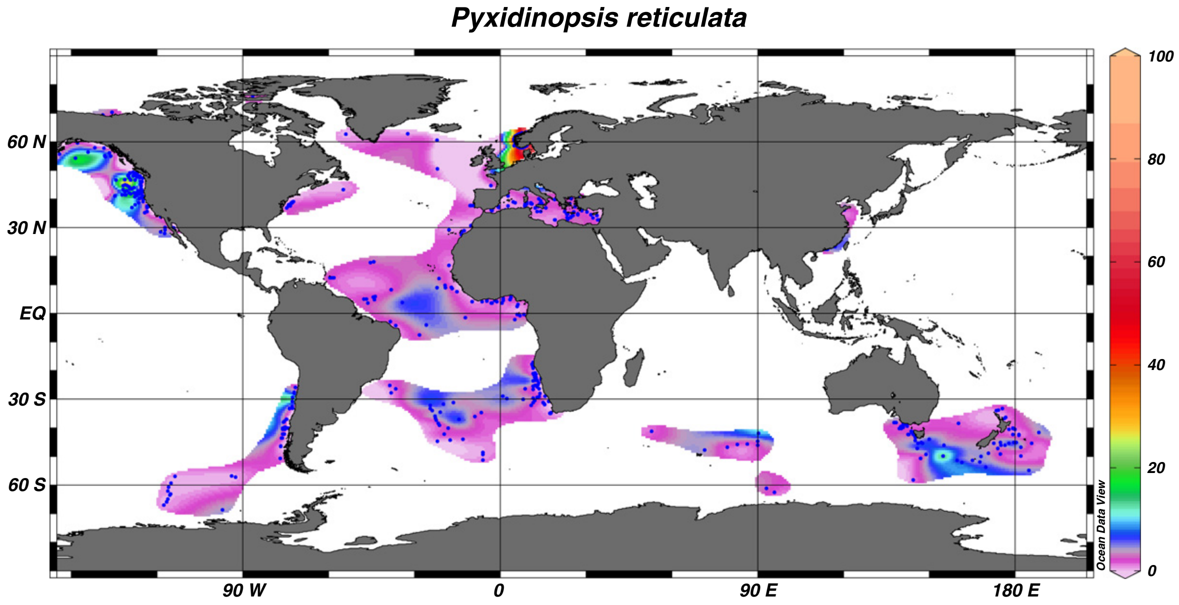

Fig. 200. Geographic distribution of *Pyxidinopsis reticulata*.

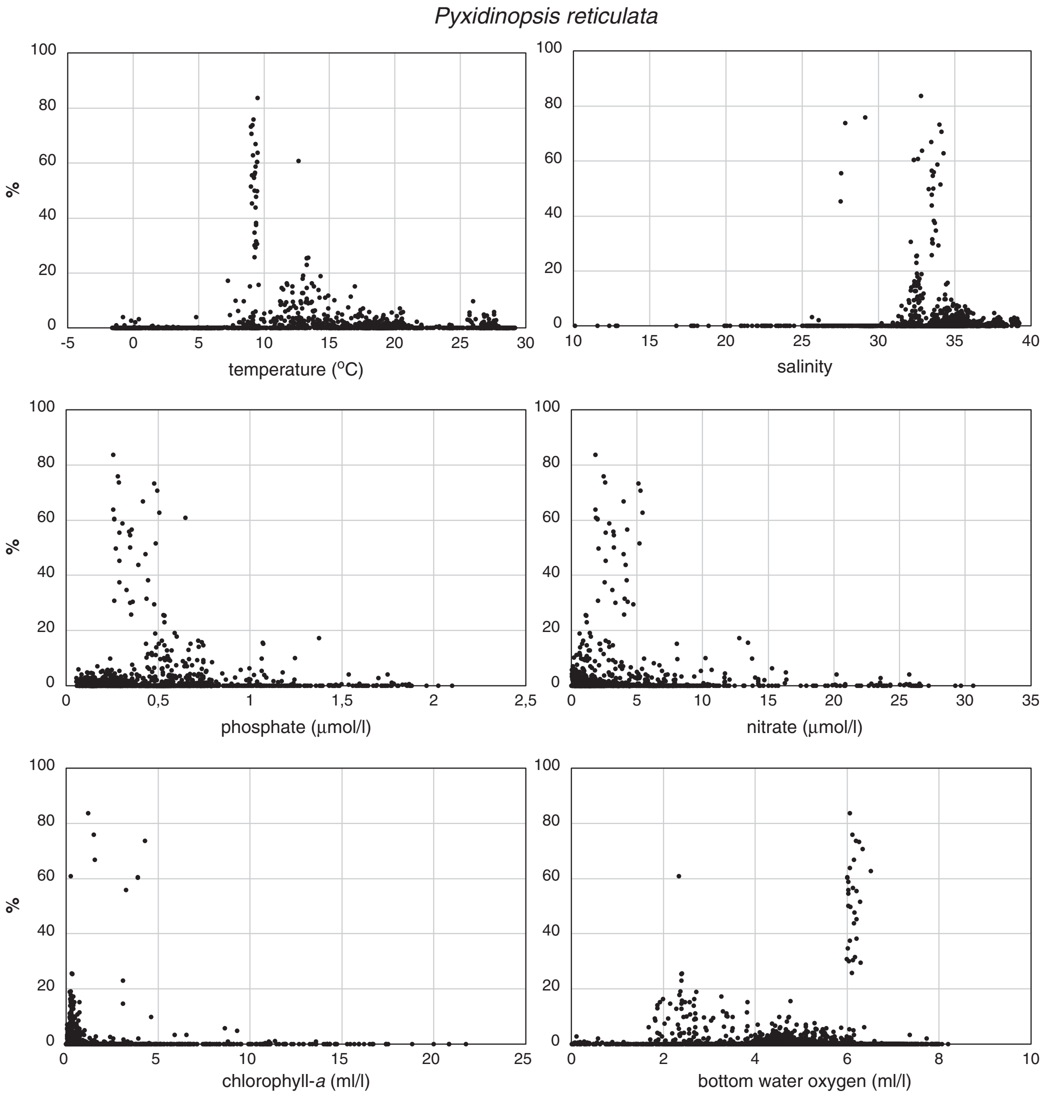

Fig. 201. Relative abundances of *Pyxidinopsis reticulata* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

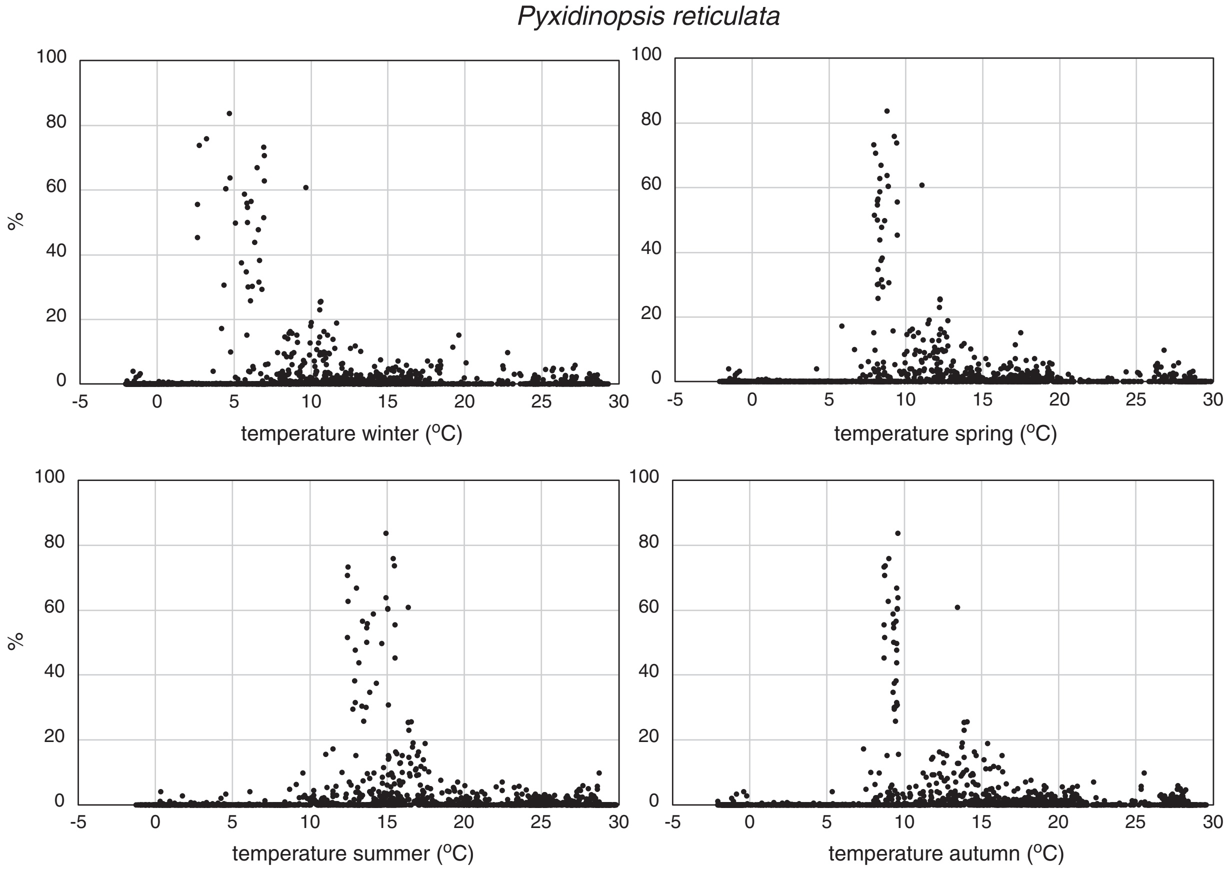

Fig. 202. Relative abundances of *Pyxidinopsis reticulata* in relationship to seasonal salinity in surface waters.

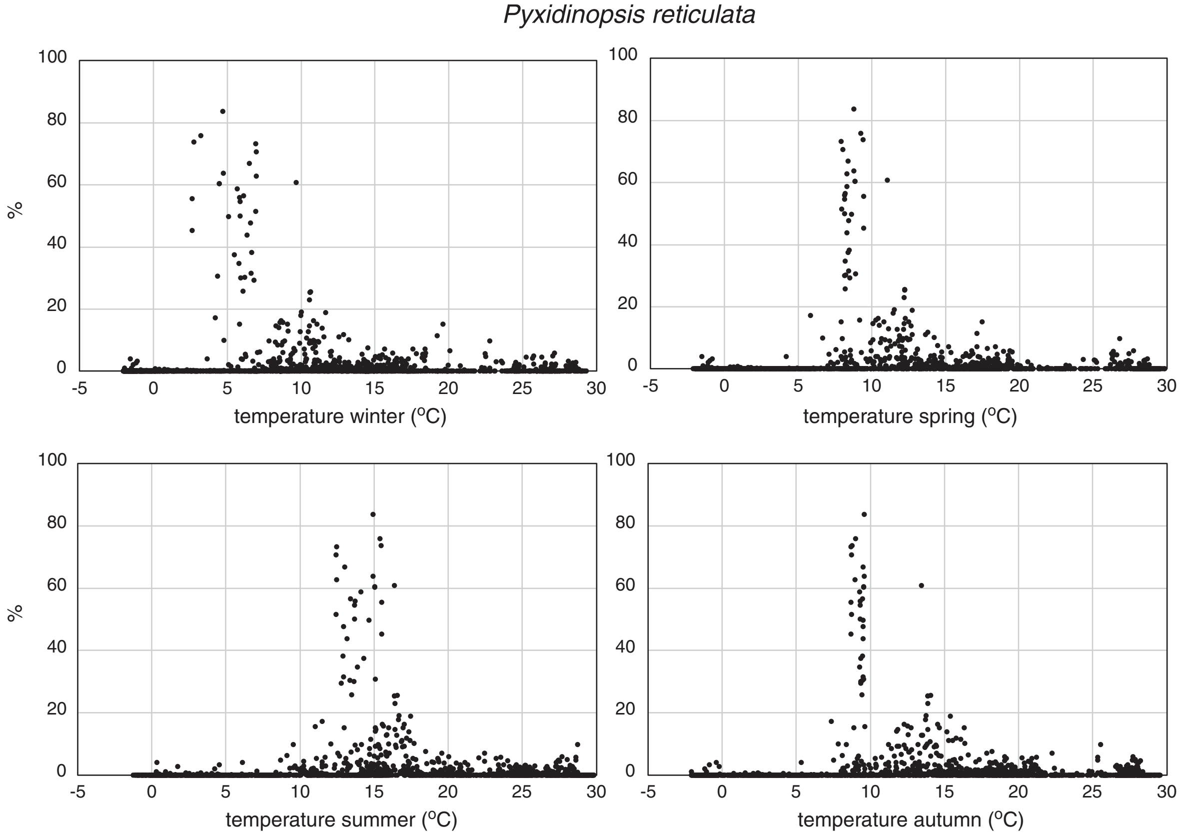

Fig. 203. Relative abundances of *Pyxidinopsis reticulata* in relationship to seasonal temperature in surface waters.

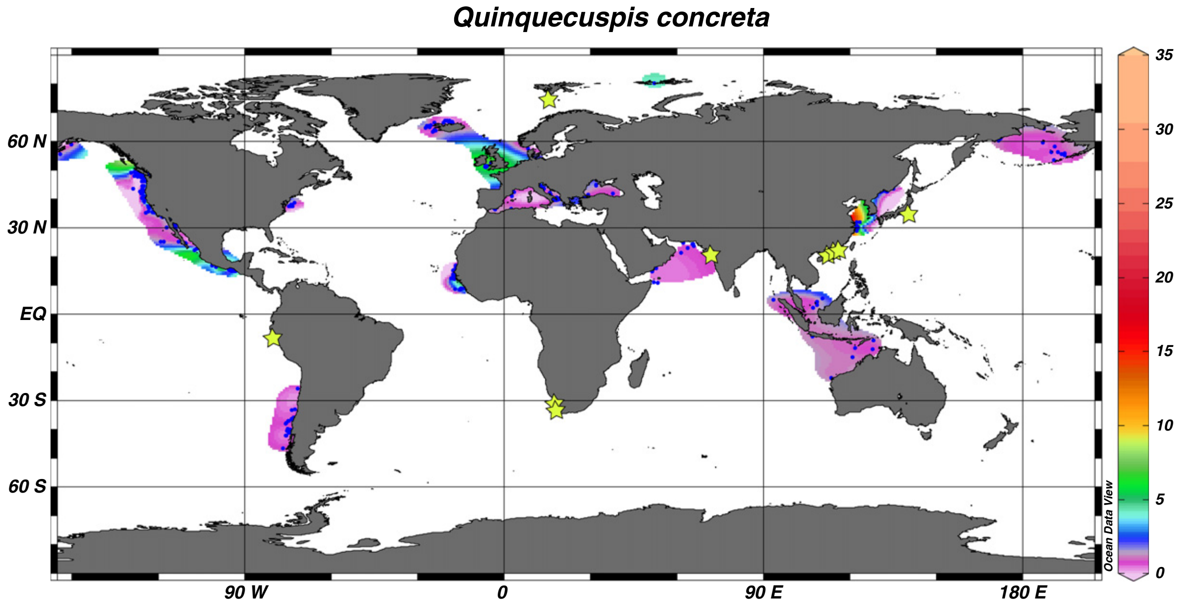

Fig. 204. Geographic distribution of *Quinquecuspis concreta*.

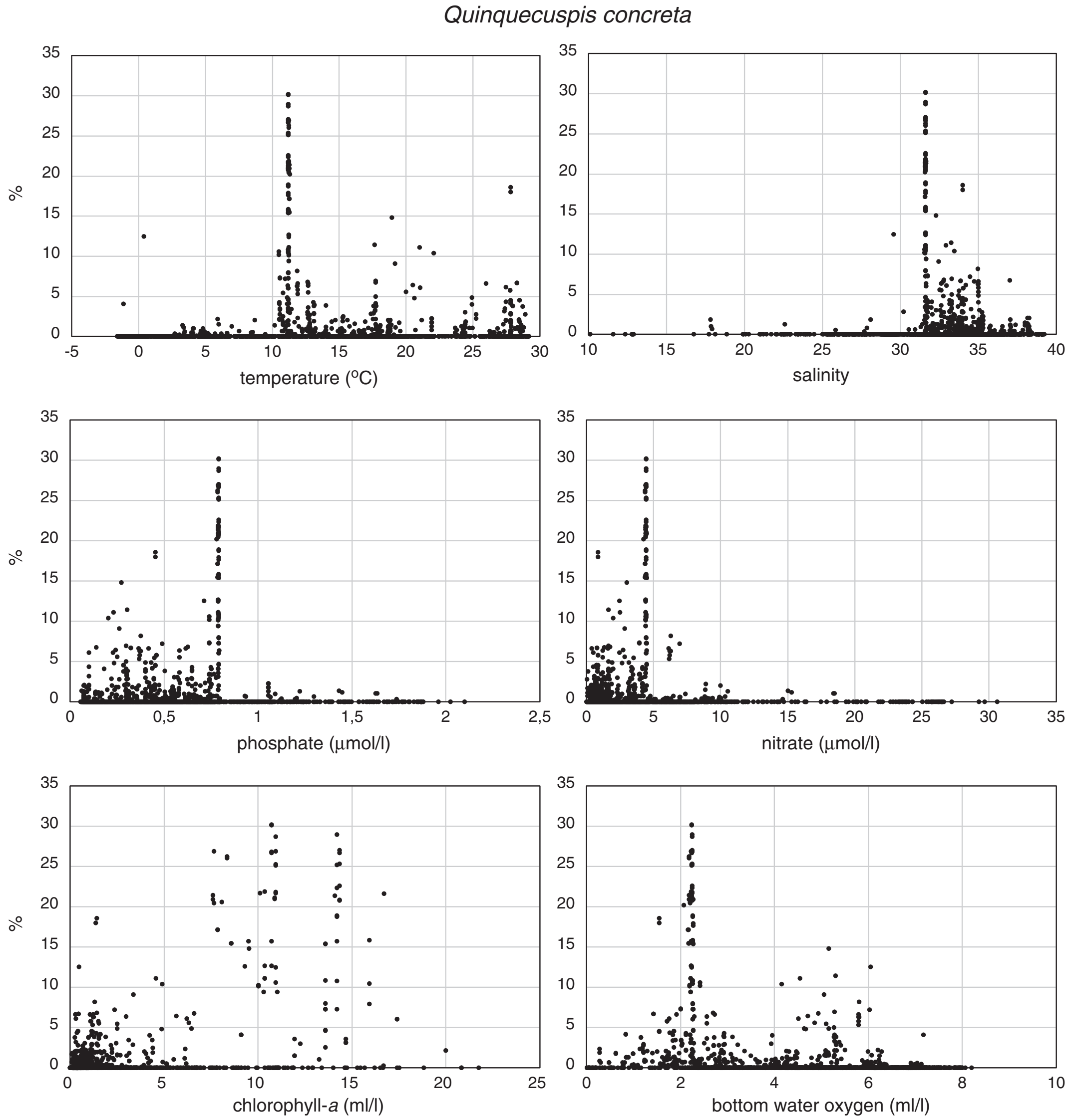

Fig. 205. Relative abundances of *Quinquecuspis concreta* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

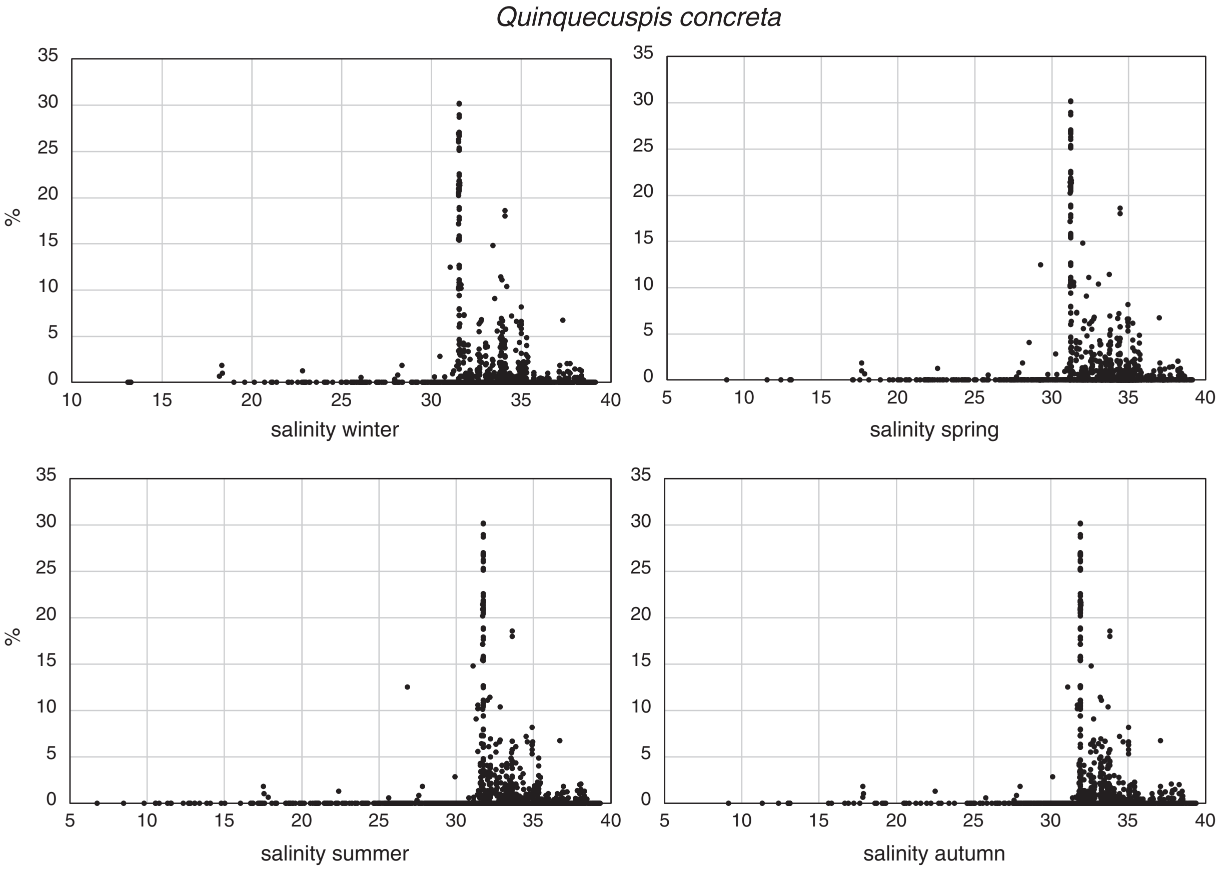

Fig. 206. Relative abundances of *Quinquecuspis concreta* in relationship to seasonal salinity in surface waters.

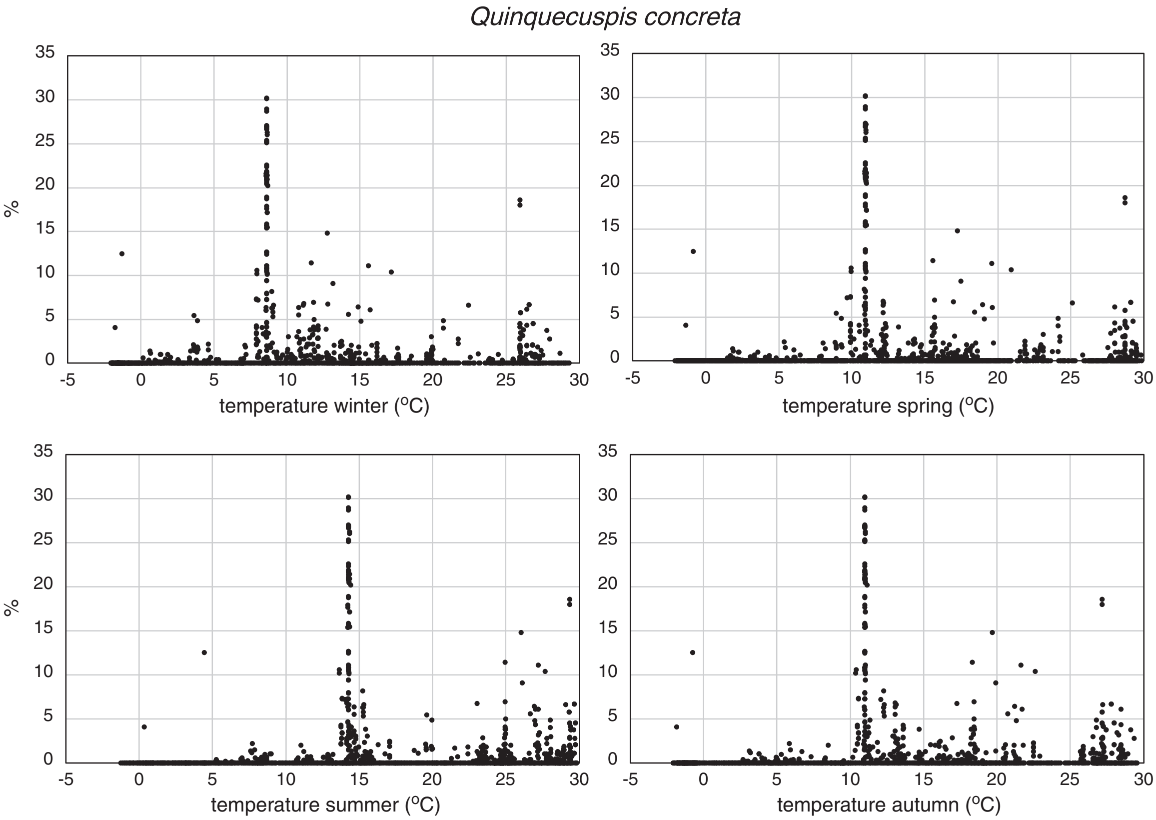

Fig. 207. Relative abundances of *Quinquecuspis concreta* in relationship to seasonal temperature in surface waters.

Peruvian upwelling area (Biebow et al., 1993) and the western Barents Sea (Grøsfjeld et al., 2009; Solignac et al., 2009). In the western Barents Sea its occurrence can be linked to sites with high productivity in spring (March–May). It also occurs in unstratified highly polluted waters of the South Korean bays (Pospelova and Kim, 2010). It is common in highly stratified nutrient-rich waters of the Marmara Sea and less common in the lower salinity strongly stratified Black Sea (Mudie et al. (2004). In coastal bays of southern Vancouver Island, *Quinquecuspis concreta* is most abundant in sediments characterised by high organic content and biogenic silica (Krepakevich and Pospelova, 2010).

Production of cysts of this species has been documented for active upwelling during the south-east Monsoon in the Arabian Sea off Somalia (Zonneveld and Brummer, 2000). In the northwestern Pacific Saanich Inlet and central Strait of Georgia (British Columbia, Canada) higher production of this species occurs when salinity is reduced due to enhanced outflow of the Cowichan and Fraser rivers (Price and Pospelova, 2011).

Concluding remarks:

Q. concreta can be found in coastal to open marine, temperate to equatorial regions. It has a broad temperature range and can be found from brackish to full marine environments. Although highest relative abundances occur in eutrophic high productivity regions, it also occurs in oligotrophic, low productivity environments. Enhanced seasonal cyst production can be related to increased river discharge or the presence of upwelling.

52. *Selenopemphix antarctica* Marret and De Vernal, 1997
Figs. 208–211.

Distribution:

Selenopemphix antarctica has a temperate to polar distribution and is observed on the Southern Hemisphere only. Its northern distribution limit is the southern Hemisphere subtropical front. Abundances >20% occur south of the polar front. In Antarctic waters it can form up to 100% of the association. *S. antactica* occurs in coastal and open ocean areas of the southern oceans.

Environmental parameters:

SST: −2.0–23.5 °C (winter–summer), SSS: 33.2–36.3 (summer–autumn), [P]: 0.19–2.10 μmol/l) and nitrate, [N]: 0.71–30.62 μmol/l, chlorophyll-*a*: 0.12–1.11 ml/l, bottom water [O_2]: 3.9–6.0 ml/l.

Selenopemphix antarctica can be abundant in regions where SST: remains <0 °C throughout the year. Abundances >20% occur where SST: are <0 °C in winter and spring and up to 10 °C in summer. *S. antactica* is not recorded from sites that are characterised by seasonal melting of ice. It is typical present in so called "high nutrient/low chlorophyll" environments. in this dataset its distribution is restricted to sites where well-ventilated bottom waters are present although it has been observed in anoxic basins around Antarctica as well (Sangiorgi pers. comm. 2012).

Comparison with other records:

Selenopemphix antarctica has not been recorded from regions not covered by this Atlas.

Concluding remarks:

Selenopemphix antarctica is a temperate to polar species endemic to the southern oceans. Its northernmost distribution is marked by the southern Hemisphere subtropical front. Highest relative abundances occur south of the polar front. It is restricted to full-marine environments with well ventilated bottom waters. These areas are characterised by high nitrate and phosphate concentrations in surface waters but low productivity.

53. *Selenopemphix nephroides* (Benedeck 1972) Bujak in Bujak et al. 1980
Figs. 212–215.

Distribution:

Selenopemphix nephroides is restricted to the coastal sites of temperate to equatorial regions with exception of a few recordings from the equatorial Atlantic Ocean and central North Atlantic Ocean. Highest abundances (up to 14%) occur in the vicinity of upwelling cells off NW Africa and off SW Africa as well as in western Mediterranean Sea, the South China Sea, the Sea of Okhotsk (Northwestern Pacific) and the Bering Sea (North Pacific). It has not been observed in river plume areas.

Environmental parameter range:

SST: −0.8–29.8 °C (winter–summer) with summer SST>5.9 °C except for 7 sites from a restricted area in the North Pacific. SSS: 27.6–39.4 (summer–autumn) apart from three recordings in the Black and Marmara Seas where SSS: 17.5–24.0 (summer–winter). [P]: 0.06–1.7 μmol/l, [N]: 0.4–17.9 μmol/l, chlorophyll-*a*: 0.07–17.4 ml/l, bottom water [O_2]: 0–7.2 ml/l.

Although *Selenopemphix nephroides* occurs in oligotrophic regions, highest abundances are in seasonally mesotrophic to eutrophic areas. These regions are mainly upwelling areas with large inter-annual trophic variability being eutrophic conditions during active upwelling or when upwelling filaments cross the sampling site and oligotrophic when upwelling is absent. High relative abundances occur where bottom waters are well ventilated.

Comparison with other records:

Apart from the records in the dataset of this Atlas, *Selenopemphix nephroides* has been observed in surface sediments of coastal sites of the Persian Gulf, off western India (Arabian Sea), off the Iberian peninsula, estuaries of New England (Atlantic USA), the upwelling area off Peru (eastern Pacific) and coastal sites off southern China (Bradford, 1975; Biebow et al., 1993; Godhe et al., 2000; Marret and Zonneveld, 2003; Pospelova et al., 2004, 2005; Wang et al., 2004c; D'Costa et al., 2008).

In sediment traps off Somalia, cysts are deposited during active upwelling (Zonneveld and Brummer, 2000). Although this holds as well for the Iberian margin, *S. nephroides* is not exclusively produced during active upwelling but also occurs in other seasons (Ribeiro and Amorim, 2008). In sediment traps off NW Africa and in British Columbia, higher cyst production of this species can be related to higher organic carbon and biogenic silica fluxes as well as active upwelling (Susek et al., 2005; Pospelova et al., 2010; Zonneveld et al., 2010). In Omura Bay this species is produced in autumn-early winter at times of enhanced bioproduction mainly of diatoms (Fujii and Matsuoka, 2006). This suggest that the production of this species might follow its prey abundance.

In arctic sediments the relative abundance of this species has a small but positive correlation with seasonal ice cover duration whereas a clear negative correlation is registered when the whole North Atlantic Ocean is taken into account (Radi and de Vernal, 2008).

Concluding remarks:

Selenopemphix nephroides occurs in temperate to equatorial regionns. Highest relative abundances are observed in mesotrophic to eutrophic environments such as upwelling areas where bottom waters may be anoxic to oxic. Its seasonal abundance is positively correlated to bioproductivity in surface waters in vicinity of the sampling site.

54. *Selenopemphix quanta* (Bradford 1975) Matsuoka 1985
Figs. 216–219.

Distribution:

Selenopemphix quanta occurs in coastal sites and near sub-tropical and equatorial front systems of polar to equatorial regions. It is not recorded from the central gyres of the Oceans. High abundances (up to 44%) occur in eutrophic regions with high sea surface Chlorophyll-*a*: concentrations. These regions include upwelling areas, fronts and regions where river discharge waters can be seasonally or permanently present.

Environmental parameter range:

SST: −2.1–29.8 °C (autumn–summer) with summer SST>0 °C except for two sites in the Arctic where SST: <0 °C throughout the year. SSS 16.8–39.2 (summer–autumn), [P]: 0.06–1.7 μmol/l, [N]: 0.04–15.6 μmol/l, chlorophyll-*a*: 0.1–21.8 ml/l, bottom water [O_2]: up to 8.0 ml/l.

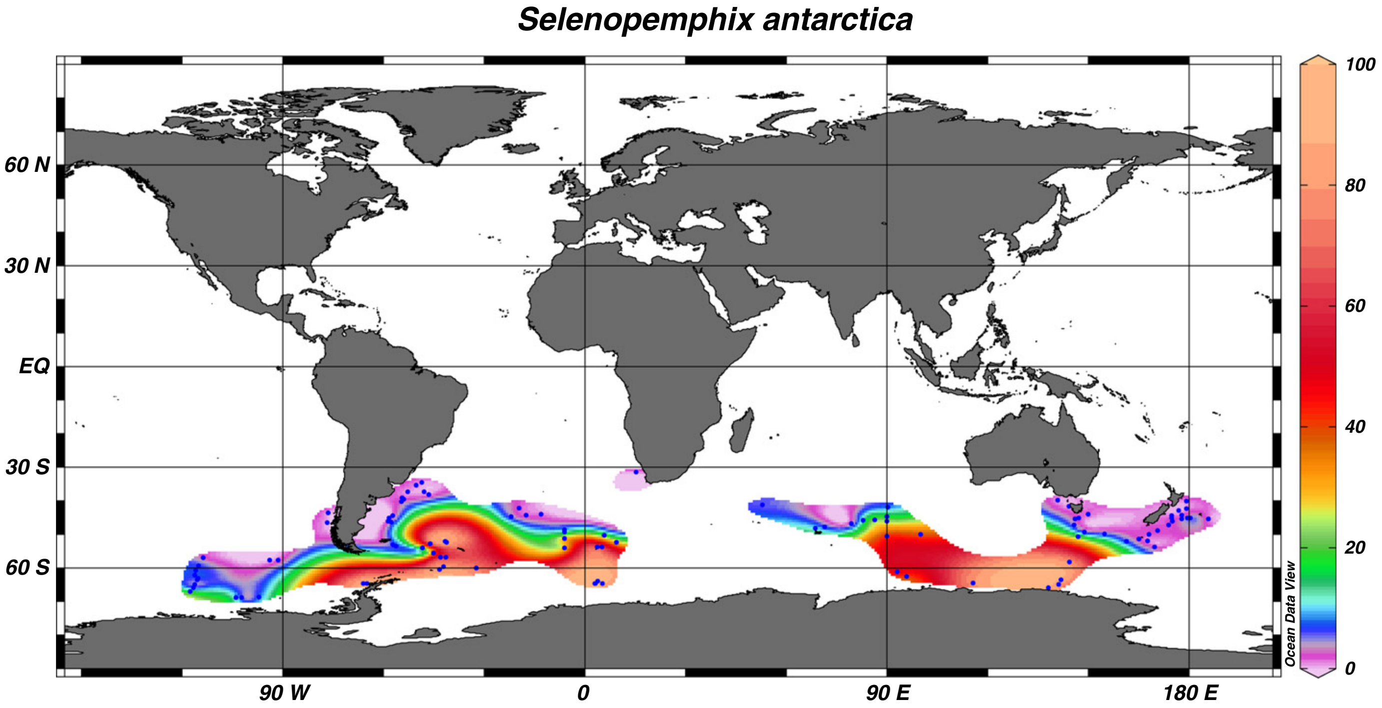

Fig. 208. Geographic distribution of *Selenopemphix antarctica*.

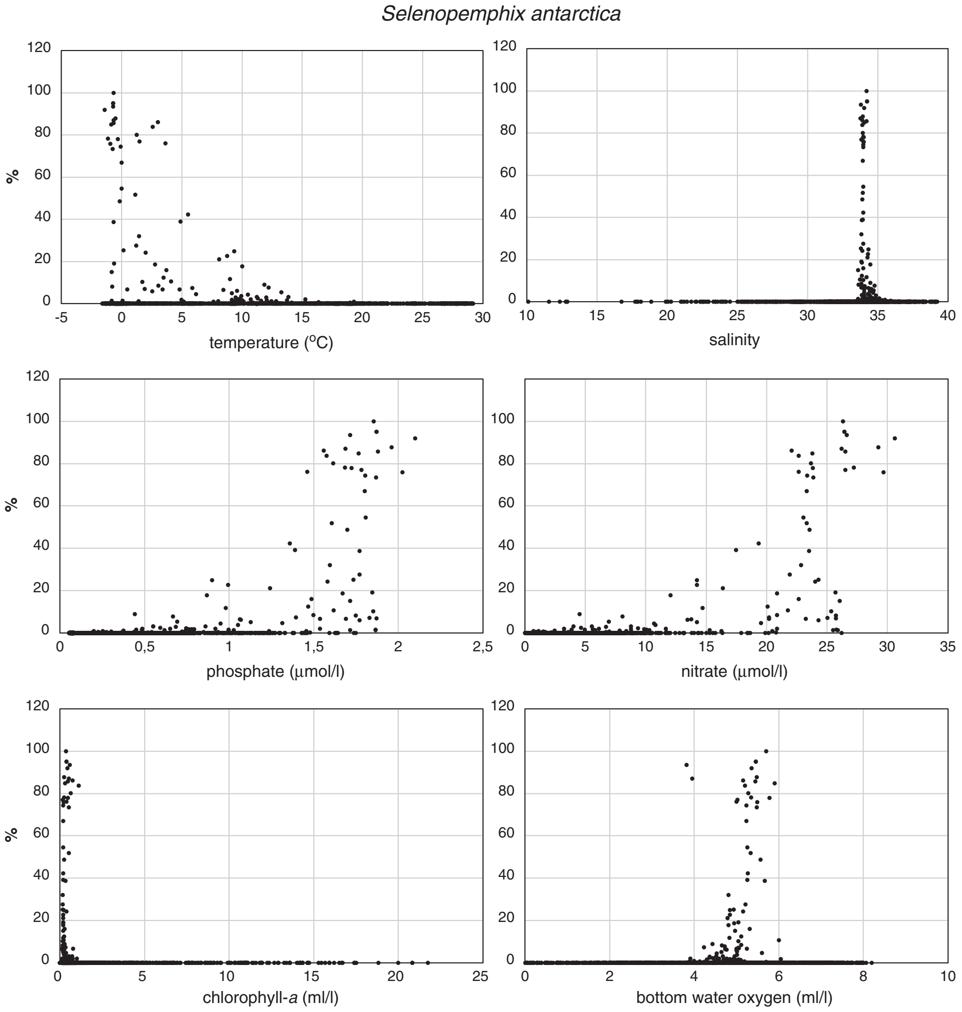

Fig. 209. Relative abundances of *Selenopemphix antarctica* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

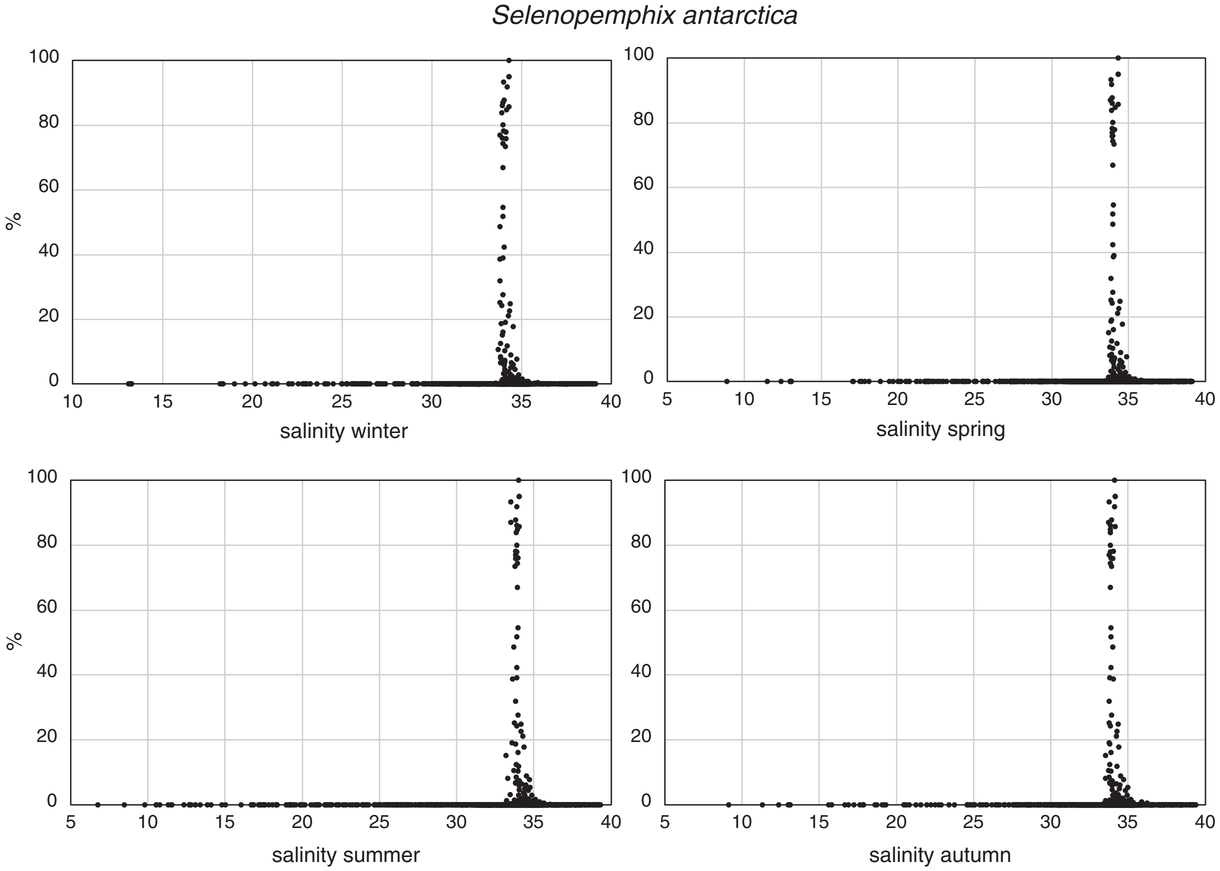

Fig. 210. Relative abundances of *Selenopemphix antarctica* in relationship to seasonal salinity in surface waters.

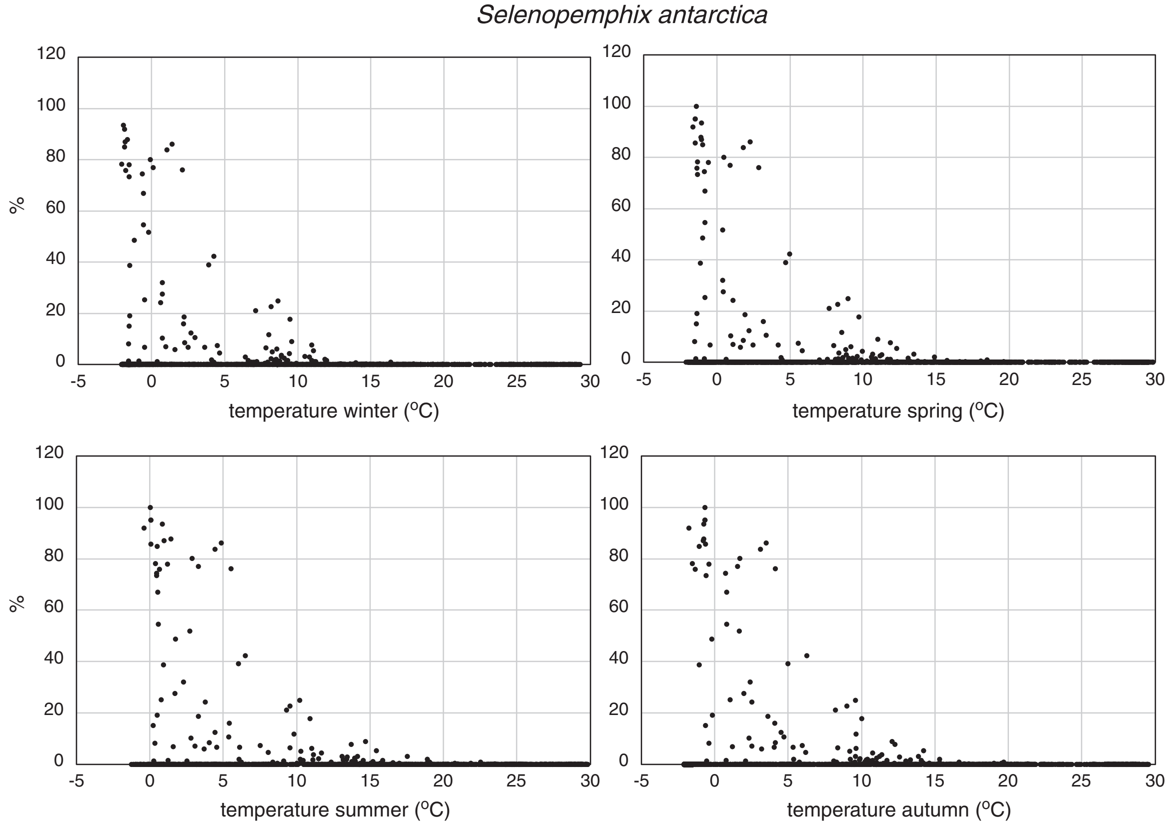

Fig. 211. Relative abundances of *Selenopemphix antarctica* in relationship to seasonal temperature in surface waters.

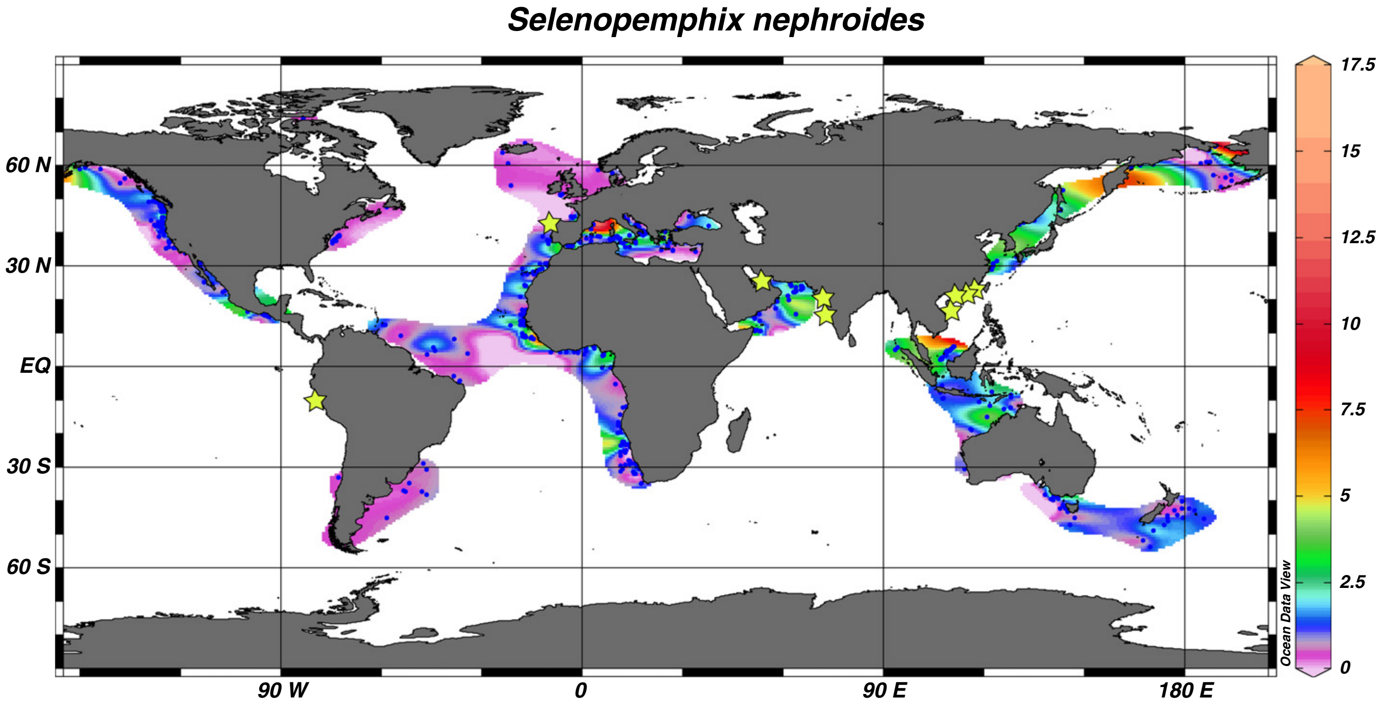

Fig. 212. Geographic distribution of *Selenopemphix nephroides*.

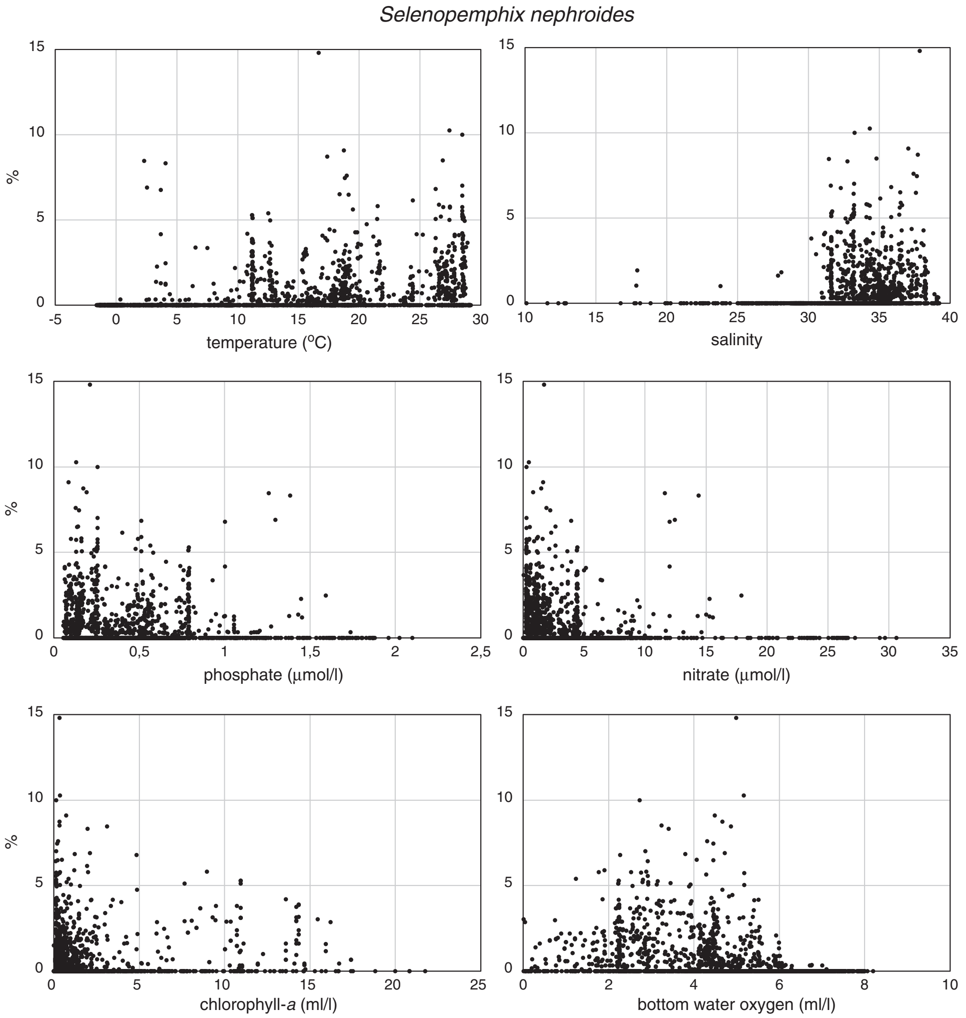

Fig. 213. Relative abundances of *Selenopemphix nephroides* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

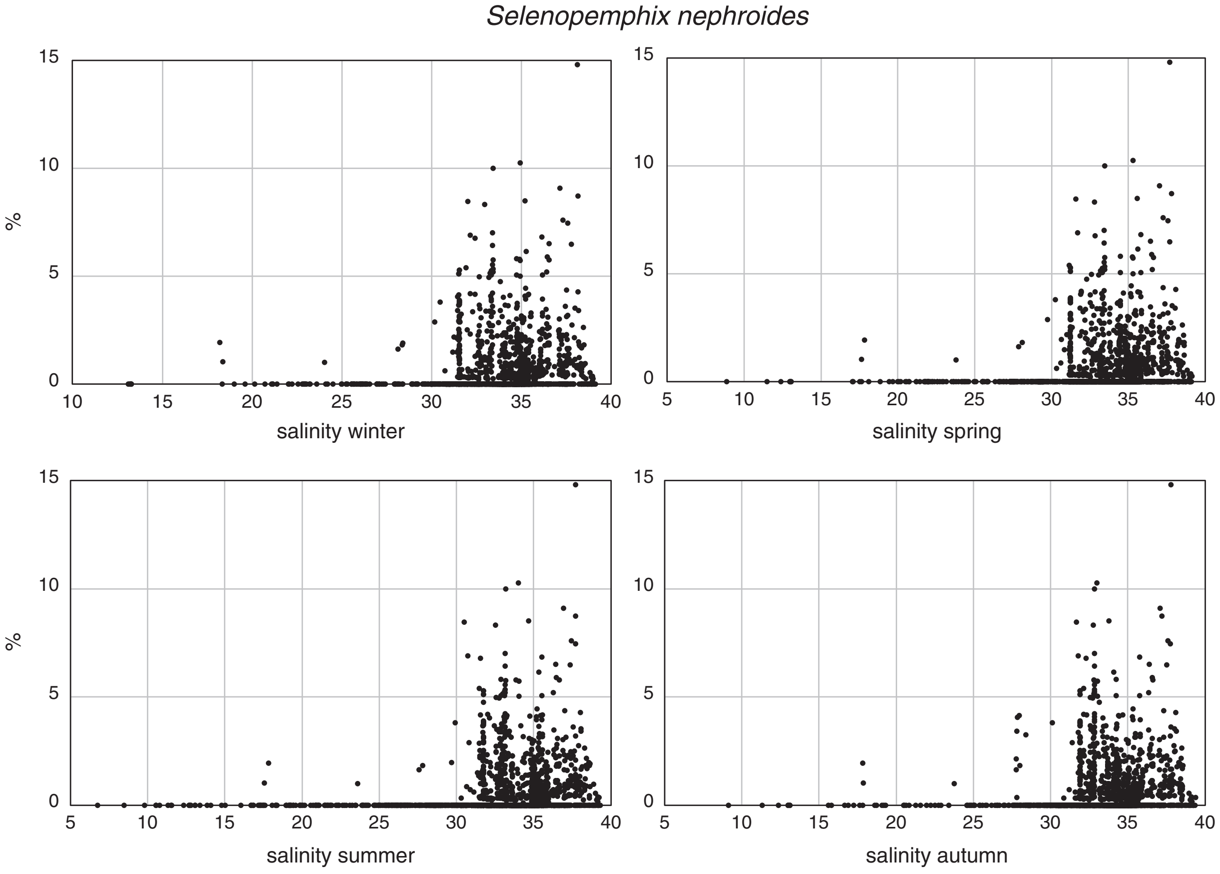

Fig. 214. Relative abundances of *Selenopemphix nephroides* in relationship to seasonal salinity in surface waters.

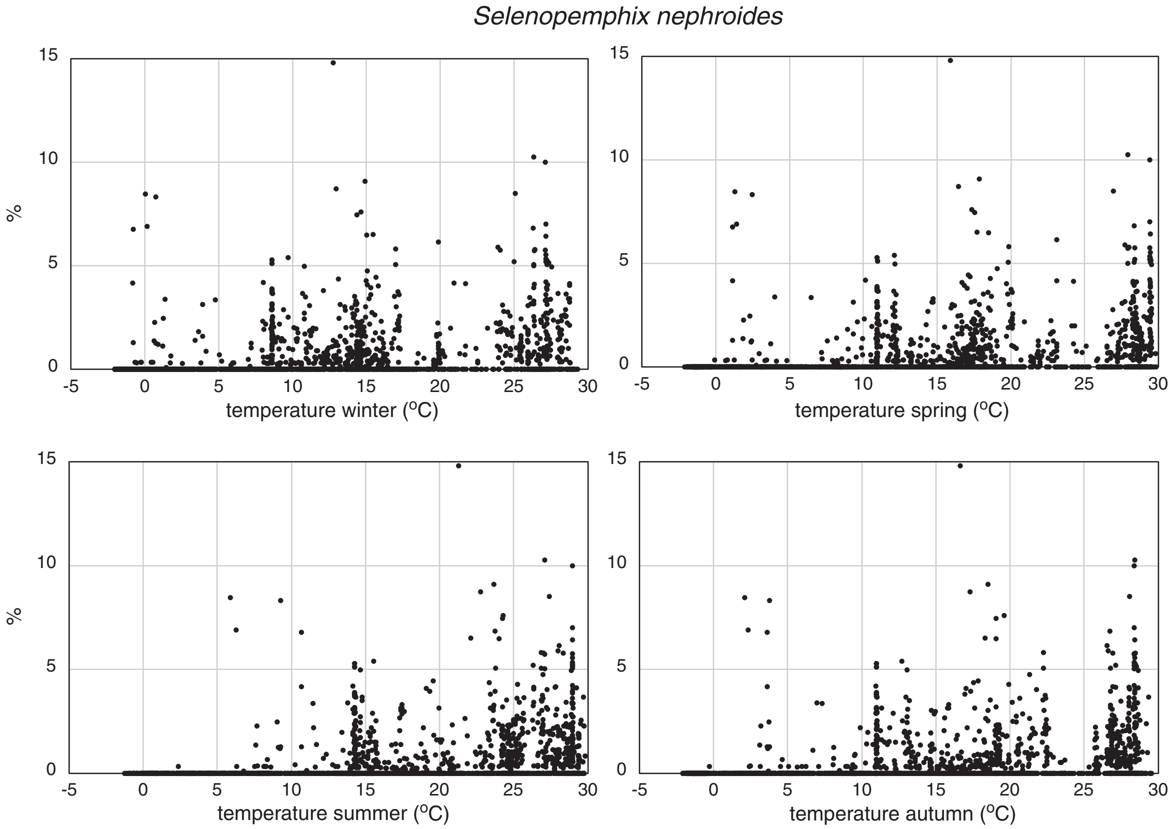

Fig. 215. Relative abundances of *Selenopemphix nephroides* in relationship to seasonal temperature in surface waters.

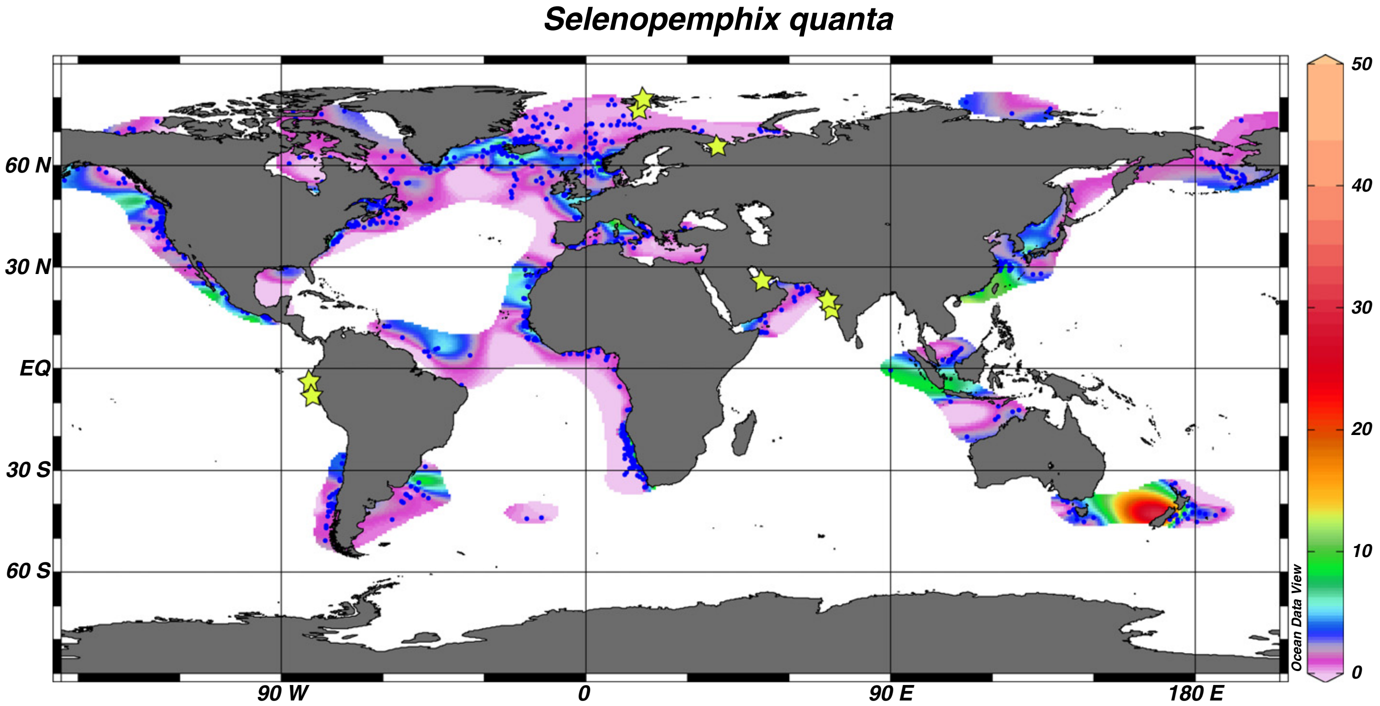

Fig. 216. Geographic distribution of *Selenopemphix quanta*.

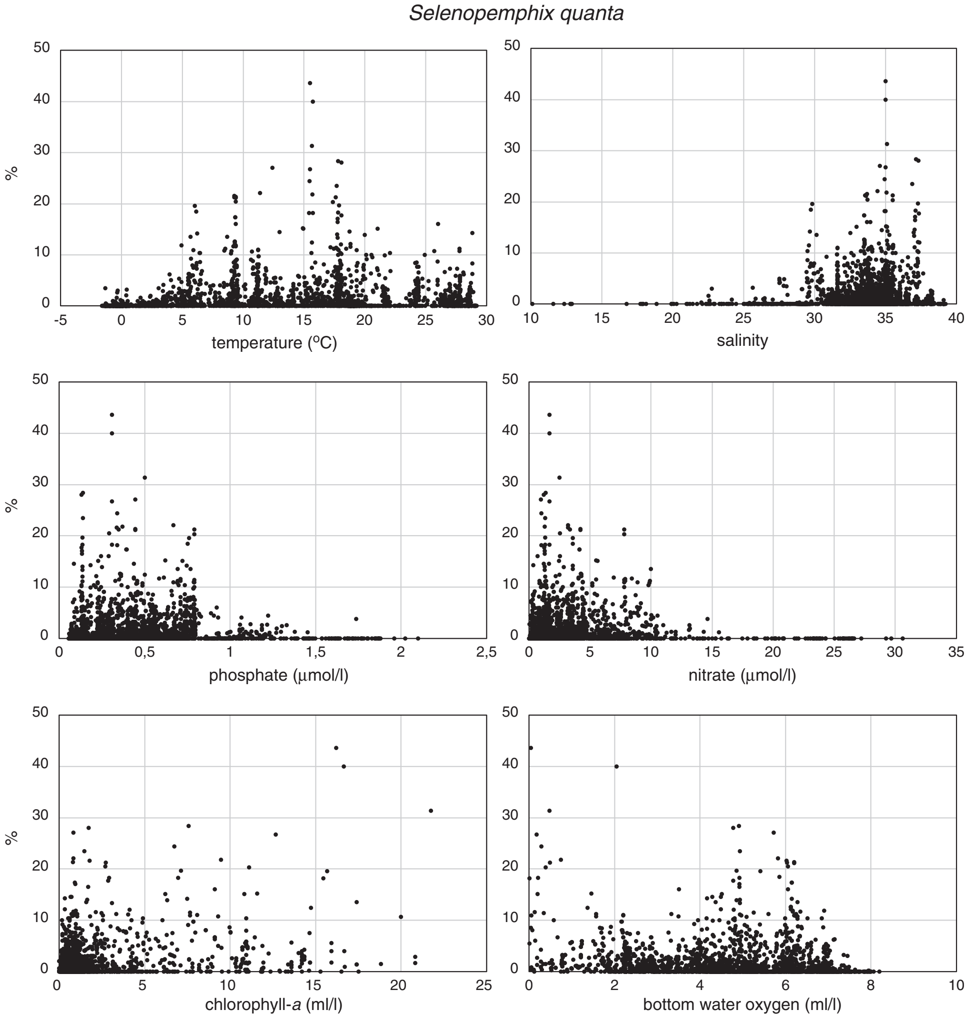

Fig. 217. Relative abundances of *Selenopemphix quanta* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

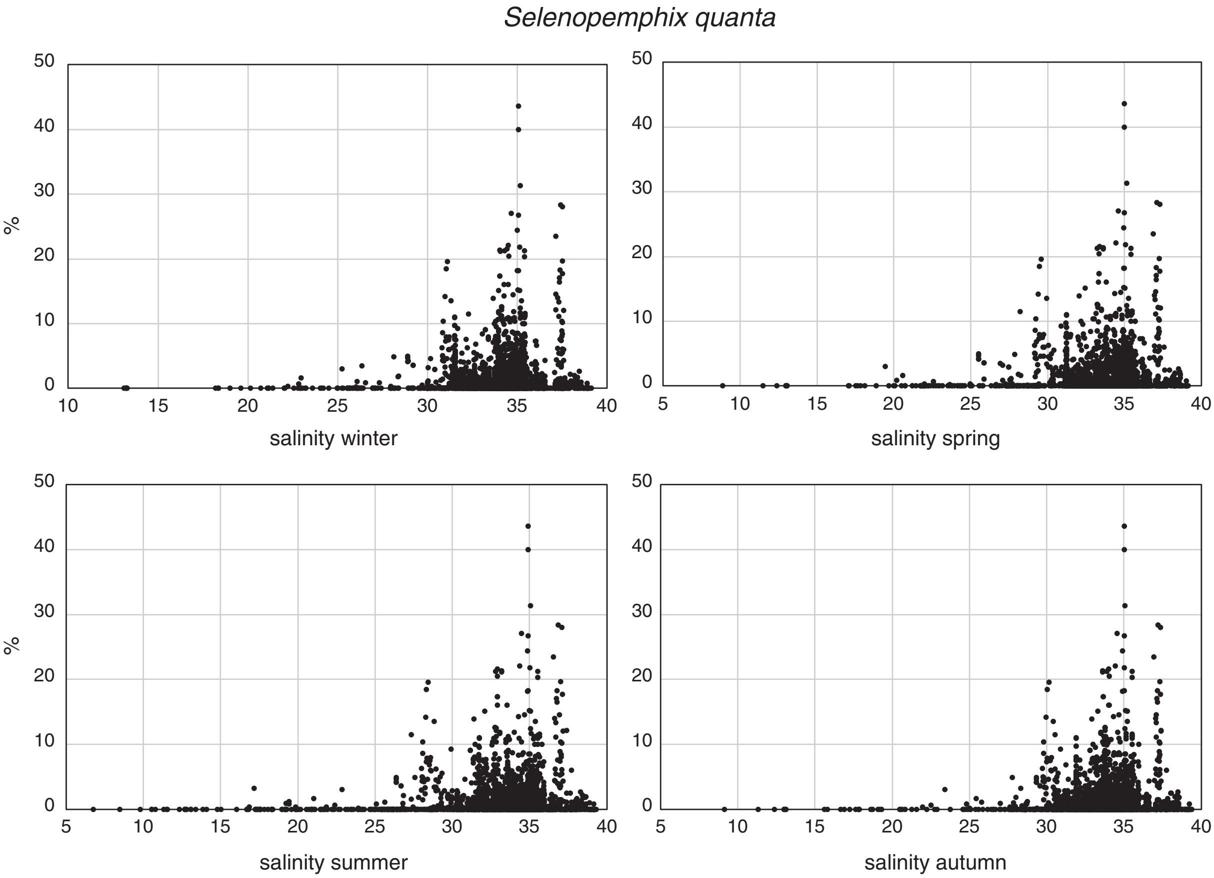

Fig. 218. Relative abundances of *Selenopemphix quanta* in relationship to seasonal salinity in surface waters.

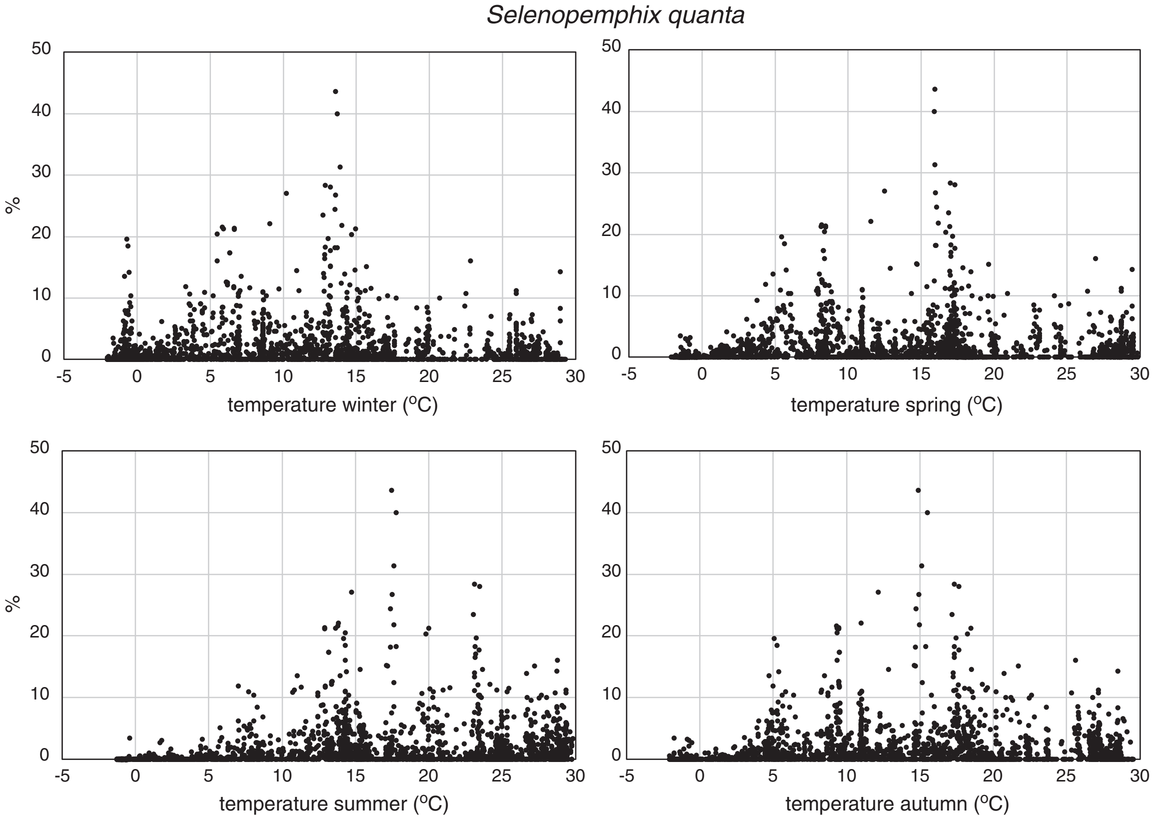

Fig. 219. Relative abundances of *Selenopemphix quanta* in relationship to seasonal temperature in surface waters.

Although *Selenopemphix quanta* can be abundant in oligotrophic environments, highest abundances occur in (seasonally) mesotrophic to eutrophic areas. These are upwelling areas, river plumes and frontal regions. Here large inter-annual variability in the trophic state of the upper waters can occur. Highest relative abundances occur in regions where bottom waters are ventilated.

Comparison with other records:

Apart from the records in the dataset of this Atlas, *Selenopemphix quanta* has been recorded from surface sediments of coastal sites of the Persian Gulf, off western India (Arabian Sea), the upwelling area off Peru, coastal sites of Svalbard (Barents Sea) and coastal sites of the White Sea (Bradford, 1975; Biebow et al., 1993; Biebow, 1996; Godhe et al., 2000; Golovnina and Polyakova, 2004; Novichkova and Polyakova, 2007; D'Costa et al., 2008; Grøsfjeld et al., 2009). Seasonal distribution and sediment trap studies reveal that cyst production is not bound to any season and cysts can be produced throughout the year (Montresor et al., 1998; Susek et al., 2005; Fujii and Matsuoka, 2006; Ribeiro and Amorim, 2008; Pospelova et al., 2010; Zonneveld et al., 2010; Price and Pospelova, 2011). In the Arabian Sea there are clear indications for mass transport from the shelf into the deeper part of the basin (Zonneveld and Brummer, 2000). Off NW Africa and in the Saanich Inlet (BC, Canada) cyst production is positively correlated to the fluxes of opal and biogenic silica suggesting a link between the production of these cysts and diatom production (Zonneveld et al., 2010; Price and Pospelova, 2011). In Fjords of Svalbard (Barents Sea) the production of *Q. concreta* can be linked to the influence of Atlantic Water (Howe et al., 2010).

In arctic sediments the relative abundance of this species shows a negative correlation with seasonal ice cover duration but it occurs at sites where ice-cover may last for 11 months a year (de Vernal et al., 1998; Radi and de Vernal, 2008).

Concluding remarks:

Selenopemphix quanta has a polar to equatorial distribution and is generally restricted to eutrophic settings such as upwelling areas, discharge plumes and frontal systems. It can be observed in coastal and offshore sites where upper waters may be full-marine or with seasonally or permanently reduced salinities. Highest relative abundances occur in mesotrophic to eutrophic regions where bottom waters are anoxic to oxic. Its seasonal distribution at some sites is positively correlated to the opal/biogenic silica flux.

55. *Spiniferites bentorii* (Rossignol 1964) Wall et Dale 1970

Figs. 219–223.

Distribution:

The distribution of *Spiniferites bentorii* is restricted to temperate to equatorial coastal regions. It is absent from the central part of the Oceans with exception of one recording in the central North Atlantic. Highest abundances (up to 28%) occur in eutrophic regions of the Yellow Sea and the East China Sea. It has not been observed where nitrate concentrations in the surface waters are low.

Environmental parameter range:

SST: 0.02–29.8 °C (winter–spring) with summer SST > 11.2 °C. SSS: 27.5–39.4 (spring–autumn),[P]: 0.06–1.06 μmol/l, [N]: 0.1–9.3 μmol/l, chlorophyll-*a*: 0.1–14.7 ml/l, bottom water [O_2]: 0–6.3 ml/l.

Although *Spiniferites bentorii* can be abundant in oligotrophic regions, highest abundances occur in (seasonally) mesotrophic to eutrophic settings such as upwelling areas, where large inter-annual variability in the trophic state of the upper waters can occur.

Comparison with other records:

Apart from the records in the dataset of this Atlas, *Spiniferites bentorii* has been observed in surface sediments of coastal sites of the Gulf of Oman, southeastern Black Sea, the Marmara Sea (Bradford, 1975; Mudie et al., 2001, 2004), the South China Sea and coastal regions off southwestern Australia (Marret and Zonneveld, 2003) and the Bahía Blanca estuary (Argentinia, Grill and Guerstein, 1995; Borel et al., 2006). In the Gulf of Oman it occurs under hypersaline conditions with salinities > 40.

In sediment trap studies it is only registered as a separate species in the Saanich Inlet (B.C. Canada) where its production appears to anticorrelate to discharge of the Fraser River, SST: and solar insolation (Price and Pospelova, 2011).

Concluding remarks:

Spiniferites bentorii has a temperate to equatorial mainly coastal distribution. It is not observed in this Atlas with salinities below 27.5. Highest relative abundances occur in mesotrophic to eutrophic environments.

56. *Spiniferites cruciformis* Wall et al., 1973

Figs. 224–227.

Distribution:

Spiniferites cruciformis is restricted to the Black Sea, Caspian Sea, Aral Sea, Marmara Sea and eastern Mediterranean Sea where it is exclusively observed in coastal sites. It can form up to 48% of the association. Apart from three sites, the environment is brackish as result of river discharge.

Environmental parameter range:

SST: 1.6–26.0 °C (winter–summer), SSS: 8.5–17.3 (summer–winter) except for three recordings from Eastern Mediterranean sites where SSS: 37.7–39.0 (spring–autumn), [P]: 0.10–0.14 μmol/l, [N]: 0.05–1.0 μmol/l, chlorophyll-*a*: 0.1–8.3 ml/l, bottom waters [O_2]: 4.2–6.6 ml/l.

Comparison with other records:

Based on recordings of this species in Greek fresh-water lakes, it has been suggested to be a fresh-water species that is transported into the marine realm by rivers (Kouli et al., 2001). It is rarely present in surface sediments of fresh to brackish lakes around the Marmara Sea as well (Mudie personal communication, 2012). Our records do not reject this hypothesis as the species is exclusively recorded from areas that are influenced by fresh water. We however do also not find evidence for this.

The species shows extreme morphological variation in process length and development which is often suggested to be linked to SSS. However although some weak relationship could be determined with downcore salinity concentrations reconstructed from planktonic foraminiferal transfer functions until now no direct unequivocal relationship with present salinity concentrations in surface waters and cyst morphology could be determined (Mudie et al., 2001; Marret personal communication, 2012).

Concluding remarks:

Spiniferites cruciformis is endemic to the Caspian Sea, Aral Sea, Black Sea and Eastern Mediterranean Sea and occurs in areas affected by river discharge. At these sites [P]: > 0.1 μmol/l and bottom waters are well ventilated.

57. *Spiniferites delicatus* Reid 1974

Figs. 228–231.

Distribution:

Spiniferites delicatus is restricted to the subtropic to equatorial coastal regions with exception of some sites in the temperate part of the North Atlantic Ocean. Highest abundances (up to 80%) occur in the eastern equatorial Atlantic and eastern Equatorial Pacific Oceans.

Environmental parameter range:

SST: −1.0–29.8 °C (winter–spring), with summer SST: > 8 °C SSS: 25.6–39.4 (spring–autumn), [P]: 0.06–0.62 μmol/l, [N]: 0.04–8.99 μmol/l, chlorophyll-*a*: 0.1–8.8 ml/l, bottom waters [O_2]: 0.4–6.9 ml/l.

Comparison with other records:

Apart from the records in the dataset of this Atlas, *Spiniferites delicatus* has been observed in surface sediments of coastal shelf-sites of the Benguela upwelling area and the Lisbon Bay (North-East Atlantic, Joyce et al., 2005; Ribeiro and Amorim, 2008; Pitcher and Joyce, 2009).

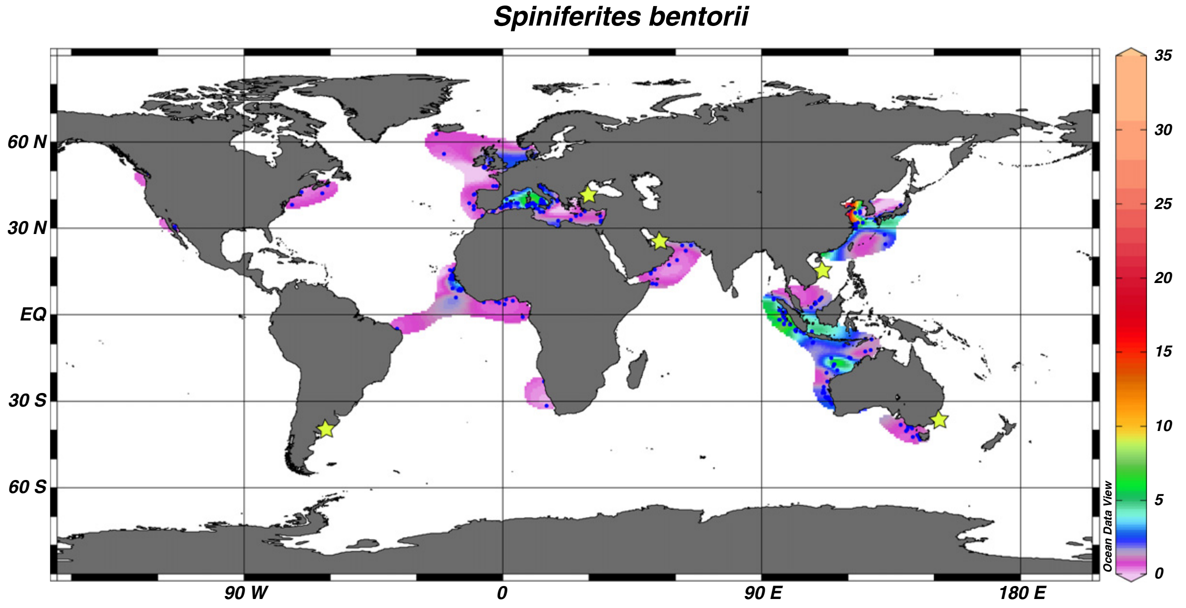

Fig. 220. Geographic distribution of *Spiniferites bentorii*.

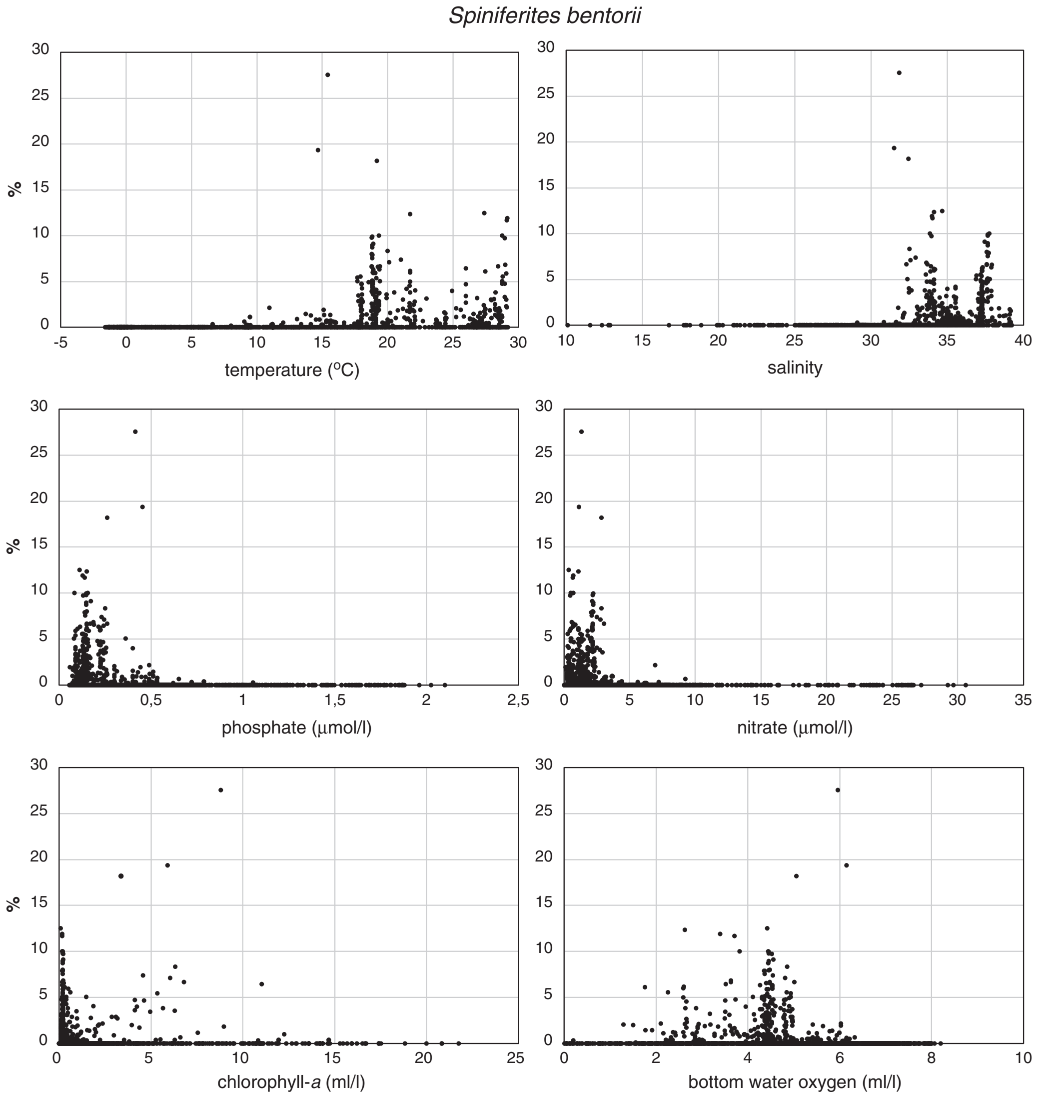

Fig. 221. Relative abundances of *Spiniferites bentorii* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

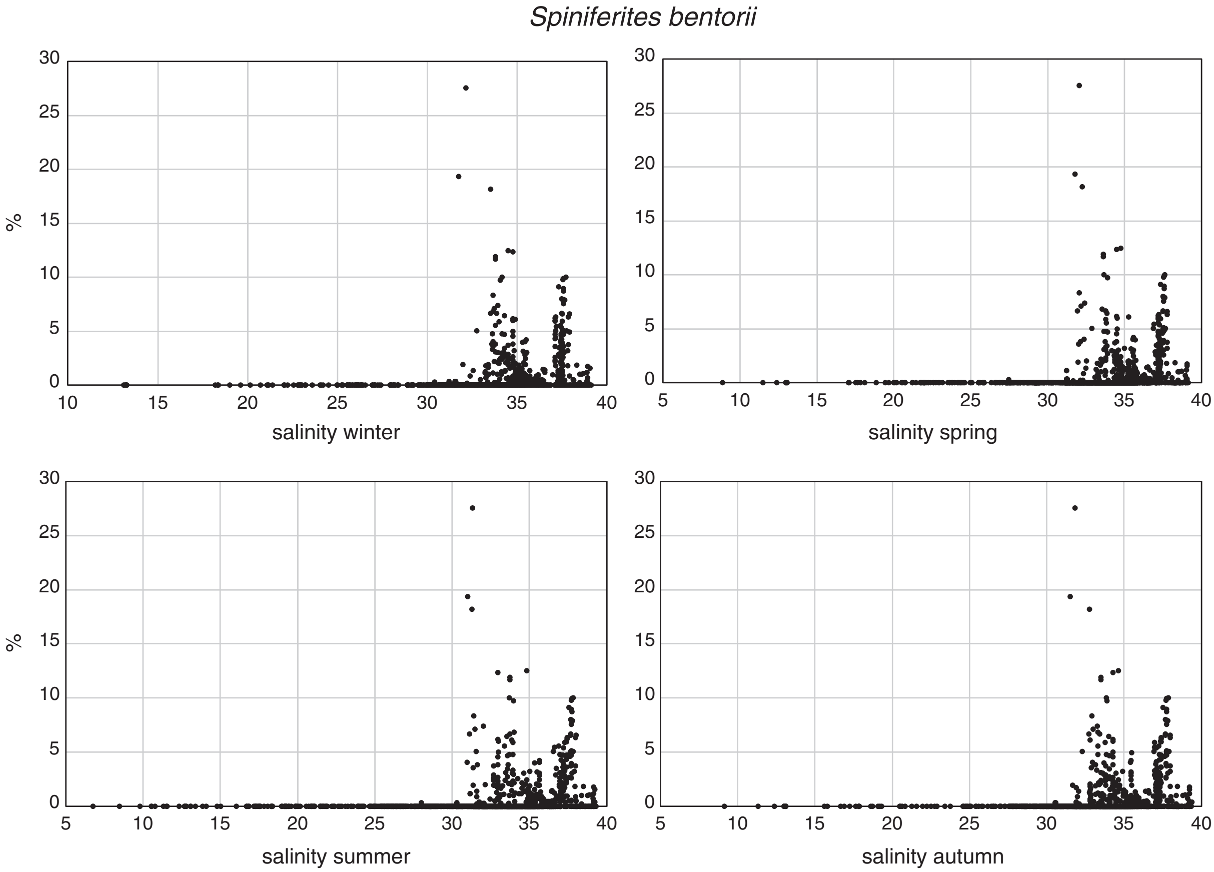

Fig. 222. Relative abundances of *Spiniferites bentorii* in relationship to seasonal salinity in surface waters.

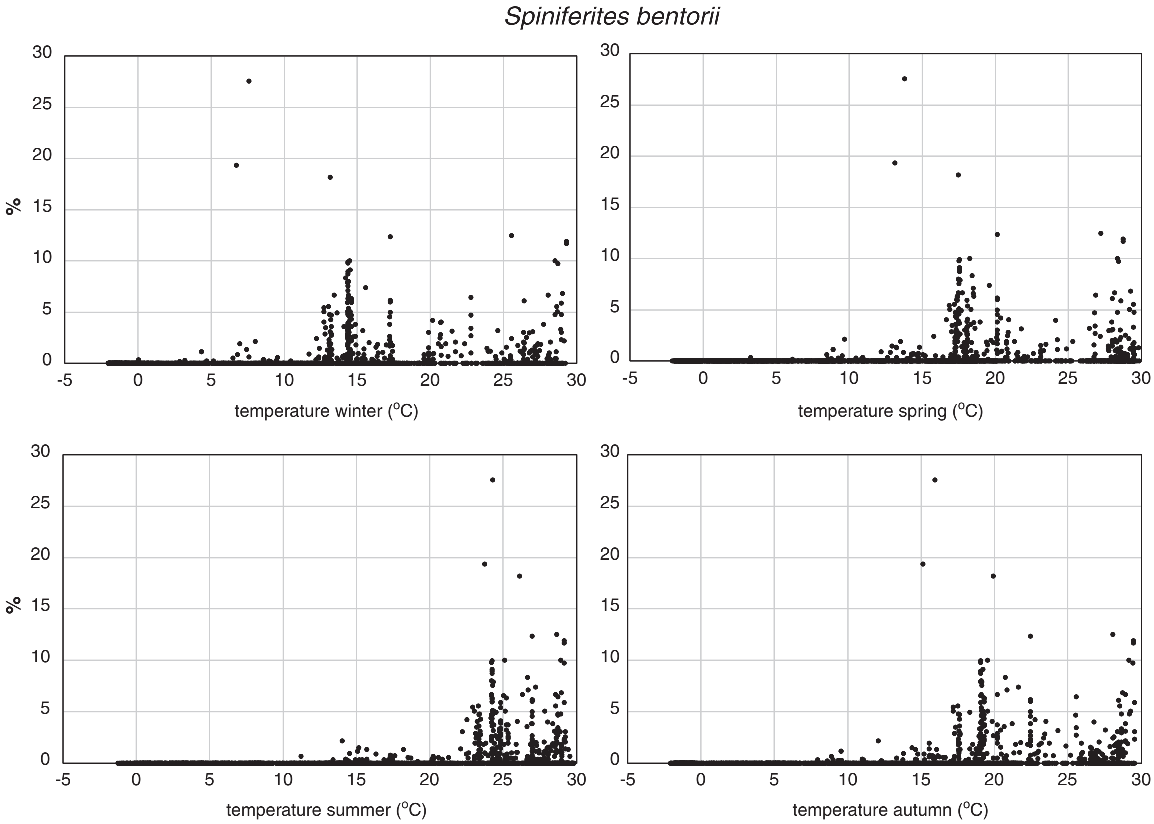

Fig. 223. Relative abundances of *Spiniferites bentorii* in relationship to seasonal temperature in surface waters.

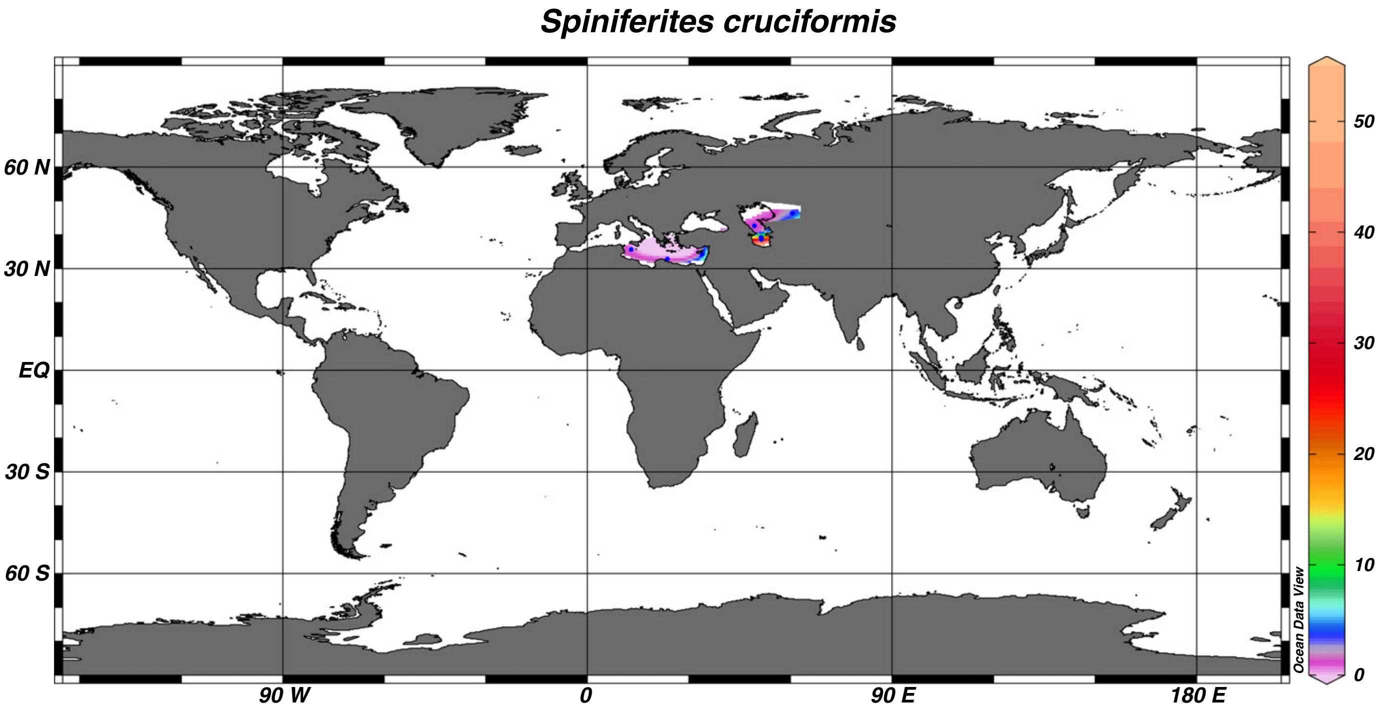

Fig. 224. Geographic distribution of *Spiniferites cruciformis*.

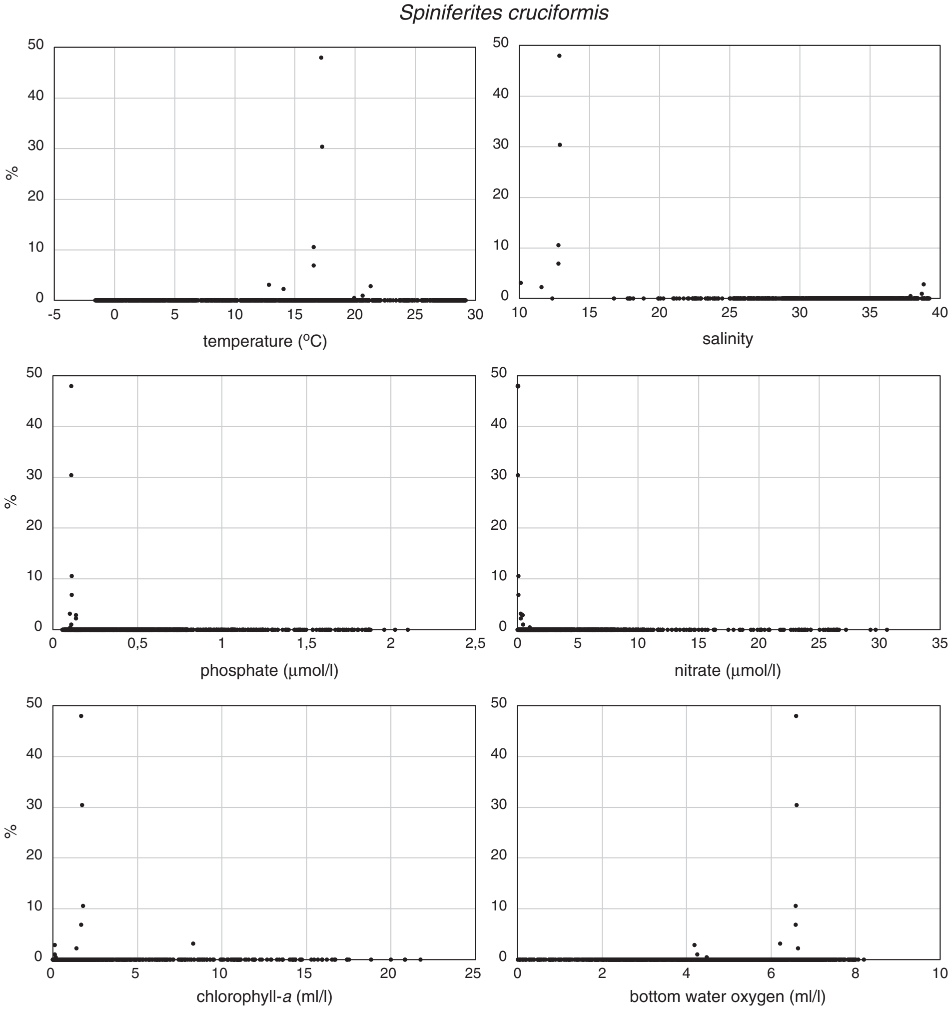

Fig. 225. Relative abundances of *Spiniferites cruciformis* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

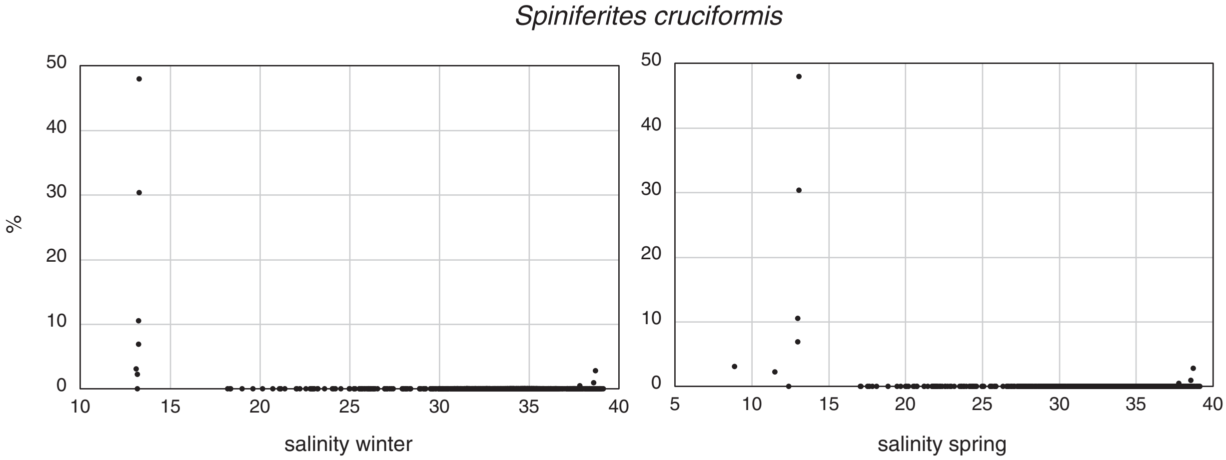

Fig. 226. Relative abundances of *Spiniferites cruciformis* in relationship to seasonal salinity in surface waters.

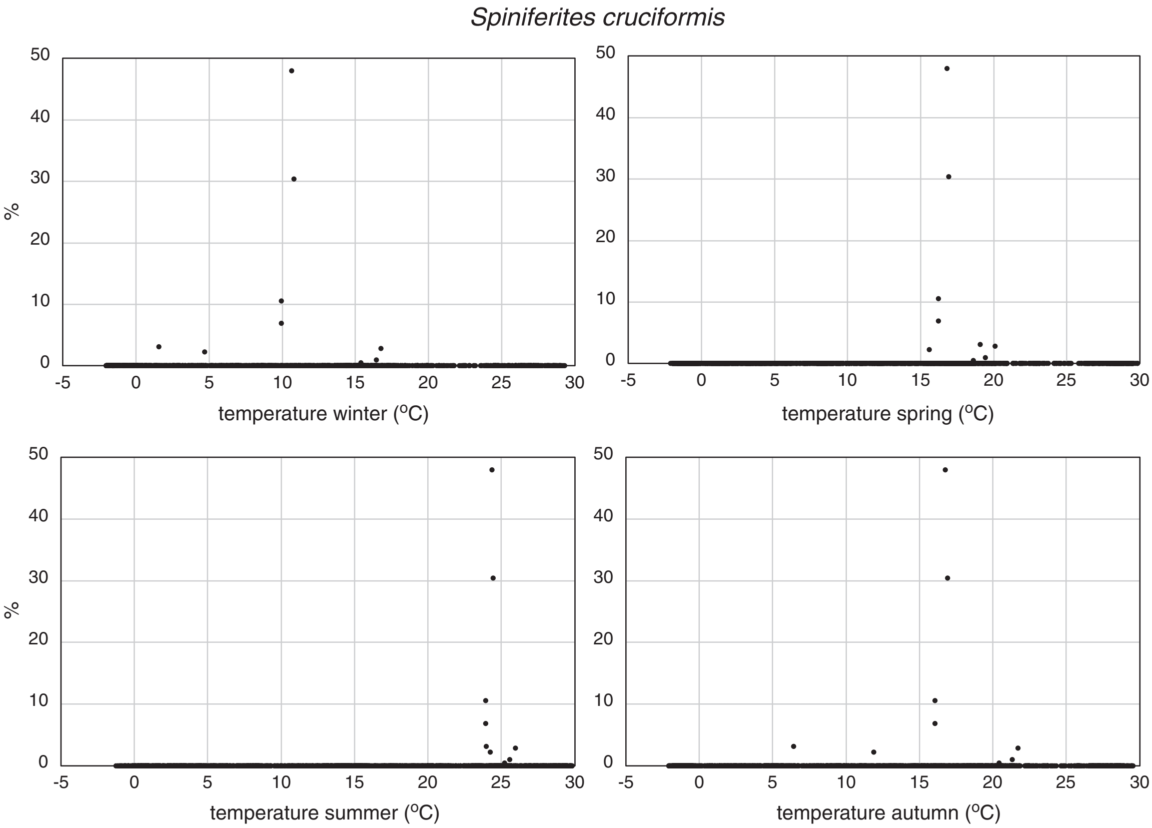

Fig. 227. Relative abundances of *Spiniferites cruciformis* in relationship to seasonal temperature in surface waters.

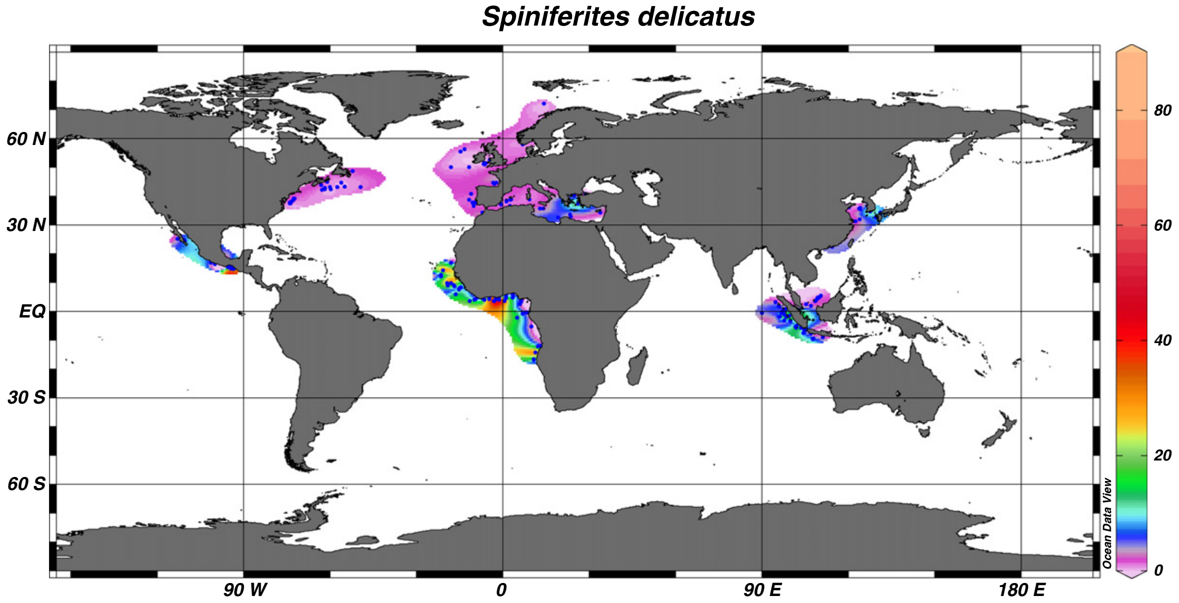

Fig. 228. Geographic distribution of *Spiniferites delicatus*.

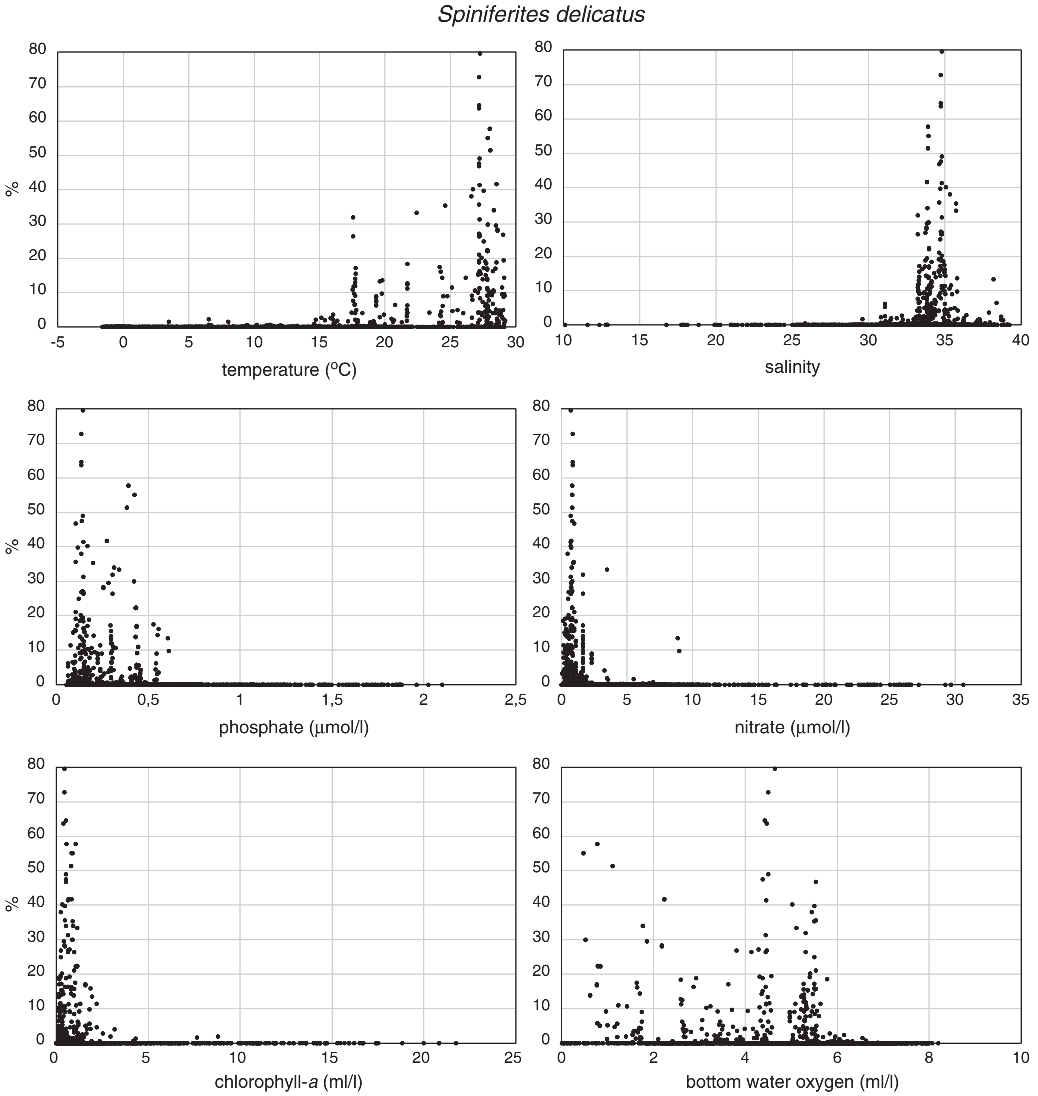

Fig. 229. Relative abundances of *Spiniferites delicatus* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

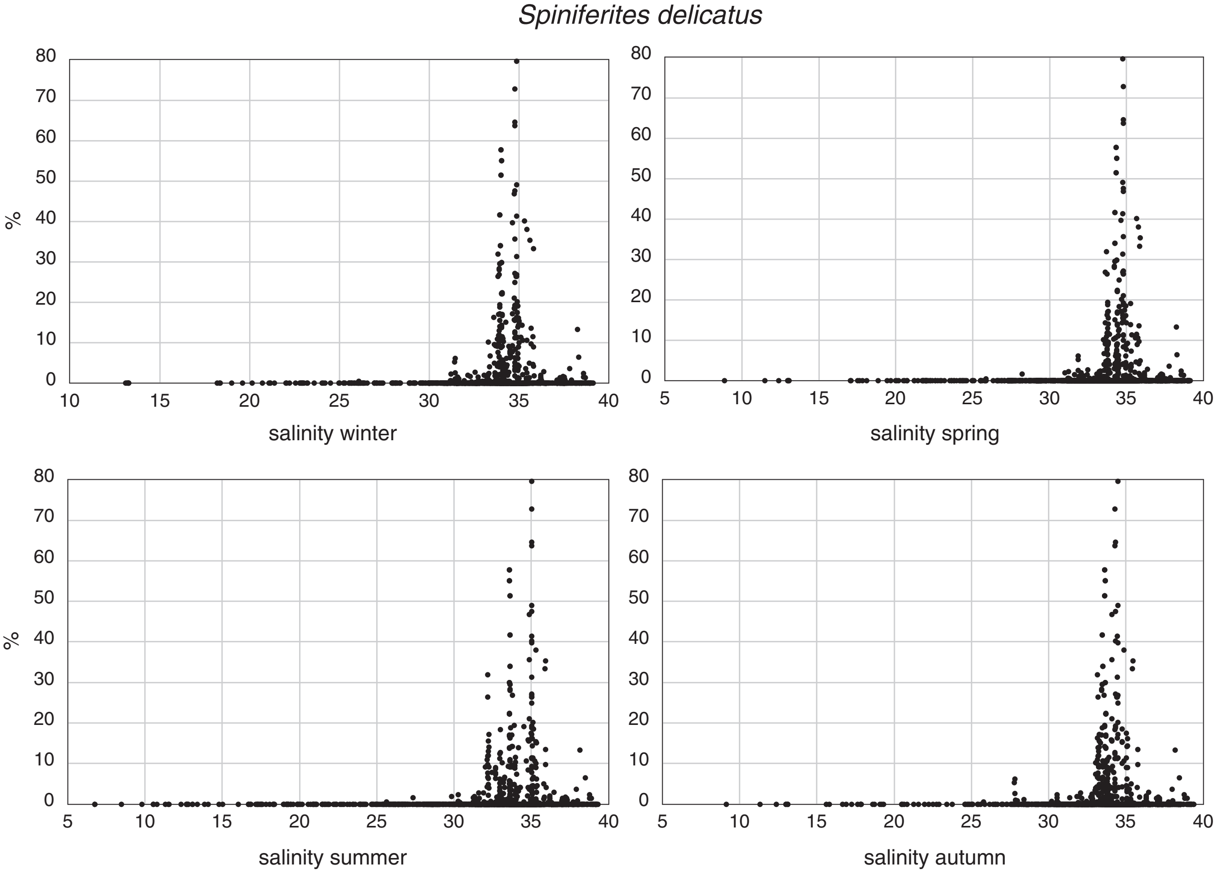

Fig. 230. Relative abundances of *Spiniferites delicatus* in relationship to seasonal salinity in surface waters.

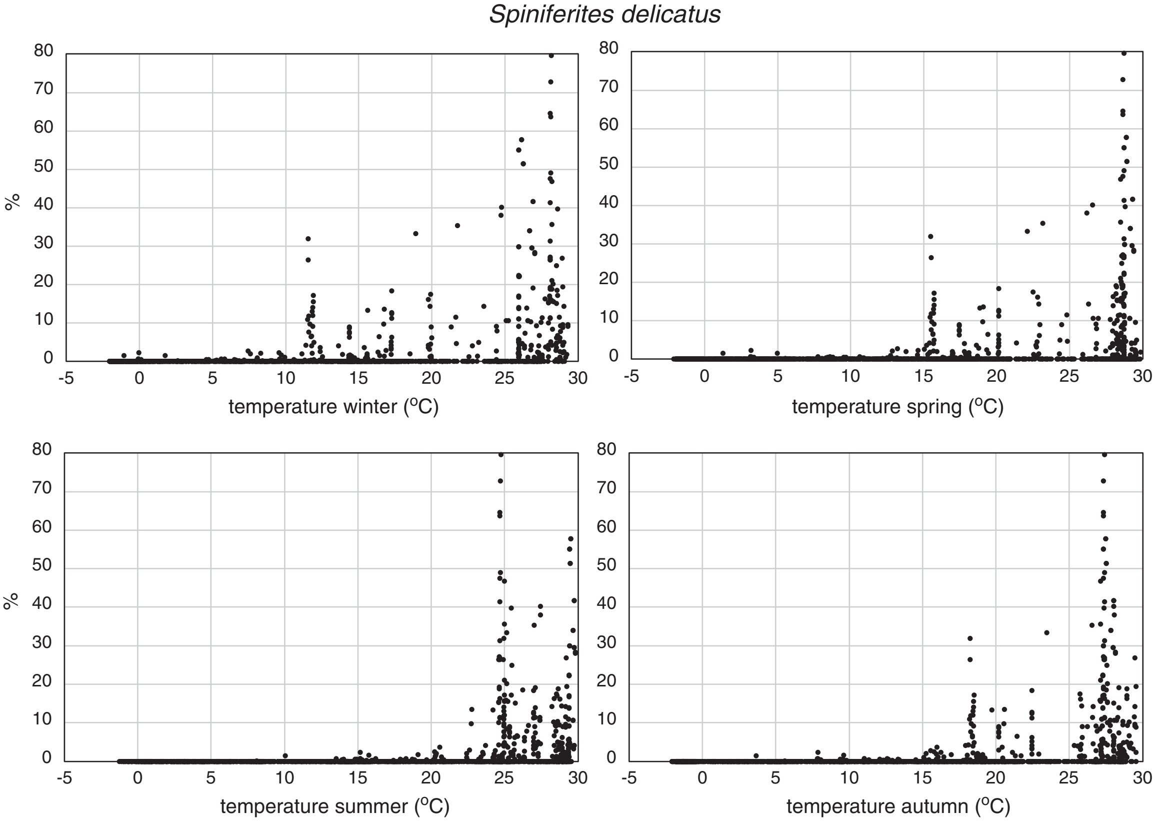

Fig. 231. Relative abundances of *Spiniferites delicatus* in relationship to seasonal temperature in surface waters.

In seasonal distribution and sediment trap studies of Omura Bay (West Japan) and Lisbon Bay (northeast Atlantic Ocean) cysts production occurs throughout the year without preference for a certain season (Fujii and Matsuoka, 2006; Ribeiro and Amorim, 2008).

Concluding remarks:

Spiniferites delicatus occurs in sub-tropical to equatorial regions with oligotrophic to mesotrophic conditions. It is mainly observed in coastal sites where upper water salinities can be slightly reduced by river discharge. Cysts are not observed where bottom waters are anoxic.

58. *Spiniferites elongatus* Reid 1974

Figs. 232–235.

Distribution:

Spiniferites elongatus is restricted to the Northern Hemispheric polar to subtropic regions. High relative abundances occur in the central North Atlantic Ocean near frontal systems, in the Baffin Bay (Labrador Sea) and in the Barents Sea (Arctic). It can account for up to 49% of the association. It can reach high relative abundances in coastal sites and it can be abundant in the central parts of the oceans.

Environmental parameter range:

SST: gradient is–2.0–29.1 °C (winter–summer) SSS: 9.8–39.2 (summer–summer), [P]: 0.09–1.73 μmol/l, [N]: 0.04–18.64 μmol/l, chlorophyll-*a*: 0.01–20.8 ml/l, bottom water [O_2]: 0.9–8.2 ml/l.

Comparison with other records:

Spiniferites elongatus can be observed in regions with permanent sea ice cover but there is no evidence of a correlation between sea ice cover duration and relative abundances in the arctic region (de Vernal et al., 1998; Radi and de Vernal, 2008).

It occurs in fjords of Svalbard (Barents Sea) where it is produced in late summer–late autumn (Grøsfjeld et al., 2009; Howe et al., 2010).

Concluding remarks:

Spiniferites elongatus is a Northern Hemisphere species with a polar to sub-tropical distribution. It occurs in full-marine conditions, which may have (seasonally) reduced salinities as a result of ice melting and/or river discharge. Highest relative abundances occur in eutrophic settings such as the North Atlantic frontal systems. It only occurs where well ventilated bottom waters prevail.

59. *Spiniferites lazus* Reid 1974

Figs. 236–239.

Distribution:

Spiniferites lazus is restricted to the coastal sites of the temperate and sub-polar North Atlantic Ocean and the adjacent North Sea and Western Mediterranean Sea. Abundances are low (up to 2%) in the North Sea and Western Mediterranean Sea. High relative abundances occur in the upwelling area off the Iberian peninsula.

Environmental parameter range:

SST: 0.8–24.8 °C (winter–summer) with summer SST>4 °C. SSS: 31.2–37.9 (summer–winter), [P]: 0.09–0.59 μmol/l, [N]: 1.22–7.80 μmol/l, chlorophyll-*a*: 0.2–2.4 ml/l, bottom waters [O_2]: 4.4–7.0 ml/l.

Comparison with other records:

Spiniferites lazus has not been recorded from regions not covered by this Atlas.

Concluding remarks:

Spiniferites lazus is a sub-polar to temperate North Atlantic species that can be observed in full marine, coastal sites with elevated nitrate concentrations and well ventilated bottom waters.

60. *Spiniferites membranaceus* (Rossignol 1964) Sarjeant 1970

Figs. 240–243.

Distribution:

Spiniferites membranaceus is observed in temperate to equatorial regions with the sub-tropical fronts forming roughly the margins of its distribution in both hemispheres. It mainly occurs coastal and in the vicinity of the continental margins although it can be found sporadically in the central part of the oceans as well. High abundances (up to 60%) occur in the East China Sea, Sea of Japan, the Iberian upwelling area (eastern North Atlantic), the southern part of the NW African upwelling area and the Congo River plume (eastern equatorial Atlantic Ocean).

Environmental parameter range:

SST: −0.9–29.8 °C (winter–spring) with summer SST: >5.6 °C. SSS: 17.5–39.1 (summer–summer), [P]: 0.06–1.06 μmol/l, [N]: 0.1–12.0 μmol/l, chlorophyll-*a*: 0.05–20.0 ml/l, bottom water [O_2]: 0.05–7.3 ml/l. *Spiniferites membranaceus* is abundant in regions where SSS is seasonally or permanently reduced as a result of river discharge influence.

Comparison with other records:

Apart from the records in the dataset of this Atlas, *Spiniferites mebranaceus* has been observed in surface sediments of coastal sites of the South China Sea, the Gulf of Oman, off India (eastern Arabian Sea), the Saanich Inlet (BC. Canada), The Bahía Blanco (Argentina) and the upwelling area off Peru (eastern equatorial Pacific, Bradford, 1975; Grill and Guerstein, 1995; Godhe et al., 2000; Biebow et al., 1993; Wang et al., 2004c; Price and Pospelova, 2011). Although it has been observed where SST are<0 °C in winter it is not observed at sites with seasonal ice cover (de Vernal et al., 1998; Radi and de Vernal, 2008). In seasonal distribution and sediment trap studies no clear relationship between *S. membranaceus* production and seasonal variations in environmental conditions (Montresor et al., 1998; Ribeiro and Amorim, 2008).

Concluding remarks:

Spiniferites membranaceus has a temperate to equatorial distribution. It occurs in coastal as well open oceanic sites which can be full-marine or experience temporarily or permanently reduced salinities. It can be present in oligotrophic to eutrophic environments and bottom waters are hypoxic to well-ventilated.

61. *Spiniferites mirabilis* ((Rossignol 1964) Sarjeant 1970

Figs. 244–247.

Distribution:

Spiniferites mirabilis is observed in temperate to equatorial regions with he sub-tropical fronts forming roughly its distribution margins on both hemispheres. It has a coastal to open oceanic distribution. It is present in all major upwelling areas world-wide but is not typically abundant in these regions. High abundances (up to 76%) occur in the northern and southern Pacific and Atlantic Oceans at around 30–40°N and 30–40° S. Another optimum is observed around the equator.

Environmental parameter range:

SST: −0.8–29.8 °C (winter–spring), SSS: 17.5–39.4 (summer–autumn), [P]: 0.06–1.24 μmol/l, [N]: 0.05–16.38 μmol/l, chlorophyll-*a*: 0.05–21.76 ml/l, bottom waters [O_2]: 0.01–7.4 ml/l.

In the North Pacific and North Atlantic *S. mirabilis* sporadically occurs in regions where winter SST are<0 °C. At these sites seasonal contrast is large and summer SST varies between 10.7 and 15.1 °C. SSS can be reduced seasonally or throughout the year for instance by river discharge e.g. in the Black Sea and Marmara Sea. High relative abundances of *Spiniferites mirabilis* occur in eutrophic regions. *Comparison with other records*:

Apart from the records in the dataset of this Atlas, *Spiniferites mirabilis* has been observed in surface sediments of coastal sites of the South China Sea, the Gulf of Oman, off India (eastern Arabian Sea), and the upwelling area off Peru (eastern equatorial Pacific, Bradford, 1975; Biebow et al., 1993; Godhe et al., 2000; Marret and Zonneveld, 2003).

In the Arabian Sea, cysts of *Spiniferites mirabilis* are typically formed during upwelling relaxation after termination of the southwest monsoon (Zonneveld and Brummer, 2000). In seasonal distribution and sediment trap studies off the Iberian paninsula and the Omura Bay (West Japan) no clear season relationship between cyst production and seasonal variability in environment can be documented (Fujii and Matsuoka, 2006; Ribeiro and Amorim, 2008).

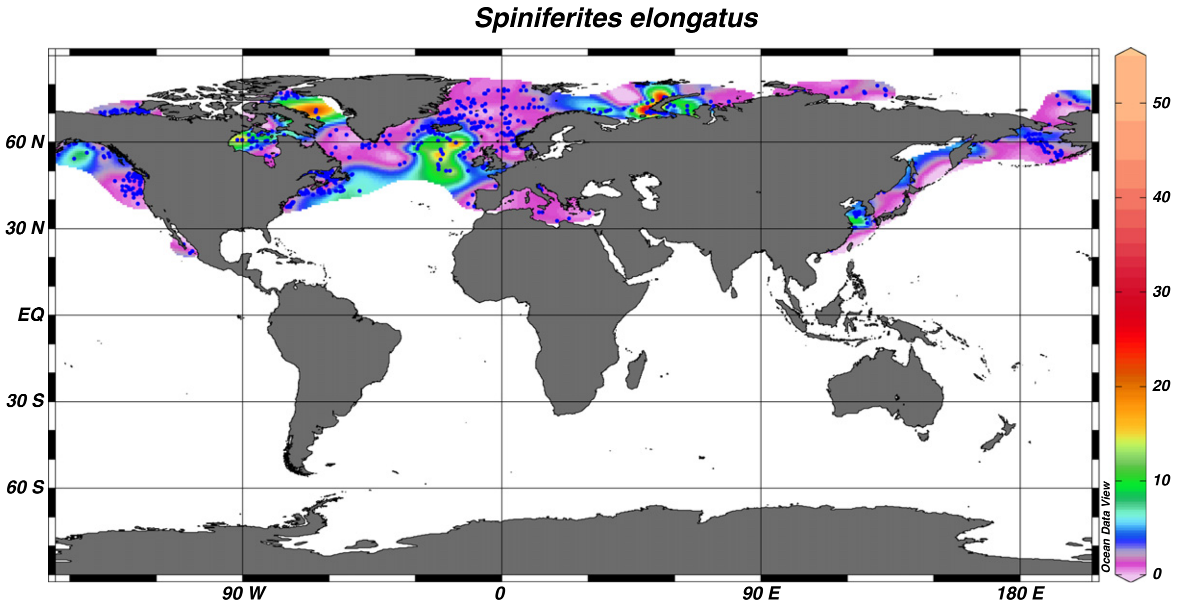

Fig. 232. Geographic distribution of *Spiniferites elongatus*.

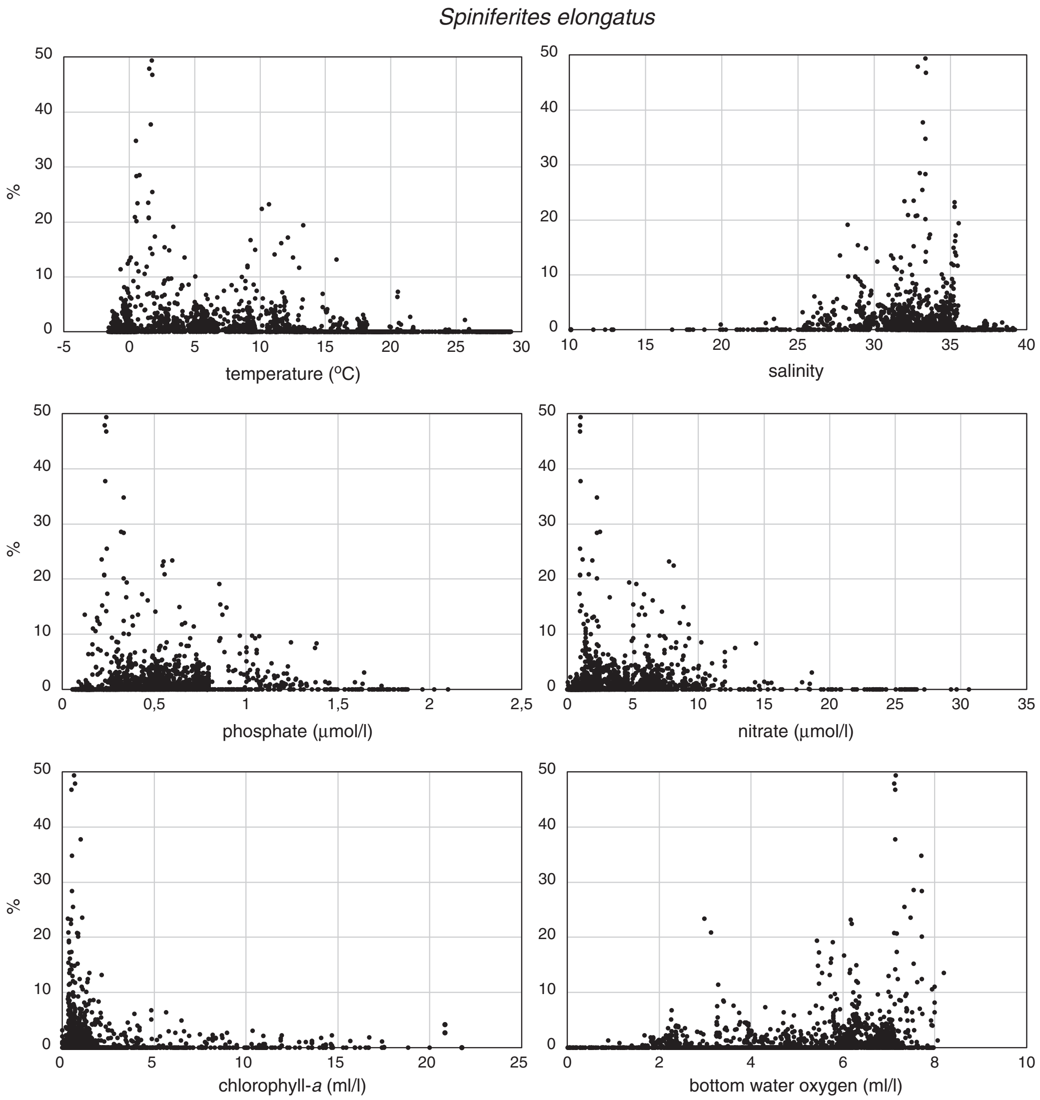

Fig. 233. Relative abundances of *Spiniferites elongatus* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

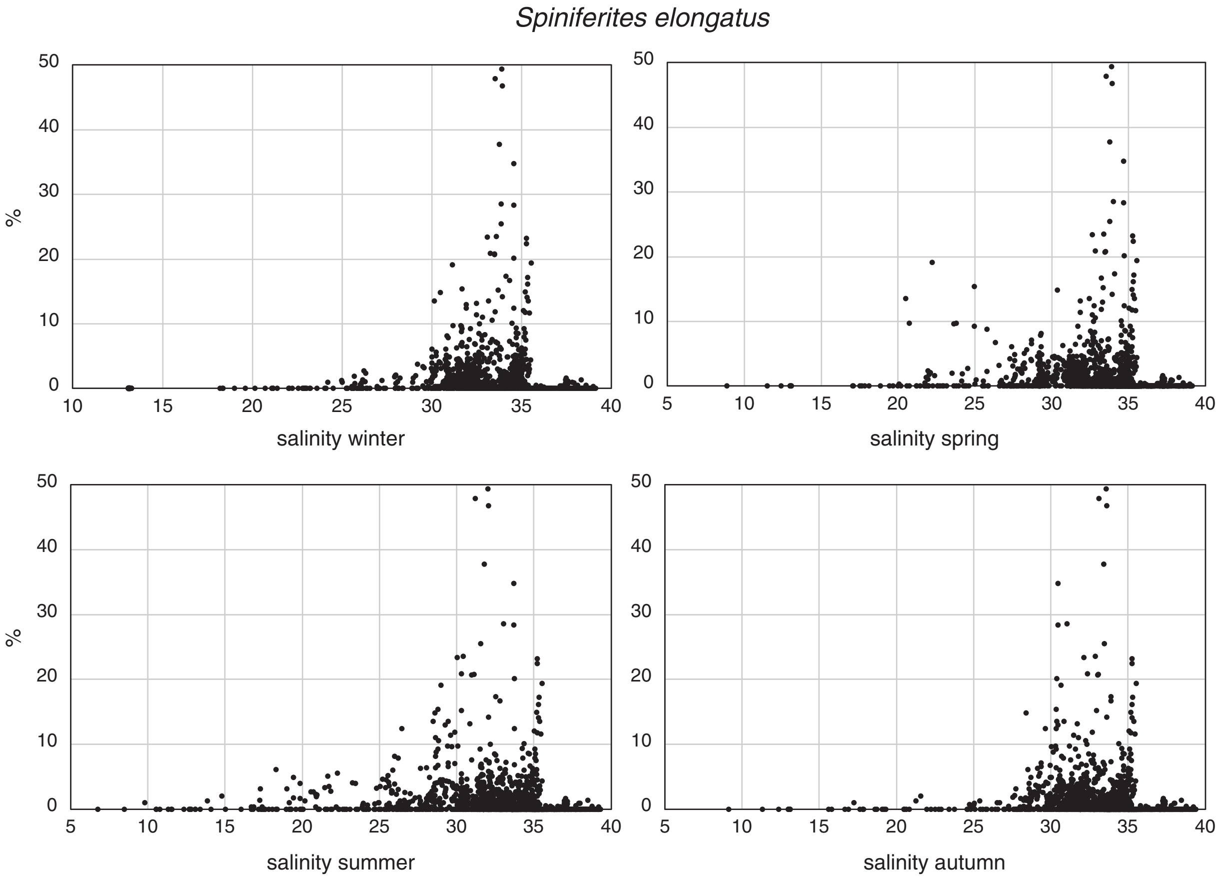

Fig. 234. Relative abundances of *Spiniferites elongatus* in relationship to seasonal salinity in surface waters.

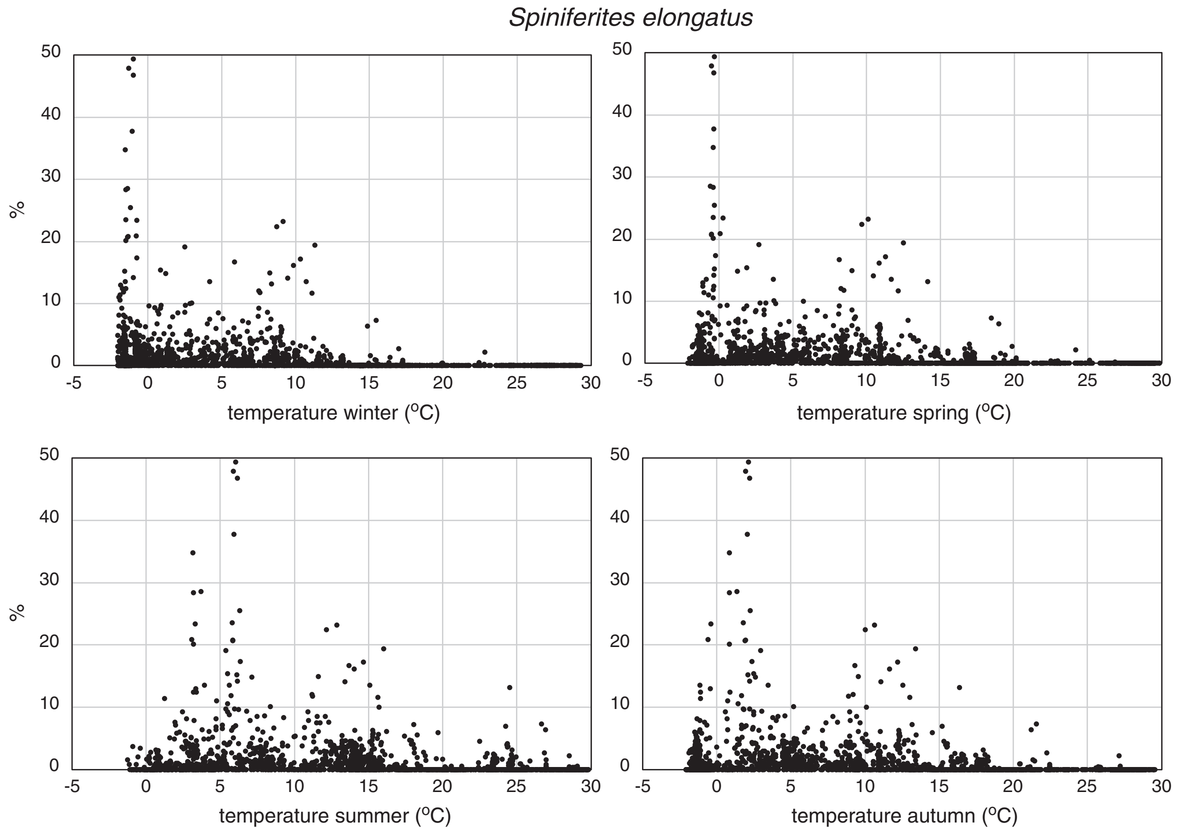

Fig. 235. Relative abundances of *Spiniferites elongatus* in relationship to seasonal temperature in surface waters.

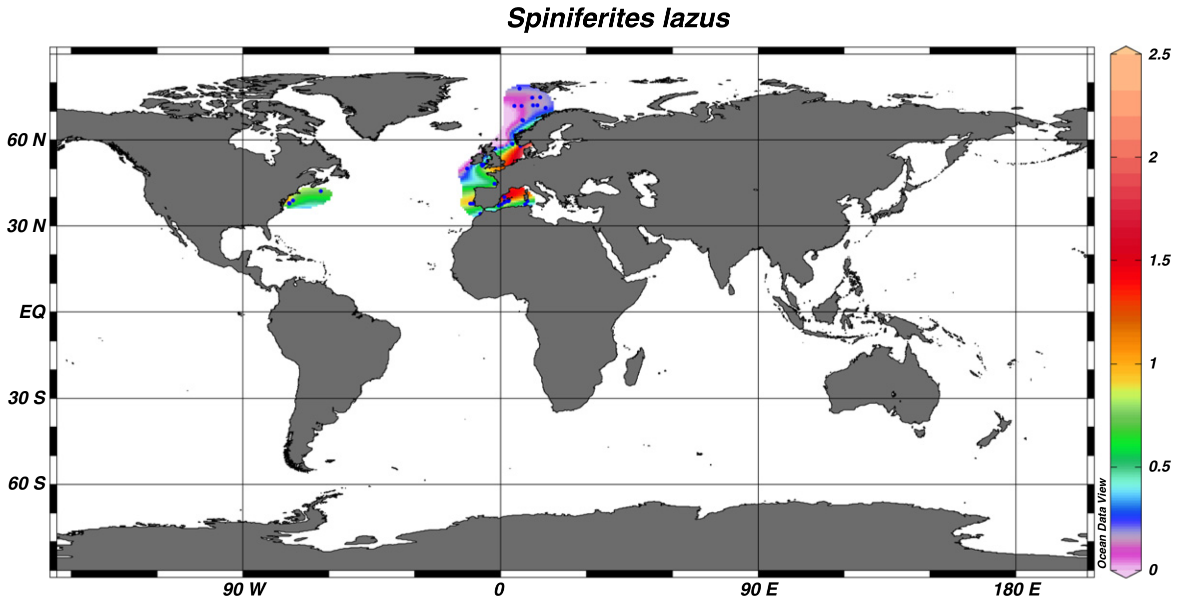

Fig. 236. Geographic distribution of *Spiniferites lazus*.

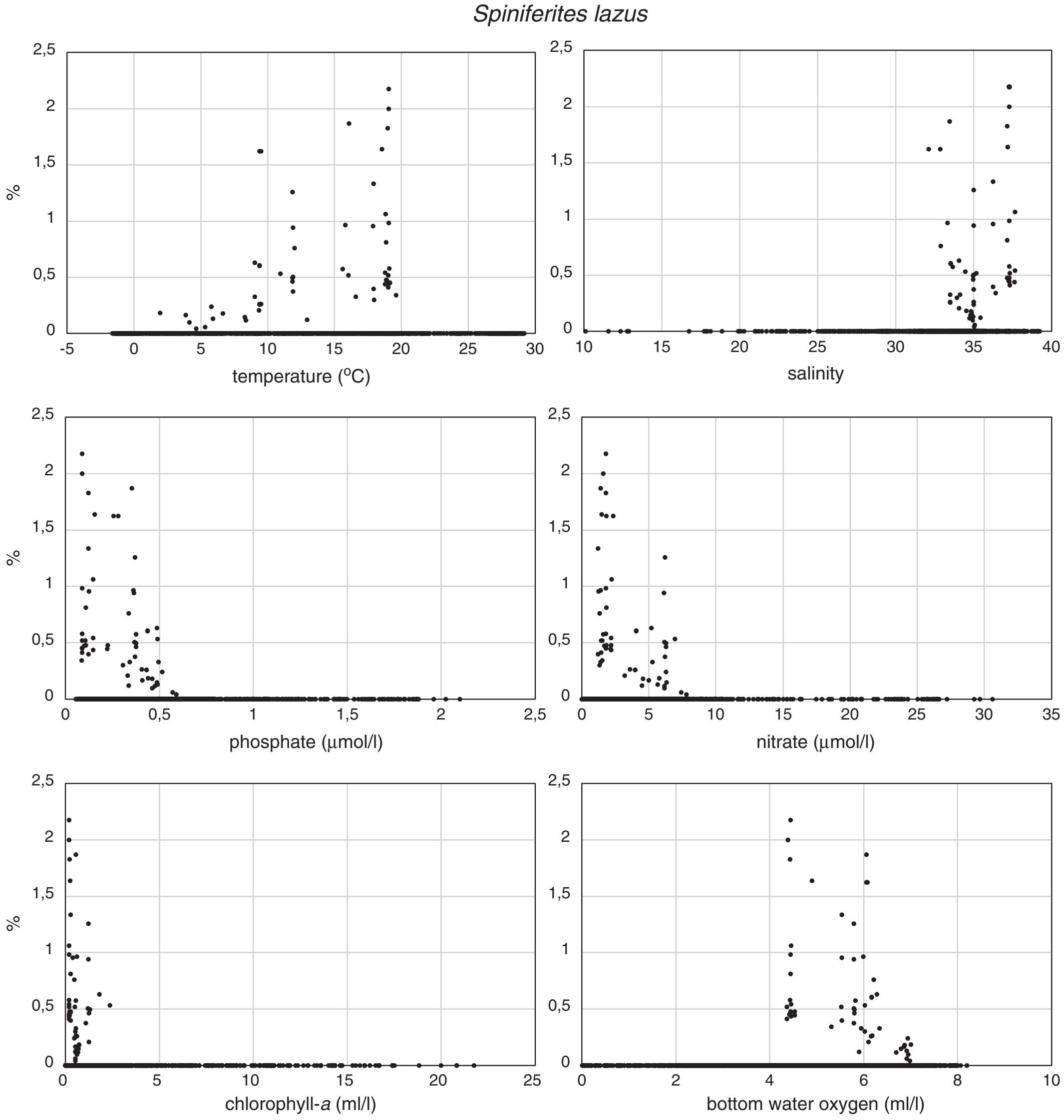

Fig. 237. Relative abundances of *Spiniferites lazus* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

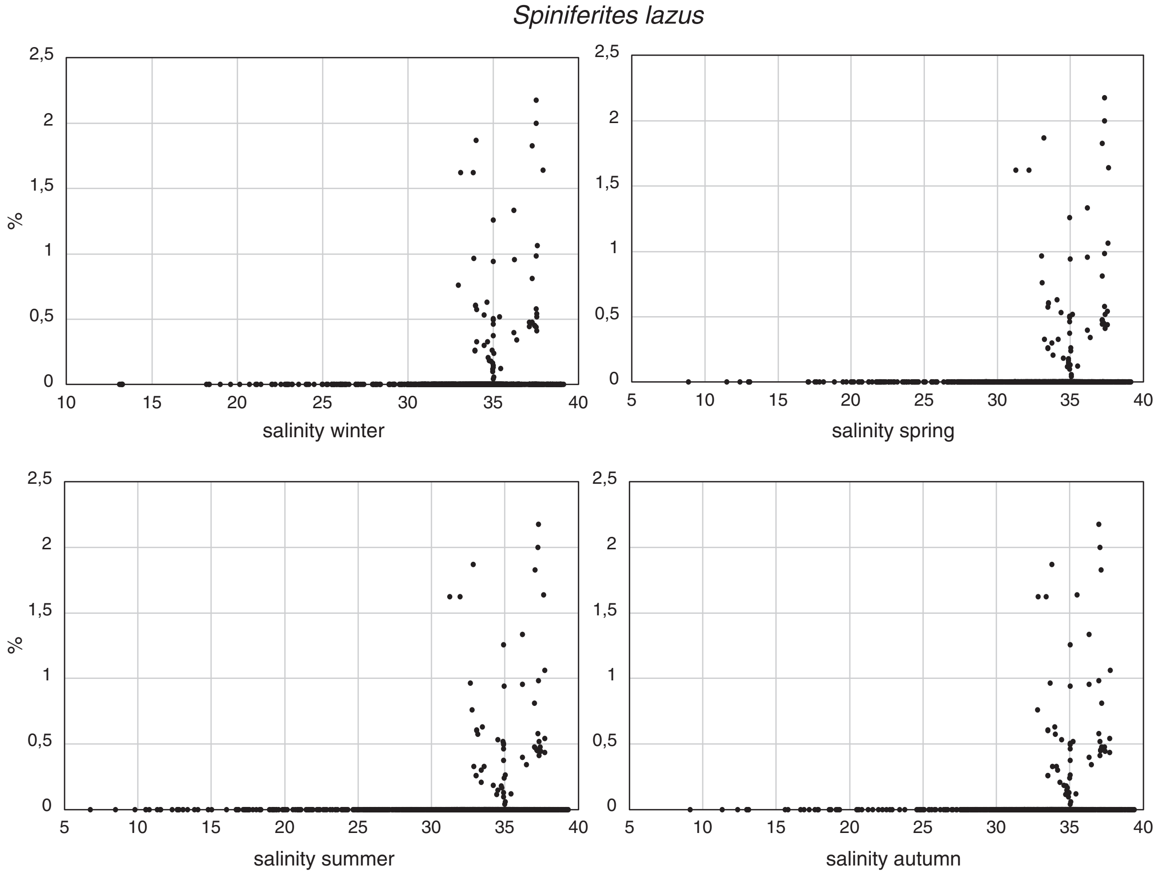

Fig. 238. Relative abundances of *Spiniferites lazus* in relationship to seasonal salinity in surface waters.

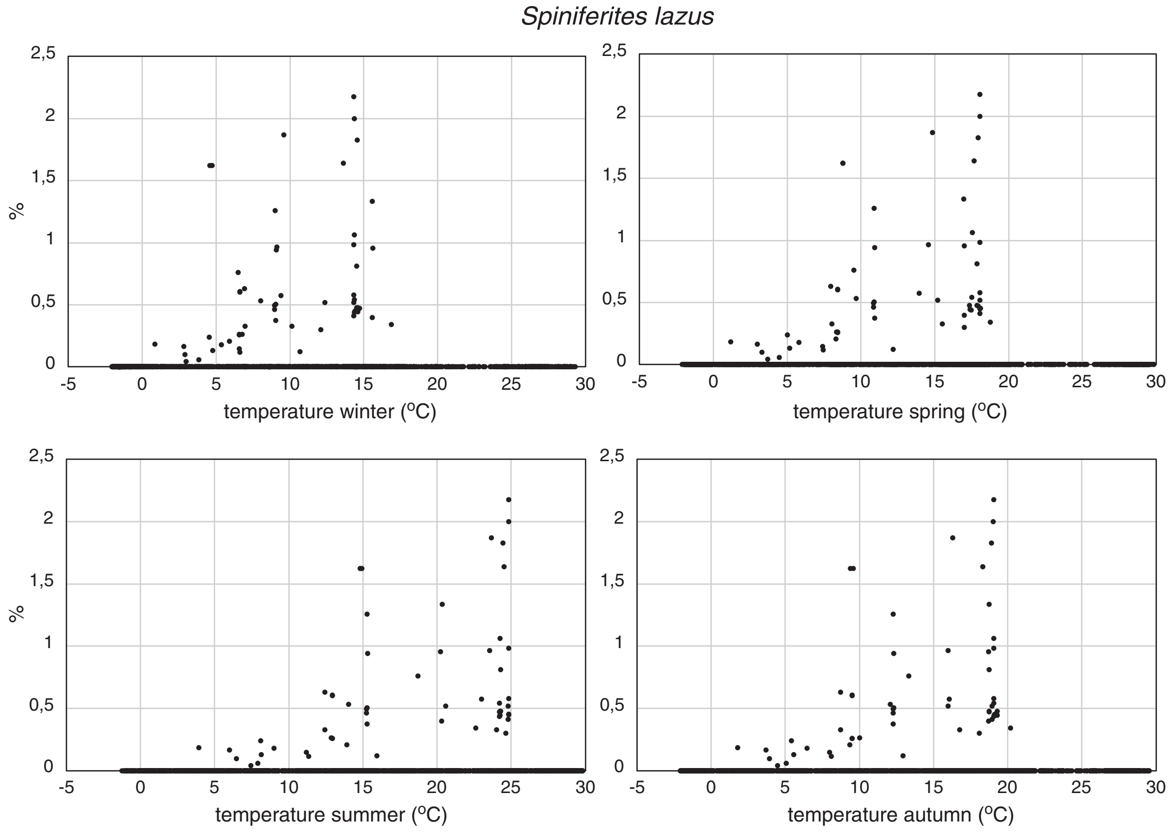

Fig. 239. Relative abundances of *Spiniferites lazus* in relationship to seasonal temperature in surface waters.

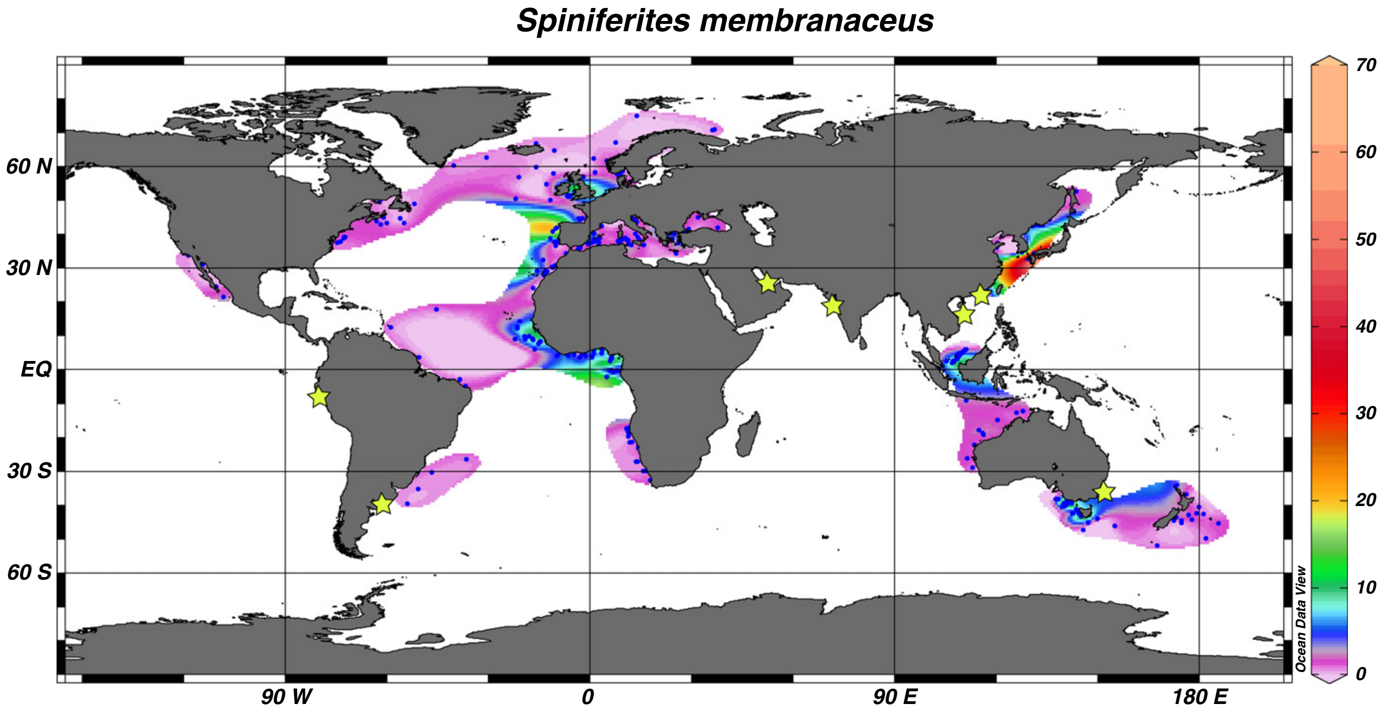

Fig. 240. Geographic distribution of *Spiniferites membranaceus*.

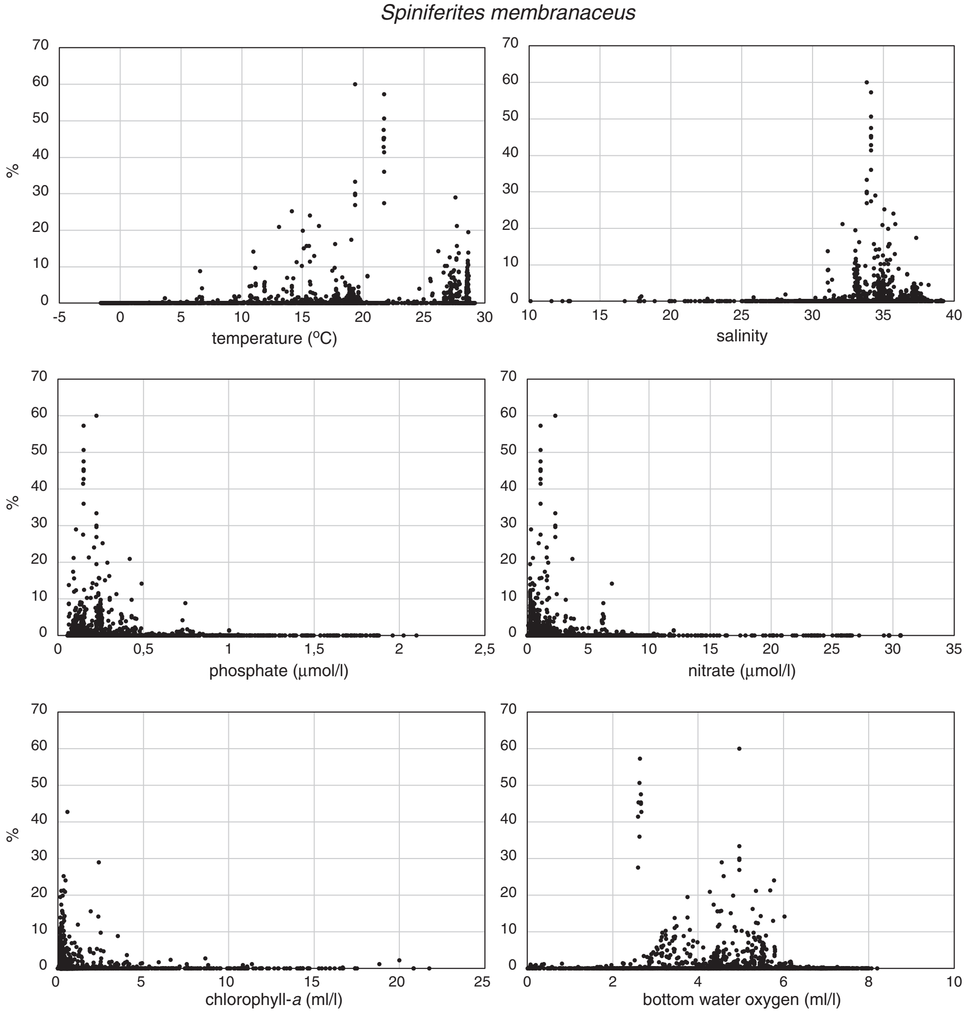

Fig. 241. Relative abundances of *Spiniferites membranaceus* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

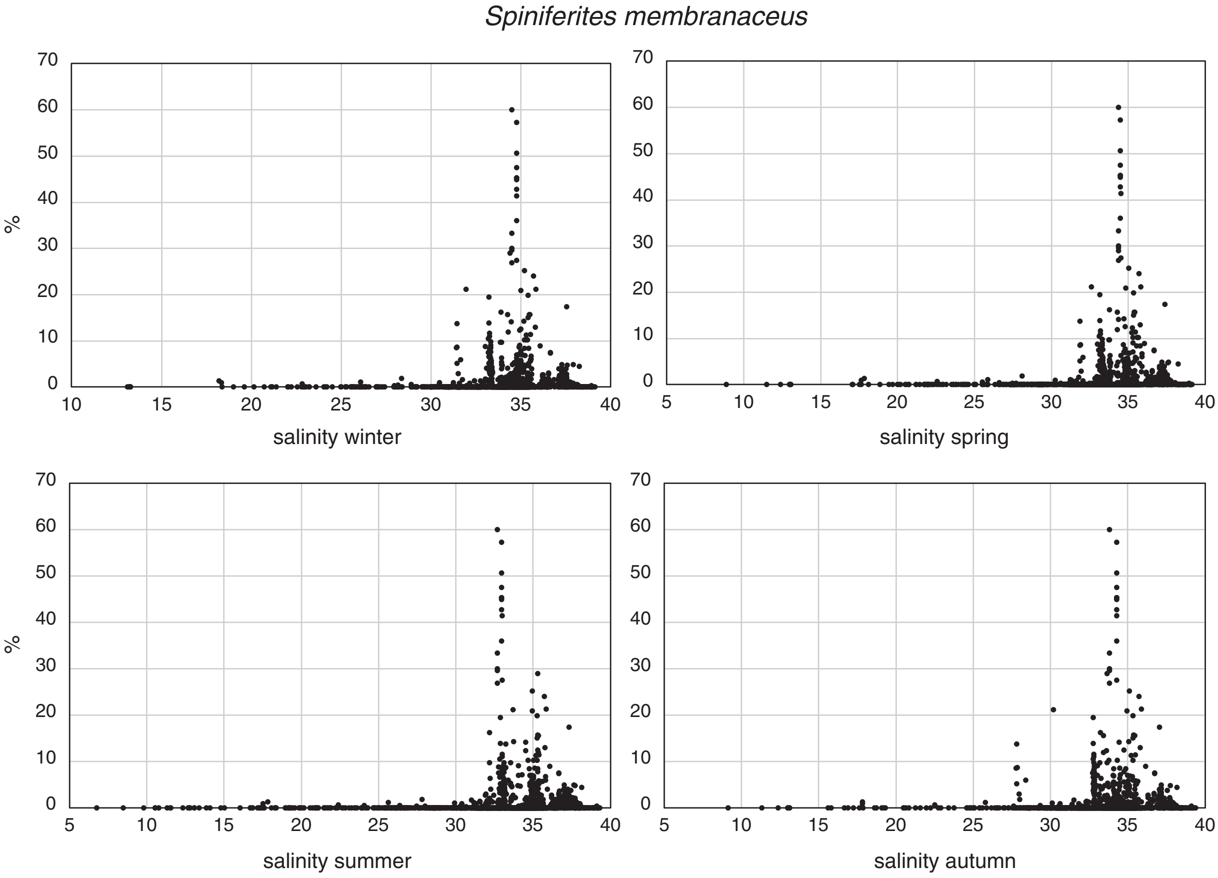

Fig. 242. Relative abundances of *Spiniferites membranaceus* in relationship to seasonal salinity in surface waters.

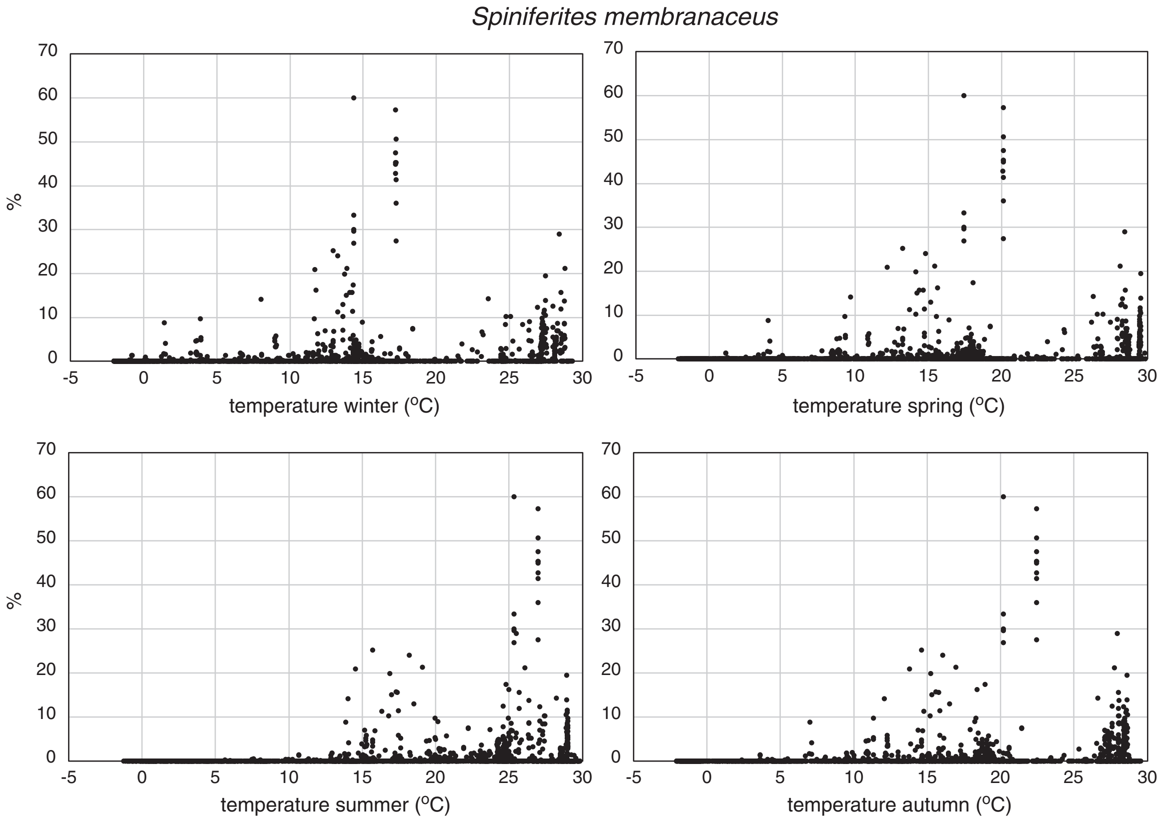

Fig. 243. Relative abundances of *Spiniferites membranaceus* in relationship to seasonal temperature in surface waters.

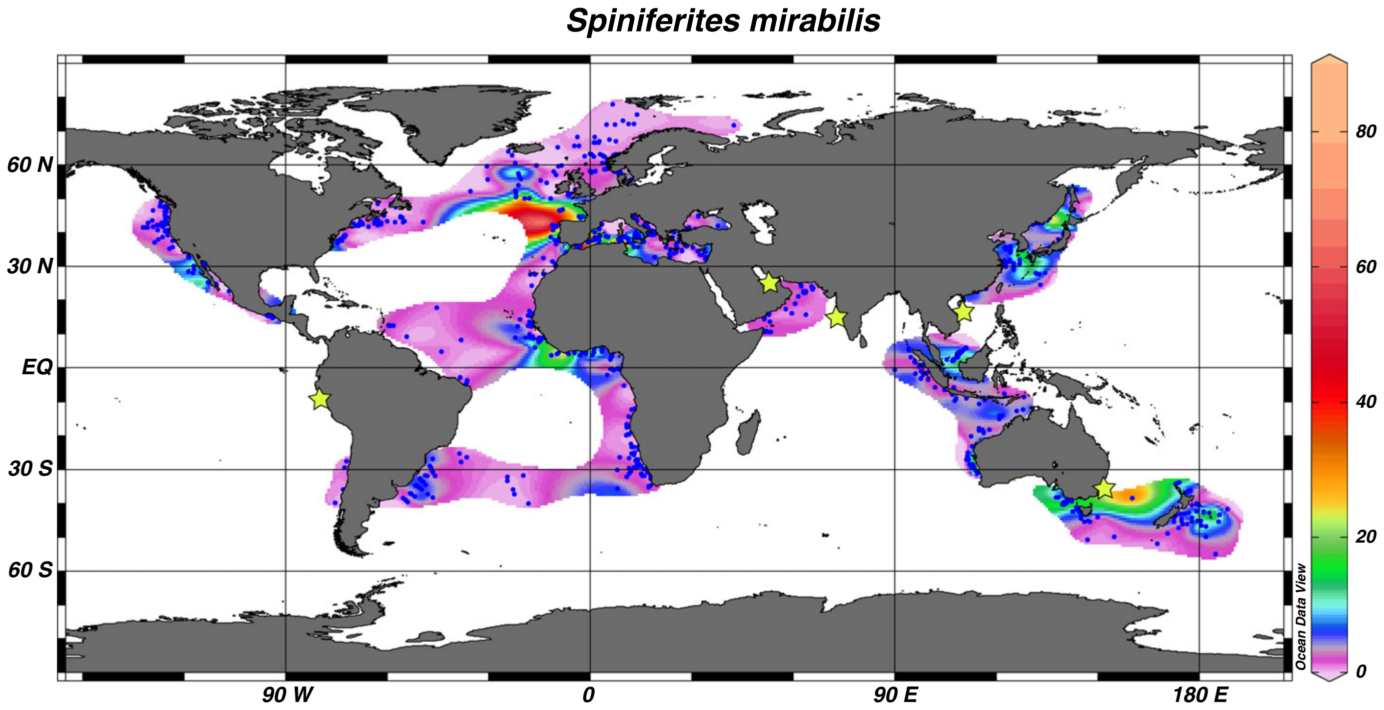

Fig. 244. Geographic distribution of *Spiniferites mirabilis*.

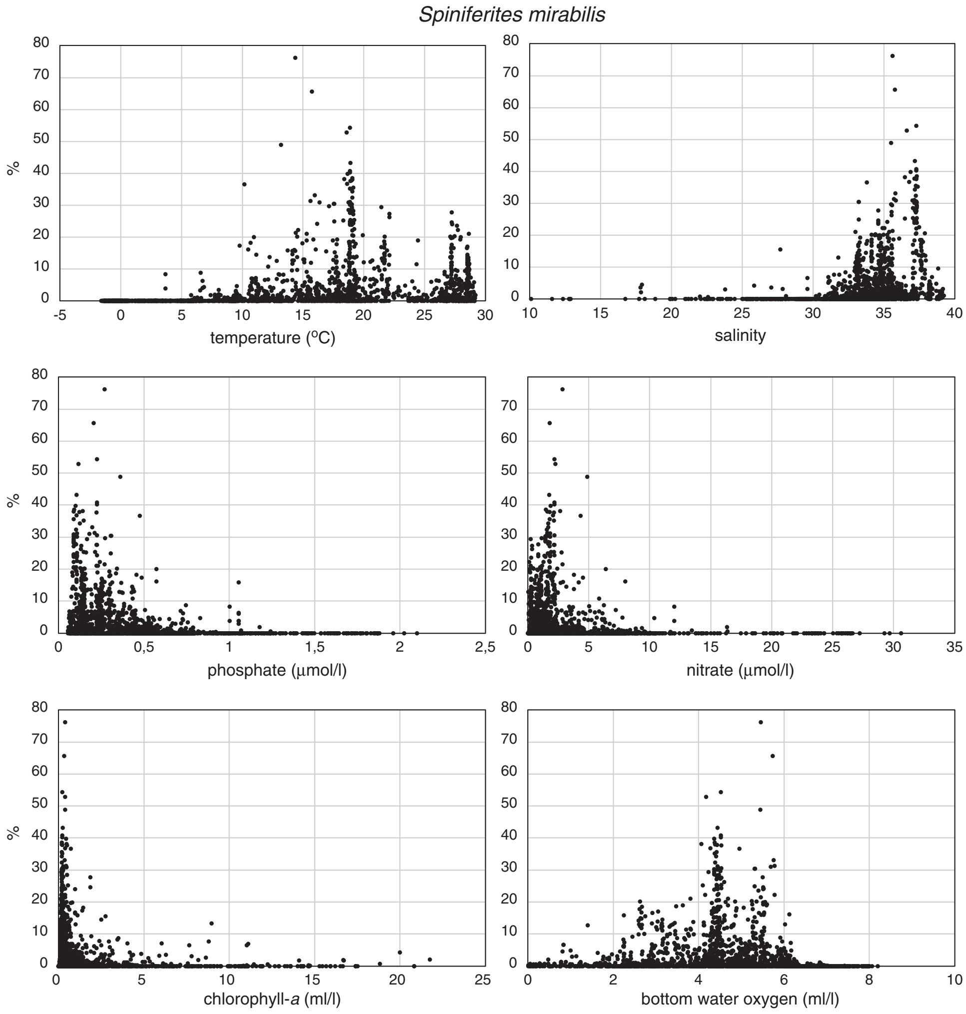

Fig. 245. Relative abundances of *Spiniferites mirabilis* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

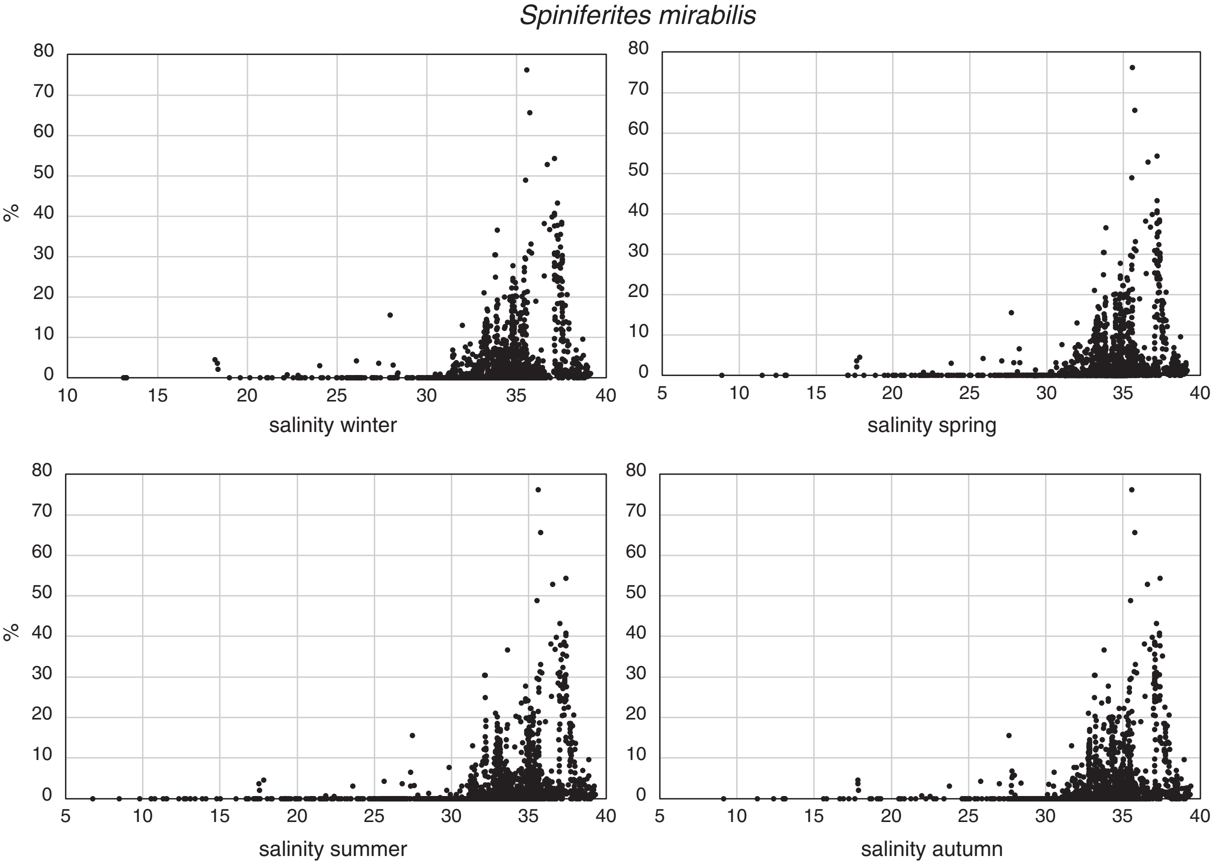

Fig. 246. Relative abundances of *Spiniferites mirabilis* in relationship to seasonal salinity in surface waters.

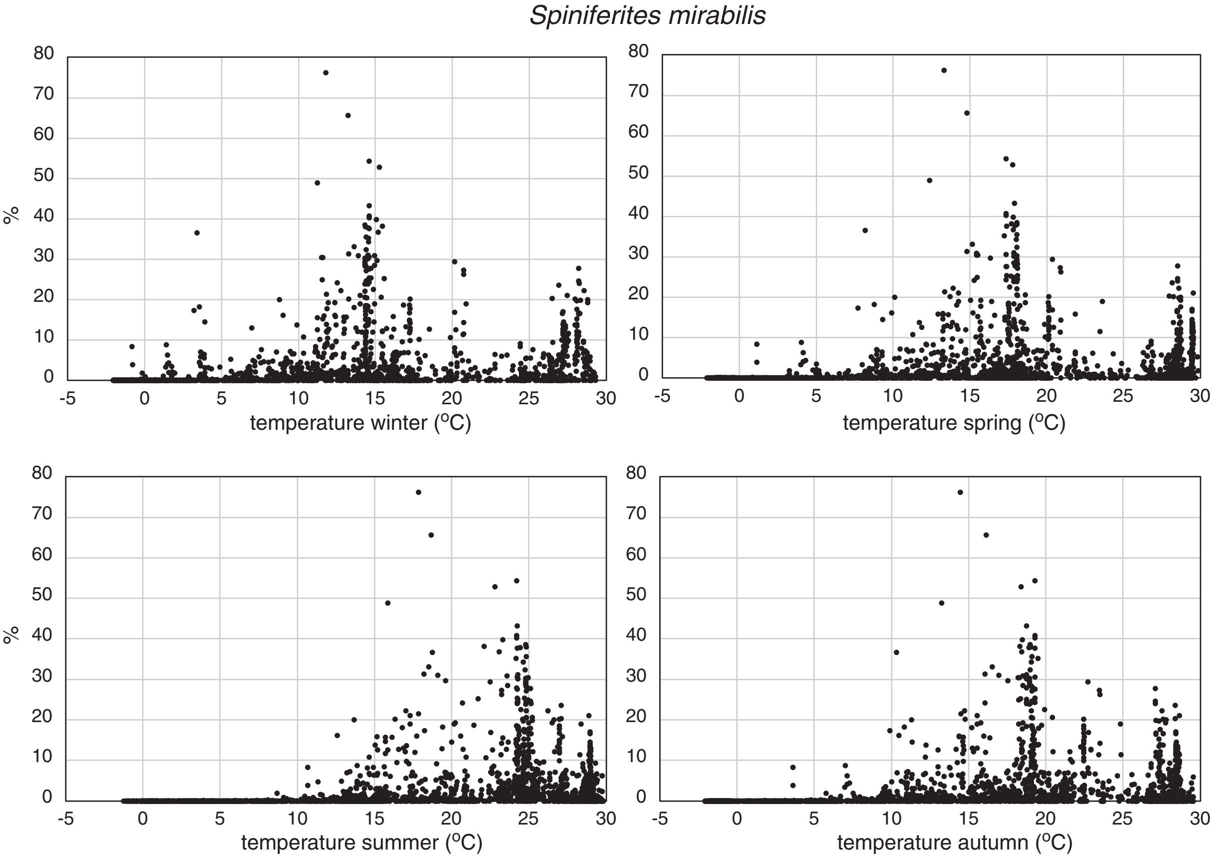

Fig. 247. Relative abundances of *Spiniferites mirabilis* in relationship to seasonal temperature in surface waters.

Although it is occasionally observed in regions where SST may be < 0 °C in winter, it is not observed in areas where seasonal ice covered occurs (de Vernal et al., 1998; Radi and de Vernal, 2008).

Concluding remarks:

Spiniferites mirabilis has a temperate to equatorial distribution and can be observed in coastal as well in open oceanic environments with the subtropial fronts forming its northern and southern boundaries. It can be present in high relative abundances in areas where salinity is reduced either seasonally or throughout the year. It can be present in oligotrophic to eutrophic environments and in regions where bottom waters are anoxic to well-ventilated.

62. *Spiniferites pachydermus* (Rossignol 1964) Reid 1974

Figs. 248–251.

Distribution:

Spiniferites pachydermus is restricted to temperate to equatorial coastal regions along the margins of the Atlantic Oceans, Mediterranean Sea, Arabian Sea and northwestern Pacific. Here full marine conditions prevail throughout the year. High abundances > 5% (up to 16%) occur in the Benguela upwelling area (southeastern South Atlantic), the Arabian Sea and the Sea of Japan. It has not been observed where nitrate is low in the surface waters.

Environmental parameter range:

SST: 0–29.0 °C with summer SST 10.7 °C except for two sites in the northwestern Pacific Ocean where winter SST: −0.8 °C. SSS: 27.8–39.0 (spring–autumn), [P]: 0.06–1.00 μmol/l, [N]: 0.2–12.0 μmol/l, chlorophyll-*a*: 0.08–20.0 ml/l, bottom water [O_2]: 1.1–6.0 ml/l.

Highest relative abundances of *Spiniferites pachydermus* occur where (seasonally) mesotrophic to eutrophic conditions occur including upwelling areas, which may have large inter-annual variability in the trophic state of the upper waters.

Comparison with other records:

Apart from the records in the dataset of this Atlas, *Spiniferites pachydermus* has been observed in surface sediments of coastal sites of the Swedish coast, the Persian Gulf and the upwelling area off Peru (eastern equatorial Pacific, Bradford, 1975; Biebow et al., 1993; Persson et al., 2000). In sediment trap studies it is only registered in the Arabian Sea where highest relative abundances were observed during upwelling relaxation but the cyst production was not restricted to a certain season (Zonneveld and Brummer, 2000).

Concluding remarks:

Spiniferites pachydermus has a temperate to equatorial mainly coastal distribution restricted to full marine environments with relatively high upper water nitrate concentrations and bottom waters that are well ventilated. Highest relative abundances occur in mesotrophic to eutrophic environments in upwelling regions in the vicinity of upwelling cells.

63. *Spiniferites ramosus* (Ehrenberg 1838) Mantell 1854

Figs. 252–255.

Distribution:

Spiniferites ramosus is observed from sub-polar to equatorial regions with the polar fronts forming roughly the margins of its distribution in both hemispheres. Highest abundances (up to 96%) occur near the coast in the Gulf of Alaska (northeastern Pacific), the Yellow Sea and Sea of Japan (northwestern Pacific), the Tasman Sea (southwestern Pacific) the equatorial eastern Indian Ocean, the Arabian Sea and the upwelling regions off NW and SW Africa. Although it is observed in river plume areas, it is not more abundant in these regions.

Environmental parameter range:

SST: 0–29.8 °C (winter–spring) except for two North Atlantic/Arctic sites off Greenland where SST drop to −2.0 °C. SSS: 17.5–39.4 (summer–autumn), P]: 0.06–1.73 μmol/l, [N]: 0.04–24.0 μmol/l, chlorophyll-*a*: 0.06–20.9 ml/l, bottom water [O_2]: between 0.01–8.0 ml/l.

Spiniferites ramosus is observed in regions where the upper water salinity conditions can be reduced permanently or seasonally by river discharge or melting of snow/ice. Although *Spiniferites ramosus* can be observed in oligotrophic regions, highest abundances occur where the environment is seasonally mesotrophic to eutrophic such as in upwelling areas.

Comparison with other records:

Apart from the records in the dataset of this Atlas, *Spiniferites ramosus* has been observed in surface sediments of coastal sites of the Persian Gulf, off western India (Arabian Sea), the upwelling area off Peru (eastern Pacific) and the coastal area off Svalbard (Bradford, 1975; Biebow et al., 1993; Godhe et al., 2000; Grøsfjeld et al., 2009).

Seasonal distribution and sediment trap studies in general, report only very few cysts of *Spiniferites ramosus* hampering the determination of a seasonal production pattern (e.g. Pospelova et al., 2010). In the Arabian Sea cysts with cell content were registered during active upwelling whereas empty cysts are were recorded throughout the year (Zonneveld and Brummer, 2000). Although no clear seasonal production pattern has been observed in the upwelling area off Portugal, low numbers of cysts were documented in the sediments during upwelling initiation and termination phases (Ribeiro and Amorim, 2008). In the North Atlantic, low numbers of *Spiniferites ramosus* cysts are observed exclusively in trap samples from the North Atlantic Current region (Dale and Dale, 1992).

In Arctic sediments the relative abundance of this species is negatively correlated to the seasonal ice cover duration (Radi and de Vernal, 2008). It has, with one exception, not been observed in areas where ice cover lasts > 8 months a year (de Vernal et al., 1998).

Concluding remarks:

Spiniferites ramosus is a cosmopolitan species with a sub-polar to equatorial distribution. Although it can reach high relative abundances in high productivity areas such as upwelling regions and areas influenced by river discharge, it is not restricted to these regions and occurs in the oligotrophic parts of the open oceans as well.

64. *Stelladinium robustum* Zonneveld 1997

Figs. 256–259.

Distribution:

Stelladinium robustum is restricted to full marine tropical and equatorial regions of the Indian Ocean and adjacent seas. High abundances (up to 5%) occur in the eastern part of the Arabian Sea and off the Island Sumatra (Bay of Bengal).

Environmental parameter range:

SST: 23.6–29.8 °C (summer–spring), SSS: 33.0–36.7 (autumn–summer), [P]: 0.13–0.73 μmol/l, [N]: 0.3–5.1 μmol/l, chlorophyll-*a*: 0.1–2.6 ml/l, bottom water [O_2]: between 1.0–4.4 ml/l.

Although *Stelladinium robustum* occurs in mesotrophic regions, highest relative abundances are found in areas, which are (seasonally) eutrophic. These regions include upwelling areas, where large inter-annual variability in the trophic state of the upper waters can occur.

Comparison with other records:

So far, *Stelladinium robustum* has only been observed outside the Indian Ocean regions in sediment trap samples of the Omura Bay and in sediments of the Southeast Asian coasts (Japan, Fujii and Matsuoka, 2006, southeast Asia: Furio et al., 2012 as *Stelladinium abei*). It is not clear if this is the result of a recent introduction of the species in this region as before 2006, this species had not been reported from this area.

In a sediment trap of Somalia (Arabian Sea) these cysts are produced during active upwelling (Zonneveld and Brummer, 2000). No seasonal production pattern has been observed in the Omura Bay (Fujii and Matsuoka, 2006).

Concluding remarks:

Although recently the species has been recorded from the Omura Bay (Japan) *Stelladinium robustum* can be considered as endemic to the Indian Ocean where it is exclusively observed in tropical to equatorial, mesotrophic to eutrophic settings where full-marine conditions

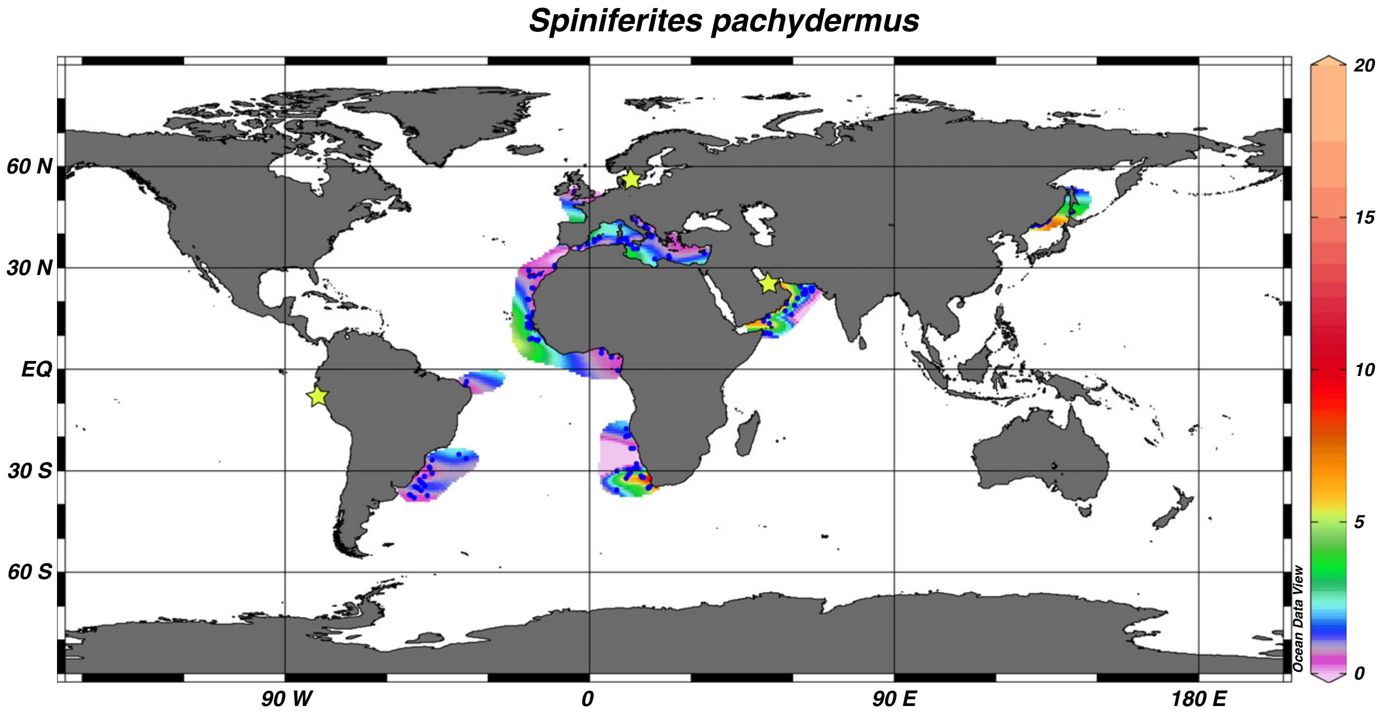

Fig. 248. Geographic distribution of *Spiniferites pachydermus*.

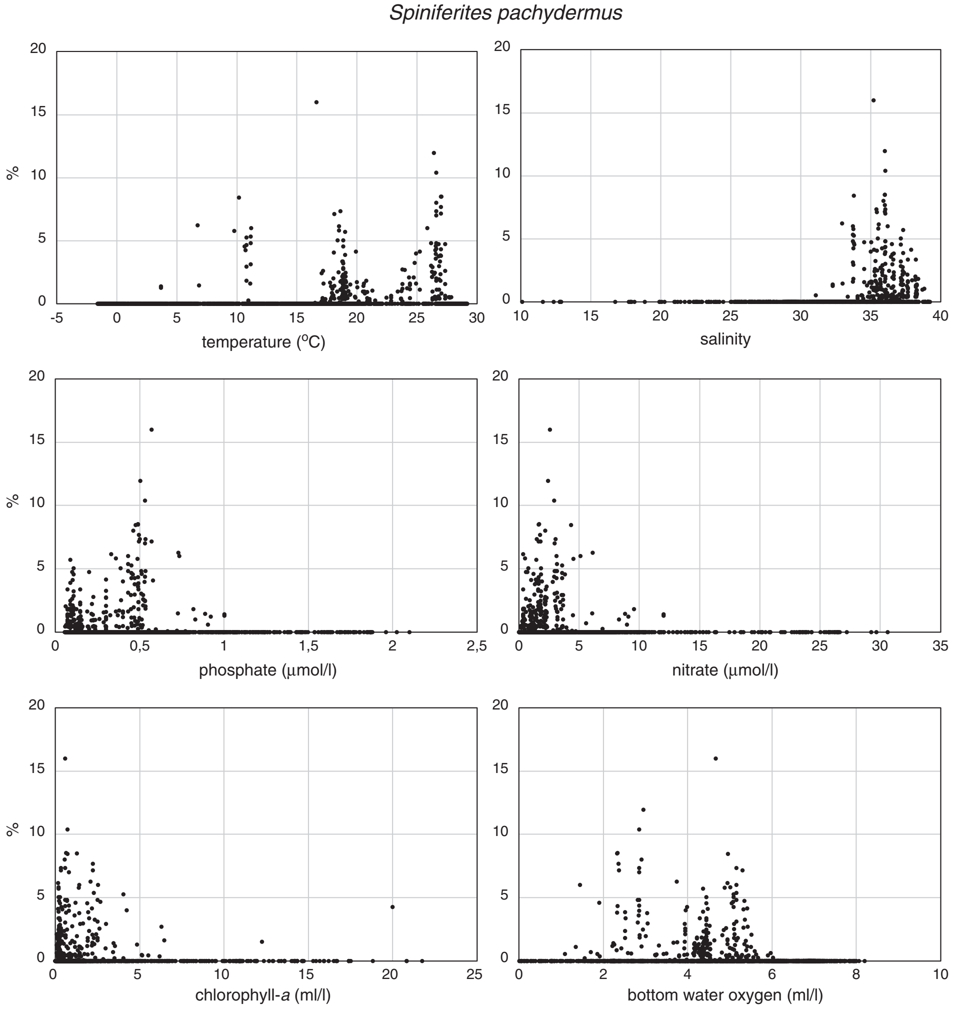

Fig. 249. Relative abundances of *Spiniferites pachydermus* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

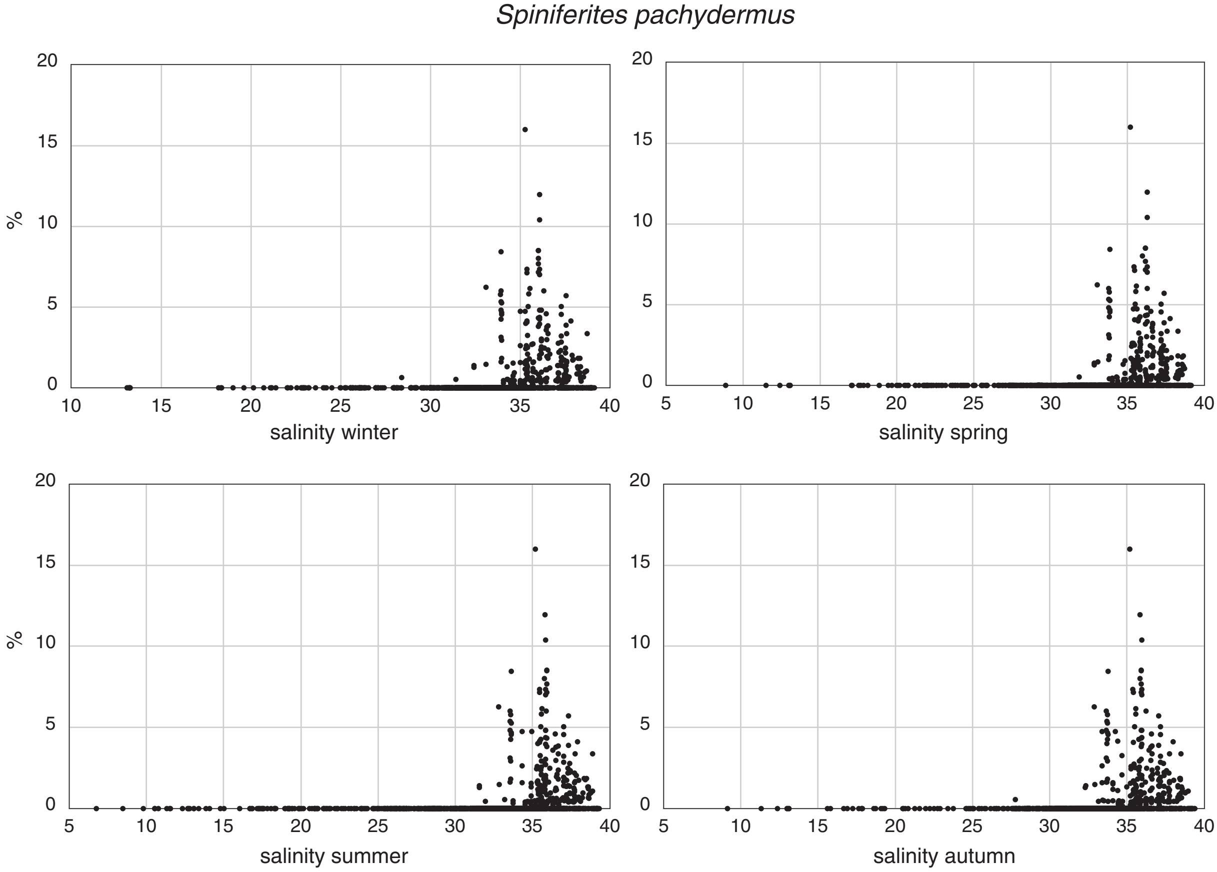

Fig. 250. Relative abundances of *Spiniferites pachydermus* in relationship to seasonal salinity in surface waters.

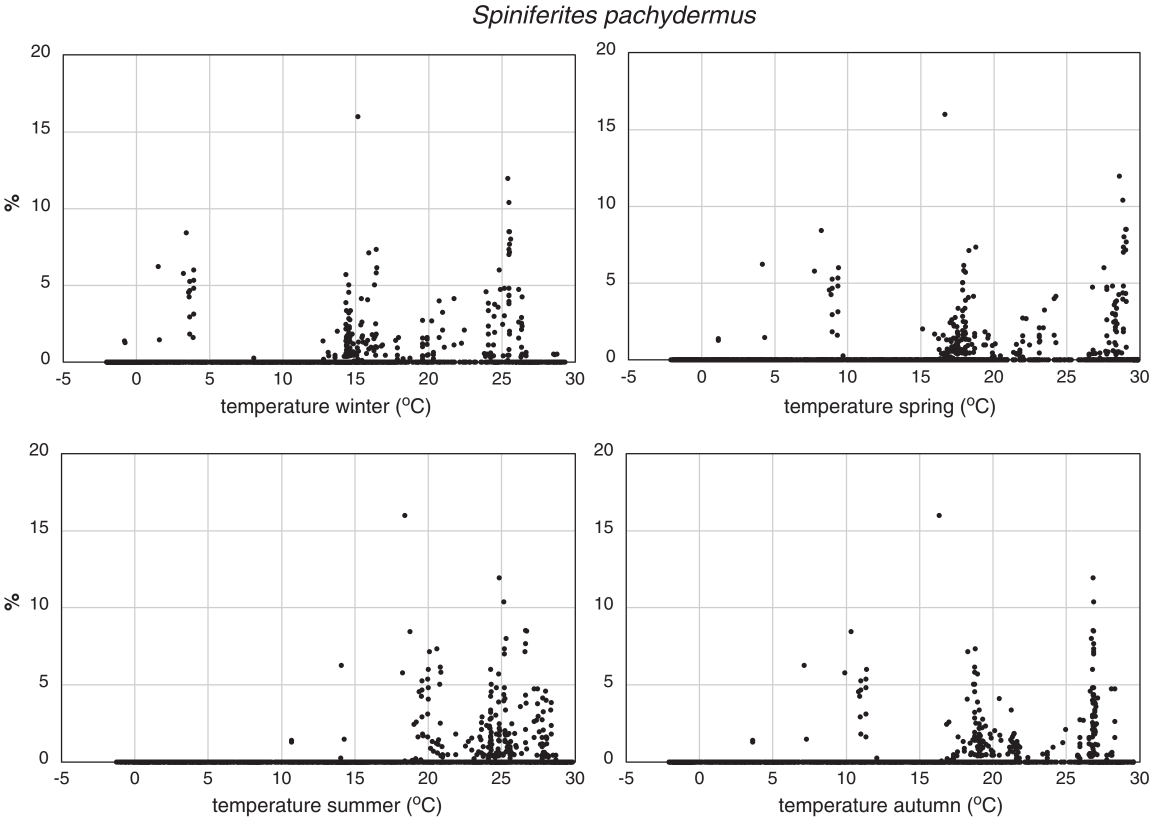

Fig. 251. Relative abundances of *Spiniferites pachydermus* in relationship to seasonal temperature in surface waters.

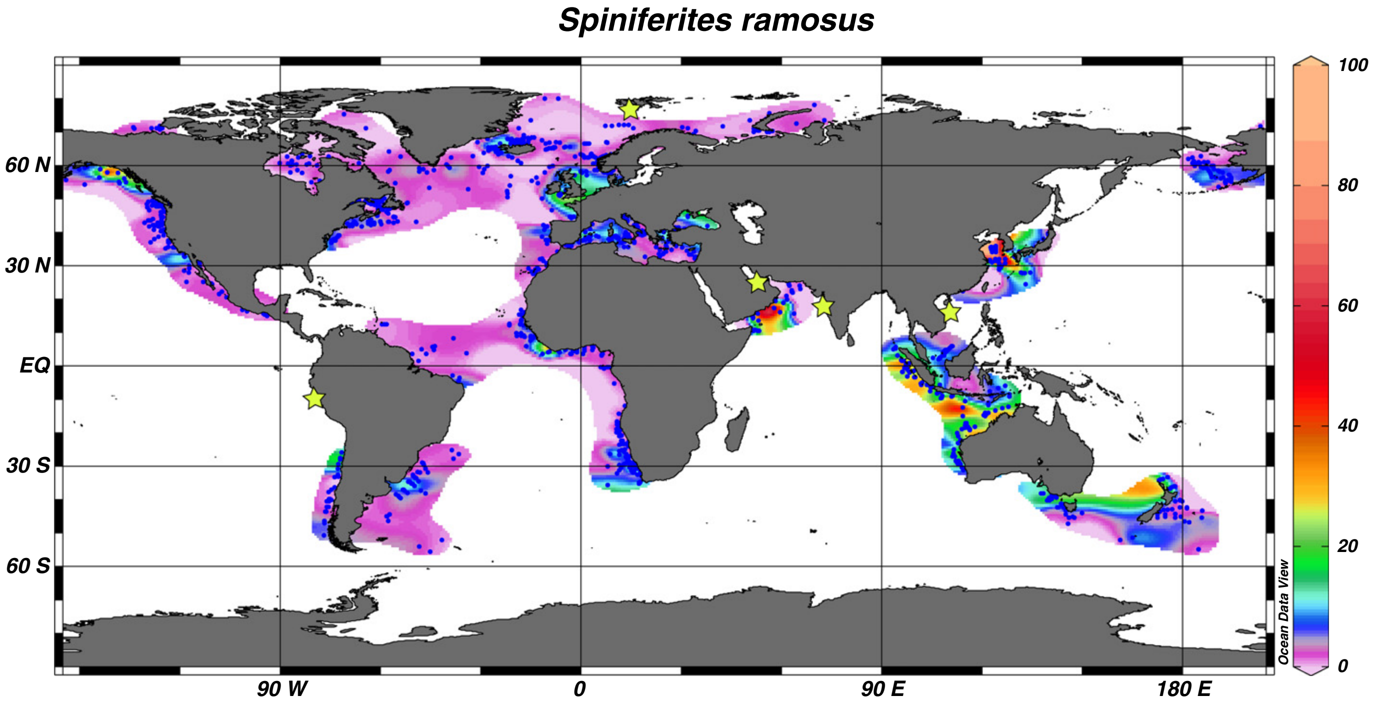

Fig. 252. Geographic distribution of *Spiniferites ramosus*.

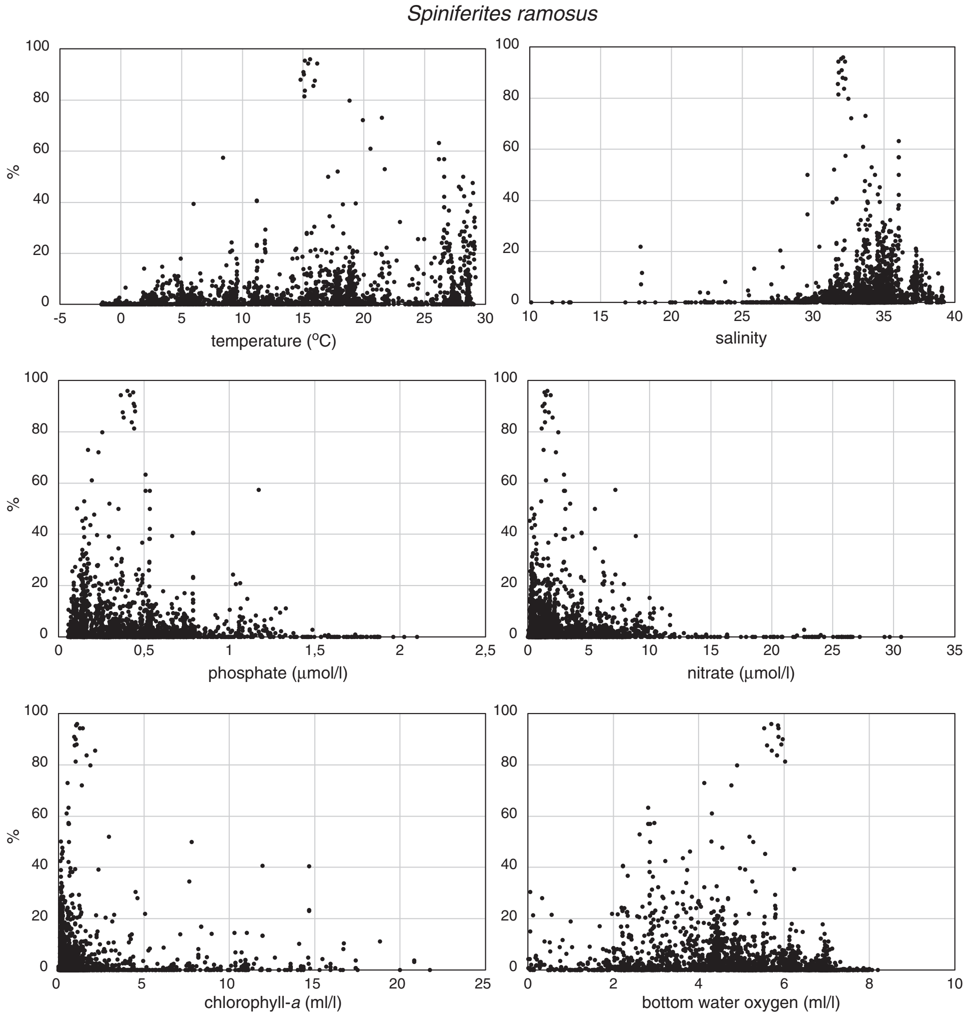

Fig. 253. Relative abundances of *Spiniferites ramosus* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

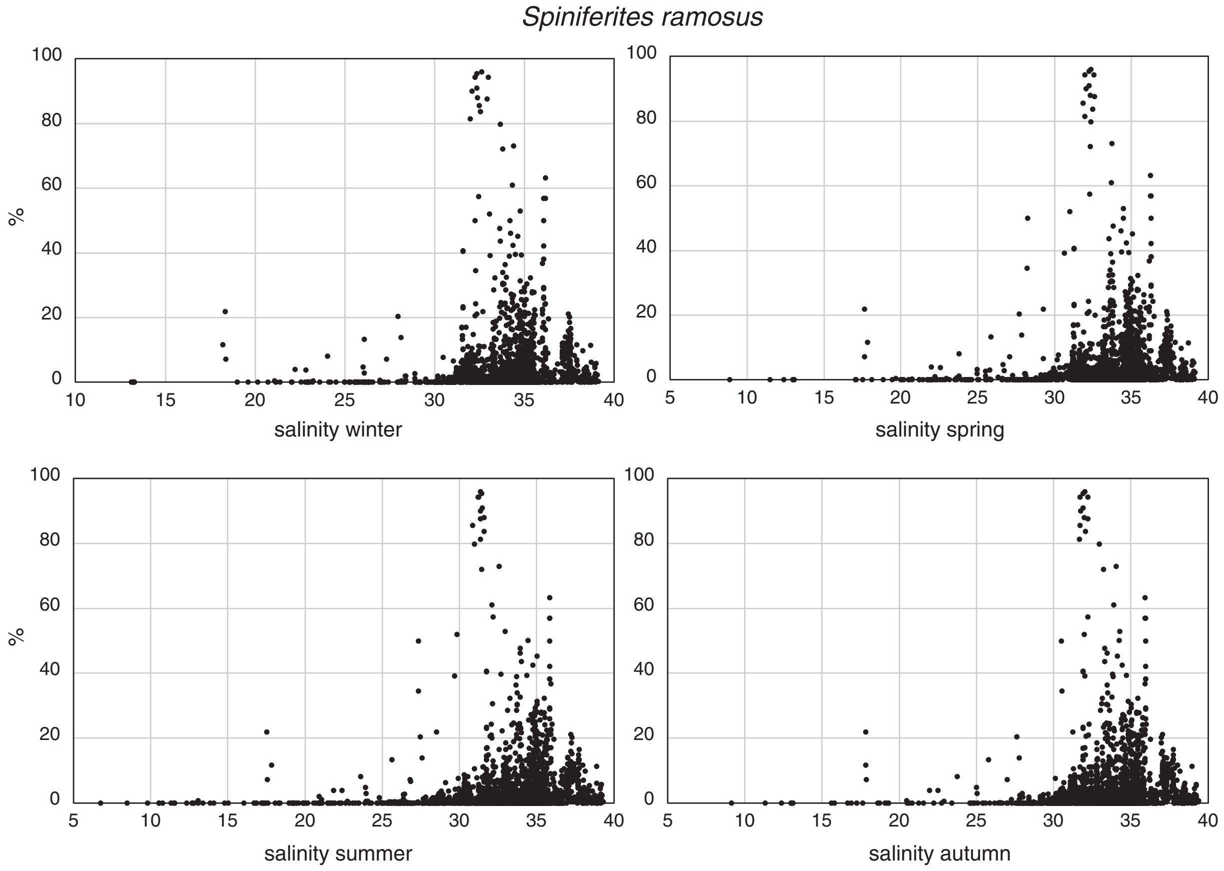

Fig. 254. Relative abundances of *Spiniferites ramosus* in relationship to seasonal salinity in surface waters.

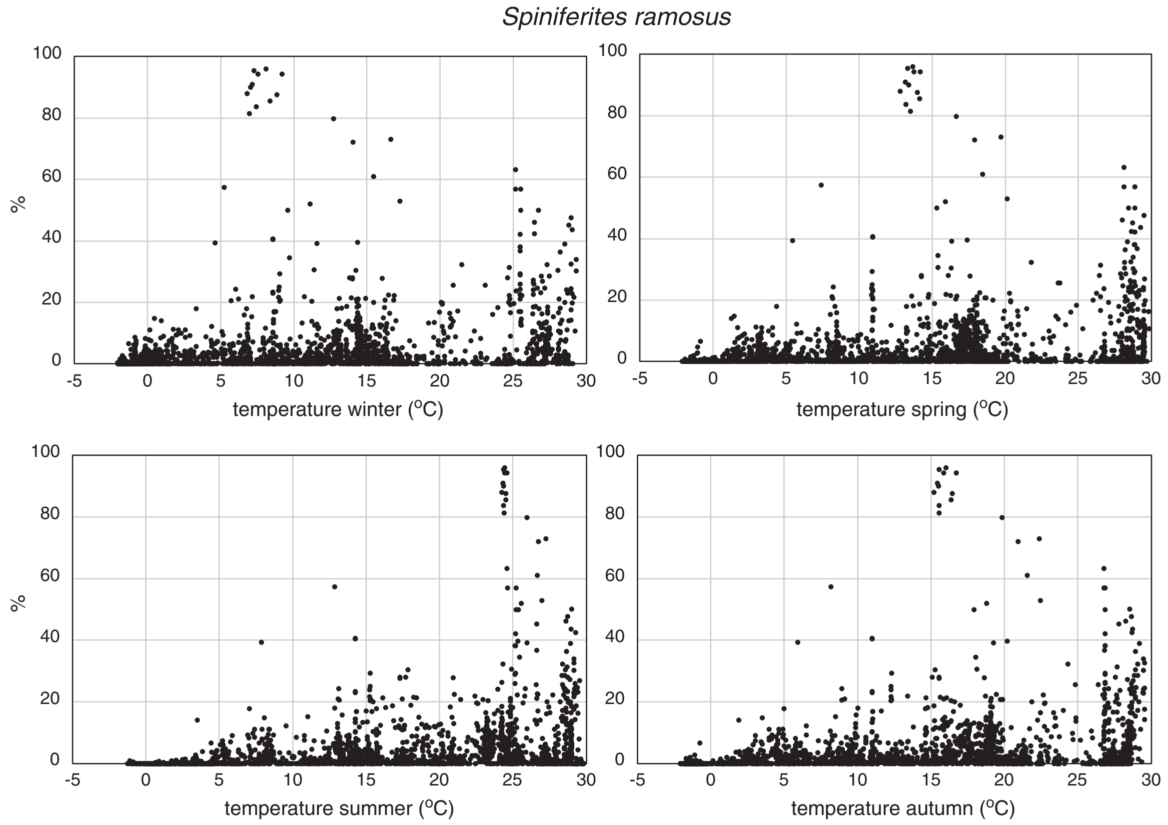

Fig. 255. Relative abundances of *Spiniferites ramosus* in relationship to seasonal temperature in surface waters.

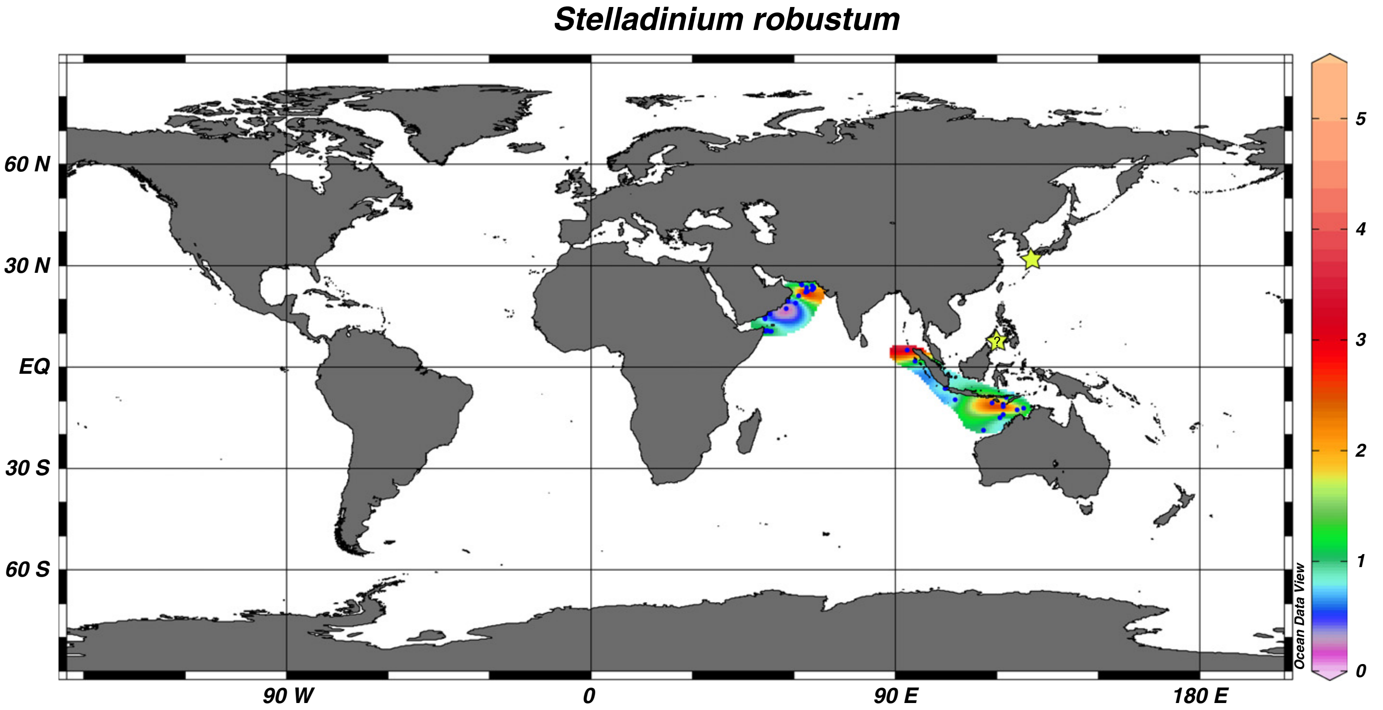

Fig. 256. Geographic distribution of *Stelladinium robustum*.

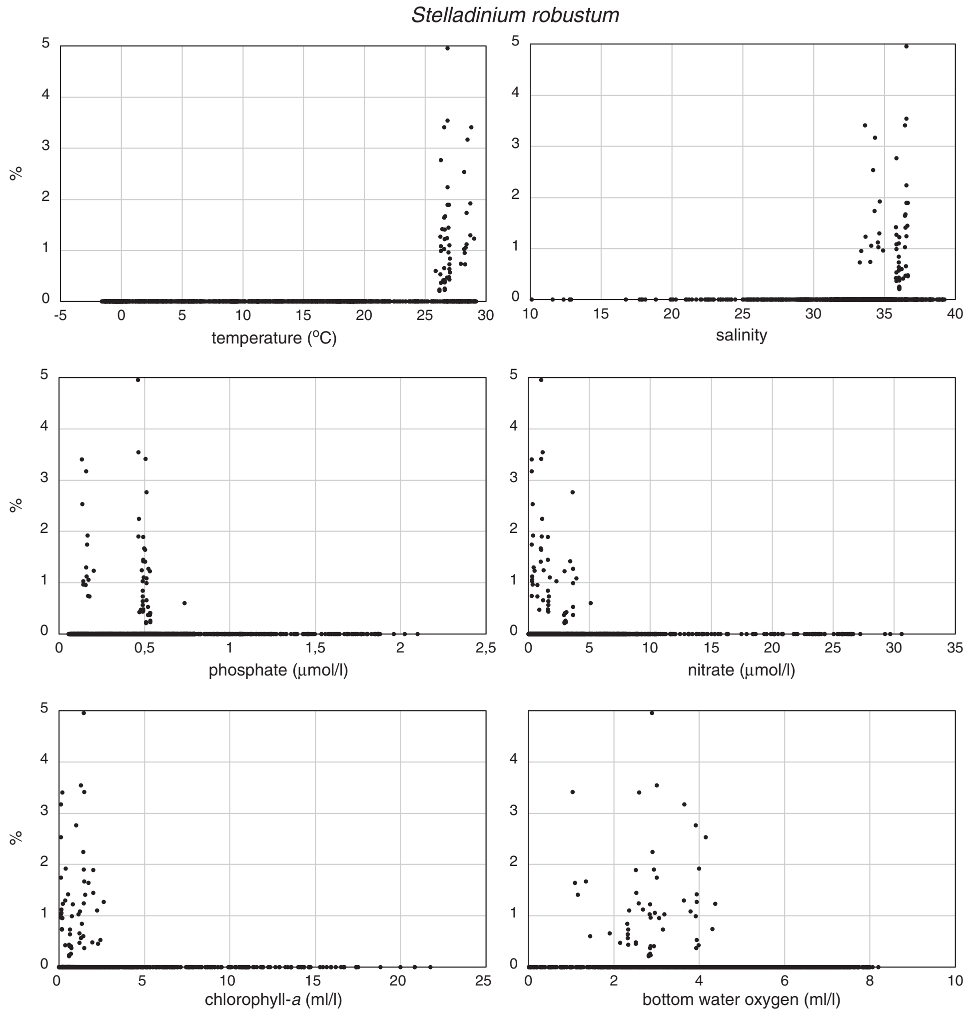

Fig. 257. Relative abundances of *Stelladinium robustum* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

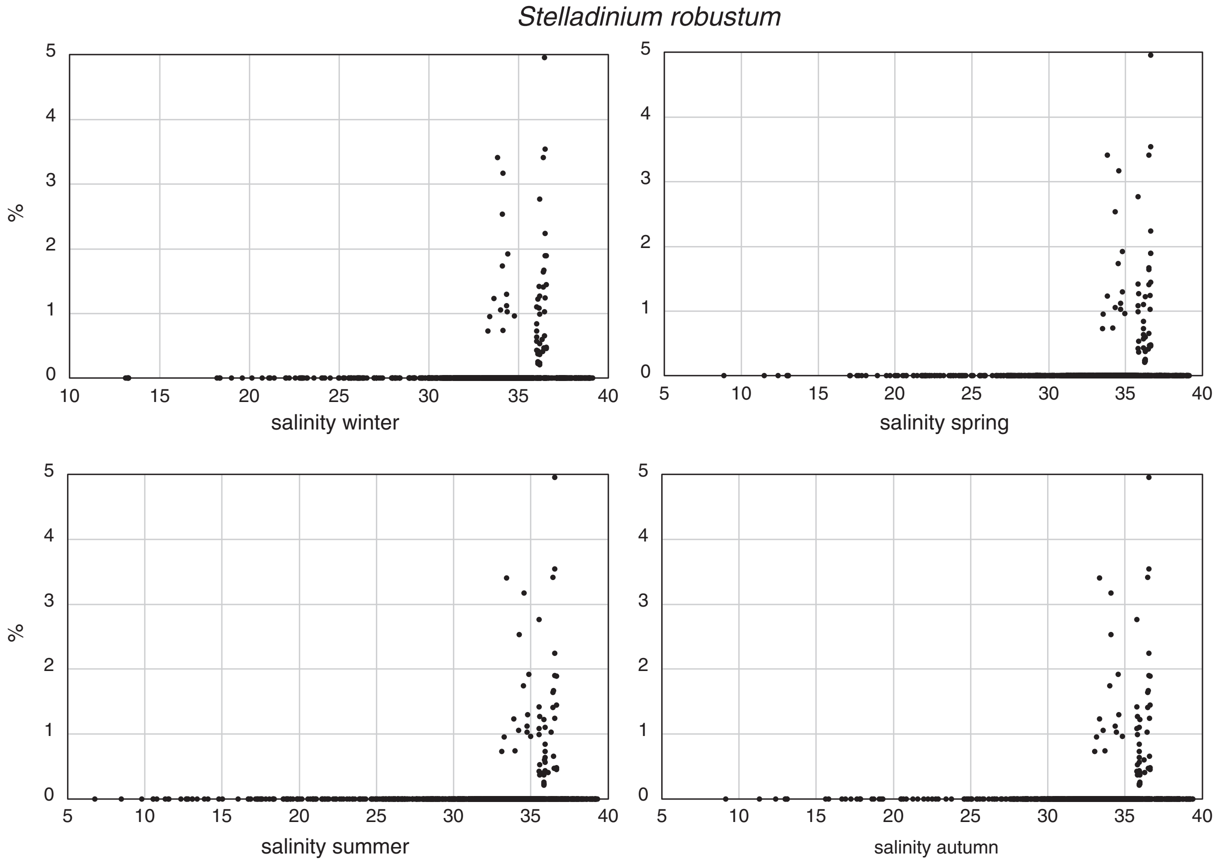

Fig. 258. Relative abundances of *Stelladinium robustum* in relationship to seasonal salinity in surface waters.

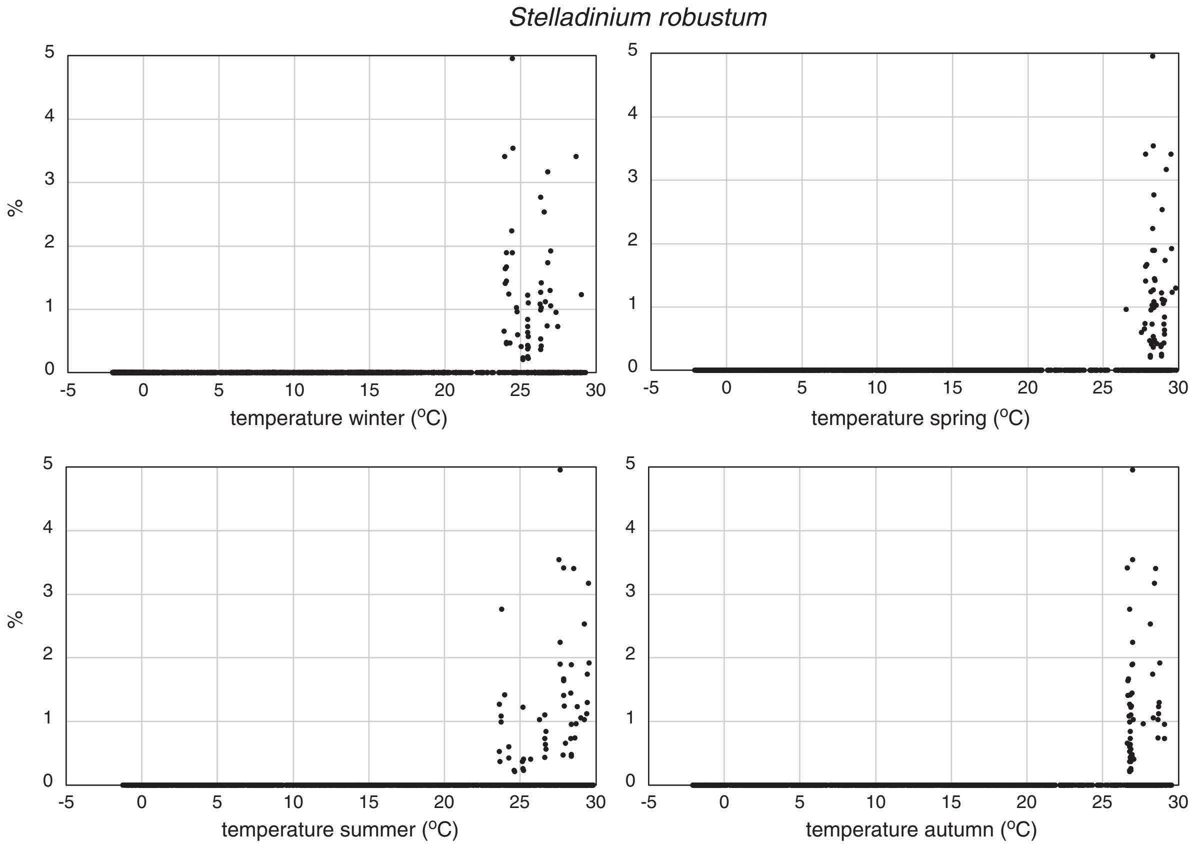

Fig. 259. Relative abundances of *Stelladinium robustum* in relationship to seasonal temperature in surface waters.

prevail and bottom waters are well ventilated. It occurs in upwelling regions and cysts are produced during active upwelling.

65. *Stelladinium stellatum* (Wall et Dale 1968) Reid 1977

Figs. 260–263.

Distribution:

Stelladinium stellatum is restricted to coastal sites from temperate/sub-tropical to equatorial regions although it is most abundant in sub-tropical to equatorial regions. Highest abundances (up to 26%) occur in the upwelling area off NW Africa.

Environmental parameter range:

SST: 8.1–29.8 °C (winter–spring), SSS: 17.8–38.9 (winter–summer), [P]: 0.06–1.06 μmol/l, [N]: 0.2–6.3 μmol/l, chlorophyll-*a*: 0.1–12.2 ml/l, bottom waters [O_2]: 0.6–5.8 ml/l.

High relative abundances occur where SSS are reduced throughout the year (up to 3% of the association) and in hypersaline environments (up to 2.3%) The Highest relative abundances occur however at full-marine sites where (seasonally) mesotrophic to eutrophic conditions occur. This includes upwelling areas, where large inter-annual variability in the trophic state of the upper waters can occur.

Comparison with other records:

Apart from the recordings in this Atlas *Stelladinium stellatum* has been observed in coastal sediments off southern China (Wang et al., 2004c), off India and Gulf of Oman in the eastern Arabian Sea (Bradford and Wall, 1984; Godhe et al., 2000; D'Costa et al., 2008), the Peruvian upwelling area (Biebow et al., 1993), the upwelling area off the Iberian Peninsula (Sprangers et al., 2004), coastal sediments of the German and Swedish coasts (North Sea, Baltic Sea, Nehring, 1994a, b; Persson et al., 2000) and coastal sediments of southern Australia, Tasmania and New Zealand (see references in Marret and Zonneveld, 2003).

Sediment trap studies document cyst formation during active upwelling in the upwelling areas off NW Africa and off Somalia (Zonneveld and Brummer, 2000; Zonneveld et al., 2010). In the Omura Bay (Japan) cysts are produced in winter when temperatures are low for the region (ca. 10 °C, Fujii and Matsuoka, 2006).

In eutrophication studies in the subtropical and tropical areas, the species can often be linked to anthropogenic pollution and/or hypertrophic conditions (Shin et al., 2010a, 2010b; Zonneveld et al., 2012).

Concluding remarks:

Stelladinium stellatum is a temperate/subtropical to equatorial coastal species. Relative abundances can be high in regions with hypersaline conditions as well as areas where salinities are reduced (such as in river plumes). Highest relative abundances occur in mesotrophic to eutrophic environments such as upwelling areas. It is not reported from oxygen minimum zones or where bottom waters are anoxic.

66. *Tectatodinium pellitum* (Wall 1967) Head et al., 1994

Figs. 264–267.

Distribution:

Tectatodinium pellitum is restricted to coastal sites from sub-tropical to equatorial regions. Although it generally is observed only in very low abundances, it can reach 15% of the association in the coastal sites in the Gulf of Mexico (western Atlantic).

Environmental parameter range:

SST: 9.2–29.5 °C (winter–summer) with summer SST > 14.4 °C. SSS: 21.9–39.2 (winter–autumn). [P]: 0.06–0.6 μmol/l, [N]: 0.2–3.3 μmol/l, chlorophyll-*a*: 0.09–9.9 ml/l, bottom water [O_2]: 0.3–5.2 ml/l. Although present in nutrient poor regions, highest abundances occur in regions with high upper water productivity.

Comparison with other records:

Apart from the records in the dataset of this Atlas, *Tectatodinium pellitum* has been observed in surface sediments of coastal sites of the upwelling area off Peru (eastern Pacific, Biebow et al., 1993), the Benguela upwelling area and the South China Sea (see references in Marret and Zonneveld, 2003).

Specimens documented from the Arctic and sub-Arctic regions that have been assigned to *Tectatodinium pellitum* are considered to represent a different species than described in this atlas (see discussions in Marret and Zonneveld, 2003).

Concluding remarks:

Tectatodinium pellitum is a coastal subtropical to equatorial species that has its highest relative abundances in mesotrophic to eutrophic environments. It is observed in regions with anoxic to well ventilated bottom waters.

67. *Trinovantedinium applanatum* (Bradford 1977) Bujak et Davies 1983

Figs. 268–271.

Distribution:

Trinovantedinium applanatum occurs between the polar front system in the North Atlantic and North Pacific and the sub-tropical front systems on the Southern Hemisphere. It has a cosmopolitic distribution. It generally occurs in the vicinity of the continents but sporadically also in central parts of the oceans where it is unlikely to have been transported from the shelf regions. Highest abundances (up to 20%) occur in equatorial regions notably in the the Amazon river discharge plume and the seasonal upwelling area off NW Africa. In the Amazon discharge plume area it is also observed in a few sites where upper water salinities are reduced.

Environmental parameter range:

SST: −0.8–29.8 °C (winter–spring), SSS: 31.1–39.2 (summer–summer) except for 4 sites where SSS drop to 19.1. [P]: 0.06–1.63 μmol/l, [N]: 0.1–18.5 μmol/l, chlorophyll-*a*: 0.1–20.0 ml/l, bottom water [O_2]: 0.01–7.1 ml/l.

High relative abundances occur in oligotrophic regions and highest relative abundances upon (seasonally) eutrophic conditions. This includes upwelling areas and river-plumes, where large inter-annual variability in the trophic state can occur.

Comparison with other records:

Apart from the recordings in this Atlas *Trinovantedinium applanatum* has been observed in coastal sediments off southern China (Wang et al., 2004c), off India and Gulf of Oman in the eastern Arabian Sea (Bradford and Wall, 1984; Godhe et al., 2000; D'Costa et al., 2008) and the Peruvian upwelling area (Biebow et al., 1993).

Sediment trap and seasonal distribution studies off NW Africa, the western Arabian Sea, and the Iberian peninsula, do not reveal a clear seasonal production pattern of *T. applanatum* (Zonneveld and Brummer, 2000; Ribeiro and Amorim, 2008; Zonneveld et al., 2010). However, in coastal sediments of the Iberian Peninsula, it occurs more often and in higher abundances when upwelling is absent than during intensive upwelling. In regions that are influenced by river discharge and by upwelling a positive correlation between cyst production and stratification in the upper waters has been recorded in some studies (see references in Marret and Zonneveld, 2003).

In the northern North Atlantic *T. applanatum* has been recorded in very few sites which experience seasonal ice cover up to 9 months a year (de Vernal et al., 1998). The relative abundance shows a strong negative correlation with sea ice cover (Radi and de Vernal, 2008).

Concluding remarks:

Trinovantidinium applanatum has a sub-polar to equatorial distribution and can be considered as a cosmopolitan species. Although it can be present in regions where upper water salinities are seasonally reduced, it is mainly observed in sites where full-marine conditions prevail. Highest relative abundances are observed in eutrophic environments.

68. *Tuberculodinium vancampoae* (Rossignol 1962) Wall 1967

Figs. 272–275.

Distribution:

Tuberculodinium vancampoae is restricted to subtropical to equatorial coastal regions. Highest abundances (up to 30%) occur in coastal embayments around Japan and the upwelling areas off equatorial Africa.

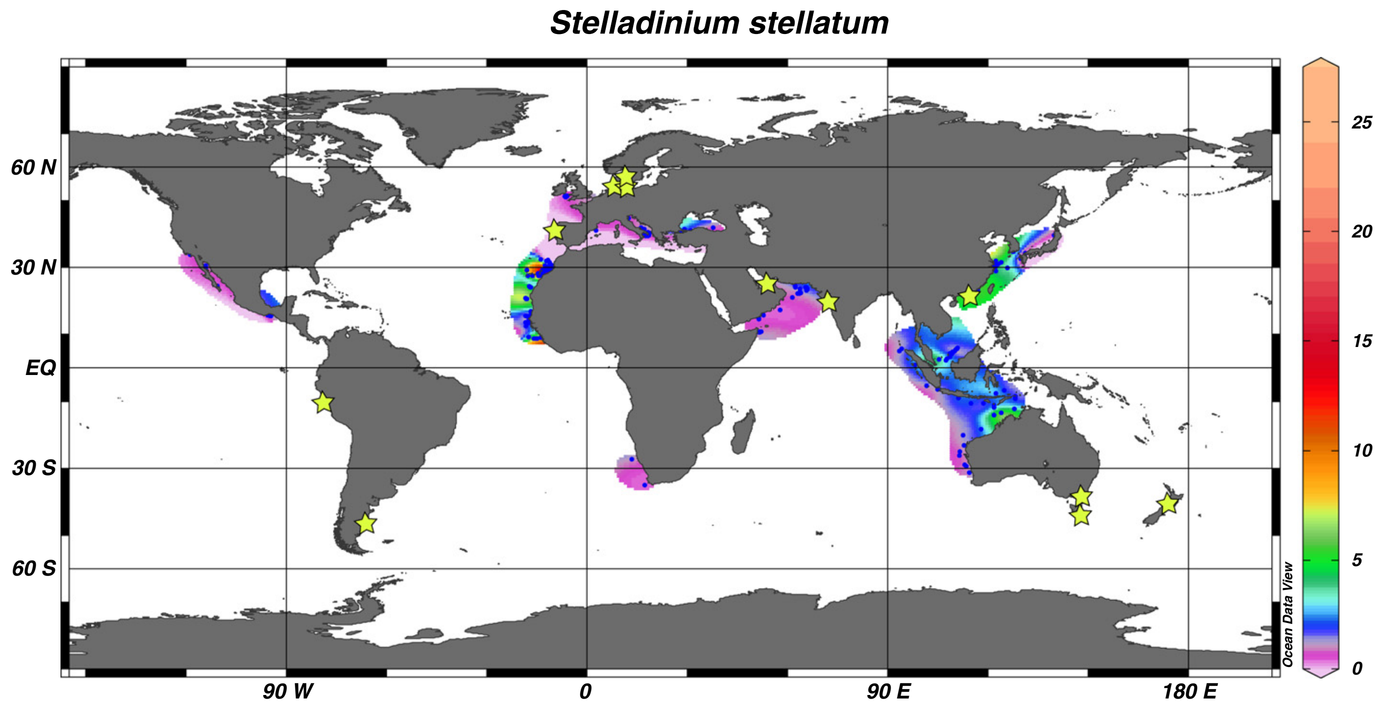

Fig. 260. Geographic distribution of *Stelladinium stellatum*.

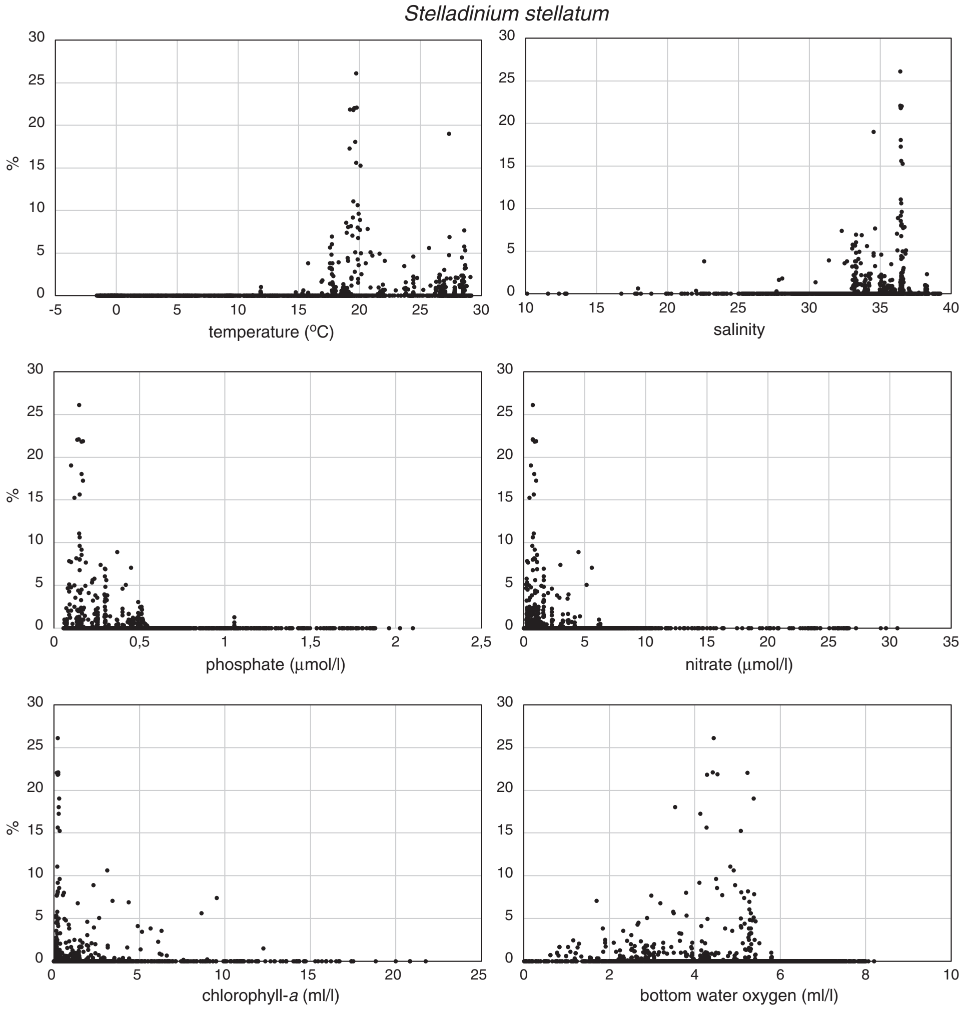

Fig. 261. Relative abundances of *Trinovantedinium applanatum* in relationship to seasonal temparature in surface waters.

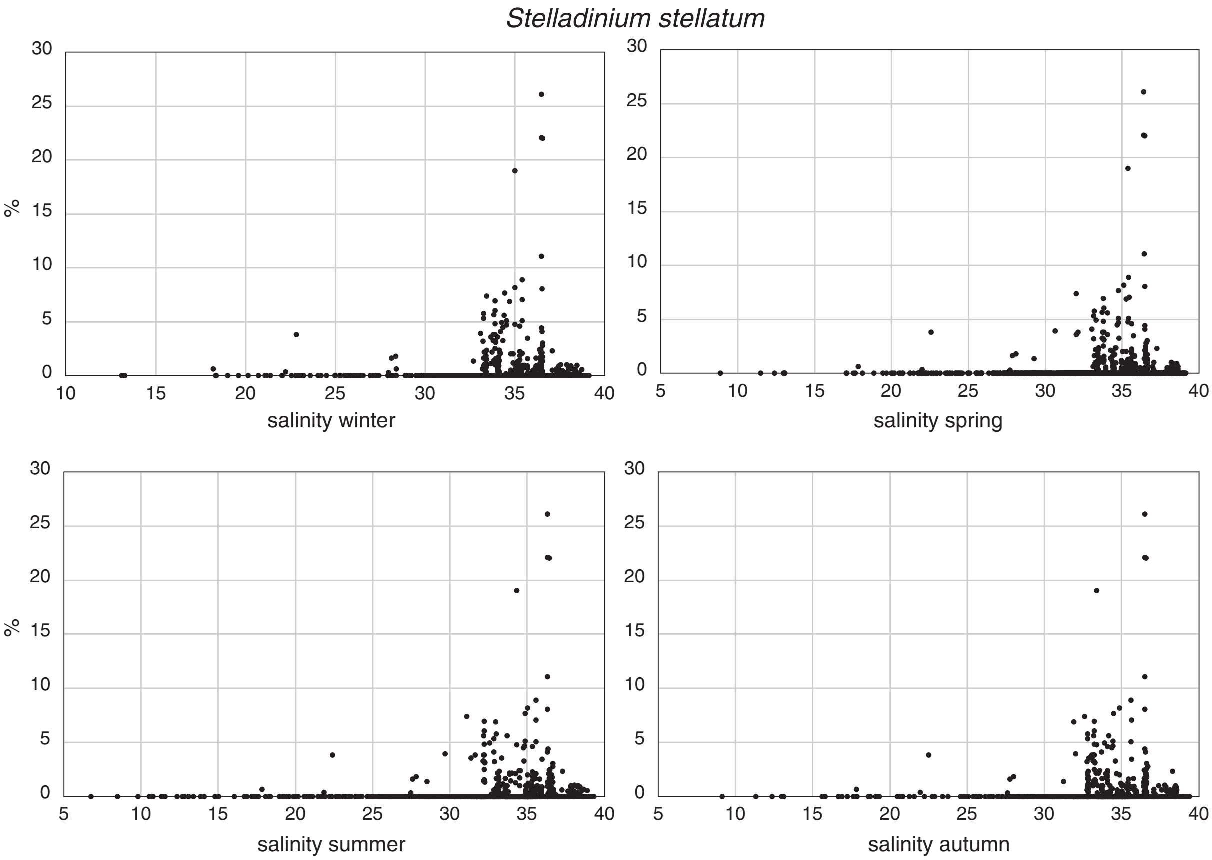

Fig. 262. Relative abundances of *Stelladinium stellatum* in relationship to seasonal salinity in surface waters.

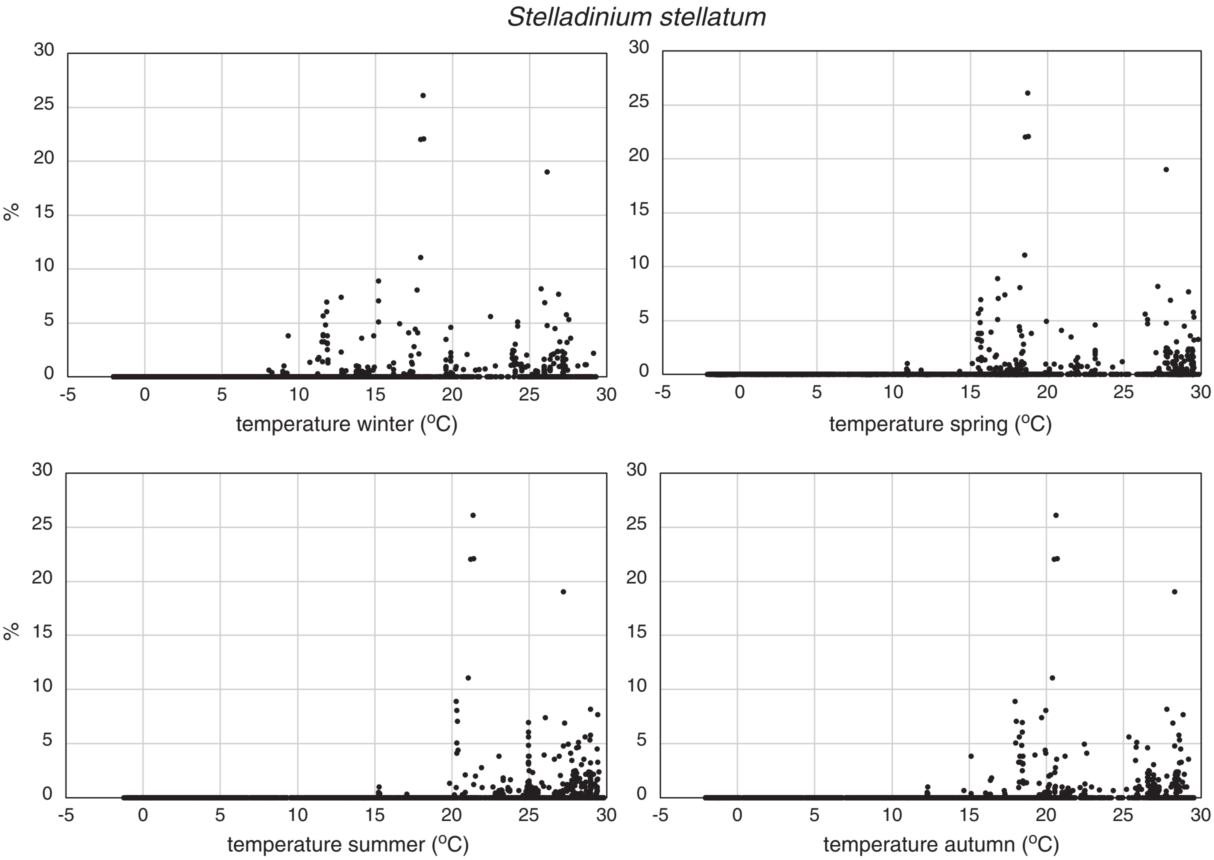

Fig. 263. Relative abundances of *Stelladinium stellatum* in relationship to seasonal temperature in surface waters.

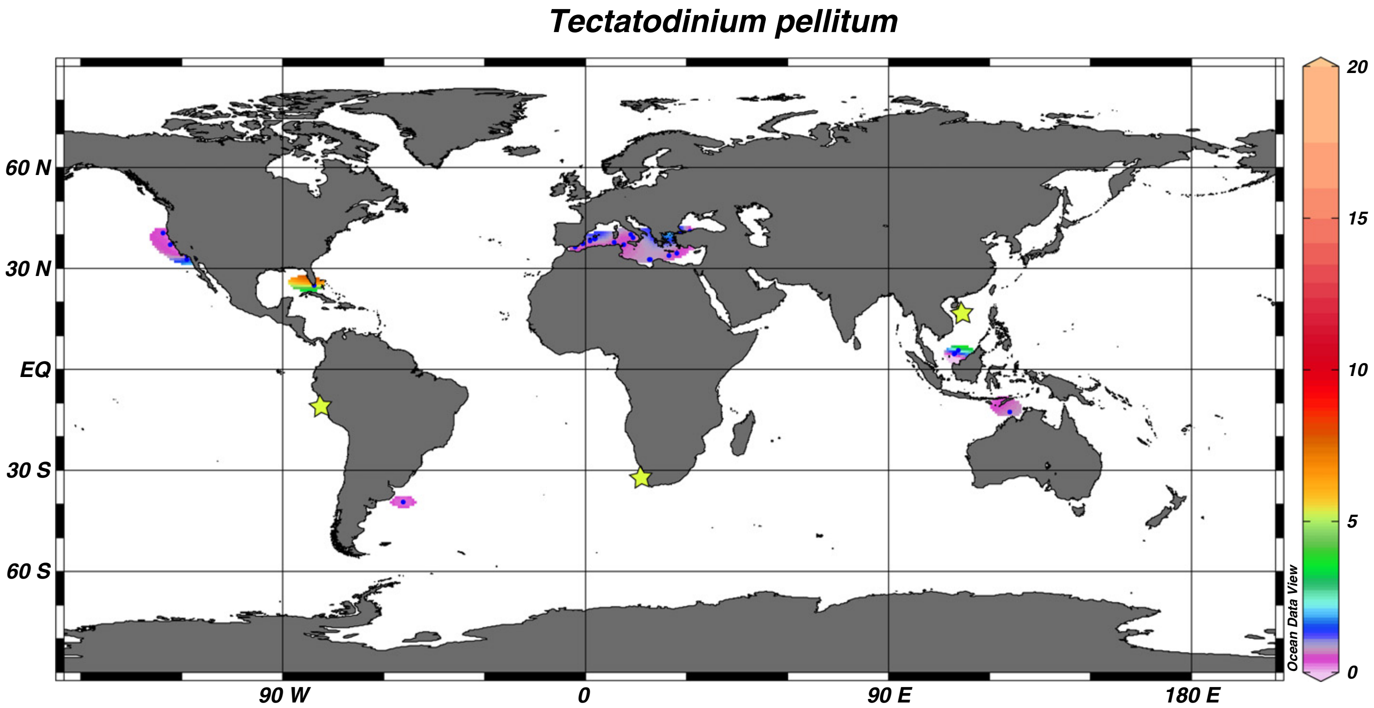

Fig. 264. Geographic distribution of *Tectatodinium pellitum*.

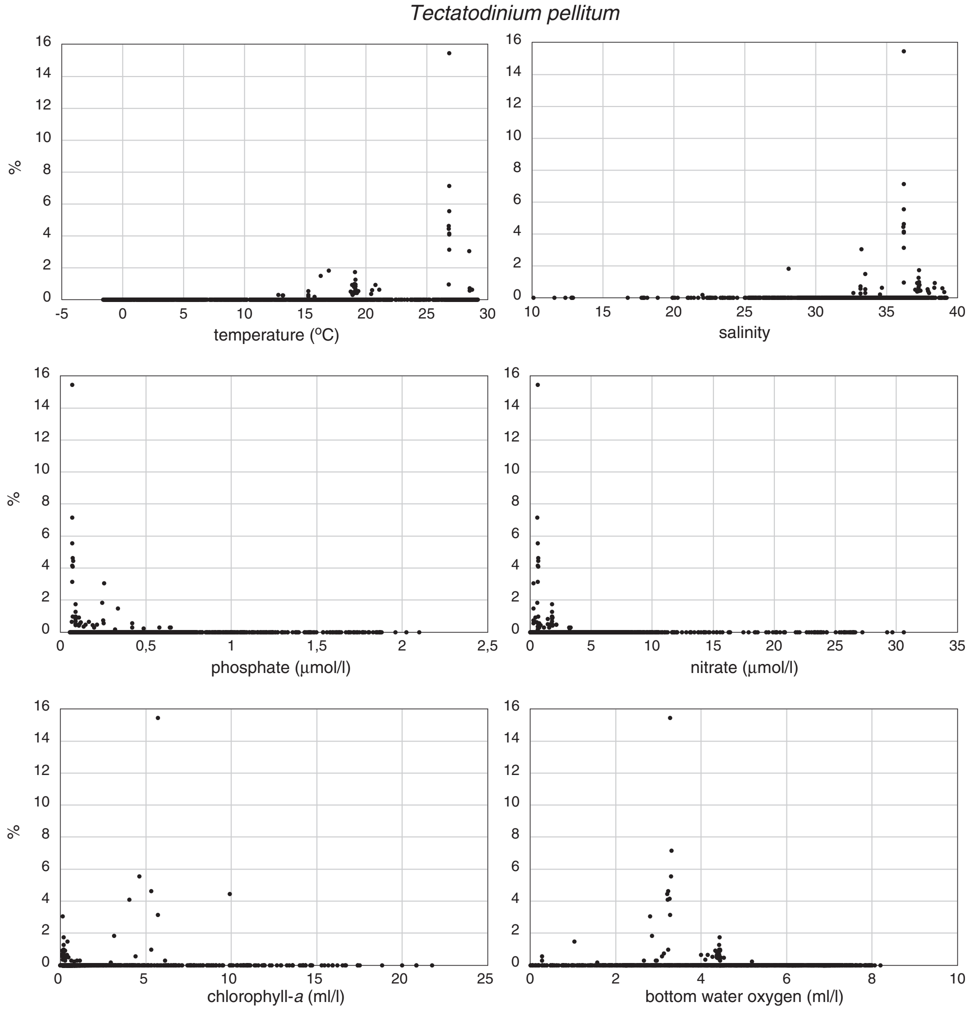

Fig. 265. Relative abundances of *Tectatodinium pellitum* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

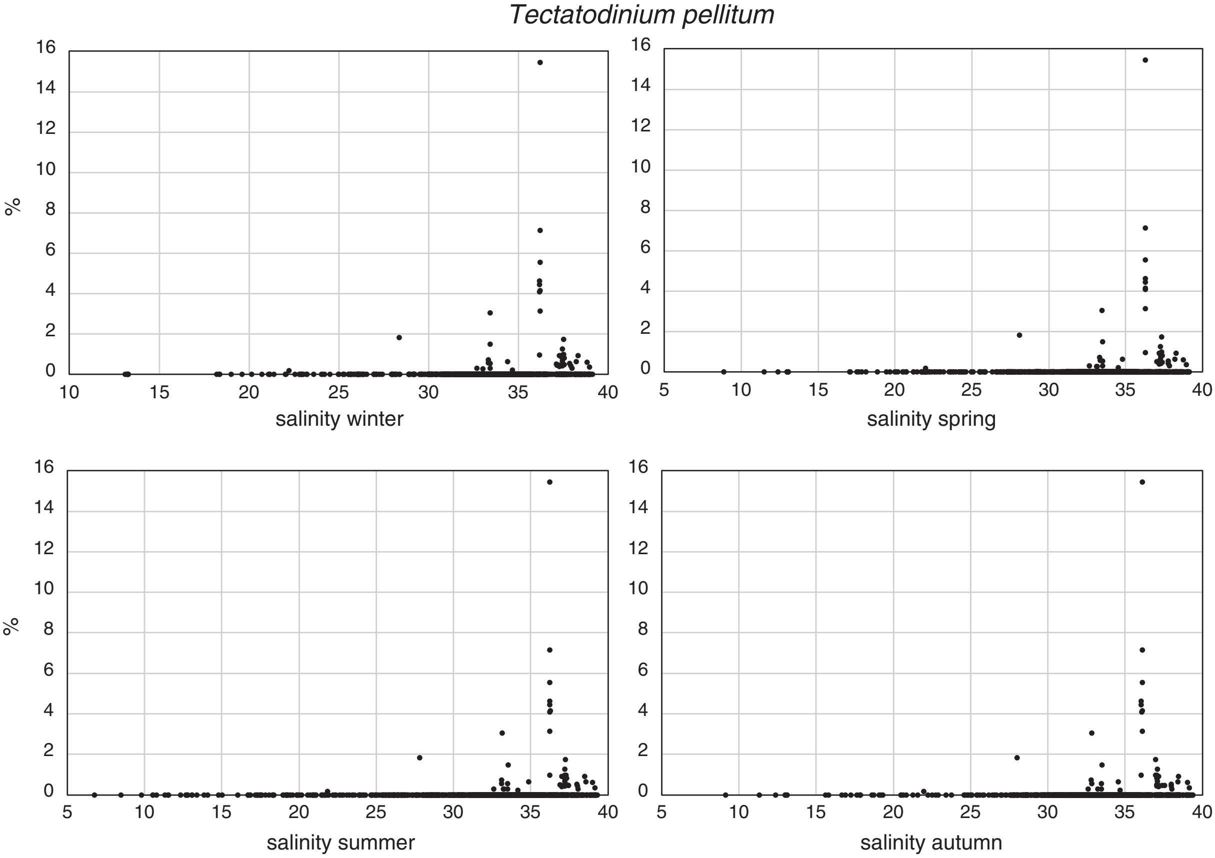

Fig. 266. Relative abundances of *Tectatodinium pellitum* in relationship to seasonal salinity in surface waters.

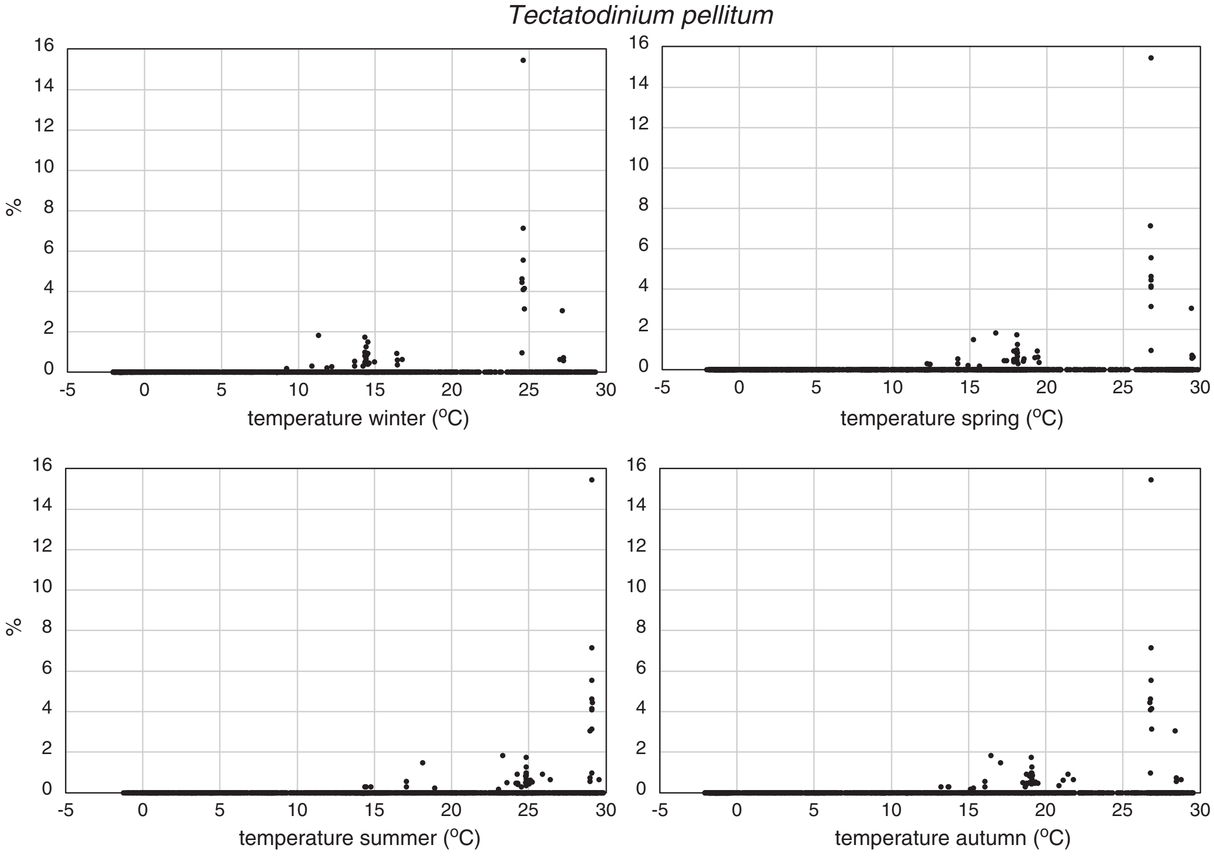

Fig. 267. Relative abundances of *Tectatodinium pellitum* in relationship to seasonal temperature in surface waters.

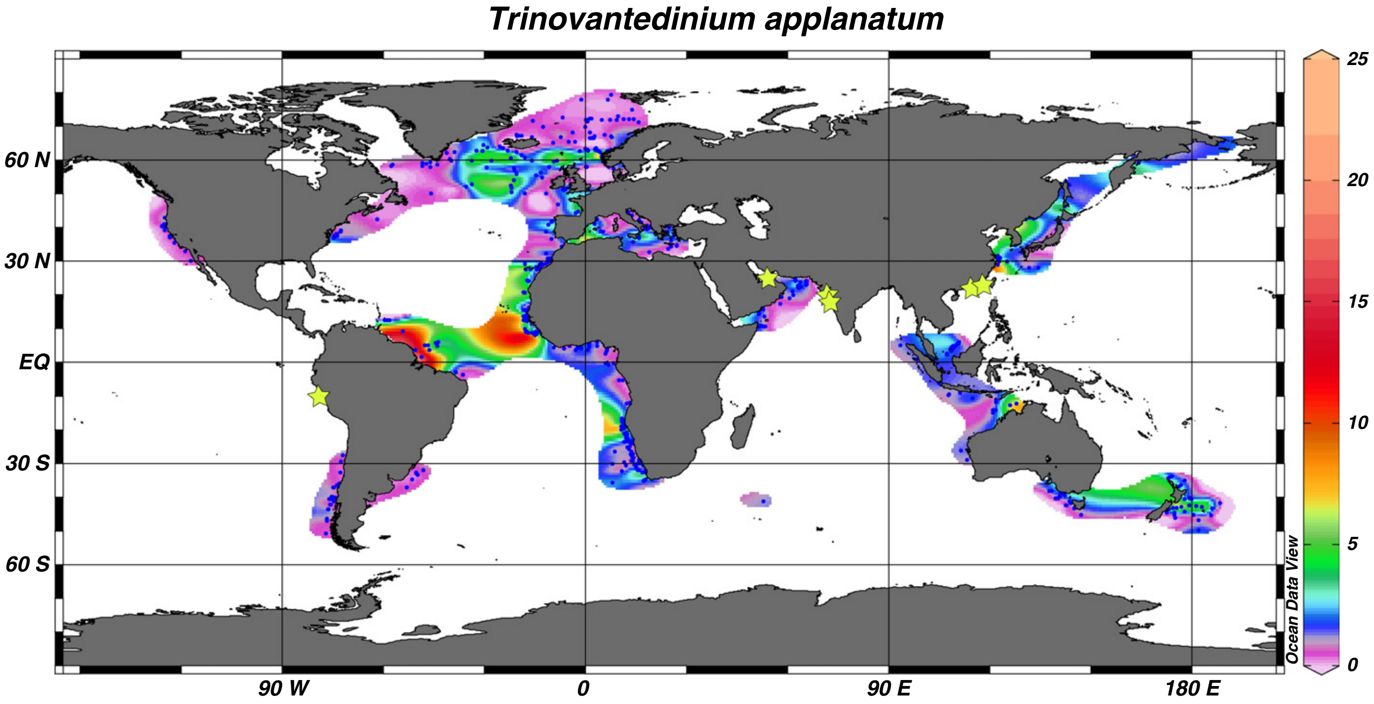

Fig. 268. Geographic distribution of *Trinovantedinium applanatum*.

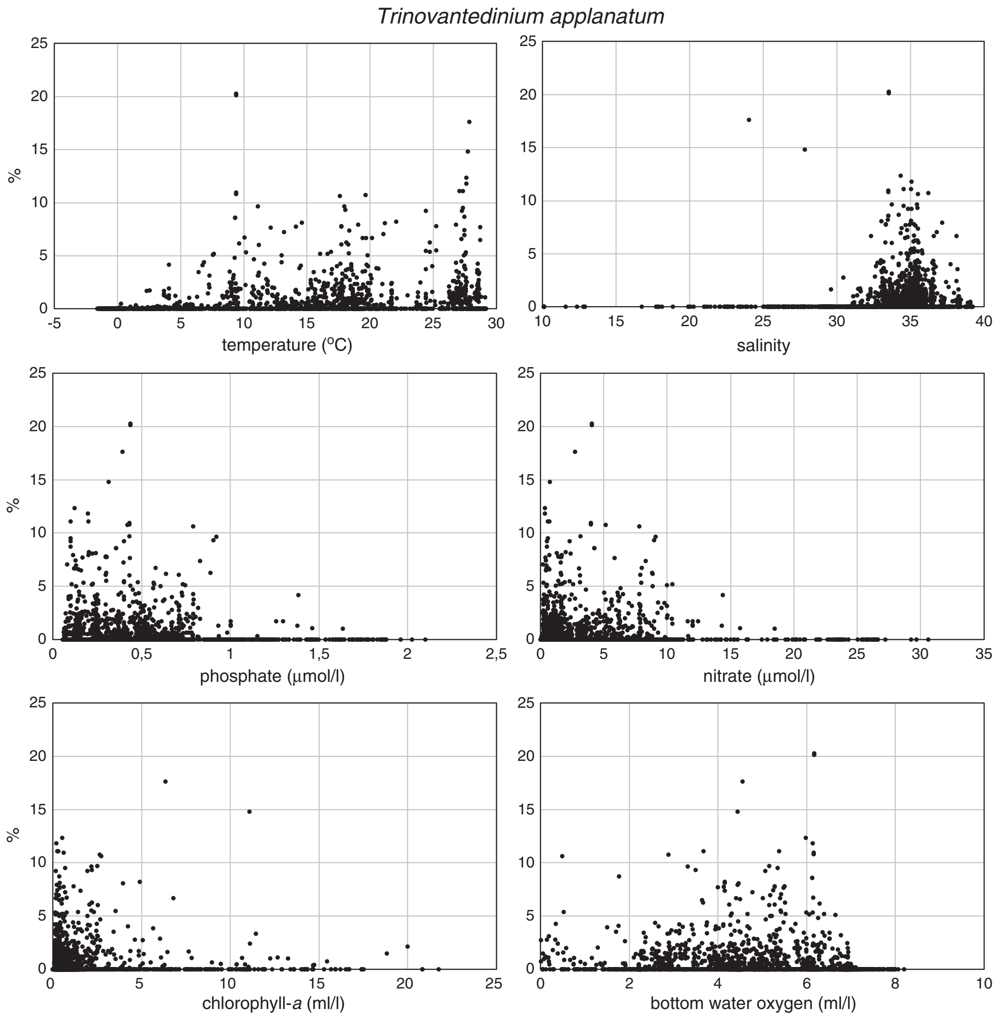

Fig. 269. Relative abundances of *Stelladinium stellatum* in relationship to seasonal temperature in surface waters.

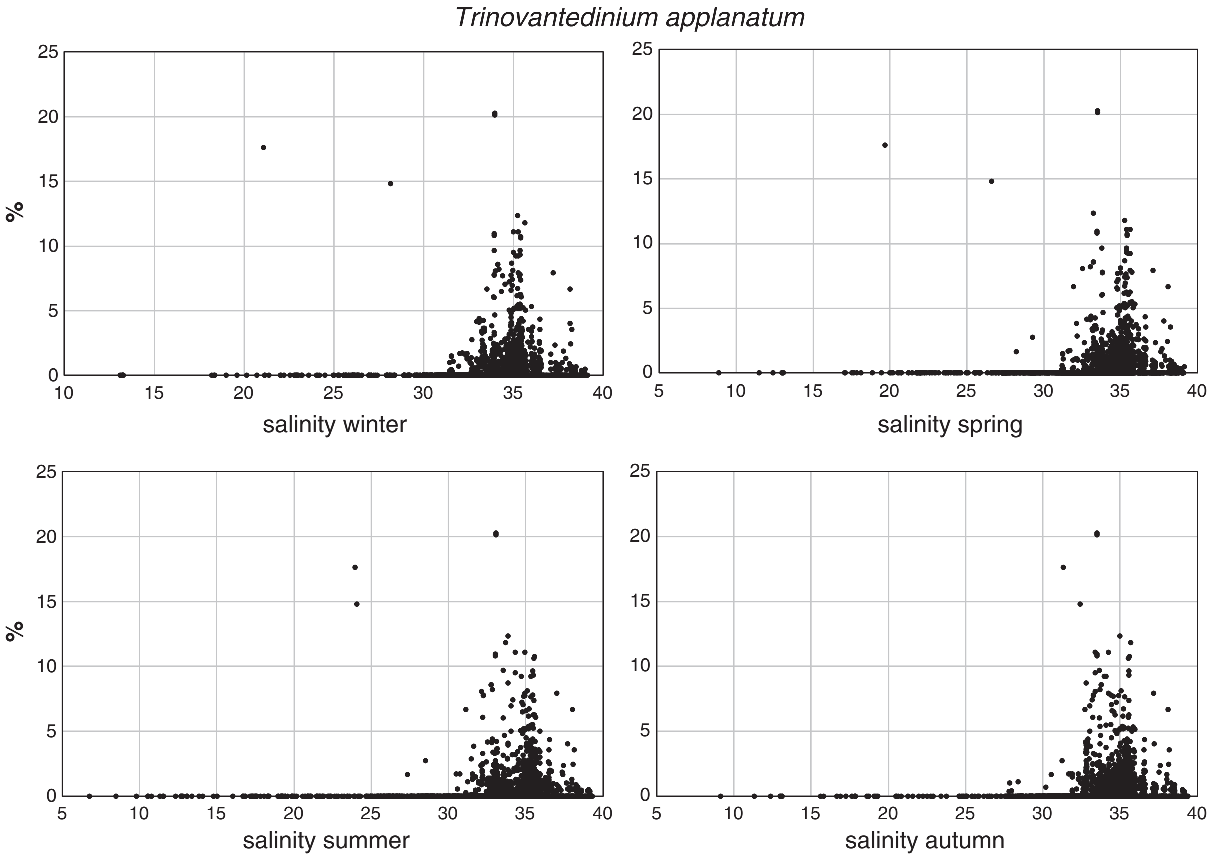

Fig. 270. Relative abundances of *Trinovantedinium applanatum* in relationship to seasonal salinity in surface waters.

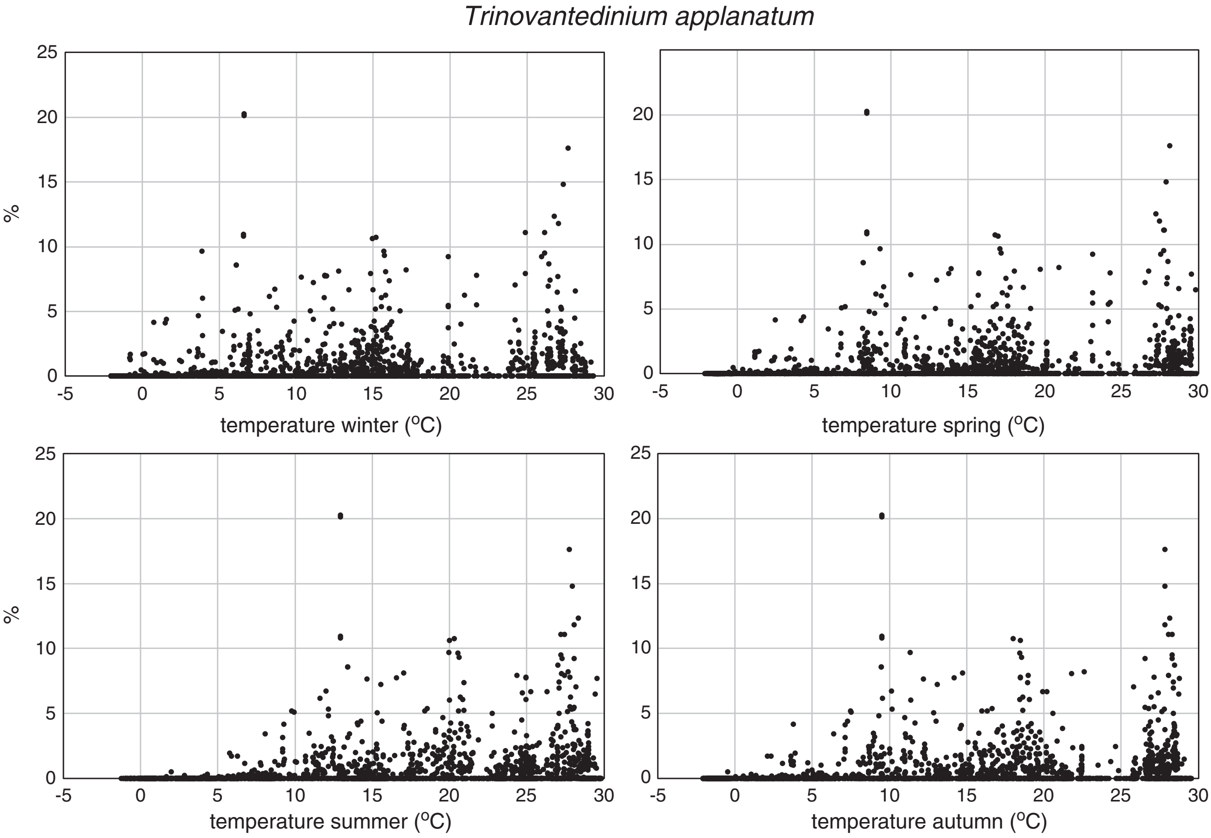

Fig. 271. Relative abundances of *Trinovantedinium applanatum* in relationship to seasonal temperature in surface waters.

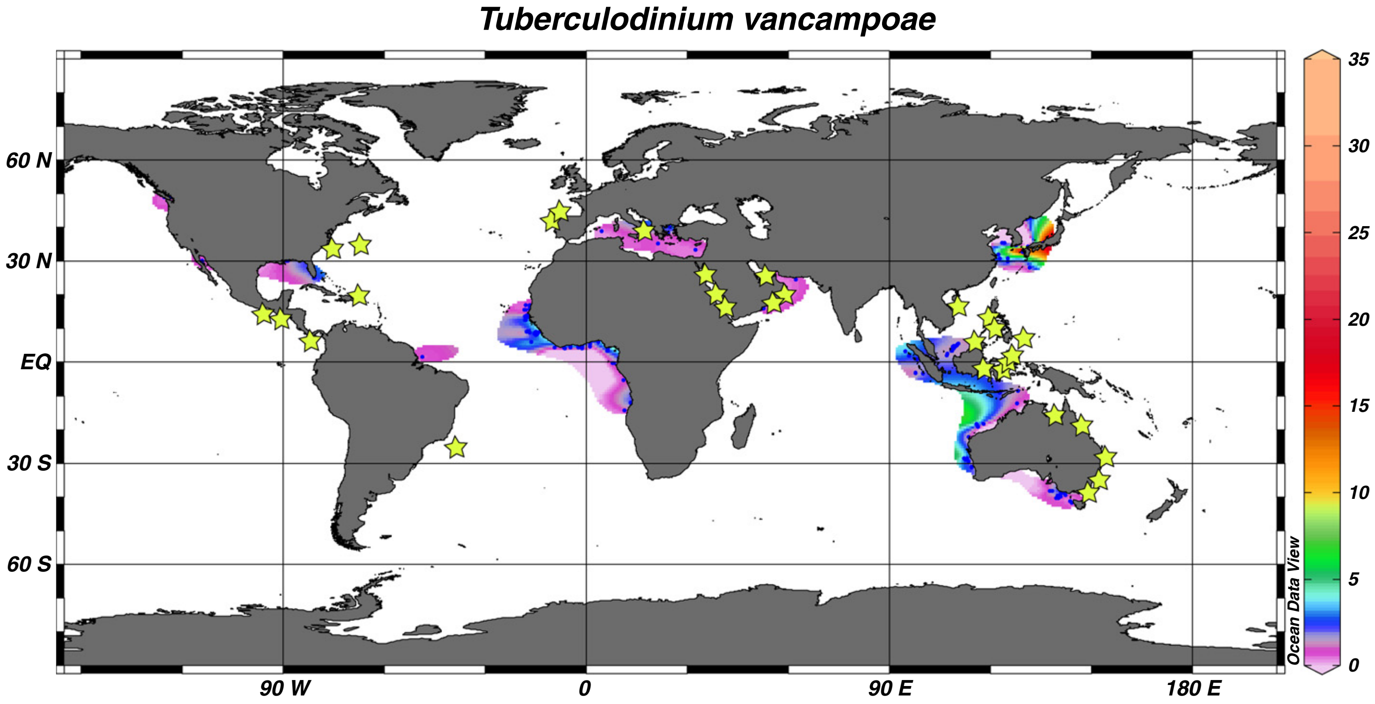
Tuberculodinium vancampoae

Fig. 272. Geographic distribution of *Tuberculodinium vancampoae*.

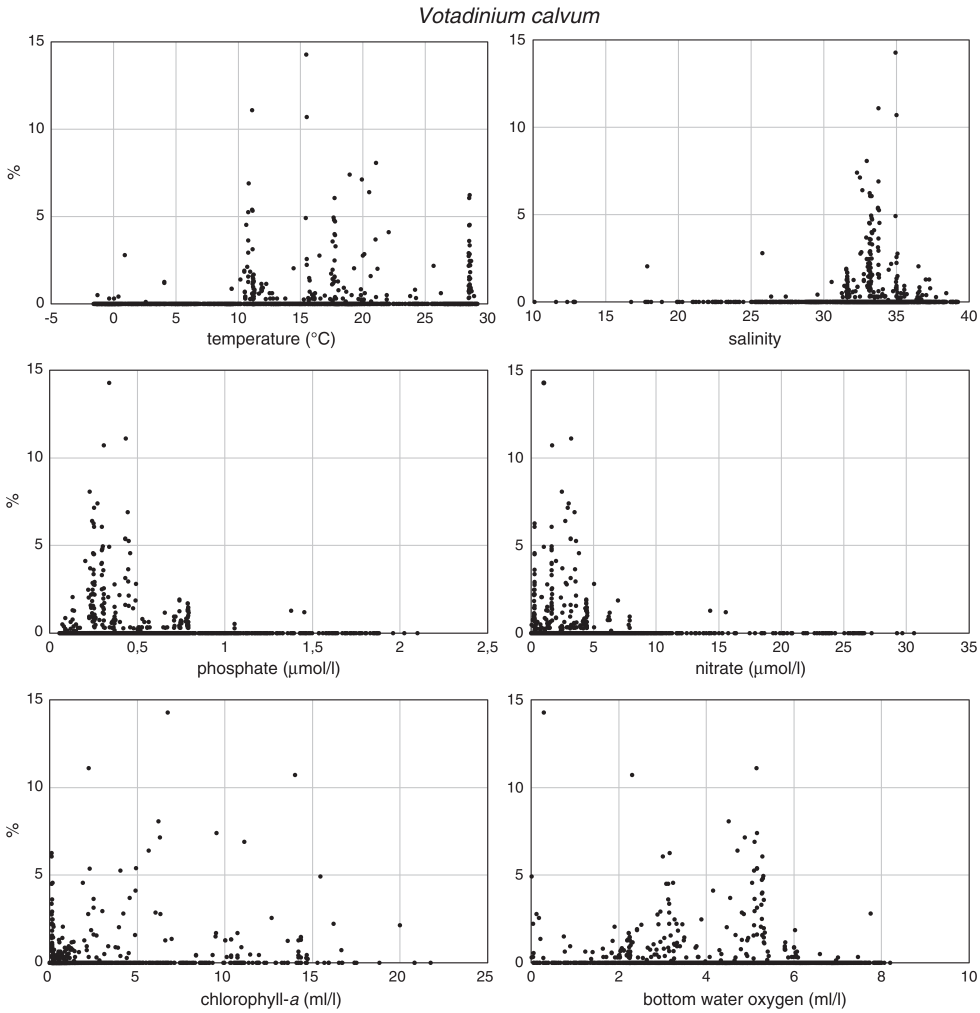
Votadinium calvum

Fig. 273. Relative abundances of *Tuberculodinium vancampoae* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

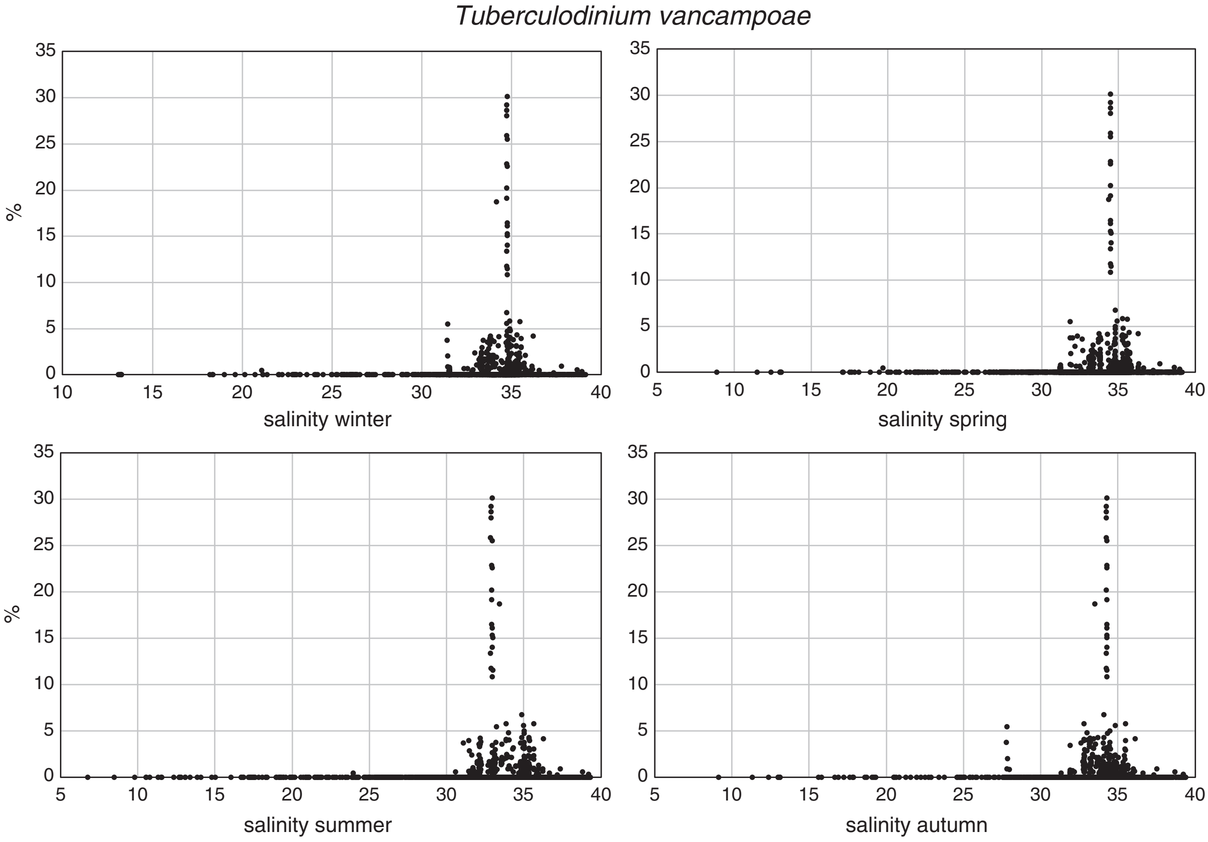

Fig. 274. Relative abundances of *Tuberculodinium vancampoae* in relationship to seasonal salinity in surface waters.

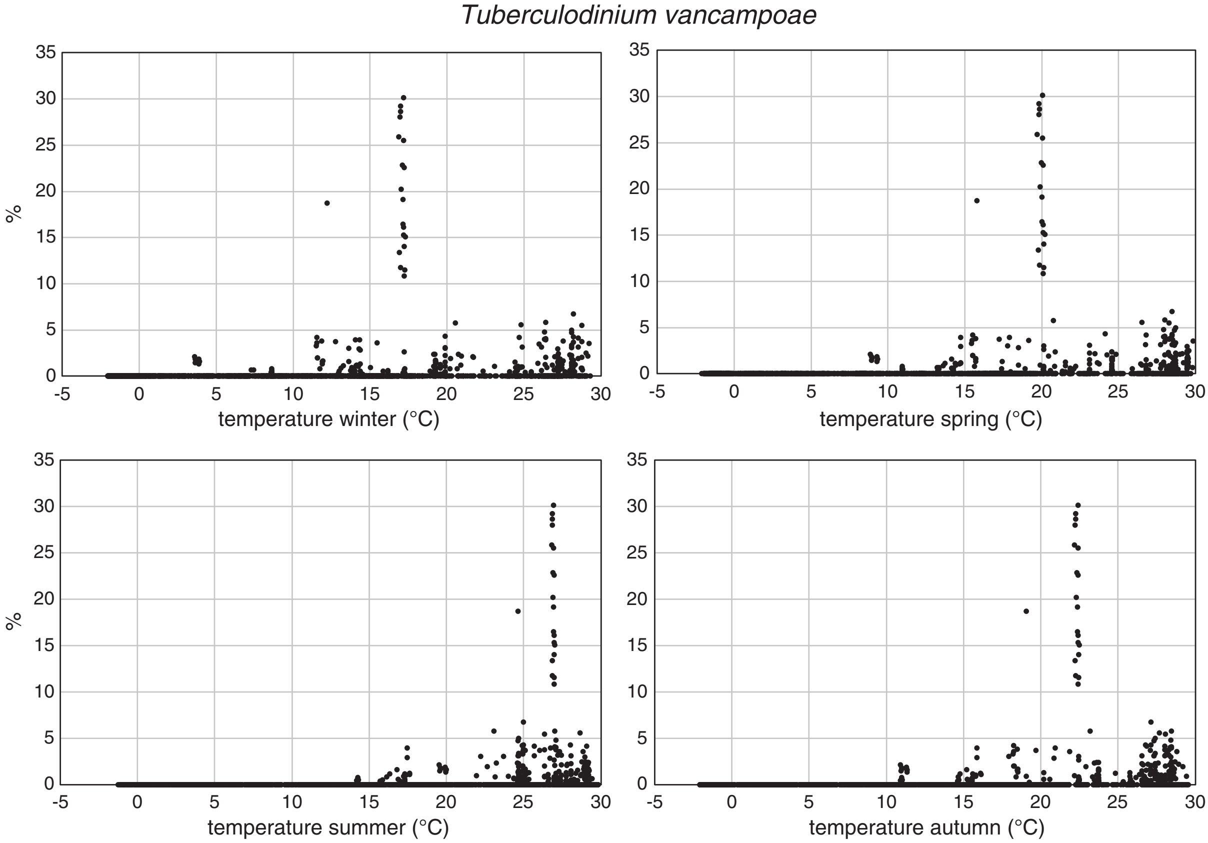

Fig. 275. Relative abundances of *Tuberculodinium vancampoae* in relationship to seasonal temperature in surface waters.

Environmental parameters:

SST: 3.9–29.8 °C (winter–spring) with summer SST: > 14.2 °C. The environment is full marine with SSS: 27.8–39.2 (autumn–summer) with exception of one site near the coast off Brazil where SSS: 19.7 (spring), 21.1 (winter), 23.9 (summer) and 31.3 (autumn). [P]: 0.06–1.06 μmol/l, [N]: 0.14–4.6 μmol/l, chlorophyll-*a*: 0.01–20.0 ml/l, bottom water [O_2]: 1.3–5.9 ml/l.

Highest relative abundances occur where SSS: is > 32.9 throughout the year.

Comparison with other records:

Apart from the recordings in this Atlas, *T. vancampoae* has been reported from coastal sites in the South China Sea, the Indonesian waters, around the Australian continent, the Red Sea, gulf of Oman, northern Arabian Sea, central western equatorial Atlantic, off the Iberian Peninsula and the eastern equatorial Pacific (Marret and Zonneveld, 2003; Usup et al., 2012 and references therein).

Concluding remarks:

Tuberculodinium vancampoae is a subtropical (warm temperate) to equatorial coastal species that occurs in oligotrophic to eutrophic environments where bottom waters are well ventilated and in general full-marine.

69. *Votadinium calvum* Reid 1977

Figs. 276–279.

Distribution:

Votadinium calvum is restricted to coastal sediments from temperate to equatorial regions with exception of a few sub-polar coastal sites of the Beaufort Sea. SSS vary from low throughout the year (e.g. Black Sea) to full-marine (e.g. coastal upwelling areas). Highest abundances (up to 14%) occur in Sea of Japan and East China Sea.

Environmental parameter range:

SST: −2.0–29.7 °C (winter–summer), SSS: 16.8–38.4 (summer–summer), [P]: 0.07–1.45 μmol/l, [N]: 0.04–15.6 μmol/l, chlorophyll-*a*: 0.1–20.0 ml/l, bottom water [O_2]: 0.01–7.8 ml/l.

Abundances up to 2% occur where surface SSS are reduced throughout the year and abundances up to 1.3% occur in hypersaline environments with SSS: > 37 throughout the year. Although present in oligotrophic regions, highest relative abundances occur in eutrophic environments such as upwelling areas, which may have large inter-annual variability in the trophic state of the upper waters.

Comparison with other records:

Apart from the recordings in this Atlas *Votadinium calvum* has been observed in coastal sediments off southern China (Wang et al., 2004c), off India and Gulf of Oman in the eastern Arabian Sea (Bradford and Wall, 1984; Godhe et al., 2000; Zonneveld and Brummer, 2000), the Peruvian upwelling area (Biebow et al., 1993), the upwelling area off the Iberian Peninsula (Ribeiro and Amorim, 2008) and the western Barents Sea (Solignac et al., 2009).

Sediment trap and seasonal distribution studies document that *Votadinium calcum* cyst production is not seasonally restricted in the upwelling regions off Iberia, NW Africa, and western Arabian Sea or in the Saanich Inlet northwestern Pacific (BC, Canada, Zonneveld and Brummer, 2000; Ribeiro and Amorim, 2008; Price and Pospelova, 2011). In the Omura Bay, cysts are typically produced in late autumn to winter (Fujii and Matsuoka, 2006). The sediment trap records from the Saanich Inlet (BC. Canada) and off NW Africa reveal that the production of cysts has a positive correlation with the production of opal (reflecting diatom production) and total organic matter in the upper waters. Since diatoms are documented as prey (Jacobson and Anderson, 1986), this suggests that it depends on prey availability. In studies investigating the relationship between the sedimentary cyst association and anthropogenic pollution, regularly a positive correlation occurs between anthropogenic influence and the abundance of this species, especially when sea surface nitrate concentrations are considered (Krepakevich and Pospelova, 2010; Satta et al., 2010; Shin et al., 2010a, 2010b).

Although this species occurs in regions that are seasonally covered by sea ice, a correlation could not be observed between cyst concentrations (relative abundances) and sea ice duration (Radi and de Vernal, 2008).

Concluding remarks:

Votadinium calvum can be considered as a (sub-polar) temperate to equatorial coastal species. It occurs in hypersaline and hyposaline environments. Highest relative abundances are observed in eutrophic environments (including upwelling areas) where bottom waters can be anoxic to well-ventilated. Enhanced cyst production can be linked to enhanced diatom and organic matter production in the upper ocean and in several areas possibly also to anthropogenic eutrophication (especially by nitrate).

70. *Votadinium spinosum* Reid 1977

Figs. 280–283.

Distribution:

Votadinium spinosum is restricted to coastal sediments from temperate to tropical regions where full marine conditions prevail. Highest abundances (up to 18%) occur in the East China Sea.

Environmental parameter range:

SST: are 0.7–29.4 °C (winter–summer) with summer SST> 9.0 °C. SSS: 25.5–37.7 (spring–autumn), [P]: 0.09–1.62 μmol/l, [N]: 0.3–18.4 μmol/l, chlorophyll-*a*: 0.13–19.99 ml/l, bottom water [O_2]: 0.2–7.8 ml/l.

Votadinium spinosum is not observed in regions where hypersaline conditions occur throughout the year. It is abundant in mesotrophic and eutrophic environments with highest relative abundances in eutrophic settings.

Comparison with other records:

Apart from the recordings in this Atlas *Votadinium spinosum* has been observed in coastal sediments off India (Godhe et al., 2000; D'Costa et al., 2008), coastal bays of the Benguela upwelling area (Joyce et al., 2005; Pitcher and Joyce, 2009;), the Peruvian upwelling area (Biebow et al., 1993), the upwelling area off the Iberian Peninsula (Sprangers et al., 2004; Ribeiro and Amorim, 2008), coastal embayments and estuaries of the north-east North American coast (Pospelova et al., 2002; Pospelova et al., 2005), Southeast Asian waters (Furio et al., 2012) and a highly polluted semi-enclosed Bay in the western Mediterranean Sea (Satta et al., 2010). Increased relative abundances of this species correlate with anthropogenic nitrate input in nutrient rich estuaries of southern South Korea and coastal bays of Southern Vancouver Island (Krepakevich and Pospelova, 2010; Pospelova and Kim, 2010).

No clear seasonal production pattern can be observed in sediment trap and seasonal distribution studies in the upwelling regions off Iberia, and the Saanich Inlet (northwestern Pacific (BC, Canada). However, in the latter area a positive correlation between cyst production and biogenic silica can be observed (Ribeiro and Amorim, 2008; Price and Pospelova, 2011). Since diatoms are a prey of this species (Jacobson and Anderson, 1986), this may suggest that its production depend on diatom availability.

Concluding remarks:

Votadinium spinosum is a coastal temperate to tropical species which distribution is restricted to full-marine environments. Highest relative abundances occur in eutrophic environments (including upwelling areas) where bottom waters can be hypoxic to well ventilated. Cyst production may be increased by anthropogenic pollution, especially Nitrate. Furthermore a positive relationship between cyst production and diatom abundance can be observed in some regions.

71. *Xandarodinium xanthum* Reid 1977

Figs. 284–287.

Distribution:

Xandarodinium xanthum is restricted to coastal sediments from temperate to tropical regions on the Northern Hemisphere with the exception of two observations in the South Atlantic Ocean. Highest

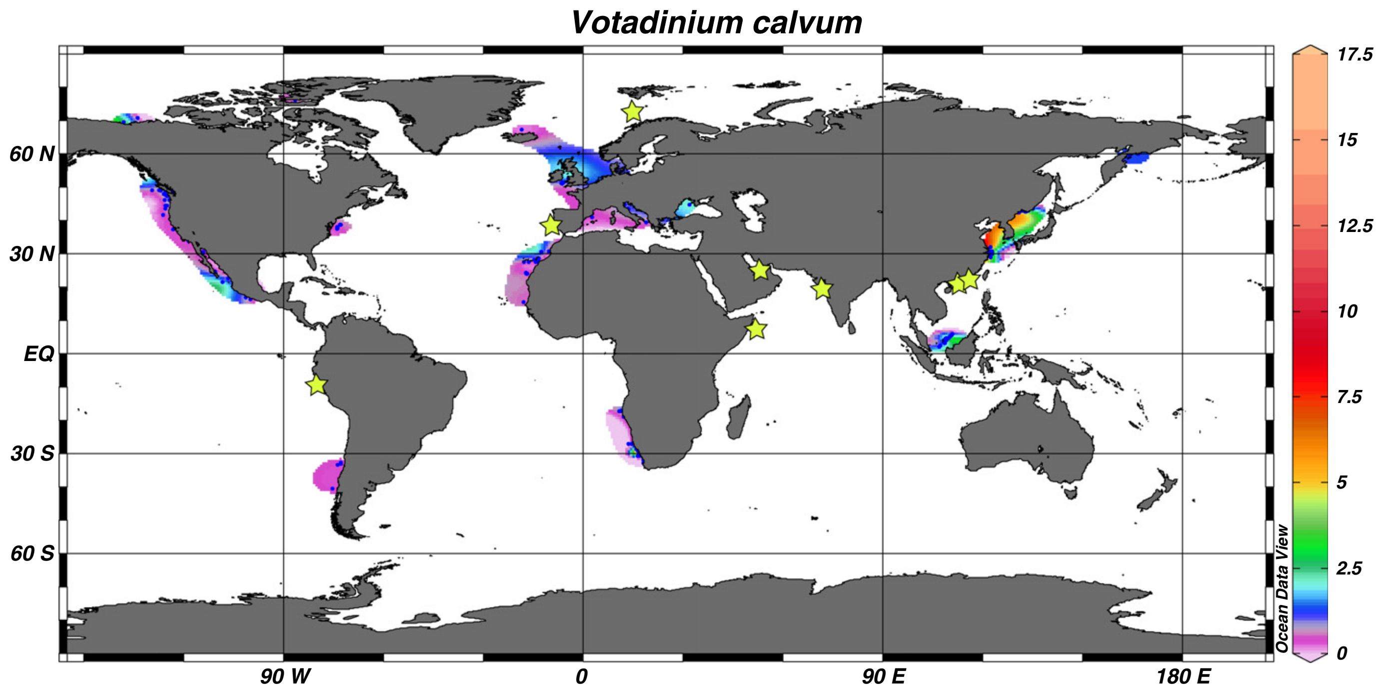

Fig. 276. Geographic distribution of *Votadinium calvum*.

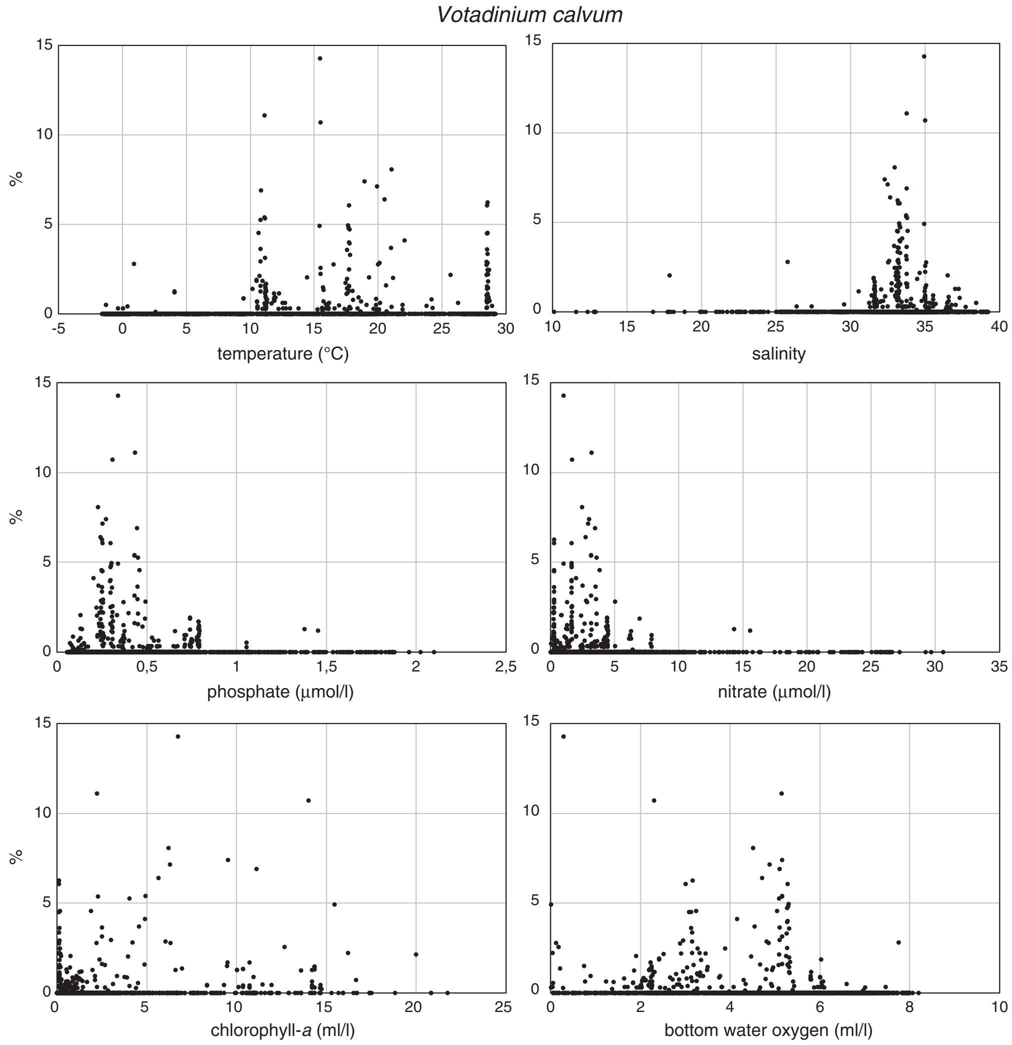

Fig. 277. Relative abundances of *Votadinium calvum* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

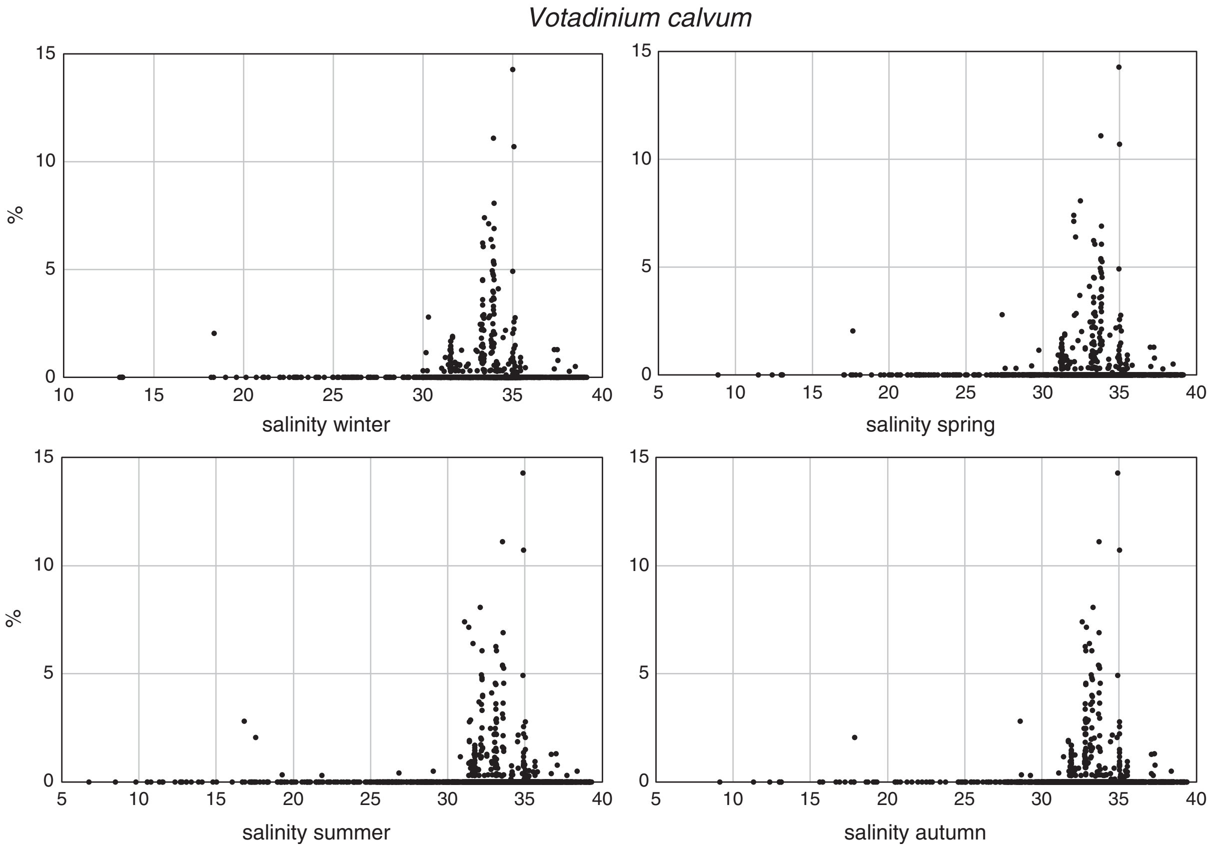

Fig. 278. Relative abundances of *Votadinium calvum* in relationship to seasonal salinity in surface waters.

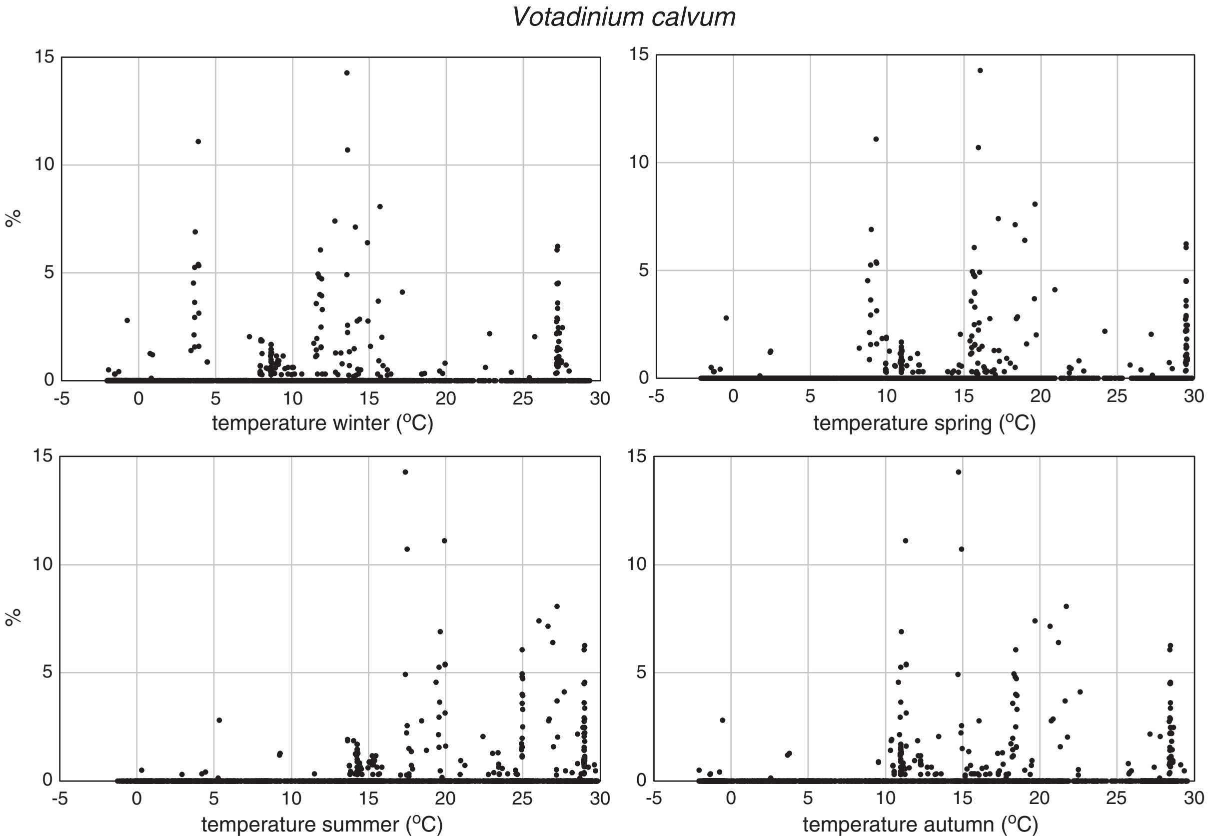

Fig. 279. Relative abundances of *Votadinium calvum* in relationship to seasonal temperature in surface waters.

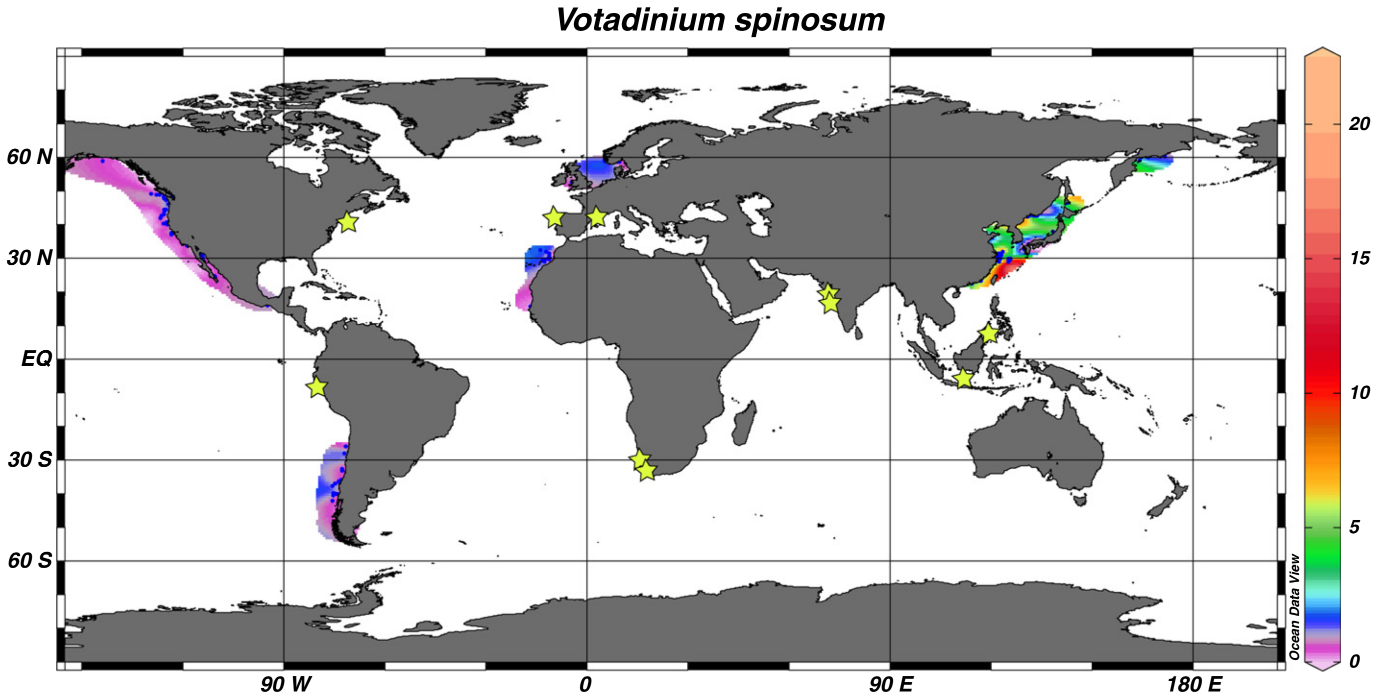

Fig. 280. Geographic distribution of *Votadinium spinosum*.

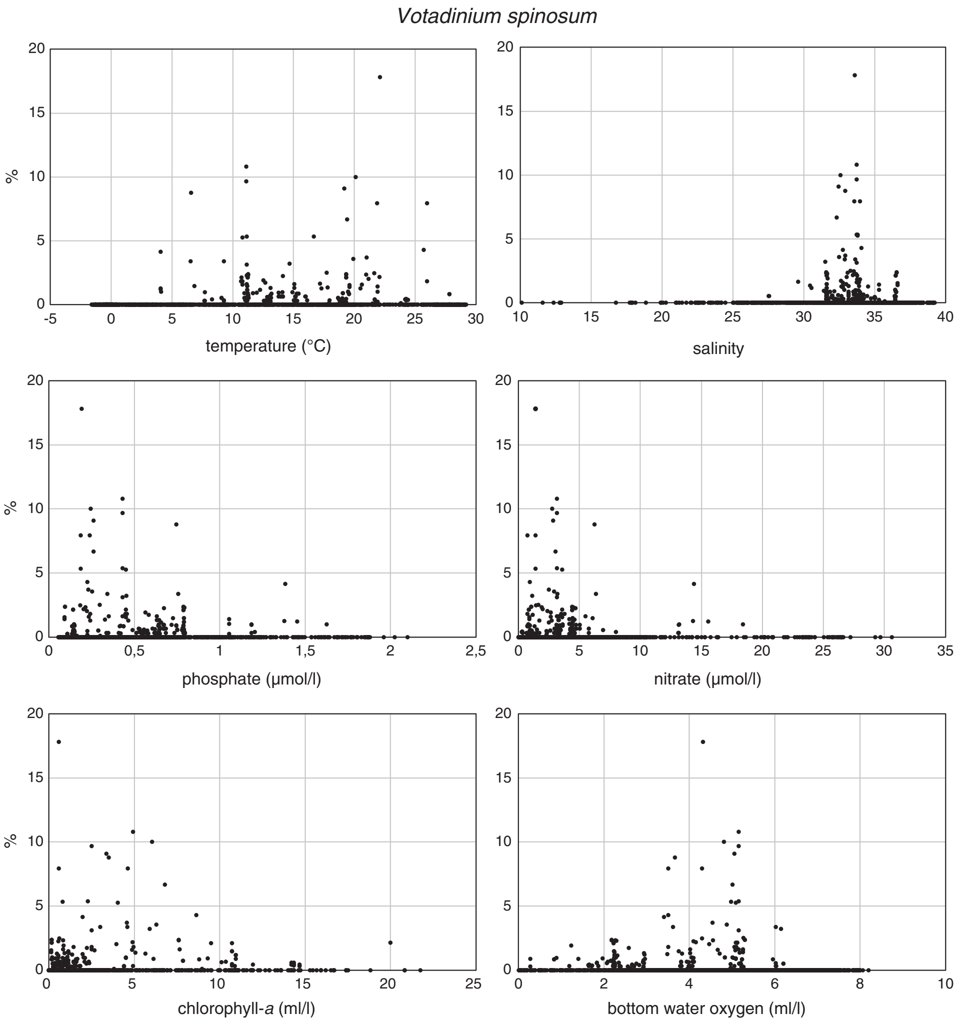

Fig. 281. Relative abundances of *Votadinium spinosum* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

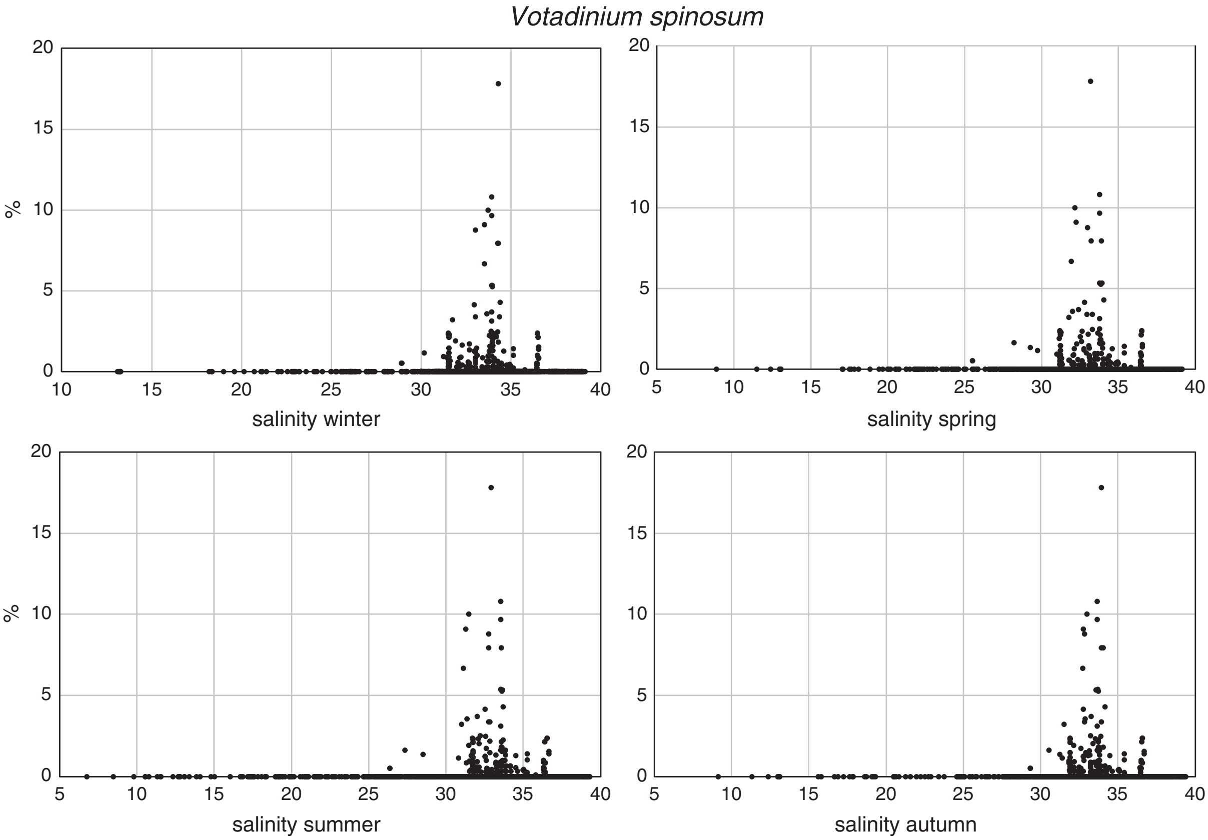

Fig. 282. Relative abundances of *Votadinium spinosum* in relationship to seasonal salinity in surface waters.

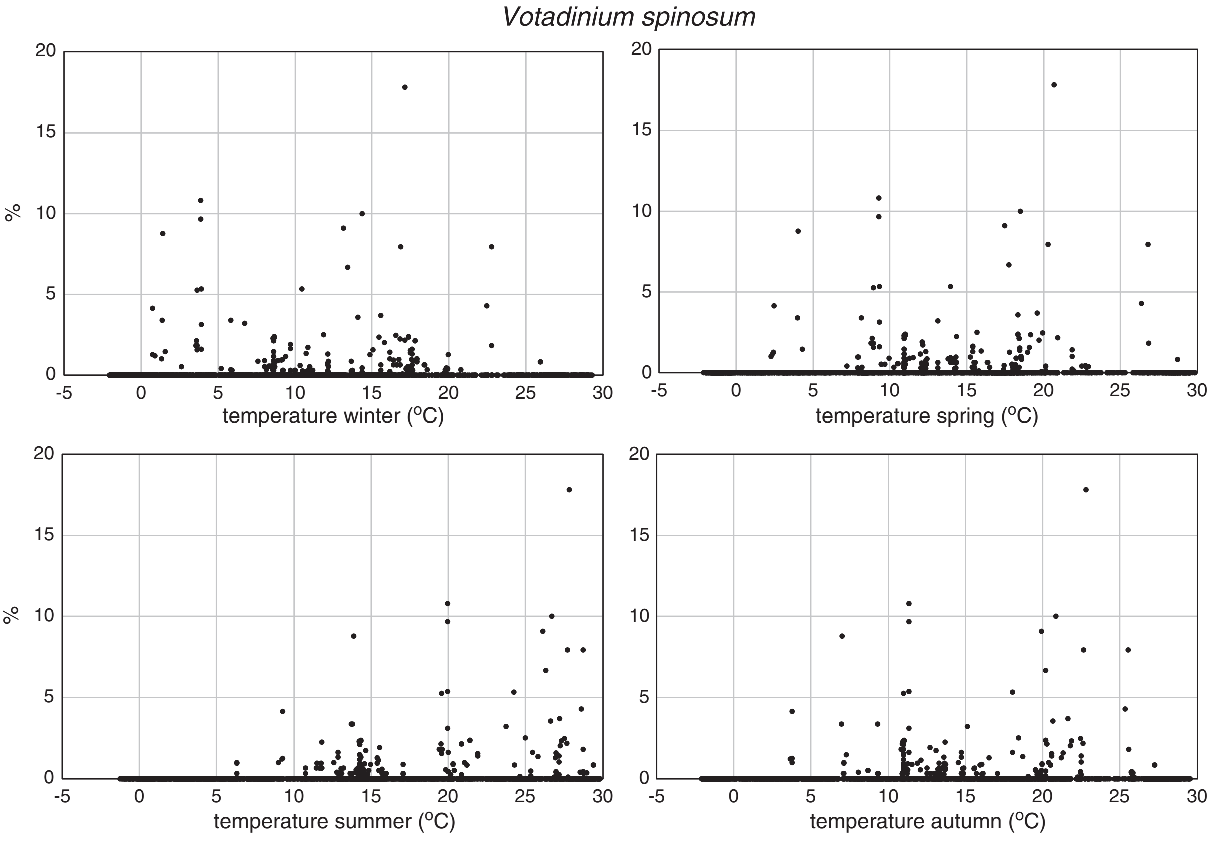

Fig. 283. Relative abundances of *Votadinium spinosum* in relationship to seasonal temperature in surface waters.

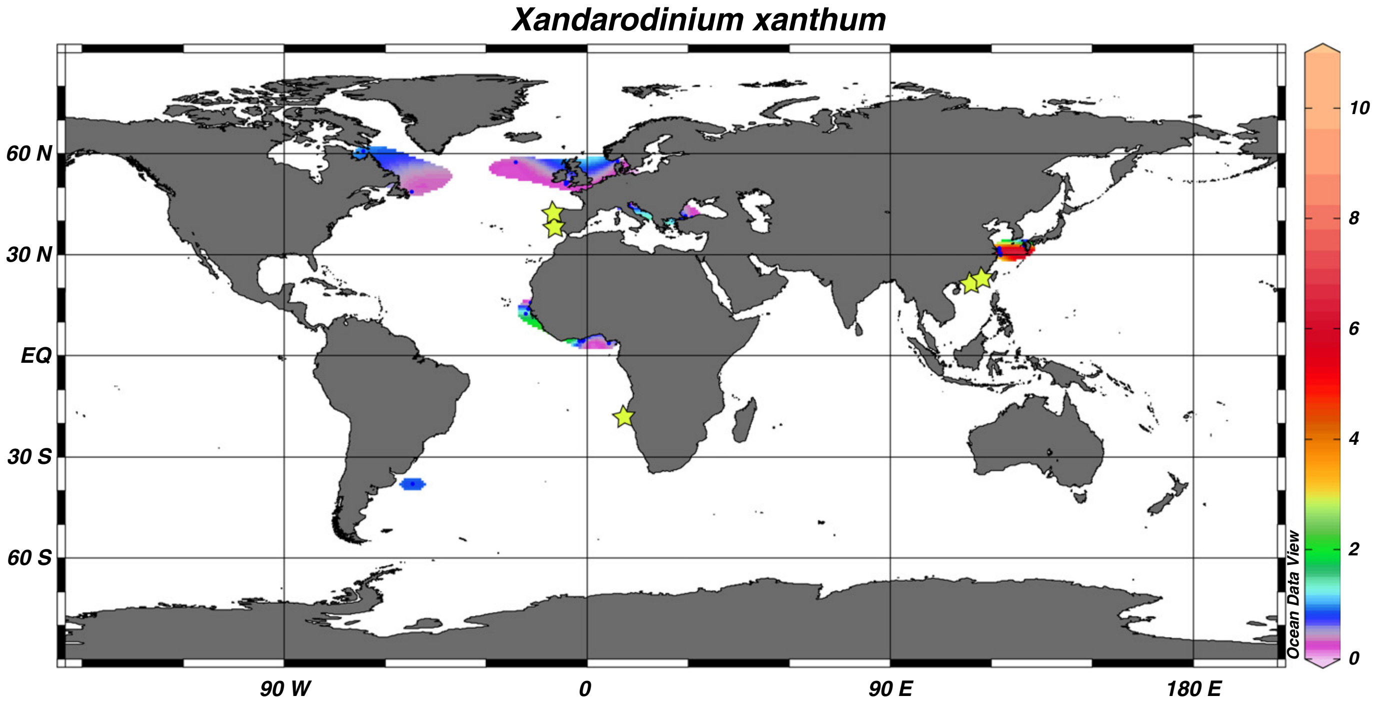

Fig. 284. Geographic distribution of *Xandarodinium xanthum*.

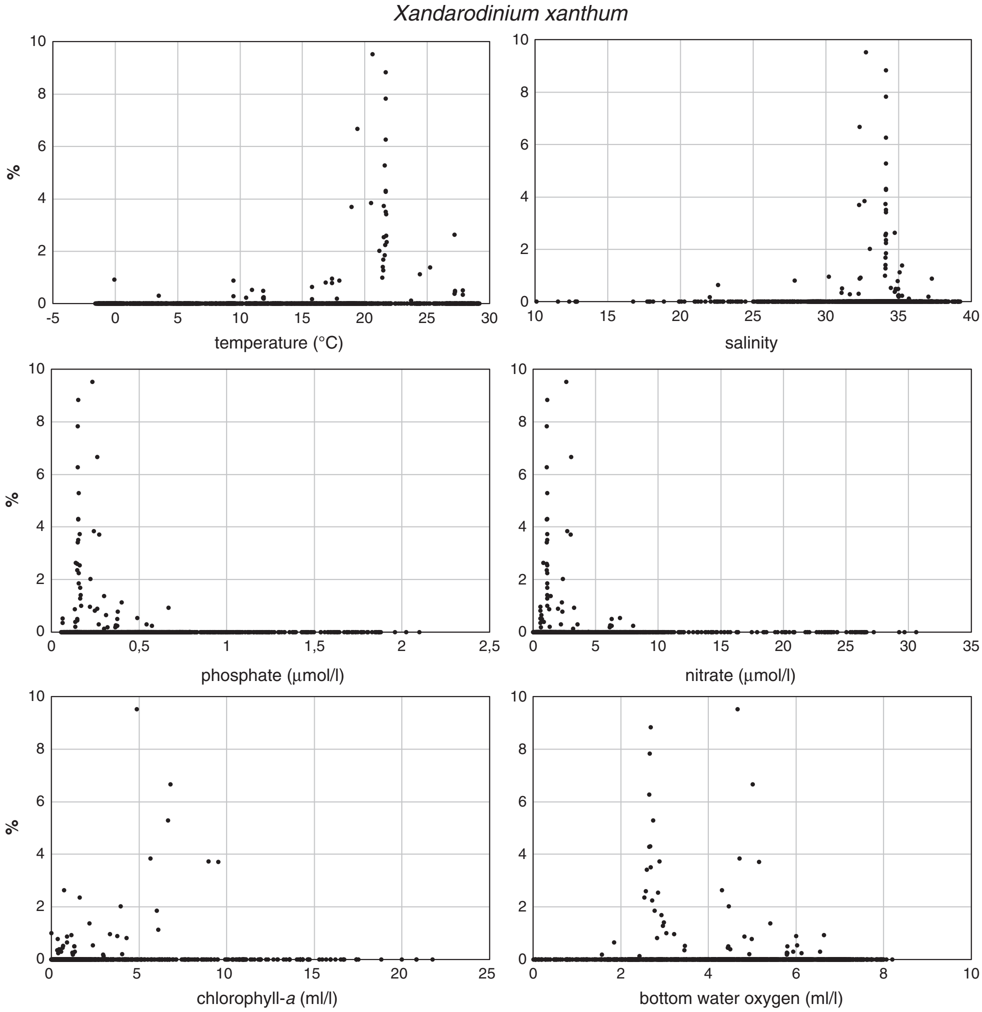

Fig. 285. Relative abundances of *Xandarodinium xanthum* in relationship to annual temperature, salinity, nitrate, phosphate and chlorophyll-*a* in surface waters as well as dissolved oxygen in bottom waters.

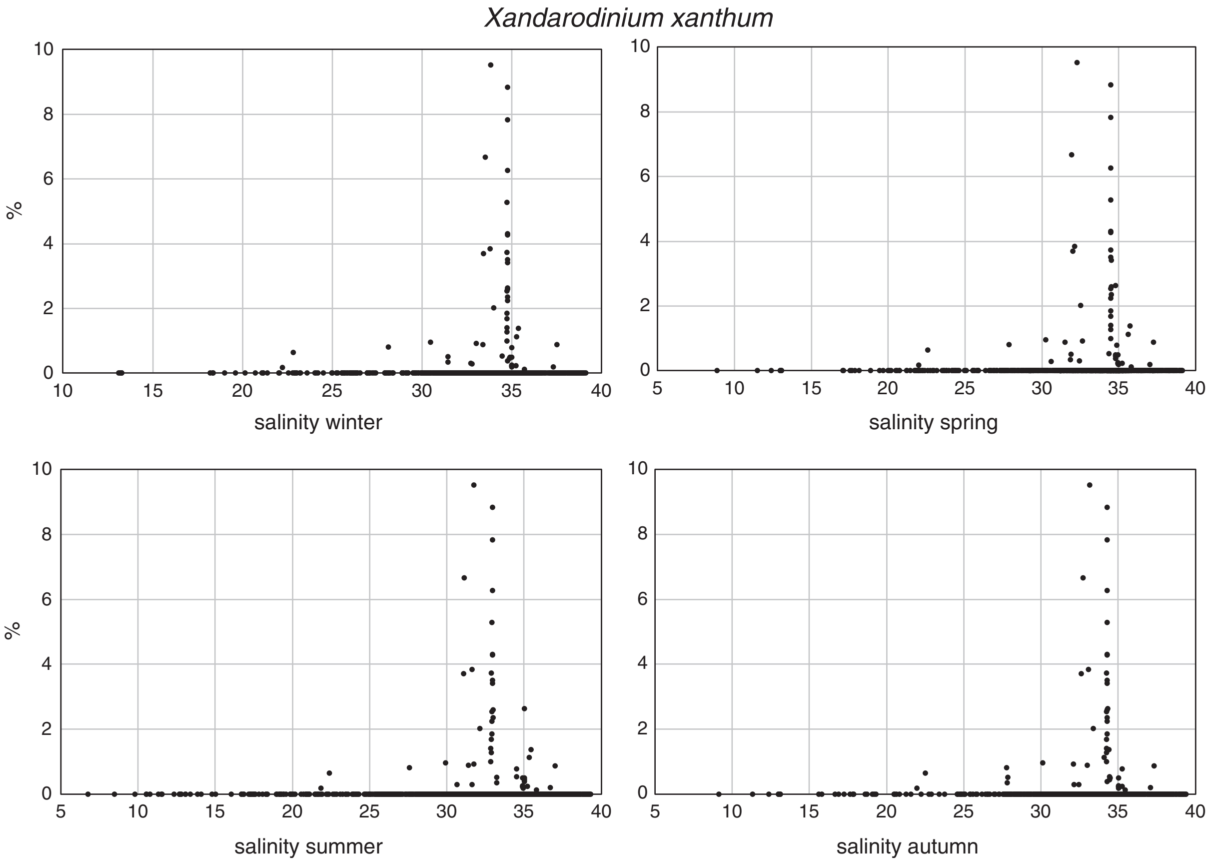

Fig. 286. Relative abundances of *Xandarodinium xanthum* in relationship to seasonal salinity in surface waters.

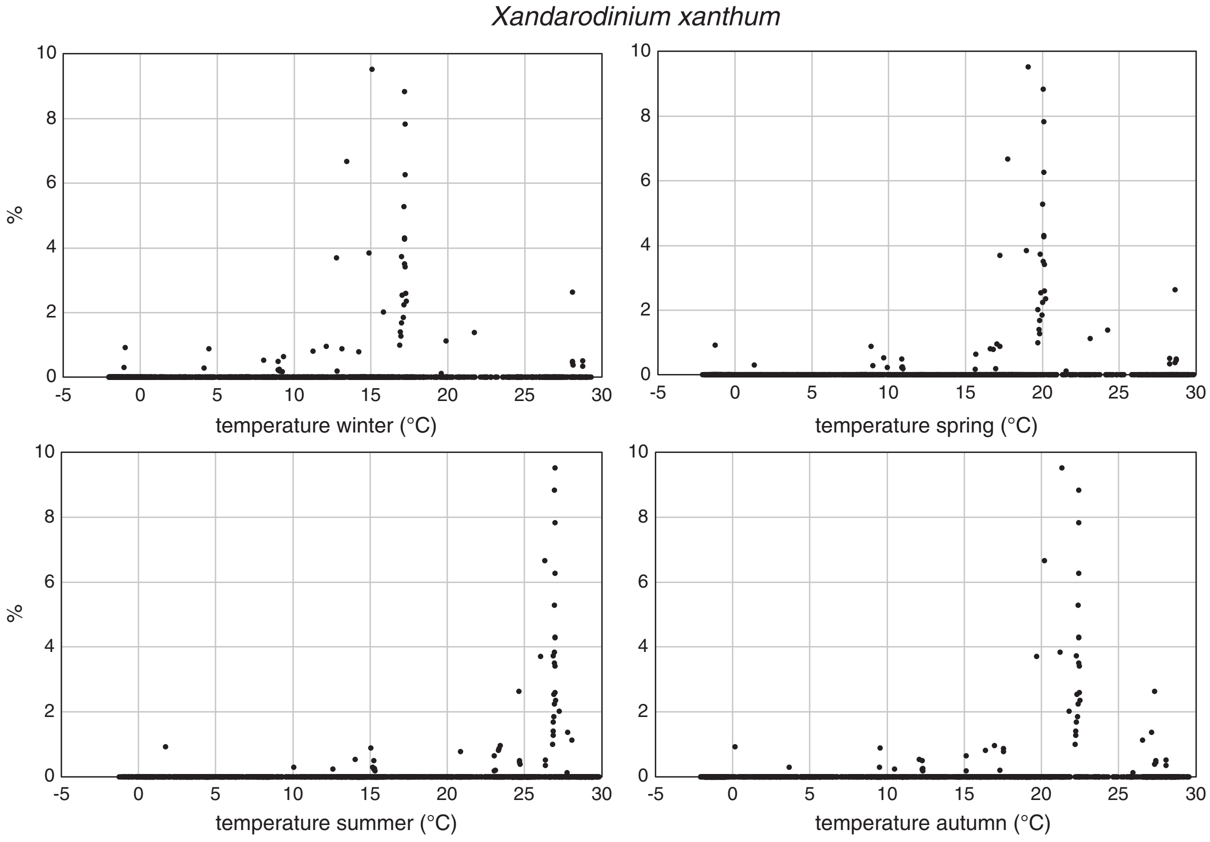

Fig. 287. Relative abundances of *Xandarodinium xanthum* in relationship to seasonal temperature in surface waters.

abundances (up to 10%) occur in the East China Sea and the upwelling areas off equatorial west Africa.

Environmental parameter range:

SST: 4.1–28.7 °C (winter–winter) with exception of one site where temperatures drop to −1 °C (winter) and −1.3 °C (spring) [P]: 0.06–0.67 μmol/l, [N]: 0.6–8.40 μmol/l, chlorophyll-*a*: 0.01–9.6 ml/l, bottom water [O_2]: 1.6–6.3 ml/l.

Xandarodinium xanthum is abundant in regions where *SSS* may be reduced to 21.9–22.2 throughout the year (e.g. Black Sea and Marmara Sea), or never drop below 37. It occurs in oligotrophic as well as eutrophic environments. These include upwelling areas where upper water conditions can vary largely throughout the year. It is not observed in regions where mean annual [N]: <0.56 μmol/l.

Comparison with other records:

Apart from the recordings in this Atlas *Xandarodinium xanthum* has been observed in coastal sediments off China (Wang et al., 2004c), sediments off India (D'Costa et al., 2008), the upwelling area off the Iberian Peninsula (Sprangers et al., 2004; Ribeiro and Amorim, 2008) and the Angola-Benguela Front region (Dale et al., 2002). No clear seasonal production pattern has been observed in the upwelling region off Iberia (Ribeiro and Amorim, 2008).

Concluding remarks:

The distribution of *Xandarodinium xanthum* is mainly restricted to coastal temperate to tropical regions on the Northern Hemisphere. Its distribution is not restricted to full marine environments but it also occurs in hypo and hypersaline settings. It is registered in oligotrophic to eutrophic environments where bottom waters are well ventilated.

4. Relationship between cyst distribution and upper water temperature, salinity, nitrate, phosphate, chlorophyll-*a* and bottom water oxygen gradients

Within this Atlas we compare individual dinoflagellate cyst distribution with environmental factors that are known to influence encystment, excystment and/or growth of cyst forming dinoflagellates (e.g. Kremp et al., 2009; Smayda and Trainer, 2010; Figueroa et al., 2011; Mertens et al., 2011a, 2011b and references therein). The environmental factors considered can influence the final cyst yield in sediments in different ways. They can influence the motile cell growth and population size and thus the amount of cells that may produce gametes. They can also influence gamete production and the production of planozygotes, the transition of planozygotes into cysts and cyst germination. The underlying mechanisms are complex and sometimes environmental conditions can have differential effects on different steps in the cyst formation/germination process. For instance conditions triggering planozygote formation can prevent encystment or germination and vice versa (e.g. Anderson et al., 1985; Anderson, 1997). Furthermore, planozygotes may divide instead of forming cysts, for instance when conditions change after planozygote formation and become favourable for cell growth (e.g. Figueroa et al., 2006, 2011; Kremp et al., 2009 and references therein).

Moreover, environmental conditions can influence cyst preservation by influencing taphonomic processes whereas transport may result in a mismatch between cysts present in the upper water column and sedimentary cyst assemblages.

The approach used in this Atlas has its limitations as we consider only the end-products of cyst formation, sinking and preservation (dinoflagellate cyst assemblages occurring in the sediments) and compare these with environmental conditions that might have influenced these processes. As a result we do not obtain information about how environmental variables influenced the process leading to cyst formation and preservation but obtain information only in how far the distribution of the species relate to the distribution of the environmental parameters. Furthermore we do not obtain insight into the effects of individual environmental variables on the different steps within the cyst, germination and taphonomic processes.

For the comparison in this Atlas a Canonical Correspondence Analysis has been carried out (Fig. 292). The results of such an analysis provide information about the degree to which variance within the dataset (distribution) corresponds to the variation within the environmental parameters. In the case an environmental variable has a causal relationship with the cyst distribution, there is a significant relationship between distribution and environmental gradient in the dataset. However, if there is a significant relationship in the dataset between the distribution and an environmental variable, it does not automatically imply that there is a causal relationship. The analysis carried out here reveals that all included environmental variables relate significantly to the species distribution on the 99% confidence level (Table 2). While this indicates that all studied environmental variables are potentially causal, they are not evidence for causality.

We observed a strong co-variation between seasonal and annual temperatures as well as between the seasonal and annual salinity gradients (Fig. 293, Table 2). This results in the fact that no differentiation can be made between the relationships of species distribution with individual seasonal gradients. Consequently our data provide no information about the time of the year (season) in which the strongest environmental pressure on the cyst distribution with respect to temperature and salinity might have occurred (assuming a causal relationship). In the following paragraphs we therefore focus on the annual gradients rather than the seasonal ones.

Some co-variation is present between the temperature, salinity and oxygen gradients as well as between annual nitrate and phosphate concentrations. As a result we carried out regression analyses between the cyst distributions and each environmental variable separately. The division of species in subgroups in the paragraphs below is based on these analyses; hence, the ordination of the species along single environmental variables (Table 2).

The most important environmental variable corresponding to the largest amount of variation in the data is temperature that corresponds to about 40% of the variation in the distribution data (Table 2, Fig. 293). Nitrate, Salinity, Phosphate and bottom water oxygen correspond to 34%, 33%, 25% and 24% of the variation in the dataset respectively. Chlorophyll-*a* concentrations in surface waters form the least important factor corresponding to 15% of the variance in the dataset. The scaling on the axes is in standard deviations (sd). Scaling is such that the unimodal response curve of a species along an environmental gradient is 4 sd.

4.1. Temperature

Culture experiments and field observations indicate that temperature can have a strong influence on the production of cysts. This can occur in different ways. (1) By influencing the vegetative growth of a population. This in turn, influences the total cell numbers, cell density and cell contact which are all factors that can effect total cyst yields of individual species (e.g. Uchida, 2001; Navarro et al., 2006; Kremp et al., 2009; Pena-Manjarrez et al., 2009; Bravo et al., 2010b and references therein). (2) In laboratory experiments and field observations temperature can directly influence the encystment process and as such the final cyst yield (e.g. Sgrosso et al., 2001; Meier et al., 2004; Nagai et al., 2004; Figueroa et al., 2011). (3). Temperature can play a key role in breaking dormancy and/or influence the dormancy period and germination success (see references in Smayda and Trainer, 2010).

In our database we can distinguish four groups of species, with respect to their distribution–temperature relationship (Table 3):

(T-1) Cold-water species: ordinated at the negative side of the temperature axis of the CCA (SST sd < −1.0).

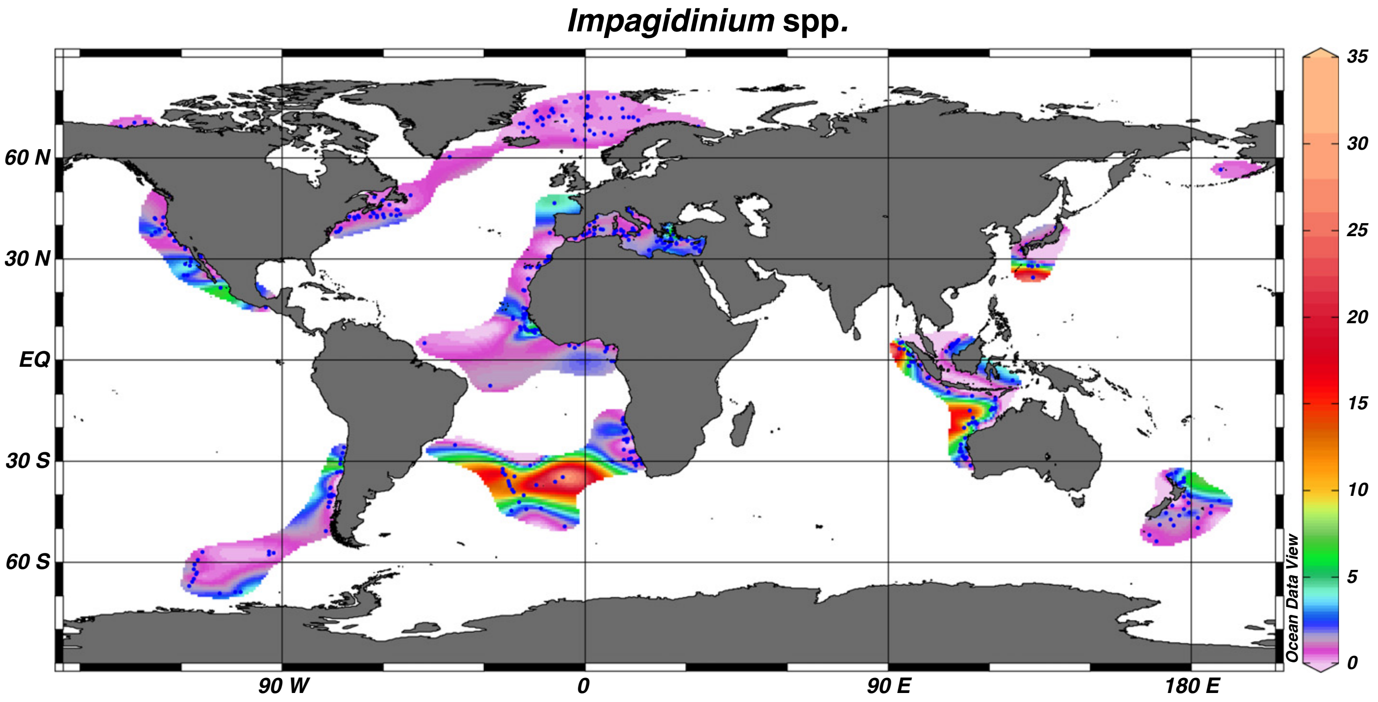

Fig. 288. Geographic distribution of *Impagidinium* spp.

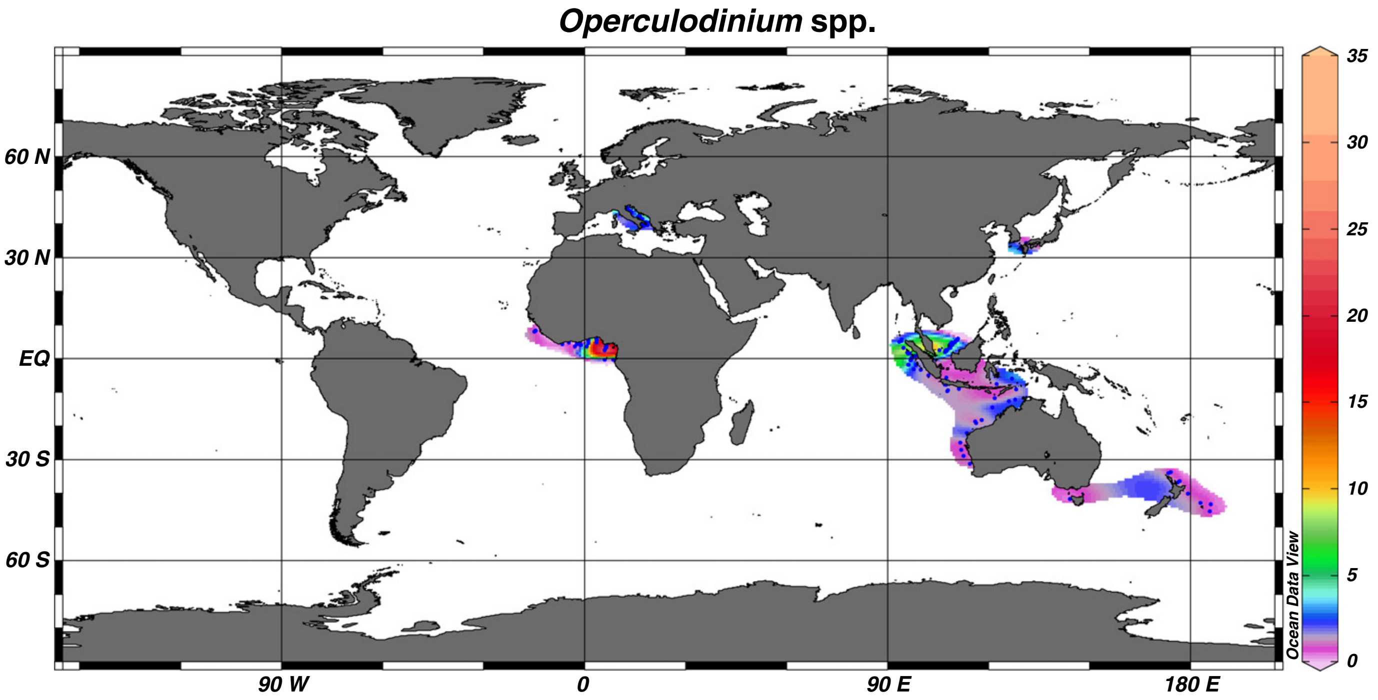

Fig. 289. Geographic distribution of *Operculodinium* spp.

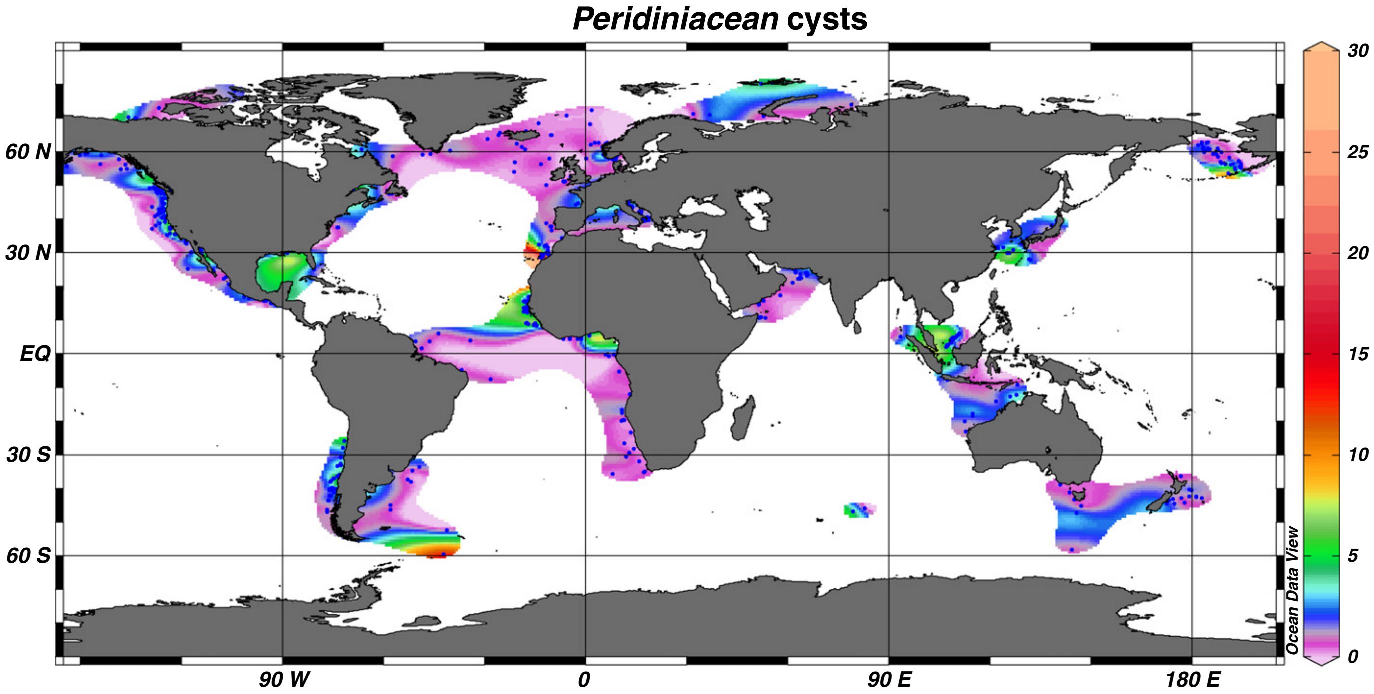

Fig. 290. Geographic distribution of *Protoperidinium* spp.

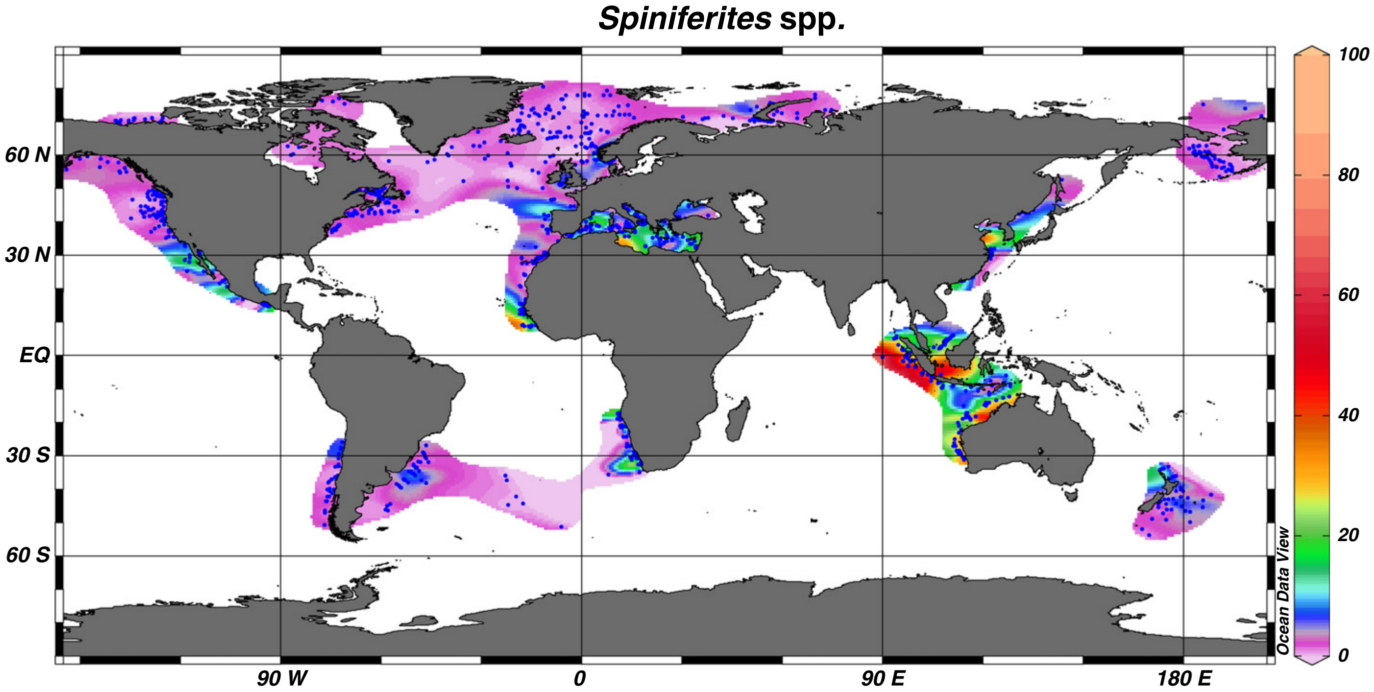

Fig. 291. Geographic distribution of *Spiniferites* spp.

These species have a geographic distribution that is restricted to the higher latitudes and can be divided into three sub-groups:

T1.1. Arctic species: *Echinidinium karaense*, *Islandinium minutum* var. *cezare*, *Operculodinium centrocarpum var. arctica*, *Spiniferites elongatus*, *Polykrikos* spp. var. *arctica*

T1.2. Antarctic species: *Cryodinium meridianum*, *Selenopemphix antarctica*

T1.3 Bipolar species: *Impagidinium pallidum*, *Impagidinium sphaericum*, *Islandinium minutum*, *Pentapharsodinium dalei*.

(T-2) Moderate warm-water species: ordinated in the centre of the temperature axis of the CCA (-1.0<SST sd <0.7).

Several species have a restricted geographical distribution with maximal cyst concentrations between 30°–60° N and/or 30°–60° S.

T2.1 Restricted Northern Hemisphere distribution: *Caspidinium rugosum*, *Impagidinium caspienense*, *Peridinium ponticum*, *Spiniferites cruciformis*, *Spiniferites lazus* (Note with exception of *Spiniferites lazus* these species are endemic for the easternmost part of the Mediterranean Sea, the Black Sea, the Marmara Sea and/or the Caspian Sea (Marret et al., 2004).

T2.2 Restricted Southern Hemisphere distribution: *Impagidinium variaseptum*

T2.3 Restricted bi-hemispheric distribution: *Ataxiodinium choane*, *Bitectatodinium tepikiense*, *Dalella chathamensis*, *Votadinium spinosum*.

T2.4 Bi-hemispheric distribution and present in higher relative abundances in the vicinity of active upwelling cells: *Dubridinium caperatum*, *Lejeunecysta oliva*, cysts of *Protoperidinium americanum*, *Quinquecuspis concreta*.

(T-3) Warm-water species: ordinated at the most positive side of the temperature gradients (SST sd >0.7).

These species appear to have a distribution restricted to sub-tropical to equatorial regions:

Bitectatodinium spongium, *Echinidinium aculeatum*, *Echinidinium bispiniformum*, *Echinidinium transparantum*, *Operculodinium israelianum*, *Operculodinium janduchenei*, *Operculodinium longispinigerum*, cysts of *Protoperidinium monospinum*, *Polysphaeridium zoharyi*, *Stelladinium robustum*, *Stelladinium stellatum*, *Tectatodinium pellitum*, *Tuberculodinium vancampoae*.

(T-4) Species with no clear relationship with the temperature gradients.

All other species

4.2. Salinity

Salinity is known to be an important factor influencing cell growth and initiating and steering encystment and germination (e.g. Anderson et al., 1983; Anderson et al., 2005; Leong et al., 2006; Bravo et al., 2010a). Furthermore it can effect the stratification/ turbulence of the upper water column, which influences cell growth, cell dispersion, cyst formation, encystment and excystment of certain species (e.g. Ribeiro and Amorim, 2008; Figueroa et al., 2011 and references therein). Despite the fact that many studies document a relationship between salinity and species distribution/cyst production, information about the underlying mechanisms is relatively scarce. It is clear, however, that the effects of salinity, and related stratification and turbulence, are highly complex and species specific. For some species, such as *Heterocapsa circularisquama* a change in salinity can quickly influence its metabolism resulting in rapid adaptation of cell growth (with increasing growth rates upon a change in salinity (Leong et al., 2006). For other species such as *Alexandrium minutum* high salinities stimulate cell growth whereas low salinities stimulate planozygote formation (Figueroa et al., 2011). For *Pfiesteria piscicida* low salinities (psu 1-15) enhance encystment whereas higher salinities (>psu 15) enhance cyst germination (Saito et al., 2007).

With respect to the relationship between cyst distribution and salinity in upper waters in our dataset, four groups of species can be observed:

(S-1) Species with highest relative abundances in low salinity environments ordinated at the negative side of the salinity gradient (sd< −2).

Based on their geographical distribution these species can be divided into two groups:

S1.1 Species restricted to or with high relative abundances in regions that are influenced by meltwater:

Echinidinium karaense, *Impagidinium pallidum*, *Islandinium minutum*, *Islandinium minutum* var. *cezare*, *Spiniferites elongatus*, *Operculodinium centrocarpum* var. *arctica*, cysts of *Polykrikos* sp. var. *arctica*.

S1.2 Species restricted to or with their highest relative abundances in the Caspian Sea, Aral Sea and Black Sea where salinities are reduced by river inflow:

Peridinium ponticum, *Spiniferites cruciformis*, *Caspidinium rugosum*, *Impagidinium caspienense*.

(S-2) Species ordinated at the most positive side of the salinity gradient (sd>1.2).

Echinidinium bispiniformum, *Echinidinium transparantum*, cysts of *Gymnodinium catenatum*, cysts of *Gymnodinium nolleri/microreticulatum*, *Impagidinium aculeatum*. *Impagidinium paradoxum*, *Impagidinium patulum*, *Impagidinium plicatum*, *Impagidinium strialatum*, *Impagidinium variaseptum*, *Impagidinium velorum*, *Lejeunecysta sabrina*, *Operculodinium israelianum*, *Stelladinium robustum*, *Spiniferites bentorii*, *Spiniferites lazus*, *Spiniferites mirabilis*, *Spiniferites pachydermus*, *Tectatodinium pellitum*,

(S-3) Species ordinated in the central part of the salinity gradient (-2<SD<1.2).

All the other species

Visual examination of the distribution patterns shows that there are several species that are characteristically abundant in river plumes or estuaries. Only a minority of these species shows a negative relationship between cyst distribution and salinity in the statistical analysis. The reason for this is that in the majority of the studied estuaries and river systems, the local salinity varies strongly during the year with low salinities when outflow is maximal and fully marine conditions when outflow is minimal. Since the time in the year of maximal outflow is system dependent, it is not synchronous between regions and therefore not reflected in our world-covering environmental seasonal gradients. Consequently it is not reflected by the statistical outcome.

Based on visual examination of the dataset, the following species are characteristically present in, but not always restricted to,

Table 2
Amount of variance within the dataset explained by the analysed environmental variables.

Environmental variable	% variance covered	P	F	% variance covered after correction co-variance
SST annual	43	0.01	103	43
SST spring	40	0.01	15.58	6
SST summer	41	0.01	12.09	4
SST autumn	41	0.01	14.25	5
SST winter	38	0.01	21.43	9
SSS annual	33	0.01	60.44	24
SSS spring	16	0.01	6.22	2
SSS summer	19	0.01	16.63	7
SSS autumn	17	0.01	13.68	5
SSS winter	16	0.01	20.17	7
NO_3	34	0.01	82.73	32
PO_4	25	0.01	18.8	7
Bottom water oxygen	24	0.01	17.2	6
Chlorophyll-*a*	15	0.01	37.37	14

Table 3
Ordinated species position (sd) on the environmental gradients.

Species	Annual SST	Annual SSS	NO$_3$	PO$_4$	Bottom water oxygen	Chlorophyll-*a*
Ataxodinium choane	−0.64	−0.29	0.19	1.82	−1.55	4.17
Cysts of *Alexandrium tamarense*	0.51	−0.77	0.01	−1.24	−1.02	−0.49
Bitectatodinium spongium	2.93	0.8	0.12	−0.95	−3.47	−0.59
Brigantedinium spp.	−0.11	−0.2	0.07	0.58	−0.44	0.37
Bitectatodinium tepikiense	−0.53	0.12	0.17	−0.93	1.29	−0.81
Cryodinium meridianum	−2.09	0.39	−4.16	5.05	3.03	0.08
Caspidinium rugosum	0.53	−14.1	0.14	−1.87	0.46	−1.12
Dubridinium caperatum	0.35	−0.14	0.27	1.1	0.33	−1.33
Dalella chathamensis	−0.49	0.75	0.07	1.66	−1.99	1.33
Echinidinium aculeatum	1.72	0.57	0.1	0.39	−3.08	1.02
Echinidinium bispiniformum	2.88	1.74	0.13	0.15	−2.54	−0.36
Echinidinium delicatum	1.06	0.54	0.06	1.14	−2.19	0.1
Echinidnium granulatum	1.24	0.53	0.13	1.12	−2.08	−0.31
Echinidinium karaense	−2.89	−3.47	0.19	1.59	2.9	−0.15
Echinidinium spp.	1.79	0.66	0	−0.77	−1.7	0.64
Echinidnium transparantum	1.83	1.33	0.06	−0.65	−1.93	1.41
Cysts of *Gymnodinium catenatum*	1.28	1.63	−0.32	−1.81	0.13	−0.88
Cysts of *Gymnodinium nolleri/microreticulatum*	0.95	1.69	−0.28	−1.46	−0.64	0.35
Impagidinium aculeatum	1.31	1.95	0.13	−1.39	−0.3	−1.41
Impagidinium caspienense	0.48	−14.23	−3.96	−1.87	2.98	0.35
Islandinium minutum var. cezare	−2.88	−4.65	0.22	−0.64	2.27	0.25
Islandinium minutum	−2.67	−2.76	0.23	0.16	2.93	0.53
Impagidinium pallidum	−2.37	−0.29	0.28	1.25	2.23	−0.94
Impagidinium paradoxum	1.33	1.43	0.16	−1.28	−0.36	−1.35
Impagidinium patulum	1.53	1.65	0.11	−1.53	−0.46	−1.37
Impagidinium plicatum	0.96	2.06	0.13	−1.51	−0.71	−1.42
Impagidinium sphaericum	−1.26	0.28	0.25	0.44	1.58	−1.05
Impagidinium spp.	1.62	1.07	0.15	−1.37	−0.29	−1.37
Impagidinium strialatum	1.28	1.44	0.13	−1.33	−0.71	−1.19
Impagidinium variaseptum	0.68	1.23	0.21	−1.52	0.35	−1.45
Impagidinium velorum	1.06	2.15	0.16	−1.5	−0.6	−1.44
Lingulodinium machaerophorum	1.48	1	−0.53	−1.85	−0.8	−0.08
Lejeunecysta oliva	0.64	0.45	0.04	−0.29	−0.72	−1.17
Lejeunecysta sabrina	1.4	1.58	0.08	−1.69	−3.27	5.03
Nematosphaeropsis labyrinthus	−0.39	0.62	0.2	0.85	0.79	−0.73
Operculodinium centrocarpum var. arctica	−2.34	−2.74	0.17	1.21	1.76	−0.3
Operculodinium centrocarpum	−0.51	0.08	0.16	0.33	0.46	−0.4
Operculodinium israelianum	1.81	2.16	0.11	−1.76	−0.69	−0.9
Operculodinium janduchenei	2.26	0.69	0.17	−1.33	0.7	−0.26
Operculodinium longispinigerum	3.26	−0.09	0.14	−1.87	−1.76	−1.47
Operculodinium spp.	2.74	0.28	0.06	−1.87	−1	−1.06
Cysts of *Protoperidinium americanum*	−0.03	−0.06	0.12	1.48	−1	0.58
Cysts of *Polykrikos* spp. var. *arctica*	−2.97	−4.21	0.21	0.18	2.75	0.13
Cysts of *Pentapharsodinium dalei*	−1.72	−1	0.03	1.06	1.66	−0.07
Peridiniaceae cysts	0.63	−0.08	0.07	0.7	−1.91	2.3
Cysts of *Polykrikos kofoidii*	1.35	0.4	0.08	−0.16	−1.67	1.67
Cysts of *Protoperidinium monospinum*	2.4	1.16	−0.16	−1.84	−1.94	0.84
Peridinium ponticum	0.36	−8.58	−0.43	−1.87	−3.45	0.03
Pyxidinopsis psilata	1.61	−3.78	−1.24	−1.87	−1.12	1.55
Pyxidinopsis reticulata	−0.37	−0.18	0.17	−0.5	0.27	−0.9
Cysts of *Polykrikos schwartzii*	1.05	0.94	0.04	−1.39	−0.84	−0.21
Polysphaeridium zoharyi	2.57	0.5	0	−1.85	−1.33	4.42
Quinquecuspis concreta	0.01	−0.64	0.12	1.45	−2.8	5.24
Selenopemphix antarctica	−2.67	0.4	0.64	6.04	0.54	−1.26
Spiniferites bentorii	1.67	1.41	0.08	−1.84	−0.49	−0.4
Spiniferites cruciformis	0.76	−13.22	0.12	−1.87	−1.48	−0.96
Spiniferites delicatus	2.74	0.66	−4.47	−1.73	2.85	0.36
Spiniferites elongatum	−1.73	−0.67	0.17	0.32	1.68	−0.46
Spiniferites lazus	0.43	1.25	0.08	−1.87	0.7	−1.2
Spiniferites membranaceus	1.76	0.61	0.09	−1.81	−0.55	−1.15
Spiniferites mirabilis	1.4	1.29	0.11	−1.68	−0.37	−1.11
Selenopemphix nephroides	1.43	0.62	0.08	−0.44	−1.67	0.5
Spiniferites pachdermus	1.65	1.64	0.1	−0.61	−1.09	−0.41
Selenppemphix quanta	0.35	0.37	0.13	−0.23	−0.47	−0.36
Spiniferites ramosus	1.12	0.44	0.12	−0.82	−2.21	−0.76
Stelladinium robustum	2.99	1.5	0.11	−0.79	−1.16	−0.48
Spiniferites spp	1.61	0.7	−0.15	−1.32	−0.88	−0.71
Stelladinium stellatum	1.78	1.21	0.09	−1.73	−0.78	1.59
Trinovantedinium applanatum	1.2	0.74	0.09	−0.83	−0.4	−0.36
Tectatodinium pellitum	2.51	1.56	0.04	−1.87	−1.94	1.35
Tuberculodinium vancampoae	1.98	0.42	0.08	−1.84	−1.47	0.01
Votadinium calvum	1.01	−0.09	0.11	−1.35	−1.25	1.75
Votadinium spinosum	0.45	0	0.08	−0.41	−0.68	1.63
Xandarodinium xanthum	1.63	0.02	0.06	−1.83	−1.29	0.93

river plume areas or estuaries: *Caspidinium rugosum*, *Echinidinium karaense Echinidinium transparantum*, *Impagidinium caspienense*, *Islandinium minutum*, *Islandinium minutum* var. *cezare*, *Lingulodinium machaerophorum*, *Quinquecuspis concreta*, *Operculodinium centrocarpum* var. *arctica*, *Operculodinium janduchenei*, cysts of *Polykrikos* sp. var. *arctica*, cysts of *Polykrikos schwartzii*, *Peridinium ponticum*, *Selenopemphix quanta*, *Spiniferites cruciformis*, *Spiniferites ramosus*.

Several species are randomly ordinated along the salinity gradient but have their highest relative abundances in both low and high salinity regions. These potentially euryhaline species are:

Cysts of *Pentapharsodinium dalei*, *Pyxidinopsis psilata*, *Stelladinium stellatum*, *Votadinium calvum*, *Xandarodinium xanthum*

4.3. Nitrate and phosphate

Nitrate and phosphate form the second and fourth most important environmental gradients in our dataset, respectively. Like temperature and salinity, nitrate and phosphate concentrations in upper water have different effects on cell growth, planozygote formation, encystment and germination, all influencing the final cyst content in the sediment (e.g. Morquecho and Lechuga-Devéze, 2004; Figueroa et al., 2007; Kremp et al., 2009; Pena-Manjarrez et al., 2009; Domingues et al., 2011 and references therein). In turn the growth and demise of dinoflagellate blooms might also influence the nitrate/phosphate concentrations in a region (e.g. Collos et al., 2011). The exact nature of these effects is not well known. Although many laboratory studies use reduced ambient nutrient conditions to promote cyst formation suggesting that nutrient stress might form one of the most important triggers for sexuality and encystment, other studies show no or opposite effects (e.g. von Stosch, 1973; Anderson et al., 1984, 1985; Kremp et al., 2009 and references therein). Recently Kremp et al. (2009) showed that an unbalanced change in nitrate and phosphate concentrations as well as a balanced decrease in concentrations of both nutrients might stimulate sexual reproduction and cyst formation of several species (e.g. Turpin et al., 1978; Olli and Anderson, 2002; Figueroa and Bravo, 2005). Several field studies document maximal cyst production during or just after maximal population growth when nutrients in the water column are not limited (Ishikawa and Taniguchi, 1996; Kremp and Heiskanen, 1999; Godhe et al., 2001; Sgrosso et al., 2001). Several sediment trap studies show that the seasonal cyst production is strongly species specific with different species reacting differently on changing nutrient concentrations (e.g. Pospelova et al., 2010; Zonneveld et al., 2010; Price and Pospelova, 2011).

Based on Canonical Correspondance Analysis we can group the species according to their relationship to nitrate and phosphate concentrations:

4.3.1. Nitrate

(N-1) Low-nitrate species.

Species that have their highest relative abundances in regions with low nitrate concentrations in surface waters; hence ordinated at the most negative side of the nitrate gradient (species $sd < -1.0$)

Caspidinium rugosum, *Impagidinium caspienense*, *Pyxidinopsis psilata*, *Spiniferites elongatus*.

(N-2) Moderate-low-nitrate species.

Species that have their highest relative abundances in regions with moderately low nitrate concentrations in surface waters; hence ordinated at the negative side of the nitrate axis ($-1.0 < sd < 0.18$)

Echinidinium transparantum, *Gymnodinium catenatum*, *Gymnodinium nolleri*/*microreticulatum*, *Lingulodinium machaerophorum*, *Peridinium ponticum*, cysts of *Protoperidinium monospinum*, *Stelladinium stellatum*.

(N-3) High-nitrate species.

Species that have their highest relative abundances in regions with hight upper water nitrate concentrations; hence ordinated at the most positive side of the nitrate axis ($sd > 0.18$)

Cysts of *Alexandrium tamarense*, *Dalella chathamensis*, *Echinidinium karaense*, *Impagidinium pallidum*, *Impagidinium sphaericum*, *Impagidinium variaseptum*, *Islandinium minutum*, *Islandinium minutum* var. *cezare*, *Nematosphaeropsis labyrinthus*, cysts of *Polykrikos* spp. var. *arctica*, *Selenopemphix antarctica*.

(N-4) Species which distribution shows no relationship with the nitrate gradient or have their highest relative abundances in regions where intermediate nitrate concentrations prevail in upper waters.

All the other species.

4.3.2. Phosphate

(P-1) Low-phosphate species.

Species that have their highest relative abundances in regions with low phosphate concentrations in surface waters; hence ordinated at the most negative side of the nitrate gradient (species $sd < -1.85$)

Caspidinium rugosum, *Impagidinium caspienensis*, *Lingulodinium machaerophorum*, *Operculodinium longispinigerum*, *Peridinium ponticum*, *Polysphaeridium zoharyi*, *Pyxidinopsis psilata*, *Spiniferites cruciformis*, *Spiniferites lazus*, *Tectatodinium pellitum*.

(P-2) High-phosphate species.

Species that have their highest relative abundances in regions with high phosphate concentrations in surface waters; hence are ordinated at the most positive side of the phosphate gradient (species $sd > 1$).

Cysts of *Alexandrium tamarense*, *Cryodinium meridianum*, *Dalella chathamensis*, *Dubridinium caperatum*, *Echinidinium granulatum*, *Echinidinium delicatum*, *Echinidinium karaense*, *Impagidinium pallidum*, *Operculodinium centrocarpum* var. *arctica*, cysts of *Pentapharsodinium dalei*/*Ensiculifera imariense*, cysts of *Protoperidinium americanum*, *Quinquecuspis concreta*.

(P-3) Species that show no relationship with the phosphate gradient or that have their highest relative abundances in regions where intermediate nitrate concentrations prevail in upper waters ($-1.85 < sd < 1$)

All the other species.

4.4. Bottom water oxygen

Oxygen in the bottom and pore waters of the upper sediments can affect the cyst recovery. It can influence the dormancy stage, the germination process or the preservation of cysts in sediments. Anaerobic conditions can inhibit cyst germination although the ability to germinate may remain, even after long periods in anoxic conditions (e.g. Anderson et al., 1987; Rengefors et al., 1996; Kremp and Anderson, 2000; McQuoid et al., 2002; Lundholm et al., 2011). Recently, Smayda and Trainer (2010) state that resting cysts of *Lingulodinium machaerophorum* require anoxic pre-conditioning for excystment. Lundholm et al. (2011) show for the same species that germination is suppressed when cysts are exposed to oxygen. However, *Pentapharsodinium dalei* and *Scrippsiella trochoidea* showed no reaction on oxygenation, indicating that the effect of oxygen is species specific.

During the last decades it became obvious that some cyst species can degrade post-depositionally in aerobic environments (e.g. Dale, 1976; Persson, 2000; Hopkins and McCarthy, 2002; Zonneveld et al., 2008; Mertens et al., 2011b and references therein). So far, no indication has been found of severe species-specific degradation of cysts in anaerobic settings and during the settling process. Therefore, it is assumed that diagenesis takes place notably at the sediment water interface and in the upper part of the sediments (Zonneveld et al., 2010). There are strong indications that the species-specific preservation might be related to the cyst wall chemistry (de Leeuw et al., 2006; Versteegh et al., 2012 and references therein).

Based on the relationship between cyst distribution and bottom-water oxygen concentration we can distinguish six groups of species.

(O-1) Restricted low-bottom water oxygen concentration species.

Species that are ordinated at the negative side of the oxygen gradient (ox sd<-2.0) and which distribution is restricted to regions where anaerobic to hypoxic conditions prevail:

Bitectatodinium spongium, Dubridinium caperatum, Echinidinium aculeatum, Echinidinium bispiniformum.

(O-2) Low bottom-water oxygen concentration species.

Species that have highest relative abundances in anoxic/hypoxic settings and are ordinated at the negative side of the oxygen gradient ($-2<$ox sd<-1).

Although the DCA analysis attributes to some of these species an sd<-2 examination of the dataset shows that these species can not be listed under O-1 since they are not restricted to anaerobic to hypoxic conditions but also occur in environments with higher oxygen levels.

Echinidinium delicatum, *Echinidinium granulatum*, *Echinidinium transparantum*, *Lejeunecysta oliva*, *Operculodinium longispinigerum*, *Peridinium ponticum*, cysts of *Polykrikos kofoidii*, *Polysphaeridinium zoharyi*, cysts of *Protoperidinium monospinum*, cysts of *Protoperidinium americanum*, *Pyxidinopsis psilata*, *Quinquecuspis concreta*, *Seleopemphix nephroides*, *Spiniferites delicatus*, *Stelladinium robustum*, *Tectatodinium pellitum*, *Tuberculodinium vancampoae*, *Votadinium calvum*,

(O-3) Moderate low bottom-water oxygen concentration species.

Species that have their highest relative abundances in low oxygen concentration settings (ox sd<-1) but are not observed in sites where anoxic conditions prevail and thus can not be included in O1 or O2:

Ataxodinium coane, cysts of *Alexandrium tamarense*, *Spiniferites pachydermus*, *Xandarodinium xanthum*.

(O-4) Anoxic/hypoxic avoiding, aerobic setting species.

Species with a distribution restricted to regions where bottom-waters are well ventilated and are ordinated at the positive side of the oxygen gradient (ox sd>0):

Bitectatodinium tepikiense, *Cryodinium meridianum*, *Caspidinium rugosum*, *Dalella chathamensis*, *Echinidinium karaense*, cysts of *Gymnodinium catenatum*, *Impagidinium caspienense*, *Impagidinium pallidum*, *Impagidinium sphaericum*, *Impagidinium variaseptum*, *Islandinium minutum*, *Islandinium minutum* var. *cezare*, *Nematosphaeropsis labyrinthus*, *Operculodinium centrocarpum*, *Operculodinium centrocarum* var. *arctica*, cysts of *Pentapharsodinium dalei/Ensiculifera imariense*, cysts of *Polykrikos* sp. var. *arctica*, *Pyxidinopsis reticulata*, *Selenopemphix antarctica*, *Spiniferites cruciformis*, *Spiniferites elongatus*, *Spiniferites lazus*.

Note: the Antarctic species *Cryodinium meridianum* and *Selenopemphix antarctica* have recently been observed in anoxic Antarctic Basins (Sangiorgi personal communication, 2012).

(O-5) Species not found in anoxic settings.

Species which are ordinated in the central part of the oxygen gradient that are not observed in anoxic settings:

Cysts of *Gymnodinium nolleri/microreticulatum*, *Impagidinium aculeatum* *Impagidinium paradoxum*, *Impagidinium patulum*, *Impagidinium plicatum*, *Impagidinium strialatum*, *Operculodinium janduchenei*, cysts of *Polykrikos schwartzii*.

(O-6) Species which distribution shows no relationship with bottom-water oxygen gradients.

All the other species.

4.5. Chlorophyll-a concentration

Within this Atlas we compare the global cyst distribution with upper water chlorophyll-*a* concentrations as a value reflecting upper water net primary production (Campbell et al., 2002), although this method has constrains and it is assumed that about 30% of the daily water-column photosynthesis is missed by satellite based estimates (Behrenfeld et al., 2005; Mouw and Yoder, 2005). A direct relationship between net primary production and cell growth, gamete formation and encystment can be expected to be present for heterotrophic species. For phototrophic species this relationship is more complex as they form part of the chlorophyll-*a* registered by the satellites. Also for this group of species a direct link might be present as many photosynthetic dinoflagellates are auxotroph and/or mixotroph (e.g. Schnepf and Elbrächter, 1992; Tang et al., 2010). A secondary relationship in the form of co-variance is expected to occur as well between cyst production and total primary production as many factors that are of advantageous for dinoflagellate growth, positively influence total bioproduction.

Within this Atlas we do not obtain information about the cyst production of individual species as we only study relative abundances. During the last decade several studies have shown that in oligotrophic to mesotrophic environments cyst production increases for generally all species (photosynthetic and non photosynthetic) with increasing upper water net primary production (Montresor et al., 1998; Elshanawany et al., 2009; Zonneveld et al., 2009, 2010; Pospelova et al., 2010; Price and Pospelova, 2011 and references therein). The increase in cyst production is however different for individual species. When chlorophyll-*a* concentrations increase the non-phototrophic species generally increase more than the phototrophic species so that the latter decrease in relative abundance.

Here we observed three groups of species based on the relationship between relative abundance data:

(Ch-1) Species with highest relative abundance in, but not restricted to, regions with low upper water chlorophyll-*a* concentrations exist. These species are ordinated at the negative side of the chlorophyll-*a* gradient (chlor sd<1):

Dalella chathamensis, *Impagidinium aculeatum*, *Impagidinium paradoxum*, *Impagidinium patulum*, *Impagidinium plicatum*, *Impagidinium sphaericum*, *Impagidinium strialatum*, *Impagidinium variaseptum*, *Impagidinium velorum*, *Lejeunecysta sabrina*, *Operculodinium israelianum*, *Operculodinium longispinigerum*, *Selenopemphix antarctica*, *Spiniferites lazus*, *Spiniferites membranaceus*, *Cryodinium meridianum*, *Spiniferites mirabilis*.

(Ch-2) Species with highest relative abundances in, but not restricted to, regions where high upper water chlorophyll-*a* concentrations exist and hence are ordinated at the negative side of the chlorophyll-*a* gradient (chlor sd>1)

Cysts of *Alexandrium tamarense*, *Dubridinium caperatum*, *Echinidinium aculeatum*, *Lejeunecysta oliva*, cysts of *Polykrikos kofoidii*, *Polysphaeridium zoharyi*, *Pyxidinopsis psilata*, *Quinquecuspis concreta*, *Selenopemphix quanta*, *Votadinium calvum*, *Votadinium spinosum*, *Tectatodinium pellitum*.

(CH-3) Species which are ordinated in the central part of the chlorophyll-*a* gradient $-1<$sd.<1

All other species.

4.6. Cosmopolitan and endemic species

Within our dataset we can observed several species which have a world-wide distribution and do not show any clear relationship with environmental gradients in the upper water column. These species that can be considered as cosmopolitan are:

Brigantedinium spp., *Echinidinium* spp., *Impagidinium aculeatum*, *Impagidinium paradoxum*, *Impagidinium sphaericum*, *Impagidinium* spp., *Nematosphaeropsis labyrinthus*, *Operculodinium centrocarpum*, *Pyxidinopsis reticulata*, *Spiniferites ramosus*, *Trinoventedinium applanatum*.

Several species have a restricted endemic distribution:

Antarctic Ocean	*Cryodinium meridianum*, *Selenopemphix antarctica*
Caspian Sea	*Caspidinium rugosum*
Caspian Sea and Aral Sea	*Impagidinium caspienense*

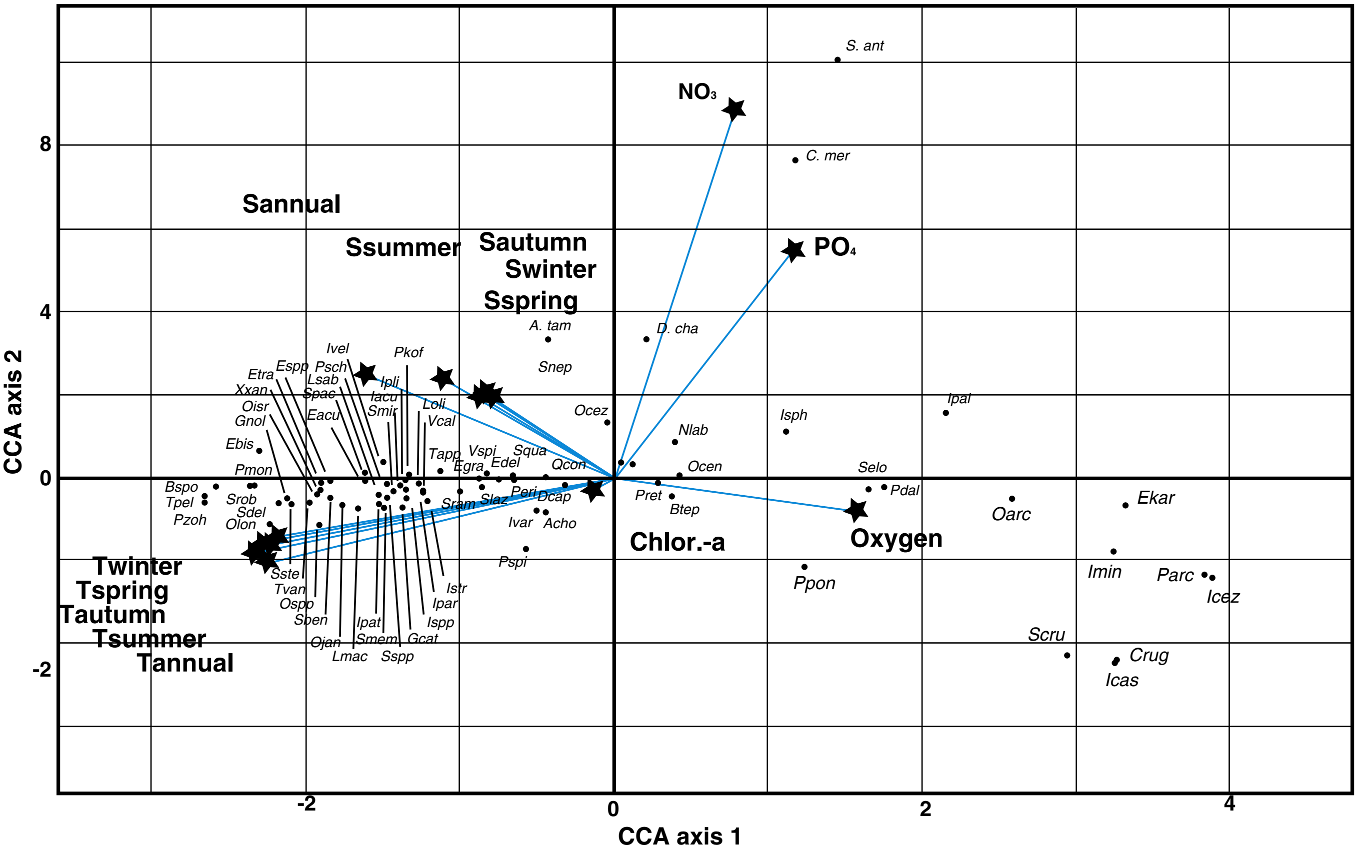

Fig. 292. Canonical Correspondence Analysis diagram of species and environmental variables. Atam = Cysts of cf. *Alexandrium tamarense*, Acho = *Ataxiodinium choane*, Bspo = *Bitectatodinium spongium*, Btep = *Bitectatodinium tepikiense*, Bspp = *Brigantedinium* spp., Crug = *Caspidinium rugosum*, Cmer = *Cryodinium meridianum*, Dcha = *Dalella chathamensis*, Dcap = *Dubridinium caperatum*, Eacu = *Echinidinium aculeatum*, Ebis = *Echinidinium bispiniformum*, Edel = *Echinidinium delicatum*, Egra = *Echinidinium granulatum*, Ekar = *Echinidnium karaense*, Espp. = *Echinidinium* spp., Gcat = cysts of *Gymnodinium catenatum*, Gnol = cysts of *Gymnodinium nolleri/microreticulatum*, Iacu = *Impagidinium aculeatum*, Icas = *Impagidinium caspienense*, Ipal = *Impagidinium pallidum*, Ipar = *Impagidinium paradoxum*, Ipat = *Impagidinium patulum*, Ipli = *Impagidinium plicatum*, Isph = *Impagidinium sphaericum*, Ispp. = *Impagidnium* spp., Istr = *Impagidinium strialatum*, Ivar = *Impagidinium variaseptum*, Ivel = *Impagidinium velorum*, Imin = *Islandinium minutum*, Imic = *Islandinium? cezare*, Loli = *Lejeunecysta oliva*, Lsab = *Lejeunecysta sabrina*, Lmac = *Lingulodinium machaerophorum*, Nlab = *Nematosphaeropsis labyrinthus*, Oarc = *Operculodinium centrocarpum* var. *arctica*, Ocen = *Operculodinium centrocarpum*, Oisr = *Operculodinium israelianum*, Ojan = *Operculodinium janduchenei*, Olon = *Operculodinium longispinigerum*, Ospp = *Operculodinium* spp., Pdal = cysts of *Pentapharsodinium dalei*, Ppon = *Peridinium ponticum*, Parc = cysts of *Polykrikos* var. *arctica*, Pkof = cysts of *Polykrikos kofoidii*, Psch = cysts of *Polykrikos schwartzii*, Pzoh = *Polysphaeridium zoharyi*, Peri = *Protoperidiniacean* cysts, Pame = cysts of *Protoperidinium americanum*, Pmon = cysts of *Protoperidinium monospinum*, Ppsi = *Pyxidinopsis psilata*, Pret = *Pyxidinopsis reticulata*, Qcon = *Quincuecuspis concreta*, Sant = *Selenopemphix antarctica*, Snep = *Selenopemphix nephroides*, Squa = *Selenopemphix quanta*, Sben = *Spiniferites bentorii*, Scru = *Spiniferites cruciformis*, Sdel = *Spiniferites delicatus*, Selo = *Spiniferites elongatus*, Slaz = *Spiniferites lazus*, Smem = *Spiniferites membranaceus*, Smir = *Spiniferites mirabilis*, Sram = *Spiniferites ramosus*, Spac = *Spiniferites pachydermus*, Sspp = *Spiniferites* spp., Sste = *Stelladinium stellatum*, Srob = *Stelladinium robustum*, Tpel = *Tectatodinium pellitum*, Tapp = *Trinovantedinium applanatum*, Tvan = *Tuberculodinium vancampoae*, Vcal = *Votadinium calvum*, Vspi = *Votadinium spinosum*, X.xan = *Xandarodinium xanthum*.

Black Sea and Marmara Sea *Peridinium ponticum*
Black Sea, Casian Sea and Aral Sea *Spiniferites cruciformis*
Arabian Sea *Echinidinium bispiniformum*, *Stelladinium robustum*

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