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Fauna of tintinnids (Tintinnida, Ciliata) during an Arctic-Antarctic cruise, with the S/V "Croatian Tern"

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Abstract

An investigation of large tintinnids was carried out during the Arctic-Antarctic cruise aboard the S/V "Croatian Tern" in the period from 1994 to 1997. Samples were collected at 33 stations by vertical tows with a Nansen net with a 53 µm mesh size in the Mediterranean Sea, North Atlantic, Labrador Sea, Baffin Bay, the Beaufort, Chukchi and Bering Seas, East North Pacific, South Pacific, South East Pacific, Scotia Sea, and South West Atlantic. A total of 47 species of tintinnids were found, with the greatest diversity in the Tropical areas of the Pacific, Arctic and Subarctic. A very high total abundance was registered in the Bering Sea of 247,393 ind.m^{-3} and in the South-eastern Pacific of 66,211 ind.m^{-3}. The dominant species in the northern areas was *Ptychocylis obtusa* and in the southern areas *Eutintinnus rugosus*.

Key words: Arctic, Antarctic, Tropical Pacific, zooplankton, tintinnids, distribution

Introduction

Tintinnids are planktonic, free-living ciliates, like copepods with a broad geographic distribution found in all seas and oceanic ecosystems. Tintinnids are characterized by their loricae in which the ciliate cell lives. Traditionally, lorica morphology is used to distinguish species. However, there is often some variability, and many species have been described on the basis of a single or few loricae. Therefore, many described species may be variants of a single species. The largest number of tintinnid species were described based on specimens in samples from great expeditions in the early twentieth century (Brandt 1906, 1907; Laackmann 1910; Jörgensen 1924; Kofoid & Campbell 1929, 1939). The need for a complete revision, which would probably change a great number of species, has been urged for some time (i.e., Laval-Peuto & Brownlee 1986). A global biogeography of tintinnids based on 272 references was summarized first by Pierce & Turner (1993) and recently updated by Dolan & Pierce (2013). Most data concern the coastal areas of the North Atlantic Ocean, the California area of the North Pacific, the Peruvian water of the South Pacific Ocean, and the western part of the South Atlantic Ocean containing the Weddell Sea. Most publications on tintinnids are qualitative, while few papers provide quantitative data, especially in ocean areas, the White Sea (Burkovsky *et al*. 1974), the Chukchi and Bering Seas (Taniguchi 1984; Dolan *et al*. 2014), and the South-western Atlantic Ocean (Thompson *et al*. 1999).

It is necessary to understand the morphology and biometry of lorica in specific ecological zones to correctly identify tintinnid species, especially for rare species, as suggested by Kršinić (2010) for the Adriatic Sea. Recent studies such as Kim *et al*. (2013) have shown that molecular markers provide vital support for the identification of tintinnids, but it is still necessary to use morphological observations. Zooplankton samples were collected during an Arctic—Antarctic cruise from 1994 to 1997 for the purpose of determining the global distribution of tintinnids. In this paper, I present the first qualitative and quantitative data for a large fraction of tintinnids. Because the samples were collected in a relatively short period in both Polar Regions, as well as in warm areas of the Pacific and the Atlantic, the presented results may be useful in estimating the biogeographical distribution abundance and diversity of large (> 50 µm) tintinnids.

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Cruise description

The Croatian offshore sailing club organized an Arctic-Antarctic cruise aboard the S/V "Croatian Tern", a 19.8 m steel ketch built in Croatia. The cruise started from Kraljevica (Northern Adriatic) on the 5th of July 1994. The route of the first leg of the cruise began in the Adriatic Sea crossed the Mediterranean Sea through Gibraltar to the North Atlantic, and continued northward to Newfoundland and alongside Labrador Sea to Cape Forewellon in Greenland. In August 1994, it was estimated that it was not possible to sail across the North West Passage because of the amount of ice, so the boat returned to Newfoundland. The next summer, the expedition reached Baffin Bay and the northernmost point of sailing at 73.2 °N in July 1995. During the summer, the expedition passed through the Beaufort Sea (St.12), the Chukchi Sea (St.13), and the Bering Sea (St.14). The trip continued to the southeastern part of the North Pacific, to the Gulf of California, and then to French Polynesia. Onward, it continued to the coast of Chile and then south to the southernmost point of the Scotia Sea reaching 62.3 °S. Then, the course of "Croatian Tern" was set to Mar del Plata, Rio de Janeiro, archipelago de Fernando de Noronha, the Canary Islands, into and then across the Mediterranean Sea: the expedition ended on Jul 6th 1997. In all, the "Croatian Tern" sailed a total of 35,926 nm.

Materials and methods

Samples were collected at 33 stations by vertical tows in the surface layer (0 - 50 m or 0-15 m), (Table 1, Fig. 1) with a Nansen net of 45 cm in diameter 250 cm in length, which was 53-µm mesh equipped with a R2 Flowmeter, Model 2030, General Oceanics. During sampling, the wind was weak and the sea was calm. The plankton net was deployed with a hand winch using a hauling speed of 0.5 m s^{-1}. The volumes filtered by the net were roughly equal at all stations and averaged about 8 m^3. The samples were preserved in a 2.5 % formaldehyde-seawater solution neutralized by $CaCO_3$. It was important that after each stage of travel, the samples were sent to the laboratory for processing in order to prevent degradation of lorica because the cruise lasted three years (Stoecker *et al.* 1994). Temperature was measured with a digital thermometer Greisinger electronic GHT 175/MO at a depth of 20 - 40 cm.

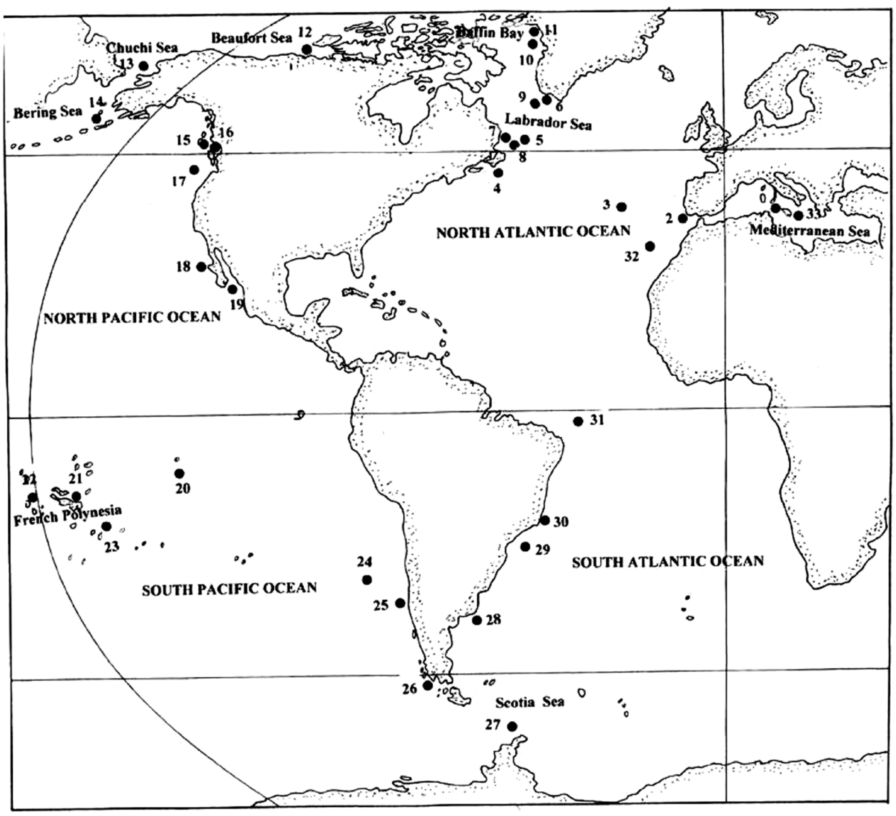

FIGURE 1. Map showing the sampling stations.

Sample aliquots were placed in a glass cell (dimensions 7 x 4.5 x 0.5 cm) and examined using an inverted microscope (Olympus IMT-2) at magnifications of 100x and 400x. Loricae were counted in aliquots of one-sixteenth of each net sample for common species and in the entire sample for rare species. Empty loricae were not taken into account for quantitative analysis. Drawings were made with the aid of a camera lucida on an Olympus BX51 differential interference contrast microscope. Specimens were measured using an ocular micrometer. Photomicrographs were made using Olympus photo equipment. The Shannon-Wiener diversity index (*H'*) was used to compare diversity between stations (Clarke & Gorley, 2001).

Results

Taxonomic consideration

Tintinnids were identified on the basis of lorica morphology using the classical taxonomic references (Brandt 1907; Laackmann 1910; Kofoid & Campbell 1929, 1939) and new taxonomic works (Cosper 1972; Davis 1979, 1981, 1985; Hedin 1974; Sassi & Melo 1986; Gold & Morales 1975; Williams *et al*. 1994; Fernandes 1999; Kršinić 2010).

Most of the 47 species registered during the cruise are well documented and determined in the mentioned taxonomic literature. However, some species are little known, and the identification of some is problematic due to the morphological variability of loricae. Therefore, in this paper, I enclose the original drawings of loricae for 17 species (Figs. 3,4) and the micrographs (Fig. 5) and the morphometric characteristics for target species (Table 3).

In the Bering sea, typical lorica of species *Ptychocylis obtusa* were noted, as shown in Fig. 3E and Fig. 5f. At some stations, a higher variation in lorica morphology and morphometric characteristics was found (Figs. 3 D,E,F; Table 3). The contribution of atypical loricae was small, so we determined that they were the same species.

Determination of species in the genus *Parafavella* is still problematic. Kofoid & Campbell (1929) described many forms and varieties that were designated as new species. According to Davis (1979), seven species are not possible to distinguish based on lorica morphology alone. Loricae variability has been investigated by Burkovsky (1973, 1974), Hedin (1974) and Davis (1979). In this study, I determined four species: *P. gigantea* (Figs. 4A,B), *P. denticulata* (Fig. 4C), *P. elegans* (Fig 4D, Fig. 5c) and *P. acuta* (Fig.4 E,F, Fig 5 d,e). It is important to mention that *P. acuta* (Jörgensen) Kofoid & Campbell 1929 is present as the typical larger form (Figs. 4F, 5d; Table 3), smaller form [?=syn. *P. obtusangula,* (Ostenfeld 1899) and *P. jorgenseni* Hada 1938)] (Figs. 4 E, 5 e, Table 3), and coxlielid (Fig. 4 G).

More than 40 species of the genus *Cymatocylis* were found in the Antarctic area by Kofoid & Campbell (1929), and 8 species with 14 forms were found by Alder (1999). Therefore, numerous investigations have focused on this genus (Balech 1973; Sassi *et al*. 1986; Boltovskoy *et al*. 1990; Williams *et al*. 1994; Culverhouse *et al*. 1994; Wasik 1998; Fernandes 1999). However I was noted only one species, *C. convallaria* Laackmann 1910. (see Fig. 3K, Table 3).

Eight species of the genus *Eutintinnus* were recorded. *E. fraknoi* and *E. elegans* were species with wide distributions. *E. latus* is described from samples collected in the eastern Mediterranean Sea during the "Thor" expedition (Jörgensen 1924). After that, *E. latus* was found in the Atlantic equatorial region (Campbell 1942) and the southern part of the Adriatic Sea (Kršinić 2010, p.176, fig.202). *E. pectinis* was found off the coast of San Diego in the California Current, and later, in the same area, it was registered by Heinbokel (1978), as well as in Chesapeake Bay (Coats & Heinbokel 1982; Dolan & Gallegos 2001); however, it was found only in the South Pacific Ocean during this cruise. The similar species *E. turris* (Fig.3M), which was mentioned by Kofoid & Campbell (1929) in the Bay Nome (Alaska), was found only in the Chukchi and Bering Seas. *E. colligatus* (Fig. 3L) is a species with characteristic aboral constriction, and it was found only in mid stations of the South Pacific; however, it was described by Campbell (1942) in the wider equatorial Pacific region. In the present study, *E. colligatus* was found only in the central station of the South Pacific Ocean. Additionally, two similar loricae, with teeth on the oral margin, were found in separate areas, so they can be considered different species. *E. rectus* (Fig. 3N, Table 3) was found at the station in the Chuchi Sea; however, *E. rugosus* (Fig. 3O, Fig. 5g, Table 3) was present only in subarctic waters with a very high abundance in the South-eastern Pacific. This species has not been recorded or listed as rare in any previous studies in southern areas. Kofoid & Campbell (1939) found only one lorica in the waters of Peru.

Polar distribution is also characteristic of some of the species of the genus *Codonellopsis*. *C. glacialis* (Fig. 3B) was found by the author at the "Gauss" station in the Antarctic, while in this study, they were found in the Chuchki Sea. *C. frigida* (Fig. 3C) was mentioned by Taniguchi (1984) in the Bering and Chukchi Seas, while in the present study, it was only found at the station in the Bering Sea. *C. gaussi* is a typical species of the Antarctic. This species is mentioned by several authors (Balech 1962, 1973; Heinbokel & Coats 1986; Monti & Fonda-Umani 1995; Fernandes 1999; Alder 1999, Thompson *et al*. 1999; Funda-Umani *et al*. 2011; Dolan *et al*. 2013). According to present data, it is distributed at stations west of the Strait of Magellan and in the Scotia Sea.

TABLE 1. General data for sampling stations during cruise of „Croatian Tern“ from 1995 to 1997.

Stations	Areas	Longitude	Latitude	Date	Houl (m)	Wind	Sea	T°C
1	Mediterranean Sea	38.2 N	11.01 E	28.5.1994	50	6	1	21
2	North Atlantic	36.4N	07.43W	11.6.1994	50	4	2	19
3	North Atlantic	37.5N	20.55W	26.6.1994	50	4	1-2	19
4	North Atlantic	45.0N	55W	16.7.1994	50	2	0-1	13
5	Labrador Sea	53.05N	49.10W	29.7.1994	50	5	1-2	13
6	Labrador Sea	60.31N	46.70W	11.8.1994	15	25	1-2	2
7	Labrador Sea	53.05N	56.00W	19.8.1994	15	0	0	5
8	Labrador Sea	52.52N	55.42W	20.8.1994	50	2	0-1	7
9	Labrador Sea	58.3N	49.5W	22.6.1995	50	0	0	5
10	Baffin Bay	73.2N	56.5W	15.7.1995	50	0	0	-1
11	Baffin Bay	75.2N	59.1W	19.7.1995	50	0	0	-1.4
12	Beaufort Sea	70.1N	124.3W	29.8.1995	50	2	1	1
13	Chukchi Sea	67.4N	168.1W	7.9.1995	50	2	1	4
14	Bering Sea	56.3N	167.3W	16.9.1995	50	2	1	8
15	East. North Pacific	51.2N	128.2W	9.10.1995	50	2	1	17
16	East North Pacific	50.3N	126.4W	11.10.1995	50	0	0	17
17	East North Pacific	47.2N	125.0W	4.5.1996	50	5	0-1	13
18	East North Pacific	26.1N	114.1W	4.6.1996	50	7	1-2	19
19	East North Pacific	24.2N	111.6W	8.6.1996	50	0	0	19
20	South Pacific	11.4N	118.5W	28.6.1996	50	8	1	27
21	South Pacific	13.4S	141.3W	24.7.1996	50	4	0	26
22	South Pacific	16.1S	151.1W	7.8.1996	50	7	2	26
23	South Pacific	23.1S	135.0W	19.9.1996	50	5	2	24
24	East South Pacific	33.4S	80.4W	17.10.1996	50	5	1	21
25	East South Pacific	37.0S	73.5W	11.11.1996	50	0	0	22
26	East South Pacific	53.2S	70.5W	5.12.1996	50	1	0	14
27	Scotia Sea	62.3S	59.3W	29.12.1996	50	0	0	1.4
28	West South Atlantic	40.4S	57.3W	13.1.1997	50	4	2	19
29	West South Atlantic	25.3S	46.1W	16.2.1997	50	0	0	18
30	West South Atlantic	21.5S	40.3W	27.2.1997	50	10	0	22
31	West South Atlantic	3.4S	32.3W	26.3.1997	50	0	0	25
32	North Atlantic	31.3N	15.5W	2.5.1997	50	5	1	19
33	Mediterranean Sea	37N	15.5E	26.5.1997	50	0	0	19

Qualitative and quantitative distribution of tintinnids

Among all the stations, the greatest number of species (8–15) was found at stations in the Tropical Pacific (St.20-24), (Fig. 2). Notably there were stations where no tintinnids were found in the eastern part of the North Pacific (St.18, 19) and Brazilian waters (St.29, 30), (Table 2). Tintinnid fauna differs significantly between the Arctic and Antarctic regions. Arctic water is characterized by species of the genera *Leprotintinnus, Parafavella, Ptychocylis* and *Acanthostomella*, while the Antarctic area is characterized by the genus *Cymatocylis* and the species *Eutintinnus rugosus* and *Codonellopsis gaussi.* A very high abundance of tintinnids of 247,393 ind.m^{-3} was observed in the Bering Sea (St.14). Additionally, a high abundance of tintinnids of 66,211 ind.m^{-3} was found in the South East Pacific (St.26). At other stations, the abundance varied from 0 to 17,728 ind.m^{-3} in the Chuchi Sea (St. 13), (Fig. 2).

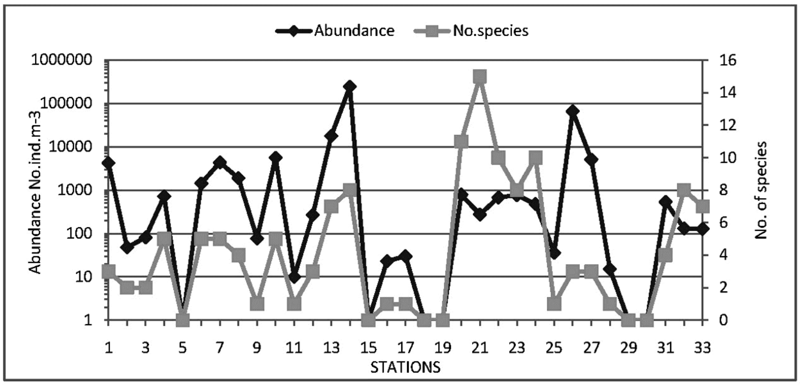

FIGURE 2. Distribution of abundances and number of tintinnid species.

In the Warm-Temperate areas (St.1-4 and 29-33), 13 species or 28% of all the recorded species were found. *Rhabdonella spiralis* with 4,200 ind.m^{-3} was the most abundant species at Station 1 in the Mediterranean Sea. The abundance of other species was low, between 4-660 ind.m^{-3}. The diversity index *H'* was 2 at Station 32 in the Eastern North Atlantic. In the Cool-Temperate area between Stations 15 and 19 only *Parafavella denticulata* at St. 17 and *Ptychocylis obtusa* at St. 16 were noted, with very low abundance (Table 2).

Thirteen species were found in the Arctic and Subarctic (St.5-14). The highest diversity of *H'* = 1.28 was found at Station 13 in the Chuchi Sea in conditions where the surface temperature was 4 °C. The most widespread and dominant species is *Ptychocylis obtusa*, which reached a very high concentration of 206.842 ind.m^{-3} or 84% of the total tintinnid abundances at Station 14 in the Bering Sea which had a surface temperature of 8 °C. The abundance at other stations was low, between 8-1,029 ind.m^{-3}. Four species and one coxlielid of the genus *Parafavella* were recorded in the same area. *P. acuta* was present at Station 14 with an abundance of 23.950 ind.m^{-3} for the smaller form and 11.975 ind.m^{-3} for the typical larger form and approximately 1% coxlielids. The same species was found at Station 6 at an abundance of 537 ind.m^{-3}. A higher abundance was observed for *P. gigantea* at Station 10 of 4,620 ind.m^{-3}, while the species *P. denticulata,* and *P. elegans* were less abundant at Station 6 with 128 ind.m^{-3} or 320 ind.m^{-3} at the Station 10, respectively. Other characteristic species were found in the Arctic and Subarctic: *Tintinnopsis gracilis* (Fig 3G), *T. beroidea*, *Codonellopsis frigida* (Fig. 3C), *Helicostomella subulata*, *Leprotintinnus pellucidus* (Fig. 3A), *Acanthostomella norvegica* (Fig. 3H), *Eutintinnus rectus* and *E. turris*. At Station 13 in Chukchi Sea dominated *T. beroidea*, *H. subulata* and *E. rectus* with abundance of 17,144 ind.m^{-3}.

In the tropical Pacific Ocean (St.20-24) and Atlantic Ocean (St.29-31), 27 species or 59% of the total number of species were registered. Their abundance was low, while the diversity of species was higher in the Pacific Ocean with a maximum *H'*=2.3 at Station 21 in the area of French Polynesia with a surface temperature of 26 °C, which was the maximum value of the cruise. The species *Rhabdonellopsis intermedia* (Fig. 3 I) was present in samples from all 4 stations in the tropical Pacific with an abundance of 276 ind.m^{-3} at Station 20. Additionally, a very interesting species, *Ascampbeliella obscura* (Fig. 3J), was found with an abundance of 532 ind.m^{-3} only at Station 23.

TABLE 2. Distribution of species abundances (No. ind.m^{-3})

Stations	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Tintinnopsis gracilis							78	153					272	3265
Tintinnopsis beroidea													7100	
Codonella aspera	6													
Codonella apicata														
Codonellopsis frigida													6	65
Codonellopsis gaussi														
Codonellopsis glacialis														
Codonellopsis orthoceras														
Helicostomella subulata							3970	568					7065	1088
Leprotintinnus pellucidus										92			199	
Cyttarocylis eucecryphalus														
Petalotricha ampulla														
Epiplocylis acuminata														
Epiplocylis undella														
Acanthostomella norvegica														77
Rhabdonella amor														
Rhabdonella elegans														
Rhabdonella spiralis	4208	38	69	40										
Rhabdonellopsis intermedia														
Parafavella denticulata						116	77			20	10	8		
Parafavella acuta						537								35929
Parafavella elegans						8	23			300				
Parafavella gigantea						12		153		4620		32		
Ptychocylis obtusa				8		760	220	1029	77	600		230		206842
Ascampbeliella obscura														
Cymatocylis convallaria														
Xystonella lohmanni				660										
Xystonella longicauda														
Xystonella treforti														
Undella claparedei														
Undella globosa														
Undella hadai														
Undella hyalina														
Undella sub.acuta														
Dictyocysta elegans														
Dictyocysta lepida														
Amphorides amphora														
Amphorides quad. v. minor														
Steenst. steenstrupii				4										
Eutintinnus colligatus														
Eutintinnus elegans														
Eutintinnus fraknoi	30	10	12	15										
Eutintinnus latus														
Eutintinnus pectinis														
Eutintinnus rectus													2979	104
Eutintinnus rugosus														
Eutintinnus turris													62	28

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TABLE 2. (Continued.)

15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
							6	152	77								6	20
						53											23	
											772	430						
											2439							
						8												
							25	8										
						8												
					15	10	44											8
					76	10	88	4								115	18	
					107	31	236											
					122	16	30	4								399	23	16
					5	6	15		12									77
					276	65	206	26								16	10	
		30																
	23																	
								538										
												4608						
								4										4
																	17	
						8	15											
						8												
					28		14											
									6									16
						6			276							6		
									15									
									10									
					3													
					15	23												
									8									
					18													
						6			15									
					122	10			8	36							17	10
																	17	
								28	14									
											63000	62	15					

In the Subantarctic and Antarctic (St.26-28), only four species were found. At the Scotia Sea at the Station 27, which had a surface temperature of 1.4 ºC, *Cymatocylis convallaria* was the only representative of the genus, with an abundance of 4,608 ind.m^{-3}. However, a very high abundance of the species *Eutintinnus rugosus*, 63,000 ind.m^{-3}, was recorded in the sample from Station 26, which had a surface temperature of 14 °C. At this station, the diversity index was *H'*= 0.22.

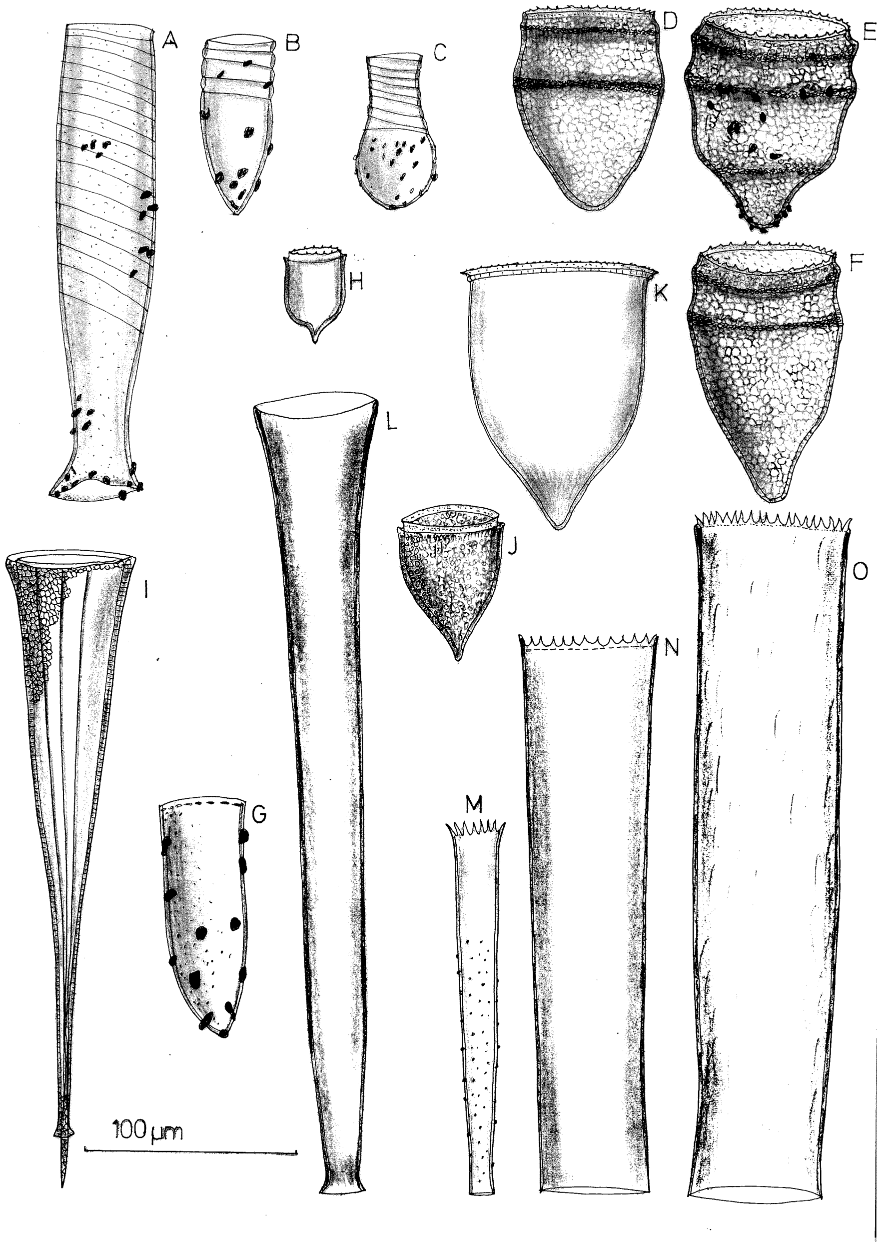

FIGURE 3. Drawings of tintinnid loricae for species: (A) *Leprotintinnus pellucidus*. (B) *Codonellopsis glacialis*. (C) *Codonellopsis frigida*. (D, E, F) *Ptychocylis obtusa*. (G) *Tintinnopsis gracilis*. (H) *Acanthostomella norvegica*. (I) *Rhabdonellopsis intermedia*. (J) *Craterella obscura*. (K) *Cymatocylis convallaria*. (L) *Eutintinnus colligatus*. (M) *Eutintinnus turris*. (N) *Eutintinnus rectus*. (O) *Eutintinnus rugosus*.

TABLE 3. Morphometric characteristics for target species.

			Total length (µm)			Oral diameter outer (µm)		
Species	St.	n	Min.	Max.	Average ± SD	Min.	Max.	Average ± SD
Parafavella gigantea	10	13	350	520	440 ± 41.6	70	75	71.5 ± 2.4
Parafavella denticulata	10	10	210	350	287 ± 49	60	65	61.7 ± 2.3
Parafavella elegans	6	8	150	280	207.5 ± 36.5	60	70	68.0 ± 13.8
	7	6	190	270	216.7 ± 33.3	60	80	70.0 ± 6.3
Parafavella acuta	6	9	140	170	153.0 ± 11.2	50	50	50.0
	14	11	130	220	174.0 ± 31	60	60	60.0
	14	11	95	160	105.4 ± 18.5	40	50	45.0 ± 2.7
Ptychocylis obtusa	6	11	90	140	121.0 ± 13.3	70	70	70
	10	10	80	150	110.9 ± 19.7	60	70	67.2 ± 3.4
	14	10	100	120	107.5 ± 7.2	70	70	70
Craterella obscura	23	6	50	70	60.0 ± 6.3	50	50	50
Cymatocylis convallaria	27	10	110	130	124.0 ± 6.9	80	90	89.0 ± 3.2
Eutintinnus rectus	13	10	210	260	238.0 ± 17.5	50	55	51.5 ± 2.4
Eutintinnus rugosus	26	10	270	350	316.0 ± 23.2	65	70	68.5 ± 2.4

Discussion

In this paper, the results of a cruise that covered the Arctic and Antarctic, Warm -Temperate and Tropical areas are presented. The plankton net used in this work was appropriate for evaluating the larger species of tintinnids. A relatively small number of species was found in samples from this cruise, 47. In comparison, Kofoid & Campbell (1929) catalogued approximately 700 species in their conspectus and listed 268 species in samples from the Agassiz expedition to the Eastern Tropical Pacific. The species found in material from the cruise of the "Croatian Tern" represent only 16% of the total number of species found during the last Cruise of the Carnegie (Campbell 1942), 46% of the total number of tintinnids, as mentioned by Alder (1999), for the South Atlantic. The primary reason for this discrepancy is likely the use of a plankton net with 53 µm mesh size, through which small species passed. The samples also included few neritic areas and missed species inhabiting deeper layers (Balech 1972; Kršinić 1998; Thompson *et al*. 1999), as well as specific annual and multi-annual cycles of abundance and presence of tintinnids. It is not clear why no tintinnids were found in samples from the stations of the North Eastern Pacific and South West Atlantic. It is possible that in these areas the most abundant tintinnids were smaller than the used net and were lost during sampling, or due to metazoans grazing pressures. This was unexpected, as previous studies have recorded tintinnids, for example, in the plankton of La Jolla, California (Beers & Stewart 1970) or the open seas off Brazil (Alder 1999; Fernandes 2004). The greatest diversity of tintinnid species was found in the Tropical Pacific Ocean, with the second highest diversity in the Arctic and Subarctic. Our findings suggest that the species richness of tintinnids in the cold surface layer is not markedly lower than in the tropical area. However, it should be noted that the cold areas were typically dominated with tintinnids that had relatively large loricae. In addition, the diversity of species in tropical and temperate regions may be higher in a layer of 100-50 m depth rather than in the surface layer in which the samples were collected during this cruise (Balech 1972; Kršinić 1998).

Tintinnid abundance in the estuaries and coastal zones around the world during the last 50 years has been well investigated, in contrast to the open parts of the seas and oceans, which are rarely studied. In addition, a comparison of the abundance results of open-sea tintinnids presents difficulties due to differences in sampling methods. Submersible pumps have been used to collect microzooplankton in the euphotic layers of the eastern tropical Pacific (Beers *et al*. 1980). Bottles were used for collection along the Strait of Magellan (Fonda-Umani *et al*. 2011) and in a transect from northern continental Norway to Svalbard (Monti & Minocci 2013), while vertical net tows were used in the Weddell Sea Heinbokel & Coats (1986) and in the Southwestern Atlantic Ocean, Thompson *et al*. (1999). Numerous stations of this cruise were in neritic ecosystems or ecosystems influenced by it, as stations in Labrador, Beaufort, the Chuchi and Bering Seas (Stations 6, 7, 8, 12, 13, 14) and Station 26 west of the Strait of Magellan. At these stations, tintinnids with agglutinated lorica were present, as well as the characteristic species *Helicostomella subulata* in the Arctic station. In addition to that, extremely numerous rotifers and the maximal abundance of tintinids were found (Kršinić, unpublished data).

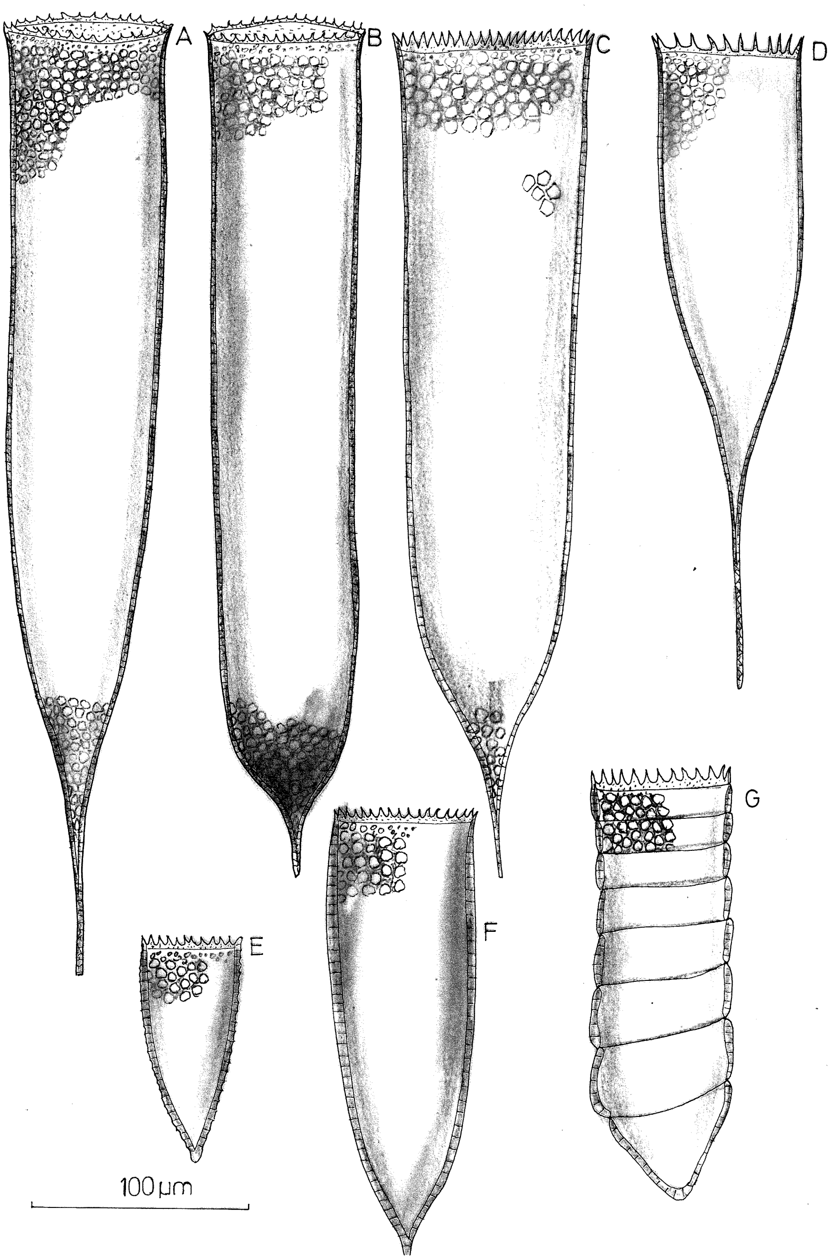

FIGURE 4. Drawings of tintinnid loricae for species: (A-B) *Parafavella gigantea*. (C) *Parafavella denticulata*. (D) *Parafavella elegans*. (E,F) *Parafavella acuta*. (G) *Parafavella acuta* coxlielid.

The samples from the "Croatian Tern" cruise in the Arctic and Antarctic were collected during the polar summer when the expected abundance of phyto and zooplankton is largest (Hedin 1975; El-Sayed & Weber 1982; Paranjape 1987a, b; Taniguchi 1984). A maximum abundance (247,393 ind.m^{-3}), in addition to the increase in diversity, of the total tintinnid concentration was registered, in which species *Ptychocylis obtusa* represented 84% of the sample taken at the station in the Bering Sea. The above mentioned abundance is an integrated value for a water column of 50 m. However, we can assume that the absolute value is much higher. Taniguchi (1984) summarized earlier quantitative data on the abundance of tintinnids in the Chukchi and Bering Seas, which is considerably lower than in the other coastal and estuarine areas of the Arctic and Subarctic zones. The author states that the maximum density of 4,173 ind.L^{-1} is on the surface at the central station in the Bering Sea. This species was dominant in the cold Ohshio water with values of 70–368 ind.L^{-1} (Taniguchi 1983). The South eastern Bering Sea is a rich biological ecosystem that is one of the world's largest fisheries (Olson & Strom 2002). The importance of mesozooplankton in the ecology of the area was noted by Eisner *et al*. (2013) and Ohashi *et al*. (2013). The abundance of tintinnids in the Chuchi Sea was high but still 93% lower than the values that were recorded in the Bering Sea, with significantly different fauna, with the dominant species being *Tintinnopsis beroidea* and *Helicostomella subulata*. Dolan *et al*. (2014) have noted a large difference in the microzooplankton communities between two summer seasons in the Chuchki Sea.

In the Subantarctic at Station 26, the dominant species was *Eutintinnus rugosus,* with 95% of the total tintinnid abundances. The area of South eastern Pacific has been poorly investigated; therefore, one of the largest species of tintinnids with high abundance is mentioned for the first time during this research. Although many species of the genus *Cymatocylis* were found in the Antarctic area, only species *C. convallaria*, with a very low abundance of 5 ind.L^{-1} was found during the present investigation at Station 27 in the South Shetland Islands of the Scotia Sea. Korb *et al*. (2010) mentions a very different structure of microphytoplankton with the possibility of high and low productivity during the summer in the Scotia Sea. According to Dolan *et al*. (2013), the abundance of tintinnids in the Amundsen Sea was clearly not related to the bulk of chlorophyll concentrations.

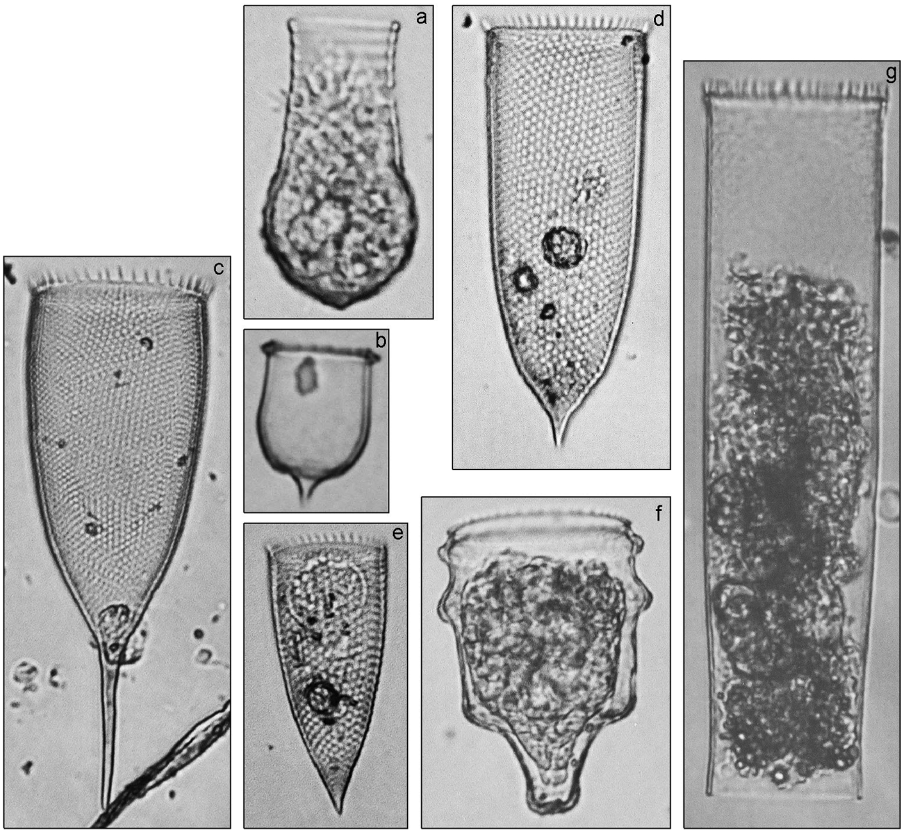

FIGURE 5. Micrograph of tintinnid loricae for species: (a) *Codonellopsis frigida*. (b) *Acanthostomella norvegica*. (c) *Parafavella elegans*. (d,e) *Parafavella acuta*. (f) *Ptychocylis obtusa*. (g) *Eutintinnus rugosus*.

Tintinnid abundance in the tropical Pacific and Atlantic was lower than expected with relatively low variability between stations. Also, significantly lower values than expected were recorded in the Labrador Sea, Baffin Bay and the Beaufort Sea (Paranjape 1987a, b). The actual role of tintinnids, especially in oligotrophic oceanic areas, is not known. According to Stoecker & Capuzzo (1990), protozoa are a particularly important factor between primary production and metazoan food webs in the oligotrophic ocean and in polar food webs. Unlike tintinnids, planktonic copepods and their earliest developmental stages or nauplii were present at all stations of this cruise. (Kršinić, unpublished data). At Station 17 in Eastern North Pacific tintinnids were rare, while the abundance of copepods was higher, with cruise nauplii maximum of 39 ind.L^{-1} and postnaupliar copepods of 26 ind.L^{-1}. Co-inciding with tintinnid abundance peaks at the stations in Bering Sea and the South-Eastern Pacific, abundance peaks of nauplii were also noted. Tintinnids prevails abundance of nauplii at stations in the Labrador Sea and Baffin Bay. On the other hand, in the Temperate and Tropical regions of the Pacific and Atlantic, nauplii abundance significantly exceeded the abundance of tintinnids. Also a high and significant correlation between nauplii and post-naupliar copepods was noted. Therefore, we can conclude that there is an important connection between copepods and tintinnids in epipelagical ecosystem, which are not sufficiently investigated in world oceans and seas. As a rule, both groups of plankton were investigated separately, and with different methods, which make it difficult to compare results.

This research has confirmed the importance of the global research of tintinnid diversity for the assessment of possible ocean changes due to global warming in areas such as the Chukchi Sea (Dolan *et al*. (2014). In addition, it is very important to properly identify species, which was the most important goal of this research.

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