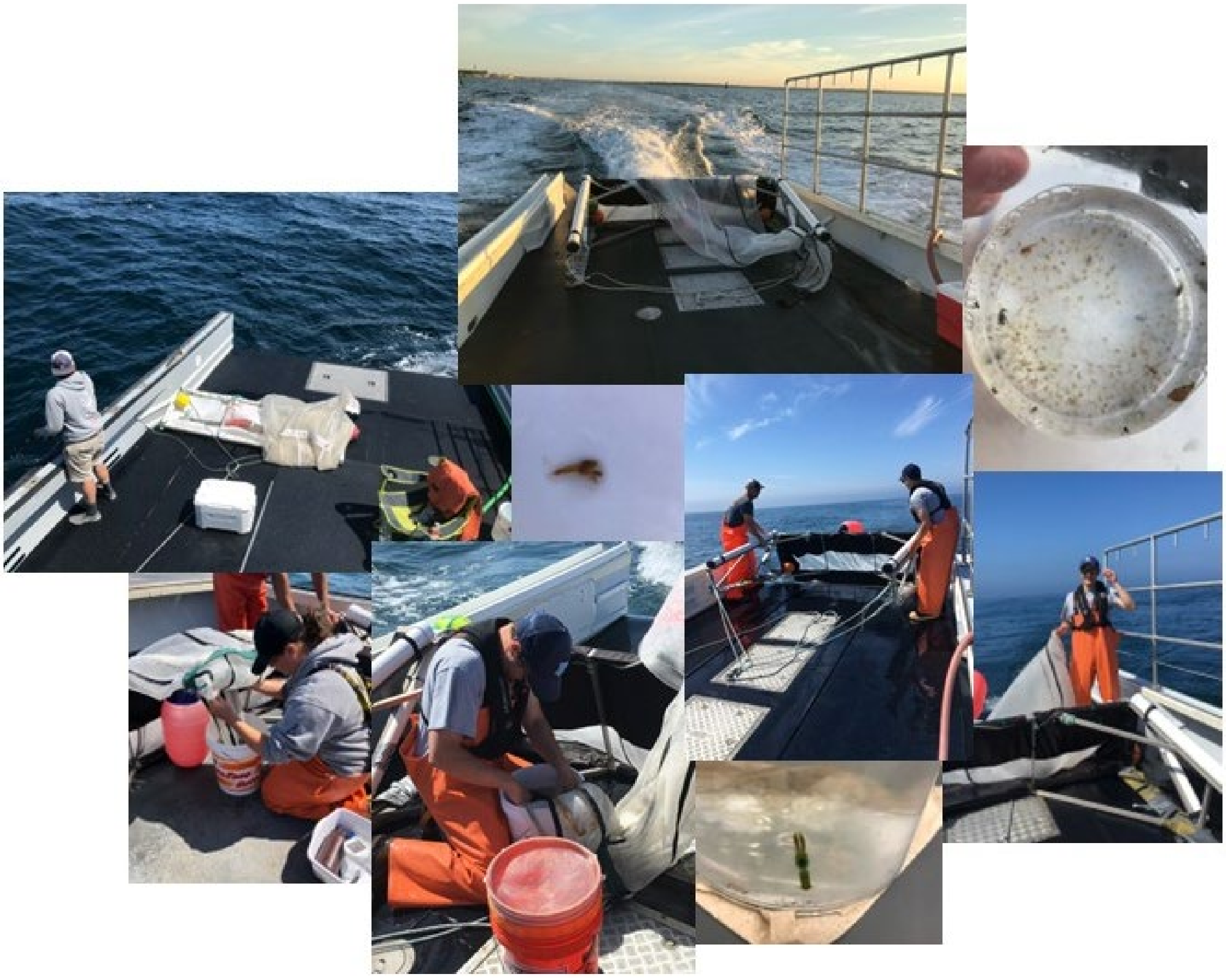
OCS Study
BOEM 2023-027

Zooplankton Survey for Regional Fisheries Monitoring in Southern New England Offshore Wind Development



U.S. Department of the Interior
Bureau of Ocean Energy Management
Office of Renewable Energy Programs

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Zooplankton Survey for Regional Fisheries Monitoring in Southern New England Offshore Wind Development

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Mohawk Bolin, Captain F/V Rock N Roll

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List of Abbreviations and Acronyms

BOEM	Bureau of Ocean Energy Management
MassCEC	Massachusetts Clean Energy Center
MLA	Massachusetts Lobstermen’s Association
MWRA	Massachusetts Water Resources Authority
SMAST	School for Marine Science and Technology

Project Snapshot

SMAST in conjunction with MLA, and another SMAST project to estimate the relative abundance and distribution of larval lobster and fish using a towed neuston net, sampled near-surface zooplankton populations that are food for North Atlantic right whales (*Eubalaena glacialis*). The zooplankton component of the study is being performed by Professor Jefferson Turner and his graduate student Evan Weig.

Introduction

The studies described here were to quantify abundance and distributions of near-surface zooplankton in the windfarm area south of Martha's Vineyard during May and June of 2021. This was being done because endangered right whales (*Eubalaena glacialis*) (Kraus et al. 2005; Meyer-Gutbrod & Greene, 2018) have historically been known to forage on zooplankton, in and around waters off southeastern New England during portions of the spring and summer periods (Wishner et al. 1988; 1995; Mayo & Marx, 1990; Kenney et al. 1995; Nichols et al. 2008; Leiter et al. 2017; Mayo et al. 2018; Ganley et al. 2019; 2022). In particular, right whales are known to occur in waters near wind energy areas on the continental shelf offshore from Rhode Island, and in waters off southeastern Massachusetts between Martha's Vineyard and Nantucket (Leiter et al. 2017).

Right whales feed primarily on surface accumulations of zooplankton, particularly late juvenile developmental stages (copepodites) and adults of the copepod *Calanus finmarchicus* (Murison & Gaskin, 1989; Mayo & Marx, 1990; Baumgartner & Mate, 2003; Baumgartner et al. 2003a; 2003b; 2017; Costa et al. 2006; Parks et al. 2012; Cronin et al. 2017). Previous studies have found associations between right whales and high abundances of *C. finmarchicus* in waters off New England and eastern Canada (Baumgartner et al. 2003b; Pendleton et al. 2009; 2012; Meyer-Gutbrod et al. 2015). Thus, in order to understand temporal and spatial distributions of right whales in wind energy areas off southeastern New England, it would be advantageous to understand spatial and temporal distributions of the zooplankton species that are the preferred prey of right whales.

Methodology

We quantified abundances and distributions of near-surface zooplankton in the wind energy area south of Martha's Vineyard on the same sampling cruises as ongoing surveys of lobster larvae and larval fish that were being performed by scientists from SMAST of the University of Massachusetts Dartmouth (UMass Dartmouth). We joined this program on short notice (approximately a month before sampling), when neuston sampling cruises for larval fish and lobster larvae had already been scheduled. This is an important consideration, since timing of our sampling cruises was not targeted for periods when right whales have been most frequently recorded in the windfarm area, but rather our sampling was added to wind energy area cruises that had already been scheduled.

Zooplankton samples were collected twice each month during May and June of 2021. Zooplankton sampling was done at each of 30 stations sampled each day in the SMAST survey, at the same stations as ongoing neuston net sampling for lobster larvae and fish larvae. Since these surveys involved two vessels, each of which sampled 15 stations on each sampling day, there were two zooplankton sampling teams, one on each research vessel. This resulted in a total of 120 zooplankton samples: 15 from each research vessel on each of 2 days per month, for 2 months in May and June of 2021.

Zooplankton sampling and microscopic analyses employed methodology that has been successfully used during the Harbor Outfall Monitoring project in Boston Harbor and Massachusetts Bay, funded by the MWRA, which has been ongoing since 1992 (Turner, 1994; Turner et al. 2011). Briefly, this involved sampling and microscopic analyses, as described below.

Zooplankton sampling included tows with 0.5-meter mouth-diameter zooplankton nets (102 µm-mesh) equipped with flowmeters for quantification of the volumes of water sampled in tows. Tows lasted approximately 90 seconds (timed with a stopwatch), in order to avoid net clogging with certain forms of phytoplankton, such as chain-forming diatoms. Net clogging occurs if the mesh of the net becomes clogged with phytoplankton and stops filtering during the tow, but the stopwatch continues to run. This results in erroneous flowmeter counts per second, which are needed to compute water volumes sampled. If a flowmeter is not still turning at the end of a net tow, indicating that net clogging had occurred, then the tow should be repeated for shorter periods until an unclogged tow is obtained. Sampling by Turner for over 30 years in the MWRA project, and for 33 years in Buzzards Bay (October, 1987-February 2020) has revealed that net clogging rarely occurs within 1.5 minutes, but if it does, this becomes apparent from flowmeters with non-turning propellers at the ends of tows. Nets were towed horizontally, just below the surface, at a depth that keeps the mouth of the 0.5 meter diameter net mouth nets completely immersed, in order to maintain correct sampling volume estimates. Collected samples were preserved immediately after collection in approximately 10% formalin:seawater solutions, and later transferred to 70% ethanol. The formalin preservation was to immediately preserve zooplankton tissues, and the subsequent transfer to ethanol was to avoid having analysts breathing carcinogenic formalin fumes during microscopic analyses.

Microscopic analyses of zooplankton samples were also according to methodology used in the MWRA surveys. Briefly, this involved splitting zooplankton samples with a Folsom plankton splitter, which divides samples into two equal portions with each split. Splitting occurred until visual estimations suggested that there were at least 250 animals in each split. Aliquots of at least 250 animals are required in the MWRA project. During the warmer months to be sampled during the present studies, targeted splits with at least 250 animals were approximately 1/256, 1/512, 1/1024, 1/2048 or 1/4096 of the total. During splitting, the two splits prior to the targeted split were also saved until analyses of each sample were completed, in case the targeted splits did not contain at least 250 animals. In such a case, initial splits that contained < 250 animals would be combined with coarser splits (for example splits of 1/128, 1/64, 1/32, 1/16) to obtain at least 250 total animals. Microscopic analyses of copepods (small crustaceans approximately the size of a sesame seed or smaller) were to species, sex (adult male or female), and developmental stage (juvenile copepodites or adults). Analyses were to major group for all non-copepod zooplankters, most of which were meroplankton (=planktonic larvae of benthic, or bottom-living animals) such as barnacle nauplius larvae, bivalve and gastropod veliger larvae, etc.. In addition, since *Calanus finmarchicus* developmental stages (which are of different sizes) have been related to right whale feeding in some studies (Baumgartner & Mate, 2003; Baumgartner et al. 2003a; 2003b; Wishner et al. 1988; 1995), we separately quantified larger female and male adults, as well as combined copepodite stages of *C.*

finmarchicus. Final data were presented as number of animals of a given category per cubic meter of water sampled (the latter determined from net mouth diameter, tow times and flowmeter readings).

The methods used in this survey were identical to those employed in the MWRA surveys (with all zooplankton samples from 1992-1994, and since 1998 having been counted by Turner), with one exception: zooplankton tows in this study were horizontal just below the water surface, rather than oblique over the water column as in the MWRA sampling. That was because right whales feed primarily on near-surface accumulations of zooplankton.

Personnel for these studies are described below. The Principal Investigator (Jefferson Turner) has been performing plankton research since 1969. Turner trained the graduate student (Evan Weig) and other personnel from the Stokesbury laboratory in zooplankton sampling. Turner participated in all sampling cruises, training Weig and other technicians in zooplankton sampling, and to help Weig and/or the technicians with sampling. Turner also trained Weig in laboratory zooplankton analyses, including zooplankton splitting, microscopic counting and taxonomic analyses, and quantification of water volumes sampled. Weig performed laboratory microscopic analyses of zooplankton when not sampling at sea. Weig will use the data from the study for his M.S. thesis research in the graduate program of the Department of Fisheries Oceanography (DFO) at SMAST.

In addition to providing zooplankton data to the Massachusetts Clean Energy Center, and for use in Evan Weig's M.S. thesis, it is intended that these zooplankton data will provide the basis for at least one peer-reviewed publication. Such has been the result of Turner's plankton projects during the MWRA sampling program (Turner, 1994; Turner et al. 2006; 2011; Jiang et al. 2007; Hunt et al. 2010,) and the Buzzards Bay monitoring program, funded intermittently by the Massachusetts Department of Environmental protection, NOAA Sea Grant, and UMass Dartmouth (Borkman & Turner, 1993; Chute & Turner, 2001; Pierce & Turner, 1994a; 1994b; Turner & Borkman, 1993; Turner et al. 2009).

Results

Sampling for this study was conducted from May through June 2021 at 30 stations during each sampling period (see Figure 1, Table 1) at stations that were randomly selected and distributed based on the proportional total area within each ten-meter depth contour of the 3670 km^2 study area. The same 30 stations were sampled twice in May (5/13-5/14, and 5/27) and twice in June (6/9 and 6/25) of 2021. At each station an approximately 90-second tow was conducted just under the surface (where right whales feed) with a 102 µm-mesh net equipped with a flowmeter, to quantitatively assess abundance and distribution of zooplankton. Samples were preserved in approximately 10% formalin:seawater solutions within minutes of collection. Laboratory processing and microscopic examination of samples began within days of collection and are completed.

Results from this study:

1) Described distributions of zooplankton taxa and species in the areas of concern
2) Compared abundance data with temperature
3) Determined the variations of zooplankton species in the wind-energy lease areas.

This work will create a baseline of data to be use in future studies and analyses as the planned windfarm projects continue.

The zooplankton component of the project was added only in early May of 2021 (approved by MCETC on 5/12/2021), and sampling commenced on 5/13/2021. We successfully completed all field research sampling identified in the list of tasks from the scope of work. Figure 2 and Table 2 contain the summarized environmental data (temperature, salinity, dissolved oxygen, and pH) for each sampling period where data are available.

Turner collected all zooplankton samples on the 5/13-14 *Rock 'n Roll* cruises, and trained Travis Lowery and Rachael Norton of the Stokesbury laboratory in zooplankton collection techniques so that they could do zooplankton collections on future cruises. Turner also collected zooplankton on the 5/27 and 6/9 *Encourager* cruises, and trained Evan Weig in collection techniques on the 6/9 *Encourager* cruise. Turner collected zooplankton on the 6/25 *Encourager* cruise, while Weig was collecting zooplankton on the same day on the *Rock 'n Roll* cruise.

In the laboratory, Turner trained Weig in transferring samples from formalin:seawater to 70% ethanol solutions, splitting samples using a Folsom plankton splitter, and identification and counting of zooplankton using a dissecting microscope. Such microscopic analyses are completed, and Turner was initially present in the laboratory whenever Weig was performing such analyses, so that Turner could teach Weig the identifications of previously unencountered zooplankton taxa as they occurred. As of early May of 2022, Weig had completed microscopic analyses of all of the total 120 samples.

After completion of microscopic analyses of zooplankton samples, Weig completed flowmeter calculations for volume of water sampled in net tows, in order to present quantitative data. These data are presented in Figures 3-11 and Tables 3-6. As expected for samples from 102 µm-mesh net tows (from Turner's zooplankton results since 1992 for the Massachusetts Water Resources Authority (MWRA) Boston Harbor Outfall Monitoring Study), copepod nauplius larvae (nauplii) were the numerically-dominant taxa, along with adults and copepodites (juveniles) of the tiny (< 1 mm total length) copepod species *Oithona similis*. Other frequently-encountered but much less-abundant copepod taxa included adults and (mostly) copepodites of *Centropages typicus*, *Pseudocalanus* spp. (includes two species that are not easily distinguished morphologically), *Temora longicornis*, and *Microsetella norvegica*. All of these copepod taxa are known to be common in continental shelf waters south of New England, such as the study area. Other sporadically-abundant taxa included the marine cladoceran *Evadne nordmanni*, the tunicate *Oikopleura dioica*, radiolarian protozoans, and meroplanktonic larvae of benthic invertebrates, such as gastropod veligers, echinoderm plutei, barnacle nauplii, polychaete larvae, and other unidentified meroplanktonic larvae. These larvae likely reflect seasonal reproductive events by their benthic-invertebrate parents, which are typical in local waters during the warmer months.

Interestingly, in the aliquots counted (always >250 total animals) from the samples collected, Weig found few adults or copepodites of the larger copepod *Calanus finmarchicus*. This copepod is a primary prey item of right whales. We speculate that the absence of *Calanus* may be a factor in the total absence of right whales observed during these cruises.

Numerically-dominant taxa are briefly summarized by date of sampling below. However, it is apparent from Figure 3 that zooplankton abundances were somewhat patchy, with substantially-different total abundances at different stations. This was despite the facts that stations were relatively close to each other (Figure 1), all sampling was done during daylight, and sea conditions during sampling periods were relatively calm. The reasons for this patchiness are unknown.

On May 13 and May 14 (Table 3), copepod nauplii and the copepodites of the small (< 1 mm total length) copepod *Oithona similis* were most abundant, together with echinoderm pluteus larvae and some gastropod veliger larvae. These larvae likely reflect seasonal spawning by their benthic (bottom-dwelling) parents.

On May 27 (Table 4), the same assemblages as in the previous sampling period were collected, together with a few *Centropages typicus* copepodites.

On June 9 (Table 5), collections were again dominated by copepod nauplii and O. similis copepodites, but with a few copepodites of the copepods *Centropages typicus* and *Pseudocalanus* spp.. There was also greater diversity of meroplankton ((echinoderm plutei, fish eggs, gastropod veligers, polychaete larvae) and other non-copepod zooplankton (the marine cladoceran *Evadne nordmanni*, small medusae, and protozoan radiolarians). Abundances of echinoderm plutei and polychaete larvae were generally lower than on the previous sampling dates.

On June 25 (Table 6) there was the highest zooplankton diversity of any of the sampling periods. Multiple copepod species, including *Calanus finmarchicus*, were present. Copepod nauplii and *Oithona similis* were most abundant, but *Centropages typicus* adults and copepodites were also moderately abundant. There was abundant meroplankton, primarily bivalve veliger larvae and fish eggs, as well as other non-copepod, non-meroplankton taxa such as *Evadne nordmanni*, *Oikopleura dioica* and radiolarians. Although the copepod *C. finmarchicus* was sporadically present, its abundances were relatively low (4,337-29,635/m^3) compared to copepod nauplii, *O. similis* copepodites and bivalve veligers.

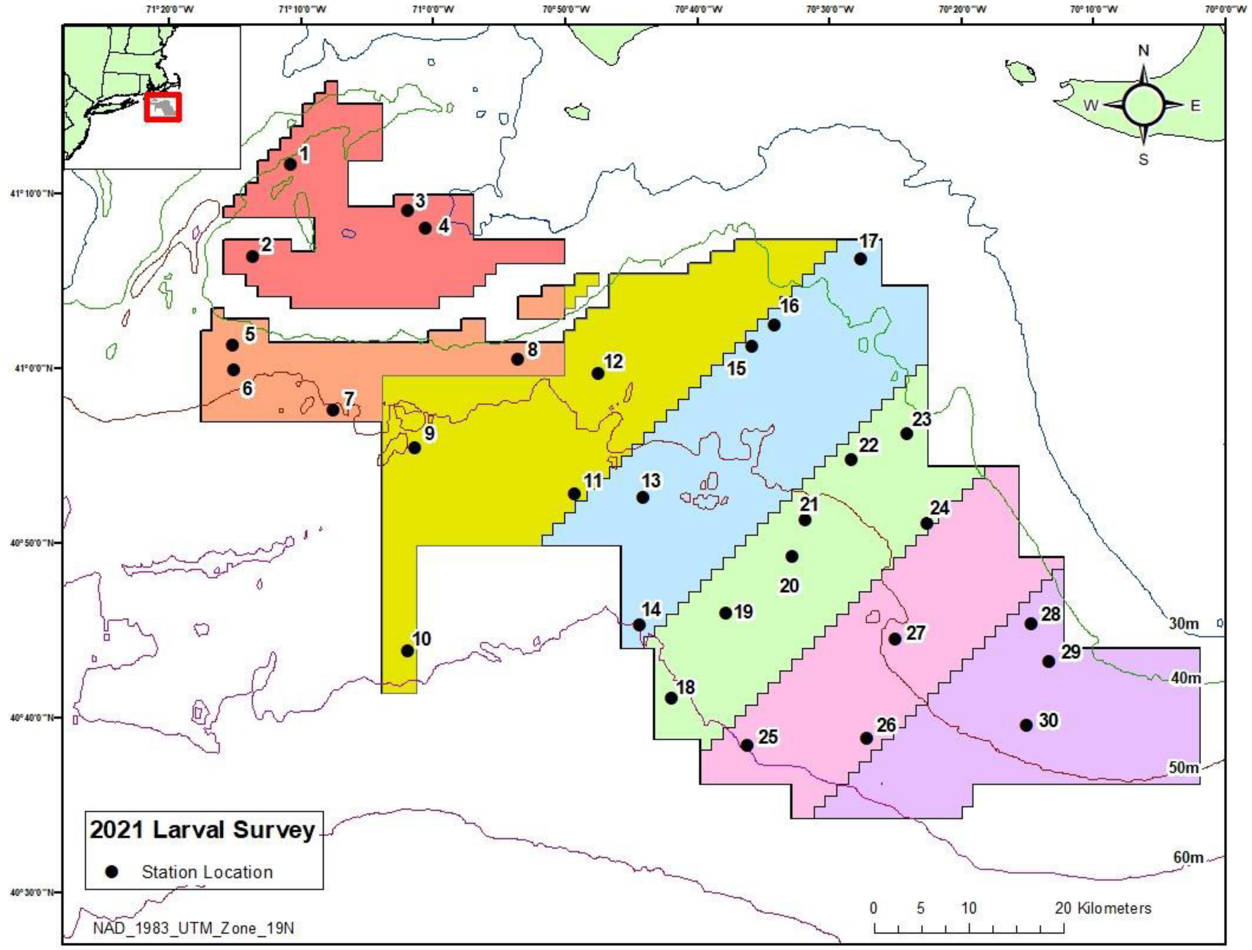

Figure 1. Sampling sites for 2021 in the southern New England offshore development areas.

Date	Sampling Period	Stations Sampled	Vessel
5/13/2021	1	15	*Rock 'n Roll*
5/14/2021	1	15	*Encourager*
5/27/2021	2	30	both
6/09/2021	3	30	both
6/25/2021	4	30	both

Table 1. List of sampling dates, sampling periods (each period consists of 1 or 2 vessels each sampling 15 stations on a given day), the vessel that operated on the sampling date.

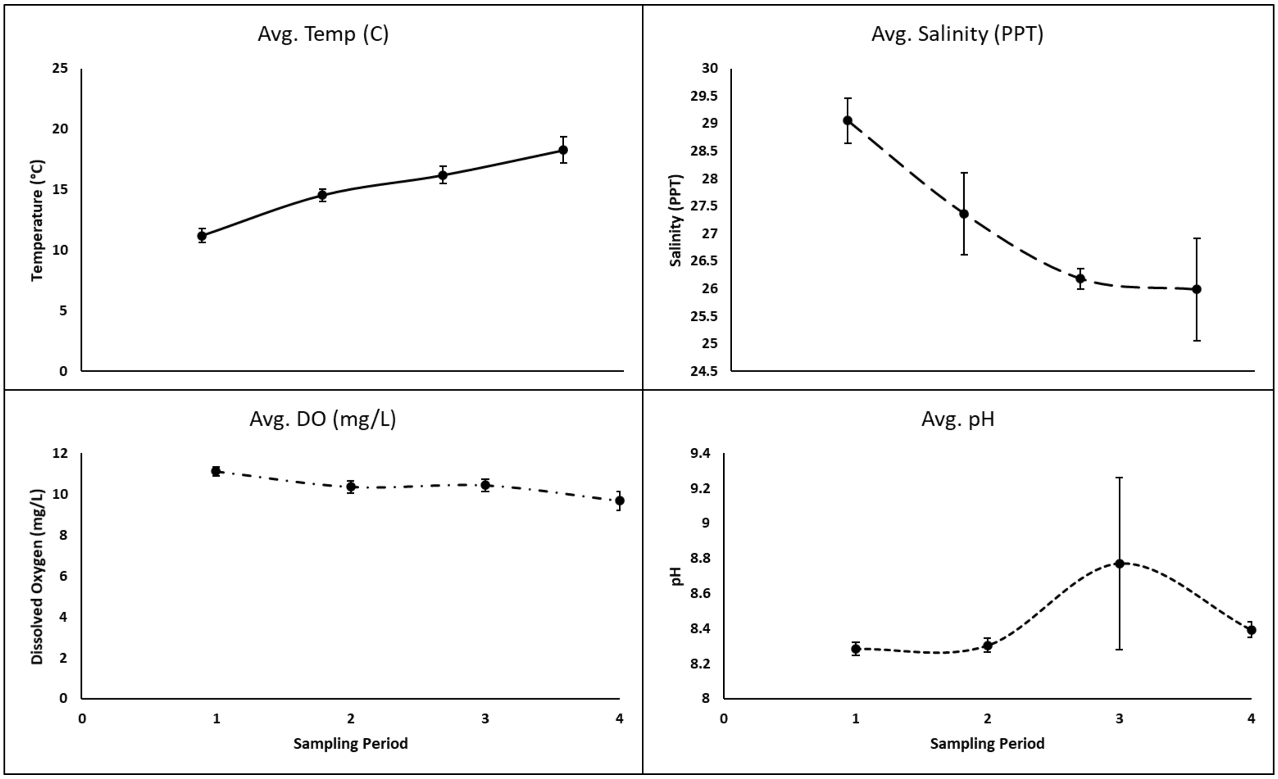

Figure 2. Environmental data by sampling period A) average temperature in degrees Celsius B) average salinity in parts per thousand C) average dissolved oxygen in milligrams per liter D) average pH. The timeframe of this dataset is May through June. All data points have their respective standard deviations (vertical lines) included.

Sampling Period	**Temp (C)**	**Salinity (PPT)**	**DO (mg/L)**	**pH**
1	11.21 (0.55)	29.05 (0.40)	11.11 (0.24)	8.29 (0.04)
2	14.55 (0.51)	27.36 (0.75)	10.36 (0.30)	8.3 (0.04)
3	16.20 (0.73)	26.18 (0.19)	10.43 (0.31)	8.77 (0.49)
4	18.26 (1.07)	25.98 (0.92)	9.68 (0.45)	8.39 (0.04)
Total	15.06 (2.70)	27.28 (1.42)	10.40 (0.61)	8.44 (0.31)

Table 2. Mean and standard deviation (in parentheses) environmental data by sampling period for the duration of the surveys.

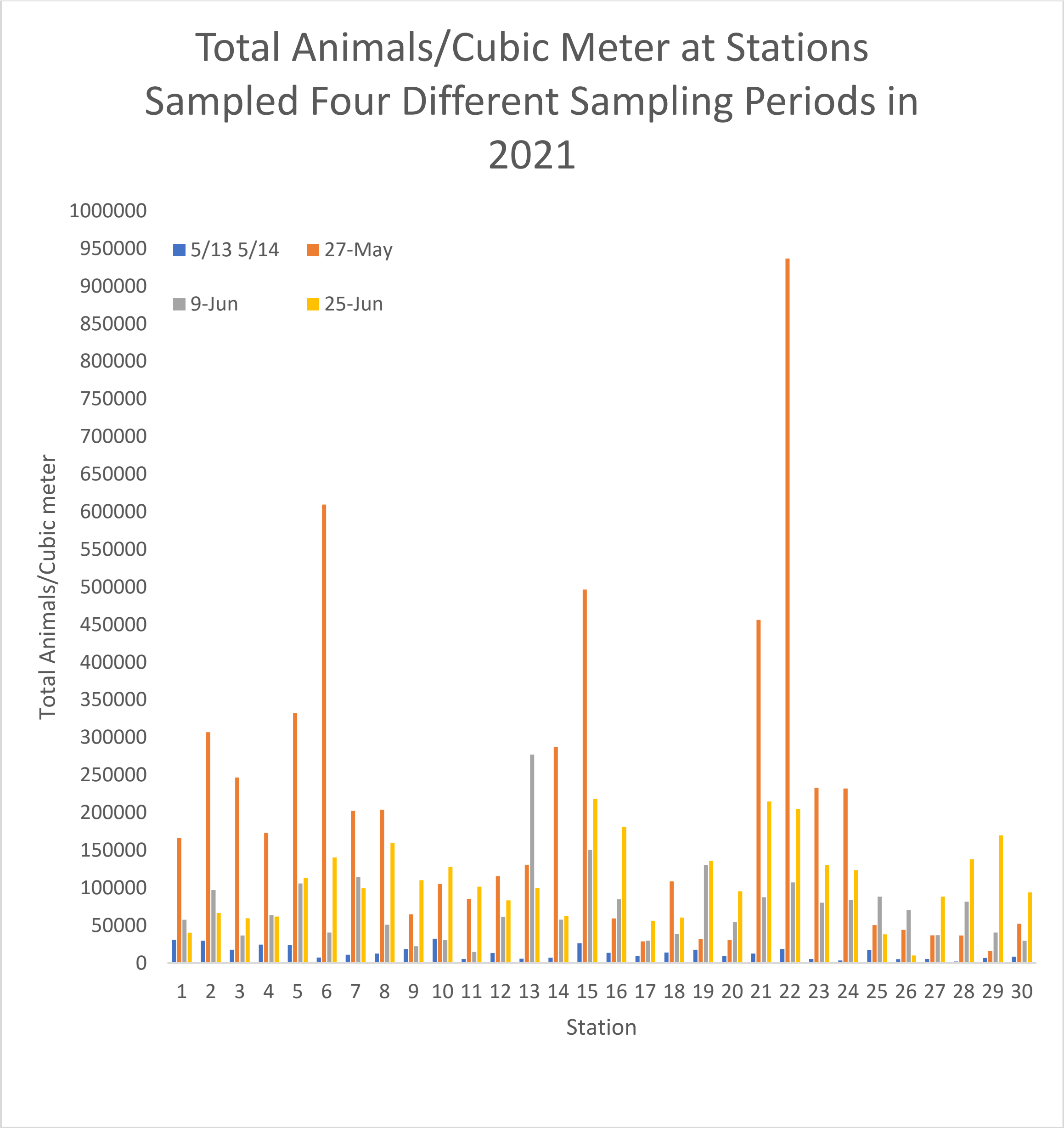

Figure 3. Total animals/cubic meter at stations sampled during four different sampling periods in 2021.

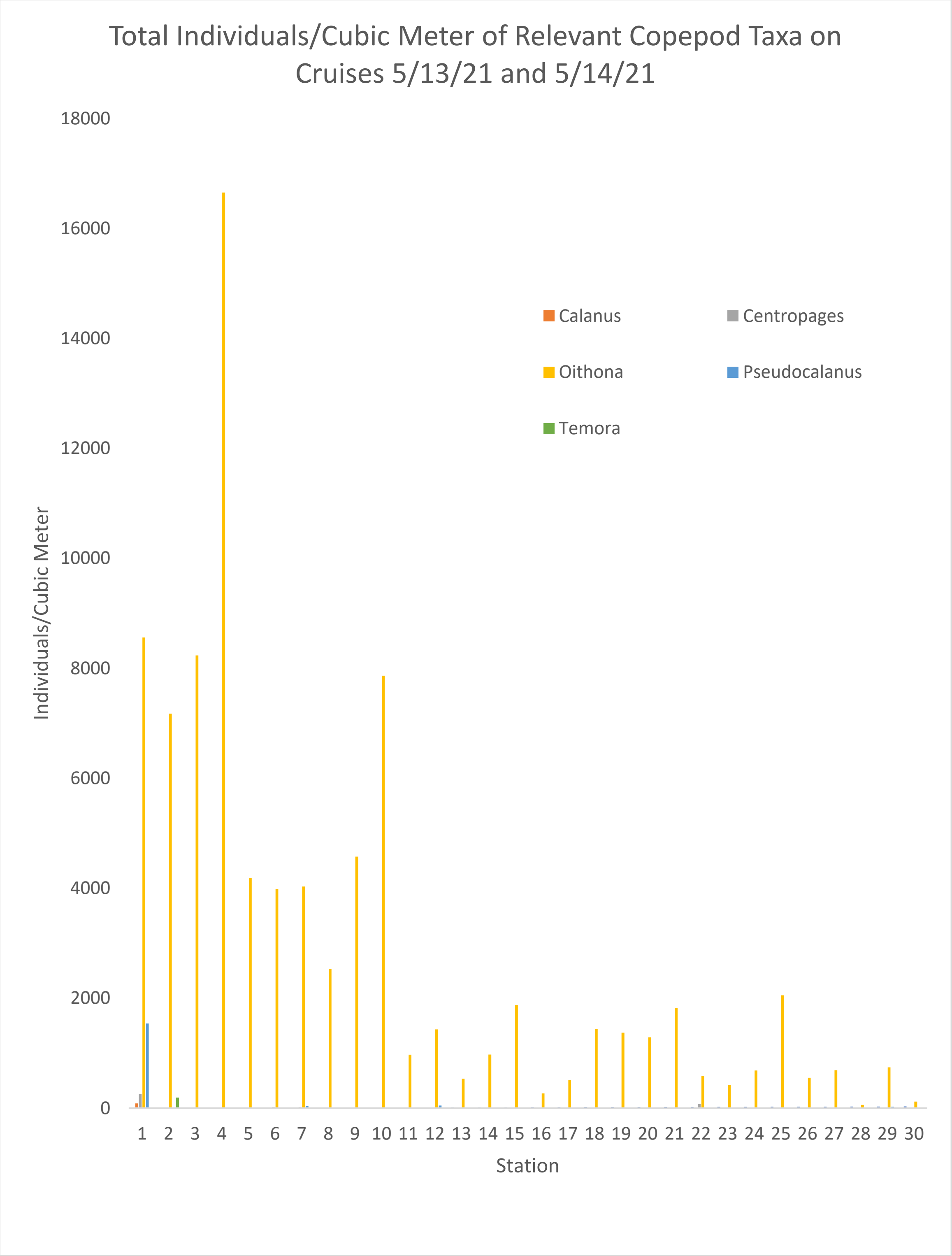

Figure 4. Total individuals/cubic meter of relevant copepod taxa on cruises on 5/13/21 and 5/14/21.

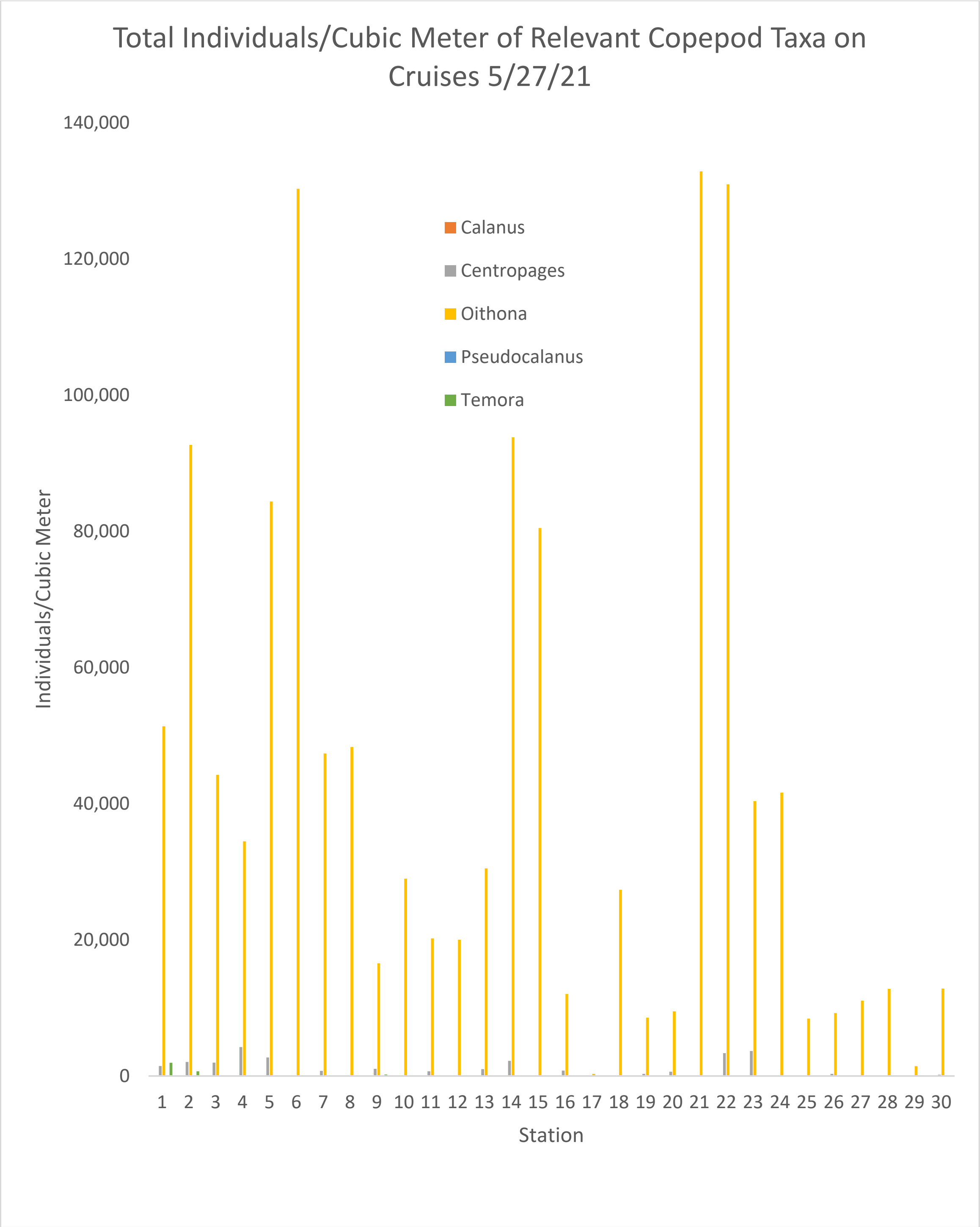

Figure 5. Total individuals/cubic meter of relevant copepod taxa on cruises on 5/27/21.

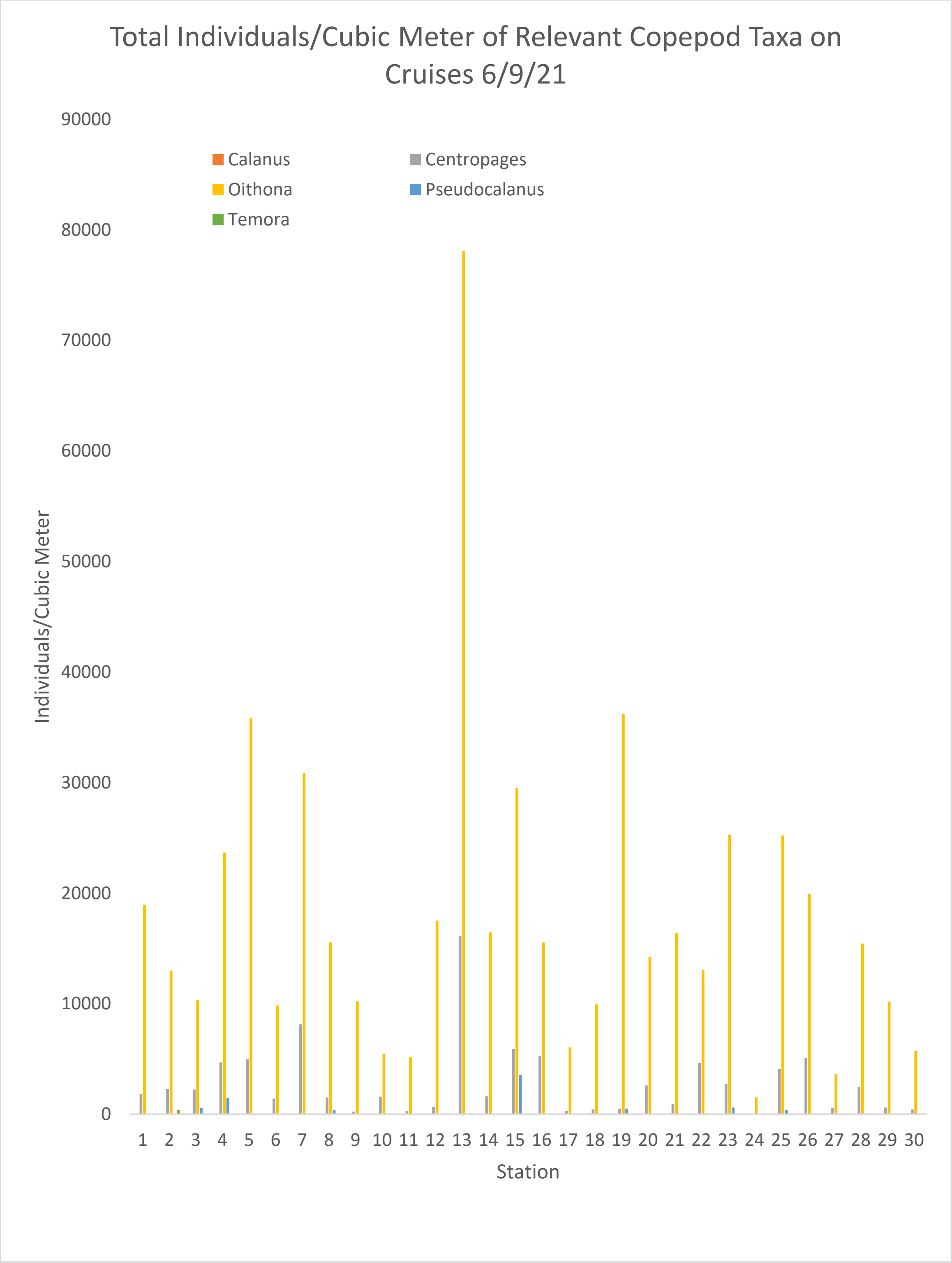

Figure 6. Total individuals/cubic meter of relevant copepod taxa on cruises on 6/9/21.

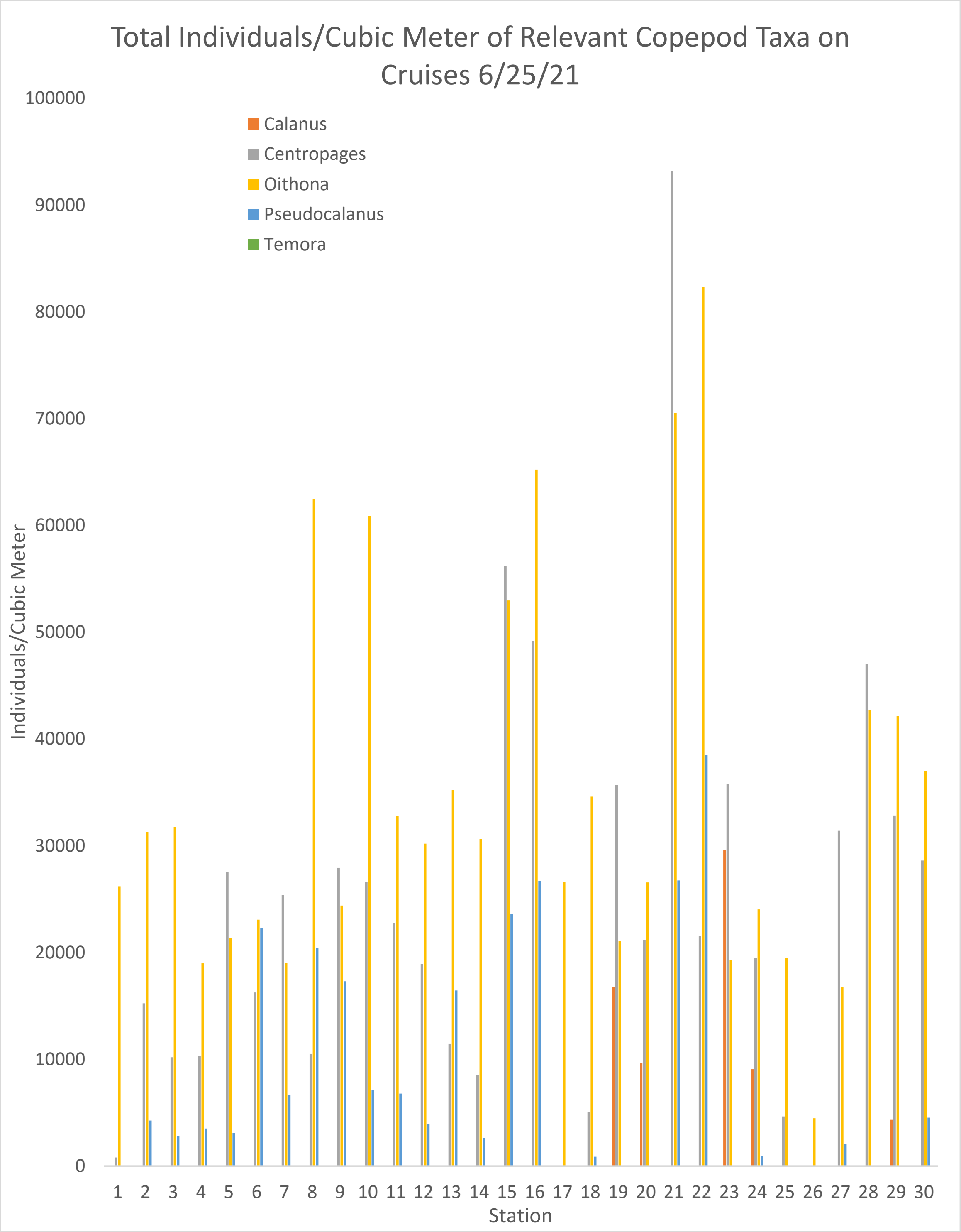

Figure 7. Total individuals/cubic meter of relevant copepod taxa on cruises on 6/25/21.

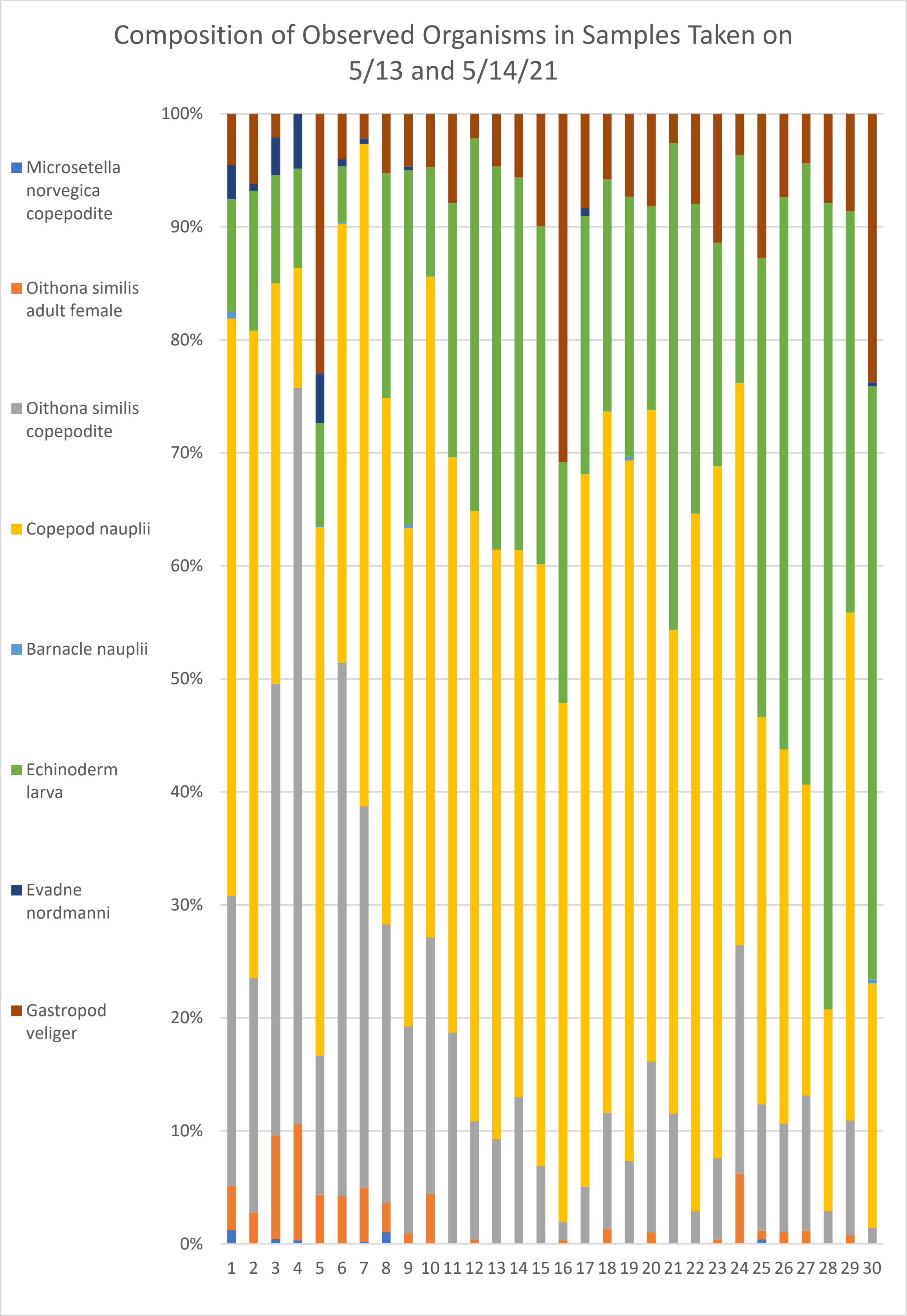

Figure 8. Composition of observed organisms in samples taken on 5/13 and 5/14/21.

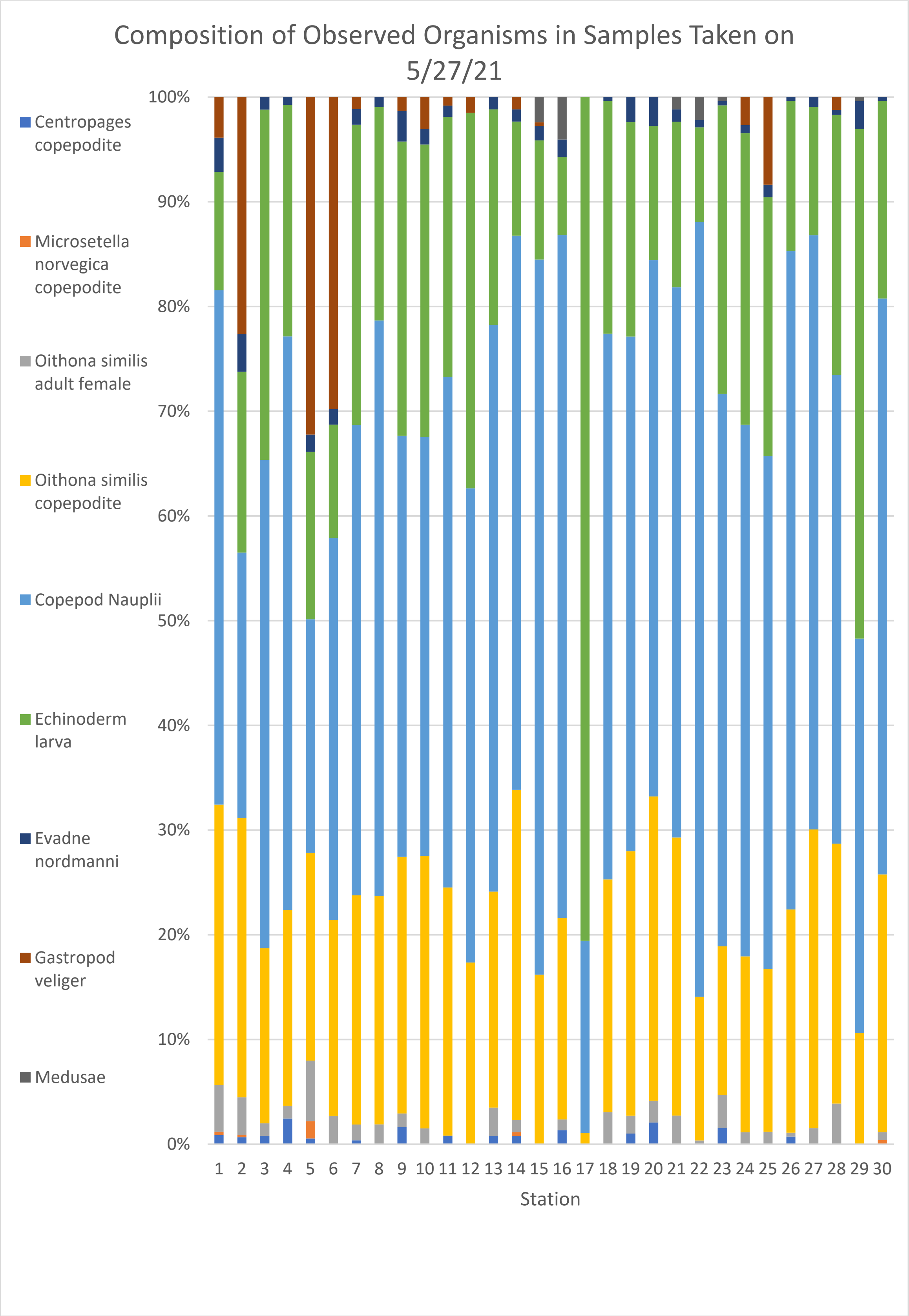

Figure 9. Composition of observed organisms in samples taken on 5/27/21.

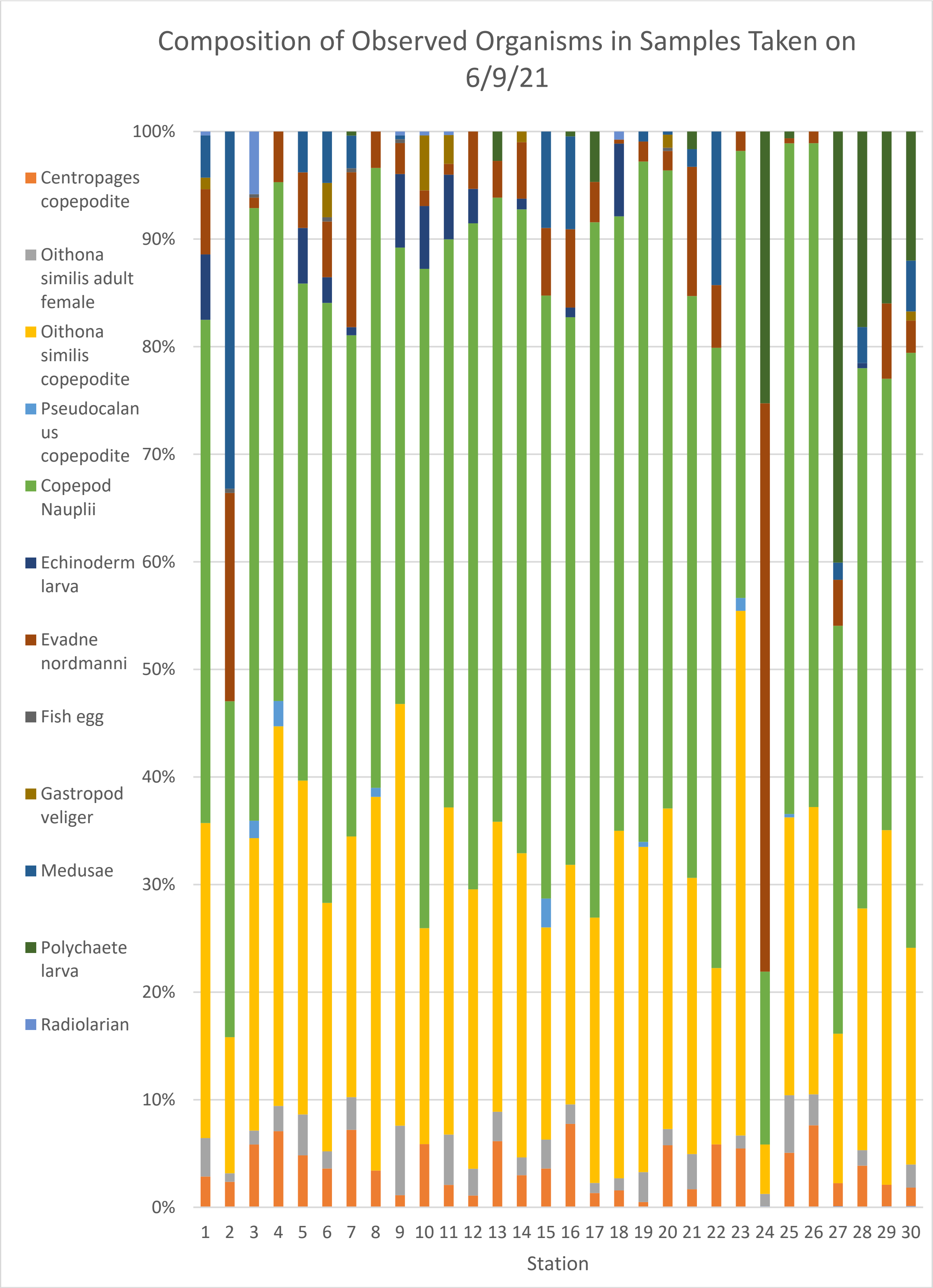

Figure 10. Composition of observed organisms in samples taken on 6/9/21.

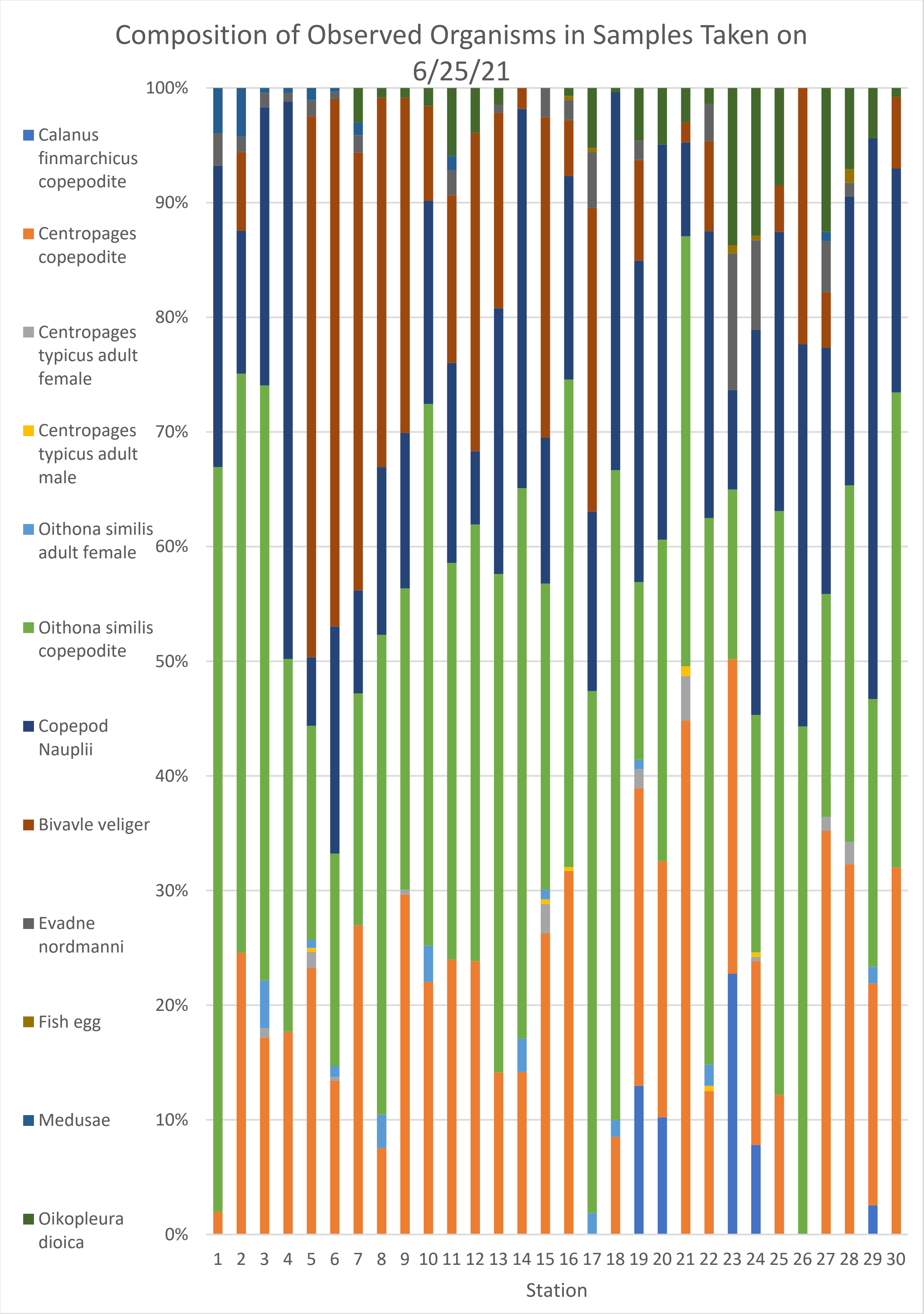

Figure 11. Composition of observed organisms in samples taken on 6/25/21.

Station	Microsetella norvegica copepodite	Oithona similis adult female	Oithona similis copepodite	Copepod nauplii	Barnacle nauplii	Echinoderm larva	Evadne nordmanni	Gastropod veliger
1	342	1113	7277	14468	171	2825	856	1284
2	0	850	6326	17468	0	3777	189	1888
3	69	1535	6700	5932	0	1605	558	349
4	67	2274	14380	2341	0	1940	1070	0
5	0	1097	3088	11744	41	2276	1097	5771
6	0	327	3661	3014	8	385	49	311
7	17	506	3524	6124	0	0	52	227
8	97	243	2286	4329	0	1848	0	486
9	0	221	4354	10480	74	7454	74	1107
10	0	1284	6581	16935	0	2809	0	1364
11	0	0	971	2640	0	1168	0	410
12	0	48	1384	7114	0	4344	0	286
13	0	0	535	3005	0	1955	0	267
14	0	0	974	3631	0	2474	0	421
15	0	0	1874	14473	0	8121	0	2707
16	0	45	223	6242	0	2898	0	4191
17	0	0	512	6361	0	2303	73	841
18	0	166	1273	7694	0	2546	0	720
19	0	0	1372	11569	60	4294	0	1372
20	0	84	1204	4604	0	1436	0	655
21	0	0	1824	6749	0	6795	0	410
22	0	0	590	12604	0	5602	0	1622
23	0	21	401	3400	0	1098	0	634
24	0	161	524	1290	0	524	0	94
25	68	137	1915	5883	0	6977	0	2189
26	0	57	495	1713	0	2531	0	381
27	0	63	627	1442	0	2884	0	230
28	0	0	59	362	0	1448	0	160
29	0	53	690	3051	0	2414	0	584
30	0	0	119	1819	30	4413	30	1998

Table 3. Total individuals/cubic meter of different taxa found in samples taken 5/13 and 5/14/21

Station	Centropages copepodite	Microsetella norvegica copepodite	Oithona similis adult female	Oithona similis copepodite	Copepod Nauplii	Echinoderm larva	Evadne nordmanni	Gastropod veliger	Medusae
1	1468	489	7338	44029	80719	18590	5381	6360	0
2	2060	686	10984	81696	77577	52862	10984	69338	0
3	1966	0	2948	41277	114986	82554	2948	0	0
4	4255	0	2128	32341	94894	38298	1277	0	0
5	1814	5443	19051	65317	73482	52617	5443	106141	0
6	0	0	16473	113816	221642	65893	8985	181207	0
7	764	0	3056	44309	90910	58060	3056	2292	0
8	0	0	3865	44452	112097	41553	1933	0	0
9	1047	0	838	15709	25763	18013	1885	838	0
10	0	0	1588	27386	42071	29370	1587	3175	0
11	697	0	0	20209	41580	21138	929	697	0
12	0	0	0	20024	52237	41355	0	1741	0
13	1016	0	3556	26925	70615	26925	1524	0	0
14	2233	1116	3350	90439	151849	31263	3350	3350	0
15	0	0	0	80475	339022	56504	6849	1712	11986
16	803	0	602	11437	38726	4414	1003	0	2408
17	0	0	0	3111	5282	23198	0	0	0
18	0	0	3314	24026	56338	24026	414	0	0
19	325	0	542	8026	15618	6508	759	0	0
20	634	0	634	8871	15630	3907	845	0	0
21	0	0	12399	120447	238236	71737	5314	0	5314
22	0	0	3357	127578	688250	83933	6715	0	20144
23	3669	0	7338	33022	122914	64209	917	0	917
24	0	0	2657	38968	117790	64651	1771	6199	0
25	0	0	602	7825	24680	12440	602	4214	0
26	313	0	157	9083	26780	6108	157	0	0
27	0	0	565	10513	20913	4522	339	0	0
28	0	0	1735	11063	19957	11063	217	542	0
29	0	0	0	1450	5126	6628	362	0	52
30	0	195	389	12453	27824	9534	194	0	0

Table 4. Total individuals/cubic meter of different taxa found in samples taken 5/27/21

Station	Centropages copepodite	Oithona similis adult female	Oithona similis copepodite	Pseudo calanus copepodite	Copepod Nauplii	Echinoderm larva	Evadne nordmanni	Fish egg	Gastropod veliger	Medusae	Polychaete larva	Radiolarian
1	1631	2038	16715	0	26703	3465	3465	0	611	2242	0	204
2	2293	764	12230	0	30193	0	18727	382	0	32104	0	0
3	2117	470	9878	588	20697	0	353	118	0	0	0	2117
4	4439	1480	22195	1480	30333	0	2959	0	0	0	0	0
5	4971	3906	31956	0	47579	5326	5326	0	0	3906	0	0
6	1429	635	9208	0	22226	952	2064	159	1270	1905	0	0
7	8142	3428	27426	0	52710	857	16284	428	0	3428	428	0
8	1516	0	15544	379	25780	0	1516	0	0	0	0	0
9	241	1447	8762	0	9485	1527	643	80	0	80	0	80
10	1595	0	5484	0	16750	1595	399	0	1396	0	0	100
11	294	687	4466	0	7753	883	147	0	393	0	0	49
12	657	1533	15985	0	38102	1971	3285	0	0	0	0	0
13	16152	7179	70889	0	152545	0	8973	0	0	0	7179	0
14	1627	904	15545	0	32898	542	2892	0	542	0	0	0
15	4725	3543	25985	3543	73822	0	8268	0	0	11811	0	0
16	4984	1173	14366	0	32837	586	4691	0	0	5571	293	0
17	295	222	5837	0	15295	0	887	0	0	0	1108	0
18	447	335	9603	0	16973	2010	112	0	0	0	0	223
19	510	3057	33123	510	69305	0	2038	0	0	1019	0	0
20	2600	684	13547	0	26958	0	821	137	547	137	0	0
21	929	1859	14559	0	30667	0	6815	0	0	929	929	0
22	4639	0	13074	0	45969	0	4639	0	0	11387	0	0
23	2743	609	24688	610	21030	0	914	0	0	0	0	0
24	0	307	1229	0	4301	0	14132	0	0	0	6759	0
25	4077	4331	20893	255	50450	0	382	0	0	0	510	0
26	5101	1943	17975	0	41537	0	729	0	0	0	0	0
27	556	0	3612	0	9863	0	1111	0	0	417	10418	0
28	2469	926	14509	0	32413	309	0	0	0	2161	11730	0
29	617	0	10187	0	12965	0	2161	0	0	0	4939	0
30	441	552	5187	0	14237	0	773	0	221	1214	3090	0

Table 5. Total individuals/cubic meter of different taxa found in samples taken 6/9/21

Station	Calanus finmarchicus copepodite	Centropages copepodite	Centropages typicus adult female	Centropages typicus adult male	Oithona similis copepodite	Oithona similis adult female	Pseudocalanus copepodite	Copepod Nauplii	Bivavle veliger	Evadne nordmanni	Fish egg	Medusae	Oikopleura dioica
1	0	804	0	0	26198	0	0	10608	0	1125	0	1607	0
2	0	15241	0	0	31294	0	4267	7722	4267	813	0	2642	0
3	0	9718	474	0	29392	2370	2844	13748	0	711	0	237	0
4	0	10317	0	0	18993	0	3517	28372	0	469	0	234	0
5	0	25595	1551	388	20554	776	3102	6593	51966	1551	0	1163	0
6	0	15889	378	0	21942	1135	22321	23456	54478	757	0	378	0
7	0	25384	0	0	19038	0	6699	8461	35960	1410	0	1058	2820
8	0	10511	0	0	58394	4088	19854	20438	44963	0	0	0	1168
9	0	27541	393	0	24394	0	17312	12590	27148	0	0	0	787
10	0	26635	0	0	57074	3805	7134	21403	9988	0	0	0	1902
11	0	22731	0	0	32769	0	6790	16532	13875	2066	0	1181	5609
12	0	18910	0	0	30199	0	3951	5080	22014	0	0	0	3105
13	0	11452	0	0	35236	0	15563	18793	13801	587	0	0	1175
14	0	8537	0	0	28894	1751	2627	19919	1094	0	0	0	0
15	0	50525	4890	815	51340	1630	23633	24448	53785	4890	0	0	0
16	0	48646	0	535	65218	0	26729	27263	7484	2673	535	0	1069
17	0	0	0	0	25544	1047	0	8794	14866	2722	209	0	2931
18	0	5069	0	0	33721	882	882	19615	0	0	0	0	220
19	16754	33508	2162	0	19997	1081	0	36210	11349	2162	0	0	5945
20	9691	21177	0	0	26561	0	0	32663	0	0	0	0	4666
21	0	84291	7294	1621	70512	0	26746	15399	3242	0	0	0	5673
22	0	20783	0	770	79283	3079	38487	41566	13085	5388	0	0	2309
23	29635	35750	0	0	19286	0	0	11289	0	15523	941	0	17875
24	9072	18597	454	454	24040	0	907	39009	0	9072	454	0	14969
25	0	4657	0	0	19474	0	0	9314	1552	0	0	0	3246
26	0	0	0	0	4485	0	0	3374	2262	0	0	0	0
27	0	30360	1047	0	16750	0	2094	18495	4188	3839	0	698	10818
28	0	44317	2702	0	42696	0	0	34589	0	1621	1621	0	9728
29	4337	32836	0	0	39651	2478	0	83019	0	0	0	0	7435
30	0	28615	0	0	36990	0	4536	17448	5583	0	0	0	698

Table 6. Total individuals/cubic meter of different taxa found in samples taken 6/25/21.

Discussion

During our May-June sampling periods, we observed no right whales and recorded few *Calanus finmarchicus* copepodites and no *C. finmarchicus* adults. The absence of the whales was possibly related to the near-absence of the copepods that are the primary prey of the whales, which may be due to the warm waters in May and June. Water temperatures during our sampling (Figure 2, Table 2) were consistently higher than 11ºC, which was warmer than the copepod's preferred temperatures of < 10ºC in the North Atlantic (Helaouët & Beaugrand, 2007). Recall that the zooplankton sampling was added to the sampling protocols shortly before sampling began, and that the already-scheduled sampling periods were geared around the May-June period which is the beginning of the period when early-stage lobster larvae are found in the plankton off southern New England (Milligan, 2010). Thus, it is not surprising that we found few *Calanus* or right whales, because the waters were already warmer than times when right whales and abundant *Calanus* aggregations have historically been recorded off southern New England.

According to Record et al. 2019 and Meyer-Gutbrod et al. (2021), the Gulf of Maine and Scotian Shelf underwent a regime shift in 2010, with warming by Gulf Stream-driven warm slope waters entering the region. This created a less-favorable foraging environment for North Atlantic right whales during their historical seasonal migrations from the western Gulf of Maine in winter and spring, to the eastern Gulf of Maine and Scotian Shelf in summer and autumn. Such movements of right whales track abundance of late-stage copepodites of *Calanus finmarchicus*, which are the main prey of right whales.

Calanus finmarchicus is a relatively large (2-4 mm total length), lipid-rich copepod that prefers cold water (Pershing & Pendleton, 2021). In the North Atlantic, this species has its maximal abundance between April and September at temperatures of 6-10ºC (Helaouët & Beaugrand, 2007), and Beaugrand et al. (2002) categorized it as a "subarctic" species. Chust et al. (2014) have characterized the recent distributions of *C. finmarchicus* in the North Atlantic as "one of the most striking examples of poleward migration related to sea warming."

This copepod can occur in surface aggregations that are much more abundant than background concentrations, and right whales are known to locate and feed on such copepod aggregations (Mayo & Marx, 1990; Keeney, R. D. et al. 2001). By the middle of the decade which began in 2010, in concert with poleward shifts in abundance of *Calanus finmarchicus*, which were coincident with warming in the Gulf of Maine, right whales had moved their late spring/summer foraging areas from the Gulf of Maine and western Scotian Shelf northward to the Gulf of St. Lawrence (Meyer-Gutbrod et al. 2021).

In the wind-energy areas off southern Massachusetts and Rhode Island, during a period of extended aerial surveys from October 2011 through June 2015, Leiter et al. (2017) found that sightings of right whales "only occurred during the winter and spring, beginning in December and ending in April." Monthly sighting rates across all years of the survey were highest in February and March. Although there were numerous right whale sightings in the areas south of Martha's Vineyard and Nantucket Island, mainly north of 41ºN latitude, Leiter et al. (2017) concluded that right whales "appear to arrive in December and leave in May, and this seasonal presence is consistent with historical records."

Accordingly, our sampling, while occurring in the right place, appears to have been slightly later than the right time. By the mid- to late-May and June periods of 2021 during our sampling, right whales appear to have already departed from the windfarm areas south of Martha's Vineyard. This was likely related to the paucity of *Calanus finmarchicus* and other larger copepods, and was indicated by our failure to observe any right whales during our sampling. Presumably this northward phenological shift will be exacerbated by further warming due to ongoing climate change. Thus, future efforts to investigate relationships between presence of right whales and abundant copepods in the windfarm areas of southern New England would benefit from sampling earlier in the spring than periods of mid-May through late June.

References

Baumgartner, M. F. & B. R. Mate. 2003. Summertime foraging ecology of North Atlantic right whales. Marine Ecology Progress Series 264: 123-135.

Baumgartner, M. F., T. V. N. Cole, P. J. Clapham, & B. R. Mate. 2003a. North Atlantic right whale habitat in the lower Bay of Fundy and on the SW Scotian Shelf during 1999-2001. Marine Ecology Progress Series 264: 137-154.

Baumgartner, M. F., T. V. N. Cole, R. G. Campbell, G. J. Teegarden, & E. G. Durbin. 2003b. Associations between North Atlantic right whales and their prey, *Calanus finmarchicu*s, over diel and tidal time scales. Marine Ecology Progress Series 264: 155-166.

Baumgartner, M. F., N. S. J. Lysiak, C. Schuman, J. Urban-Rich, & F. W. Wenzel. 2011. Diel vertical migration behavior of *Calanus finmarchicus* and its influence on right and sei whale occurrence. Marine Ecology Progress Series 423: 167-184.

Baumgartner, M. F., F. W. Wenzel, N. S. J. Lysiak, & M. R. Patrician. 2017. North Atlantic right whale foraging ecology and its role in human-caused mortality. Marine Ecology Progress Series 581: 165-181.

Beaugrand, G., P. C. Reid, F. Ibañez, J. A. Lindley, & M. Edwards. 2002. Reorganization of North Atlantic marine copepod biodiversity and climate. Science 296: 1692-1694.

Borkman, D. G. & J. T. Turner. 1993. Plankton studies in Buzzards Bay, Massachusetts, USA. II. Nutrients, chlorophyll *a* and phaeopigments, 1987 to 1990. Marine Ecology Progress Series 100: 27-34.

Chust, G., C. Castellani, P. Licandro, L. Ibaibarriaga, Y. Sagarminaga, & X. Irigoien. 2014. Are *Calanus* spp. Shifting poleward in the North Atlantic? A habitat modelling approach. ICES J. Mar. Sci. 71: 241-253.

Chute, A. S. & J. T. Turner. 2001. Plankton studies in Buzzards Bay, Massachusetts, USA. V. Ichthyoplankton, 1987 to 1993. Marine Ecology Progress Series 224: 45-54.

Costa, A. D., E. G. Durbin, C. A. Mayo, & E. G. Lyman. 2006. Environmental factors affecting zooplankton in Cape Cod Bay: implications for right whale dynamics. Marine Ecology Progress Series 323: 281-198.

Cronin, T. W., J. I. Fasick, L. E. Schweikert, S. Johnsen, L. J. Kezmoh, & M. F. Baumgartner. 2017. Coping with copepods: do right whales (*Eubalaena glacialis*) forage visually in dark waters? Philosophical Transactions of the Royal Society B 372: 20160067.

Ganley, L. C., S. Brault, & C. A. Mayo. 2019. What we see is not what there is: estimating North Atlantic right whale *Eubalaena glacialis* local abundance. Endangered Species Research 38: 101-113.

Ganley, L. C., J. Byrnes, D. E. Pendleton, C. A. Mayo, K. D. Friedland, J. V. Redfern, J. T. Turner & S. Brault. 2022. Effects of changing temperature phenology on the abundance of a critically endangered baleen whale. Glob. Ecol. Conserv. 38: e02193, 15 pp.

Helaouët, P. & G. Beaugrand. 2007. Macroecology of *Calanus finmarchicus* and *C. helgolandicus* in the North Atlantic Ocean and adjacent seas. Mar. Ecol. Prog. Ser. 345: 147-165.

Hunt, C. D., D. G. Borkman, & J. T. Turner. 2010. Phytoplankton patterns in Massachusetts Bay—1992-2007. Estuaries and Coasts 33: 448-470.

Jiang, M., M. W. Brown, J. T. Turner, R. D. Keeney, C. A. Mayo, Z. Zhang, & M. Zhou. 2007. Springtime transport and retention of *Calanus finmarchicus* in Massachusetts and Cape

Cod Bays, USA, and implications for right whale foraging. Marine Ecology Progress Series 349: 183-197.

Keeney, R. D., C. A. Mayo & H. E. Winn. 2001. Migration and foraging strategies at varying spatial scales in western North Atlantic right whales. Journal of Cetacean Research and Management Special Issue 2: 251, https://doi.org/10.47536/jcrm.vi.283.

Keeney, R. D., H. E. Winn, & M. C. Mccaulay. 1995. Cetaceans in the Great South Channel, 1979-1989: right whale (*Eubalaena glacialis*). Continental Shelf Research. 15: 385-414.

Kraus, S. D., M. W. Brown, H. Caswell, C. W. Clark, M. Fujiwara, P. K. Hamilton, R. D. Jeeney, A. R. Knowlton, S. Landry, C. A. Mayo, W. A. McLellan, M. J. Moore, D. P. Nowacek, D. A. Pabst, A. J. Read, & R. M. Rolland. 2005. North Atlantic right whales in crisis. Science 309: 561-562.

Leiter, S. M., K. M. Stone, J. L. Thompson, C. M. Accardo, B. C. Wikgren, M. A. Zanii, T. V. N. Cole, R. D. Kenney, C. A. Mayo, & S. D. Kraus. 2017. North Atlantic right whale *Eubalaena glacialis* occurrence in offshore wind energy areas near Massachusetts and Rhode Island, USA. Endangered Species Research 34: 45-59.

Mayo, C. A. & M. K. Marx. 1990. Surface foraging behavior of the North Atlantic right whale and associated plankton characteristics. Canadian journal of Zoology 68: 2214-2220.

Mayo, C. A., L. Ganley, C. A. Hudak, S. Brault, M. K. Marx, E. Burke, & M. W. Brown. 2018. Distribution, demography, and behavior of North Atlantic right whales (*Eubalaena glacialis*) in Cape Cod Bay, Massachusetts, 1998-2013. Marine Mammal Science 34: 979-996.

Meyer-Gutbrod, E. L. & C. H. Greene. 2018. Uncertain recovery of the North Atlantic right whale in a changing ocean. Glob. Change Biol. 24: 455-464.

Meyer-Gutbrod, E. L., C. H. Greene, P. J. Sullivan, & A. J. Pershing. 2015. Climate-associated changes in prey availability drive reproductive dynamics of the North Atlantic right whale population. Marine Ecology Progress Series 535: 243-258.

Meyer-Gutbrod, E. L., C. H. Greene, K. T. A. Davies, & D. G. Johns. 2021. Ocean regime shift is driving collapse of the North Atlantic right whale population. Oceanography 34(3): 22-31.

Milligan, P. J. 2010. Abundance, distribution and size of American lobster (*Homarus americanus*) larvae in Buzzards Bay, Massachusetts. M. S. thesis, University of Massachusetts Dartmouth, 122 pp. (thesis advisor Jefferson Turner, thesis committee member Kevin Stokesbury).

Murison, L. D. & D. E. Gaskin. 1989. The distribution of right whales and zooplankton in the Bay of Fundy, Canada. Canadian Journal of Zoology 67: 225-232.

Nichols, O. C., R. D. Kenney, & M. W. Brown. 2008. Spatial and temporal distribution of North Atlantic right whales (*Eubalaena glacialis*) in Cape Cod Bay, USA, and implications for management. Fishery Bulletin 108: 270-280.

Parks, S. E., J. D. Warren, K. Stamieszkin, C. A. Mayo, & D. Wiley. 2012. Dangerous dining: surface foraging of North Atlantic right whales increases risk of vessel collisions. Biology Letters 8: 57-60.

Pendleton, D. E., A. J. Pershing, M. W. Brown, C. A. Mayo, R. D. Kenney, N. R. Record, & T. V. N. Cole. 2009. Regional-scale mean copepod concentration indicates relative abundance of North Atlantic right whales. Marine Ecology Progress Series 378: 211-225.

Pendleton, D. E., P. J. Sullivan, M. W. Brown, T. V. N. Cole, C. P. Good, C. A. Mayo, B. C. Monger, S. Phillips, N. R. Record, & A. J. Pershing. 2012. Weekly predictions of North

Atlantic right whale *Eubalaena glacialis* habitat reveal influence of prey abundance and seasonality of habitat preferences. Endangered Species Research 18: 147-161.

Pershing, A. J. & D. E. Pendleton. 2021. Can right whales out-swim climate change? Can we? Oceanography 34(3): 19-21.

Pierce, R. W. & J. T. Turner. 1994a. Plankton studies in Buzzards Bay, Massachusetts, USA. III. Dinoflagellates, 1987 to 1988. Marine Ecology Progress Series 112: 225-234.

Pierce, R. W. & J. T. Turner. 1994b. Plankton studies in Buzzards Bay, Massachusetts, USA. IV. Tintinnids, 1987 to 1988. Marine Ecology Progress Series 112: 235-240.

Record, N. R. & 16 co-authors. 2019. Rapid climate-driven circulation changes threaten conservation of endangered North Atlantic right whales. Oceanography 32(2): 162-169.

Turner, J. T. Planktonic copepods of Boston Harbor, Massachusetts Bay and Cape Cod Bay, 1992. Hydrobiologia 292/293: 405-413. 1994

Turner, J. T. & D. G. Borkman. 1993. Plankton studies in Buzzards Bay, Massachusetts, USA I. Hydrography and bacterioplankton, 1987 to 1990. Marine Ecology Progress Series 100: 17-26.

Turner, J. T., D. G. Borkman, J. A. Lincoln, D. A. Gauthier, & C. M. Petitpas. 2009. Plankton studies in Buzzards Bay, Massachusetts, USA. VI. Phytoplankton, and water quality, 1987 to 1998. Marine Ecology Progress Series 376: 103-122.

Turner, J. T., D. G. Borkman, & C. D. Hunt. 2006. Zooplankton of Massachusetts Bay, USA, 1992-2003: relationships between the copepod *Calanus finmarchicus* and the North Atlantic Oscillation. Marine Ecology Progress Series 311: 115-124.

Turner, J. T., D. G. Borkman, & P. S. Libby. 2011. Zooplankton trends in Massachusetts Bay, USA: 1998-2008. Journal of Plankton Research 33: 1066-1080.

Wishner, K., E. Durbin, A. Durbin, M. Maccaulay, H. Winn, & R. Kenney. 1988. Copepod patches and right whales in the Great South Channel off new England. Bulletin of Marine Science 43: 825-844.

Wishner K. F., J. R. Schoenherr, R. Beardsley, & C. Chen. 1995. Abundance, distribution and population structure of the copepod *Calanus finmarchicus* in a springtime right whale feeding area in the southwestern Gulf of Maine. Continental Shelf Research 15: 475-507.

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