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Temporal Patterns of Arctic and Subarctic Zooplankton Community Composition in Jones Sound, Canadian Arctic Archipelago (1961–62, 1963)

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ABSTRACT. An analysis of overwinter (1961–62) and early summer (1963) collections of zooplankton in Jones Sound, Canadian Arctic Archipelago, found 31 life forms and species, of which 11 species of copepods were dominant. The collections are the earliest on record from the archipelago. These 50-year-old data form a historical base that may assist in analyzing impacts of changing patterns of sea ice distributions. Water-mass-diagnostic copepod species in this study varied with the seasons; those with boreal Atlantic-Subarctic water affinities were present in the winter, but absent or few in number in the summer. Those with Arctic Basin water affinities were few or absent in winter but present or found in greater numbers in the summer. These variations in copepod species may be related to varying presence or proportions of boreal Atlantic water or Arctic Basin water in Jones Sound as also suggested by concurrent physical and chemical oceanographic data. The copepod species found in Jones Sound are also present or dominant in comparable Arctic waters from East Greenland to the Beaufort Sea and in the Arctic Basin, as reported elsewhere, and all reports differ significantly in the relative numbers of the species present from season to season or year to year. Such differences within Jones Sound are documented between the data reported here and those from the summer of 1980 reported elsewhere. It is suggested that these variations also reflect the differing presence or proportions of boreal Atlantic and Arctic Basin water. The conclusion is that Jones Sound and other High Arctic waters are subject to the presence or absence of Arctic Basin waters and boreal Atlantic waters and that the composition of the copepod communities is indicative of those changes.

Key words: Arctic zooplankton, Arctic and Subarctic waters, copepods, water masses

RÉSUMÉ. L’analyse d’ensembles de zooplancton prélevés au cours d’un hiver (1961-1962) et au début d’un été (1963) dans le détroit de Jones, archipel arctique canadien, a permis de repérer 31 espèces et formes de vie, dominées par 11 espèces de copépodes. Ces ensembles sont les plus anciens ensembles à avoir été répertoriés au sein de l’archipel. Ces données prélevées il y a 50 ans forment un fondement historique susceptible d’aider à analyser les incidences des tendances changeantes de la répartition des glaces de mer. Les espèces de copépodes relevées en fonction du diagnostic de la masse d’eau dans le cadre de cette étude variaient d’une saison à l’autre. Les copépodes ayant des affinités avec l’eau boréale subarctique atlantique étaient présents en hiver, mais absents ou en quantité restreinte en été, tandis que ceux ayant des affinités avec l’eau du bassin arctique étaient absents ou en quantité restreinte l’hiver, mais présents ou en plus grand nombre l’été. Ces variations sur le plan des espèces de copépodes pourraient être attribuables à la présence ou aux proportions variées d’eau atlantique boréale ou d’eau du bassin arctique dans le détroit de Jones, telles que le suggèrent également les données physiques et chimiques océanographiques concurrentes. Les espèces de copépodes repérées dans le détroit de Jones sont également présentes ou dominantes dans des eaux arctiques comparables, de l’est du Groenland jusqu’à la mer de Beaufort et dans le bassin arctique, tel que signalé ailleurs, et tous les rapports diffèrent considérablement quant au nombre relatif d’espèces présentes de saison en saison ou d’année en année. Les différences relevées au détroit de Jones sont répertoriées entre les données communiquées ici et celles de l’été 1980 communiquées ailleurs. On suggère que ces variations sont aussi le reflet de la présence ou de proportions différentes d’eau boréale atlantique et d’eau du bassin arctique. On en conclut que les eaux du détroit de Jones et celles d’autres endroits de l’Extrême-Arctique sont assujetties à la présence ou à l’absence d’eau du bassin arctique et d’eau boréale atlantique, et que la composition des communautés de copépodes est indicative de ces changements.

Mots clés : zooplancton de l’Arctique, eaux arctiques et subarctiques, copépodes, masses d’eau

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INTRODUCTION

Temporal and spatial variations in the numbers and species compositions of Arctic marine copepods have previously been noted in a number of reports. This paper, together with oceanographic data reported elsewhere, supports the hypotheses that those variations reflect variations of Arctic and Subarctic water masses and that Jones Sound is a sensitive region for monitoring such changes. Previous to this work in Jones Sound in 1961–62 and 1963, the only comparable year-round zooplankton work in northern Canada was that of Grainger (1959) in Foxe Basin. None had been undertaken within the Canadian Arctic Archipelago. This work was part of a larger project concerned with physical and chemical oceanography through much of the year (Apollonio and Townsend, 2011), the first such study in the archipelago. That project also examined the effects of glaciers on Arctic waters (Apollonio, 1973) and nutrient chemistry, chlorophyll, and primary production in summer months (Apollonio and Matrai, 2011). The intent was to estimate primary production and to characterize zooplankton ecology within the context of physical and chemical oceanographic parameters. The zooplankton community of the archipelago, as was then anticipated, is dominated by pelagic copepods, which are the major link in the energy transfer between the primary producers and higher trophic levels in the pelagic food chain (Michel et al., 2006). Prior to 1961, year-round zooplankton research had been undertaken in East Greenland (Ussing, 1938; Digby, 1954), and since 1963, a number of reports have documented summer zooplankton studies in the Canadian Arctic Archipelago and in adjacent waters. In all cases, copepods were the most numerous of all zooplankton species. Among other results, those studies documented a community of dominant copepod species in the zooplankton communities over a broad range of Arctic waters, and they noted substantial seasonal and interannual variation in the proportions of those species.

Zooplankton collections from a single location on the south side of Jones Sound off Devon Island in the Arctic Archipelago of Canada (Fig. 1) were made periodically from November 1961 into May 1962, and in June and July 1963, as part of a research program of the Arctic Institute of North America (AINA). This paper records the species and numbers of the collections on each sampling date. These data could contribute to the documentation of spatial-temporal distributions of zooplankton assemblages that can be used in modeling the impacts of a shift in sea ice regime on the trophodynamics and biogeochemical cycles of Arctic shelves (Wassman, 1998; Darnis et al., 2008).

Site Description

Jones Sound lies between Ellesmere Island and Devon Island and is about 210 km in length and 29–72 km in width. The sound has a maximum depth of about 800 m, but the zooplankton sampling site lay over a shelf extending from the north shore of Devon Island. The depths do not

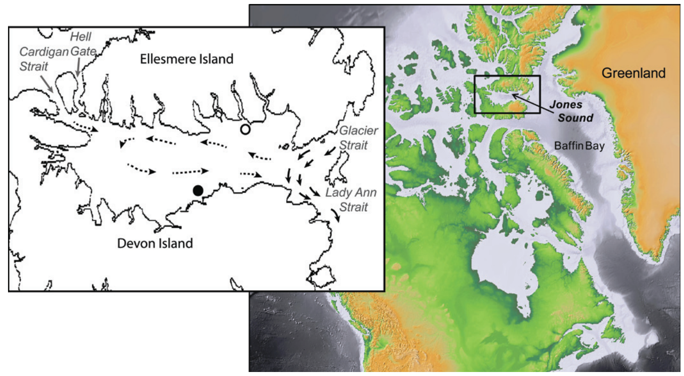

FIG. 1. Jones Sound, showing locations of sampling stations for this study. The black dot shows the zooplankton sampling and oceanographic location November 1961–May 1962 and zooplankton sampling location June–July 1963. The white dot shows the oceanographic stations on the north side of Jones Sound in May 1962 and May 1969. The inferred movement of water to 100 m depth in 1963 is from Barber and Huyer (1977).

exceed about 100 m for about 8 km from shore or 200 m at 11 km from shore. Water from the Arctic Basin enters the sound from the west through Cardigan Strait and Hell Gate, two narrow channels with strong south-flowing currents. Water from northern Baffin Bay and the North Water enters Jones Sound from the northeast through Glacier Strait. The main exit of water is Lady Ann Strait at the southeastern corner of Jones Sound. The sun is continuously below the horizon from 23 October to 8 February and continuously above the horizon from 30 April until early September. Sea ice forms along the coasts of Jones Sound in October, and most of the sound is ice-covered by December or early January. During the 1961–62 winter, the sea ice attained a thickness of about 2 m, with a maximum snow cover of 10–12 cm. The ice was snow-free by 12 June and broke up on 5 July 1962. In the spring of 1963, snow depth was 15–16 cm over 2 m of sea ice, and the ice broke up on 10 August. Collections were not feasible after breakup.

METHODS

The collections began in mid November 1961, when the strength of sea ice was sufficient to sample more than 80 m of water about 3.6 km off the north shore of Devon Island. All the collections in 1961–62 were made from a heated hut over a hole in the ice at 75˚44′ N, 84˚40′ W. Samples were collected at approximately two-week intervals except in April 1962, when no collections were made. In 1961–62, the plankton net was 30 cm in diameter, with 76 µm mesh and 158 µm mesh in the collecting cup. In 1963, the net was 38 cm in diameter, with 239 µm mesh in the net and collecting cup. In 1961–62, a first slow tow from 50 m was followed by a slow tow from 80 m. In 1963, a slow tow from 50 m was made on each sampling date at approximately two-week intervals. Only one slow tow from 80 m was made in 1963, on 5 July. The volume of water filtered in theory was calculated from the area of the mouth of the net multiplied by the length of the tow. A tow in 1961–62

TABLE 1. Numbers of zooplankton, Jones Sound, November 1961–May 1962, collected from 50–0 m, with the number collected from 80–0 m in parentheses.

Zooplankton	Date								
	Nov 14	Nov 28	Dec 24	Jan 17	Feb 1	Feb 19	Mar 7	Mar 18	May 25
Silicoflagellates								0 (1)	
Foraminifera	3 (1)	1 (2)	3 (5)	1 (1)	1 (4)				
Medusa	4 (4)	1 (6)	2 (0)	0 (1)	4 (3)	0 (1)	0 (2)	0 (2)	
Polychaete larvae	0 (2)	1 (0)			0 (1)				3 (5)
Calanus finmarchicus	37 (44)	20 (24)	4 (22)	6 (11)	18 (55)	4 (13)	2 (3)		1 (4)
Pseudocalanus spp.	510 (1006)	434 (416)	274 (441)	110 (83)	224 (368)	72 (232)	34 (58)	560 (545)	37 (34[1])
Microcalanus pygmaeus					67 (98)	89 (152)	71 (117)	36 (35)	171 (192)
Metridia longa	3 (7)	8 (9)	5 (8)	6 (5)	26 (30)	2 (24)	1 (22)	6 (11)	10 (0)
Acartia longiremis						5 (5)	1 (1)	9 (4)	
Oithona similis	370 (420)	407 (528)	436 (462)	172 (183)	463 (487)	133 (297)	203 (337)	169 (115)	120 (114)
Ovigerous *O. similis*	6 (9)	2 (6)		6 (14)	23 (17)	17 (41)	16 (19)	12 (6)	11 (6)
Oncaea borealis	3 (15[1])	2 (0)	28 (6)	11 (20)	23 (17)	4 (28)	11 (37)	0 (9)	5 (5)
Harpacticoids						0 (1)			1 (1)
Unidentified copepods	4 (4)	3 (0)	3 (0)	3 (1)	0 (3)	82 (154)	70 (167)	93 (29)	66 (53)
Copepod nauplii	78 (78)	192 (285)	553 (457)	329 (373)	273 (391)	138 (309)	158 (436)	735 (395)	511 (322)
Zoea larvae									0 (8)
Ostracods						1 (0)		0 (1)	
Decapod			0 (1)						
Euphausiid	1 (0)								
Veliger larvae	1 (2)	3 (4)			0 (4)				
Sagitta elegans	3 (2)	0 (1)	1 (0)		4 (4)	1 (0)		0 (1)	1 (1)
Pluteus larvae						0 (2)	1 (0)	0 (1)	2 (14)
Blastula larvae									0 (163)
Echinoderm juvenile					0 (1)				
Larvacea	0 (4)	3 (5)	1 (0)	3 (1)	15 (6)	3 (1)	4 (7)	4 (0)	3 (5)
Oikopleura	1 (0)								
Fish larvae									1 (1)

[1] One ovigerous female found in tow from 80–0 m.

from 50 m filtered 3.5 m^3; a tow from 80 m filtered 5.6 m^3. In 1963, a tow with the larger net filtered 5.6 m^3 from 50 m and 9 m^3 from 80 m, but 100% filtering efficiency cannot be assumed. Dawson (1978) estimated filtering efficiency at about 50%. Grainger (1959) was similarly cautious in his estimate of filtering efficiency. Collections were preserved in 5% formalin. The entire contents of all but one tow were identified when possible and counted. Because of the high numbers of cirriped nauplii, only one-third of the contents of the tow from 50 m on 23 July 1963 was counted. Those counts were multiplied by three to estimate the total numbers. Counts were made with a binocular microscope (25×) at the AINA research station on Devon Island.

RESULTS

All the data are shown in Tables 1 (for overwinter 1961–62) and 2 (for June–July 1963). The overwinter and summer tows found 31 species and life forms, of which 11 copepod species, including unidentified species, were predominant. Frost (1989) reported that throughout the range of *Pseudocalanus*, *P. minutus*, and *P. acuspes* may co-occur extensively in the Arctic regions and may overlap extensively in size, so that these species were often confused. This information was not known at the time the samples from 1961–63 were analyzed, and this report does not attempt to distinguish between the two species. Those copepods considered here are referred to only as *Pseudocalanus* spp.

Acartia longiremis, not shown in Figure 2, was absent prior to mid February but then appeared in very small numbers (< 10) in all samples through July. Unidentified copepods were found in all samples except the 23 July sample. The highest numbers (154 and 167) were found in late February and early March.

Ovigerous *Pseudocalanus* spp. were found only in June and July. Ovigerous *O. similis* were found in all samples except in December. There does not appear to be a preponderance of egg-bearing *O. similis* in any one season. Copepod nauplii were found in large numbers (200–700) in all samples except the mid November sample (< 80). Cirriped nauplii were found only in June and July, increasing from approximately 80 in mid June to 1964 in early July.

The other life forms all occurred at irregular times and always in small numbers (< 10) except for polychaete larvae, which numbered 154 in late July; harpacticoids (49 in July): and *Fritillaria* (597 on 23 July). These high numbers may reflect reproduction or attraction into the euphotic zone of maximum primary production in July (Apollonio and Matrai, 2011). The relative numbers of ostracods and larvacea reflect the observations of Longhurst et al. (1984) that the former remain deep but the latter are found in near-surface waters. The small numbers of silicoflagellates and foraminifera were perhaps the result of undersampling of those single-cell organisms.

TABLE 2. Numbers of zooplankton, Jones Sound, June–July 1963. Tows from 80 m occurred only on July 5. Parentheses show number of ovigerous females.

	Date				
			July 5		
Zooplankton	June 6	June 19	50–0 m	80–0 m	July 23
Silicoflagellates		1			
Medusa *Aglantha digitale*	4	1	0	9	9
Siphonophore			0	9	
Polychaete larvae		1	0	143	154
Calanus glacialis	15	35	290	341	18
Calanus hyperboreus			25	29	7
Pseudocalanus spp.	109 (9)	75 (1)	164	351	59 (1)
Microcalanus pygmaeus	349	131	132	530	1038
Metridia longa	3	1	3	7	
Acartia longiremis	5	1	7	4	3
Oithona similis	123 (12)	85 (8)	182 (1)	372 (48)	128 (14)
Oncaea borealis	31	20	20	70	48
Harpacticoids		7(1)	0	1	49
Unidentified copepods	66	41	83		
Copepod nauplii	458	353	328	530	337
Cirriped nauplii	78	81	1235	1964	1043
Amphipods		1	2		1
Decapods			1		
Sagitta elegans	3	1	1	5	2
Pluteus larvae	38	3			5
Oikopleura			228		
Fritillaria			0	546	597

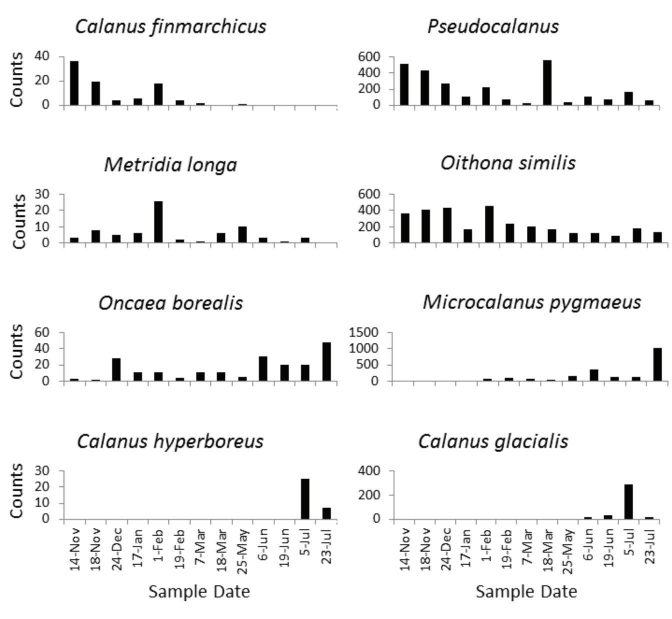

FIG. 2. Numbers of copepods, by species and sampling dates. Note that the vertical scales differ among species. Graphs are arranged to show variations of numbers by seasons.

Figure 2 shows the copepod species from this collection that exhibit characteristic changes in numbers over time. *Calanus finmarchicus* was found in moderate and declining numbers in all but one of the winter-spring samples, but was not found in any of the June–July samples. *Pseudocalanus* spp. and *Oithona similis* were the most numerous of all taxa, the two comprising about 50% of the total number of individuals found. Both species occurred in all winter-spring and summer samples, but in summer, the numbers of both species collected from the 50 m tows averaged about one-half the numbers collected from 50 m in winter-spring. The apparently anomalous high number of *Pseudocalanus* spp. on 18 March could reflect the opportunistic, tidally dependent feeding on ice algae concentrated at the ice-water interface documented by Conover et al. (1986). *Metridia longa* occurred in all samples, in small numbers in the winter-spring and in very small numbers in June–July. *Oncaea borealis* was found in all samples and in rather small but nearly constant numbers from 50 m (average 9.7) in winter-spring 1961–62; it was three times more numerous (average 29.7) in June–July 1963. *Microcalanus pygmaeus* was not found prior to February but then was found in moderate numbers (up to 192) into May and increased to 1038 by 23 July, exceeding numbers of all species except cirriped nauplii. *Calanus glacialis* was found only in the June and July samples, and *C. hyperboreus*, only in July. *C. glacialis* was the more numerous of the two in any sample, reaching 341 individuals in the 80 m tow on 5 July. Figure 2 shows a progression of species from those most numerous in winter-spring to those most numerous in summer.

DISCUSSION

The variations of species and numbers in this collection suggest that the results were influenced by differing proportions of Arctic Basin water and boreal Atlantic (or Subarctic) water, or by the presence or absence of those water masses at the zooplankton sampling site on the south side of Jones Sound. This hypothesis is reinforced by physical and chemical oceanographic data collected from the south and north sides of the sound in May 1962 and by comparable oceanographic data from the north side collected in

May 1969 (Apollonio and Townsend, 2011). Those oceanographic data suggest both regional and annual variations in the presence or absence of the two water masses.

The dominant species in this collection include *C. finmarchicus*, which is indicative of boreal Atlantic water (Grainger, 1962); *Oithona similis*, of no specific affinity; and *C. glacialis*, *C. hyperboreus*, *M. pygmaeus*, and *O. borealis*, which are indicative of Arctic Basin water (Smith and Schnack-Schiel, 1990) and are found from East Greenland (Digby, 1954) to the Chukchi and Beaufort Seas (Darnis et al., 2008).

A number of reports show commonality among the dominant copepod species over broad Arctic regions, but there is considerable variation in the relative proportions or presence or absence of those species, even among those considered to be characteristic of Arctic Basin water (e.g., Ussing, 1938; Grainger, 1959; Cairns, 1967). It is possible that the differences reflect differences among species in their vertical migrations. *C. hyperboreus* carries on seasonal migrations (Dawson, 1978), but it is unlikely that four species with Arctic Basin water affinities would carry out synchronized seasonal vertical migrations, as might be inferred from the present data. Longhurst et al. (1984) noted that diurnal migrations in Arctic species have rarely been demonstrated unequivocally, and that in their work, diurnal migration was nowhere a major factor in the distribution of biota. It is more likely that the differences reported within and among the several reports are functions of water masses originating from the Arctic Basin or from boreal Atlantic regions (Tidmarsh, 1973). The present data (Tables 1 and 2, Fig. 2) show that species showing affinities with Arctic water either appeared only in summer (e.g., *C. glacialis*, *C. hyperboreus*) or increased their numbers (averaged over each sampling date over the winter-spring season and from the summer season) from winter-spring to summer (87 v. 412 for *M. pygmaeus*; 9.7 v. 29.7 for *O. borealis*). *M. pygmaeus* is the dominant copepod in the Arctic Basin for much of the year (Hughes, 1968). The large number found in late July 1963 in this work is consistent with the presence of other copepods with Arctic Basin water affinities, and its increase in summer is consistent with the decline and disappearance from winter to summer of *C. finmarchicus*, a species indicative of boreal Atlantic water.

Canadian Arctic Archipelago waters originate mainly from the Arctic Ocean (Jones and Coote, 1980; Michel et al., 2006), as shown by the widespread occurrence of *C. glacialis*, *C. hyperboreus*, *M. pygmaeus*, and *O. borealis* (Smith and Schnack-Schiel, 1990). Arctic Basin water and its characteristic species enter Jones Sound through Hell Gate and Cardigan Strait in the northwestern corner of the sound. The present data also include species (*C. finmarchicus*, *A. longiremis*, Tidmarsh, 1973) associated with boreal Atlantic or Subarctic water, which enters Jones Sound from the east through Glacier Strait. Glacier Strait receives water from northern Baffin Bay and the North Water, both of which contain portions of boreal Atlantic water. After passing through Glacier Strait, the Subarctic water flows westward along the northern part of Jones Sound (Fig. 1). Barber and Huyer (1977) suggest a cyclonic circulation across Jones Sound west of Cape Sparbo, Devon Island, which brings some boreal Atlantic water from the north side of Jones Sound to the vicinity of this zooplankton sampling site on the south side. The present data indicate that the inflow through Glacier Strait and this gyre may have seasonal or interannual variability. Water with species of boreal Atlantic affinity was present in the winter-spring of 1961 – 62 but much reduced (or absent) in the summer of 1963, when Arctic Basin water was in greater proportion. Unfortunately, the timing of the present data do not permit identification or direct comparison of specific seasonal versus interannual differences; winter-spring data were from 1961 – 62, but summer data were from 1963.

Pseudocalanus spp. and *O. similis* are widespread, common species in both Arctic and Subarctic waters, but are not diagnostic of either water mass (Tidmarsh, 1973). Their occurrence in these collections is consistent with other reports, but the marked reduction of both species in summer further suggests a change in the character of water masses at the sampling site.

Comparisons among several reports suggest year-to-year variations in water mass composition in both Lancaster Sound (Longhurst et al., 1984 vs. Pomerleau et al., 2011) and Jones Sound (this paper and Longhurst et al., 1984). Further, the comparisons suggest variation in the relative proportions of species and mixing of Arctic Basin and boreal Atlantic waters in Jones Sound from year to year and within the year (this paper). For example, the Jones Sound collections in the summer of 1963 showed *C. glacialis* and *C. hyperboreus*, as did the observations in the summer 1980 (Longhurst et al., 1984). But the 1963 collections included *M. pygmaeus* and *O. borealis*, both indicative of Arctic Basin water, while the 1980 data did not. Thus the 1963 composition from the south side of the sound is more indicative, or shows a higher proportion of Arctic Basin water, than the 1980 composition from the north side. One can imagine Arctic Basin water entering Jones Sound from the west and flowing with little mixing along the south side of the sound, whereas boreal Atlantic water enters the sound from the east and mixes in varying proportions on the north side of the sound with Arctic Basin water coming from the west. The difference may also be indicated by oceanographic data from Jones Sound (Apollonio and Townsend, 2011). Those data indicate water at the zooplankton sampling site on the south side of Jones Sound that was less saline and somewhat colder, indicative of Arctic Basin water, than comparable oceanographic data (Apollonio and Townsend, 2011) from the north side of the sound and 65 km from the zooplankton sampling site, also collected in May 1962. That water was more saline and warmer, indicative of boreal Atlantic water. Interannual variation in the presence of different waters on the north side of the sound is suggested by comparison of 1962 and 1969 data (Apollonio and Townsend, 2011), which indicate a greater proportion of Arctic water in 1969 than in 1962. These differences in water masses could be caused by several factors (e.g., wind, ice cover). Bailey (1957) attributed such differences to changes of atmospheric pressure patterns. In the springs of 1961 and 1962, high pressure prevailed over the Arctic Basin northwest of the Canadian Arctic Archipelago, with low pressure east of Greenland. The pressure pattern was reversed in spring 1963, and the change of patterns may be the cause of the variations in copepod communities from 1961–62 to 1963 reported here.

CONCLUSION

Overwinter and summer collections of copepods from Jones Sound in the Canadian Arctic Archipelago, when compared with copepod data from other High Arctic areas, show a high degree of commonality of species but indicate considerable seasonal and interannual variation in the proportions of species. The reports from each area suggest that the changes in species composition result from the presence or absence of boreal Atlantic water in the several areas and the degree of mixing of that water with Arctic Basin water, which generally dominates the entire region. This conclusion is supported by previously published oceanographic data. Copepod data, together with oceanographic data from Jones Sound, provide support for the hypothesis that copepod community compositions reflect areal, seasonal, and interannual variations in the presence or mixing of Arctic Basin and Subarctic, or boreal Atlantic, water masses. These variations, observed 50 years ago, must be taken into account when considering the impacts of climate change on Arctic waters.

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REFERENCES

Apollonio, S. 1973. Glaciers and nutrients in Arctic seas. Science 180(4085):491–493.

Apollonio, S., and Matrai, P. 2011. Marine primary production in the Canadian Arctic, 1956, 1961–1963. Polar Biology 34:767–774.

Apollonio, S., and Townsend, D.W. 2011. Over-winter oceanographic profiles in Jones Sound, Canadian Arctic Archipelago, November 1961–June 1962: Temperature, salinity, oxygen, and nutrients. Arctic 64(4):413–420.

Bailey, W.B. 1957. Oceanographic features of the Canadian Archipelago. Journal of the Fisheries Research Board of Canada 14(5):731–769.

Barber, F.G., and Huyer, A. 1977. On the oceanography of Jones Sound, NWT. Manuscript Report Series, No. 40. Ottawa: Marine Sciences Directorate, Department of Fisheries and Environment.

Cairns, A.A. 1967. The zooplankton of Tanquary Fjord, Ellesmere Island, with special reference to calanoid copepods. Journal of the Fisheries Research Board of Canada 24(3):555–568.

Conover, R.J., Herman, A.W., Prinsenberg, S.J., and Harris, L.R. 1986. Distribution of and feeding by the copepod *Pseudocalanus* under fast ice during the Arctic spring. Science 232(4755):1245–1247.

Darnis, G., Barber, D.G., and Fortier, L. 2008. Sea ice and the onshore-offshore gradient in pre-winter zooplankton assemblages in southeastern Beaufort Sea. Journal of Marine Systems 74(3-4):994–1011.

Dawson, J.K. 1978. Vertical distribution of *Calanus hyperboreus* in the central Arctic Ocean. Limnology and Oceanography 23(5):950–957.

Digby, P.S.B. 1954. The biology of the marine planktonic copepods of Scoresby Sound, East Greenland. Journal of Animal Ecology 23(2):298–338.

Frost, B.W. 1989. A taxonomy of the marine calanoid copepod genus *Pseudocalanus*. Canadian Journal of Zoology 67:525–551.

Grainger, E.H. 1959. The annual oceanographic cycle at Igloolik in the Canadian Arctic. 1. The zooplankton and physical and chemical observations. Journal of the Fisheries Research Board of Canada 16(4):453–501.

———. 1962. Zooplankton of Foxe Basin in the Canadian Arctic. Journal of the Fisheries Research Board of Canada 19(3):377–400.

Hughes, K.H. 1968. Seasonal vertical distribution of copepods in the Arctic water of the Canadian Basin of the North Polar Sea. MSc thesis, University of Washington.

Jones, E.P., and Coote, A.R. 1980. Nutrient distributions in the Canadian Archipelago: Indicators of summer water mass and flow characteristics. Canadian Journal of Fisheries and Aquatic Sciences 37(4):589–599.

Longhurst, A., Sameoto, D., and Herman, A. 1984. Vertical distribution of Arctic zooplankton in summer: Eastern Canadian archipelago. Journal of Plankton Research 6(1):137–168.

Michel, C., Ingram, R.G., and Harris, L.R. 2006. Variability in oceanographic and ecological processes in the Canadian Arctic Archipelago. Progress in Oceanography 71(2-4):379–401.

Pomerleau, C., Winkler, G., Sastri, A.R., Nelson, R.J., Vagle, S., Lesage, V., and Ferguson, S.H. 2011. Spatial patterns in zooplankton communities across the eastern Canadian sub-Arctic and Arctic waters: Insights from stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope ratios. Journal of Plankton Research 33(12):1779–1792.

Smith, S.L., and Schnack-Schiel, S.B. 1990. Polar zooplankton. In: Smith, W.O., Jr., ed. Polar oceanography Part B: Chemistry, biology and geology. San Diego, California: Academic Press. 527–598.

Tidmarsh, W.G. 1973. The copepods (Calanoidea, Cyclopoidea) of northern Baffin Bay and southern Kane Basin; their distribution and aspects of their biology. MSc thesis, Marine Sciences Centre, McGill University, Montreal.

Ussing, H.H. 1938. The biology of some important plankton animals in the fjords of East Greenland. Meddelelser om Grønland 100. 108 p.

Wassmann, P. 1998. Retention versus export food chains: Processes controlling sinking loss from marine pelagic systems. Hydrobiologia 363:29–57.