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Geographical differences in abundance and body size of calanoid copepods *Pseudocalanus newmani* and *P. minutus* in the Sanriku coast, Japan, during spring

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Abstract — *Pseudocanalus* copepods dominate the Sanriku coastal area in the spring. In this study, the geographical changes in the abundance and body size of *P. newmani* and *P. minutus* in the nearshore and offshore waters of the northern and southern Iwate Prefecture were investigated. The abundance of *P. newmani* varied between 96 and 286,513 ind. m^{-2} and was significantly abundant in the nearshore stations. *P. minutus* appeared in the range of 0–1,610 ind. m^{-2}, and no significant differences were seen between the sampling stations. The mean prosome length (PL) of *P. newmani* and *P. minutus* at each collection ranged from 0.73 to 1.01 mm and from 1.02 to 1.38 mm, respectively, and were significantly different at each sampling time. For both species, significant negative correlations were recognized between PL and water temperature at the nearshore stations, however, not at the offshore stations. There were various types of water masses in the offshore area compared with the nearshore area, suggesting that the populations of *Pseudocalanus* copepods consist of a single local population in the nearshore area, whereas the offshore area may include populations with different origins. This suggestion is supported by the fact that the PL frequency distributions of *Pseudocalanus* copepods in the nearshore area were mostly monomodal, whereas those in the offshore area were generally multimodal.

Key words: Copepod, *Pseudocalanus newmani*, *P. minutus*, abundance, prosome length, Oyashio, Sanriku coast

Introduction

In the Sanriku coastal area in early spring, seasonal intense west wind accelerates the exchange of seawater between nearshore and offshore area, and bringing in cold and nutrient-rich water masses, including Oyashio Current (Furuya et al. 1993). Such changes in the water mass structure and nutrient concentrations promote increase of phytoplankton biomass, particularly centric diatoms (Tachibana et al. 2017) and are associated with an increase in zooplankton biomass in the spring season (Nishibe et al. 2016). Zooplankton provide an important prey source for the higher trophic level organisms dwelling in the Sanriku coastal area, particularly for the chum salmon (*Oncorhynchus keta*) fry that descend from the river and inhabit the nearshore waters (Terazaki and Iwata 1983, Yamada et al. 2019). During spring, more than 30% of the zooplankton biomass is occupied by the small copepod genus *Pseudocalanus* (Yamada et al. 2019) in Yamada Bay, which is near the middle portion of the coastal Iwate Prefecture, then which are absent from the Sanriku coastal area for the rest of the year (Nishibe et al. 2016).

Of the genus *Pseudocalanus*, *P. newmani* and *P. minutus* are both known to inhabit the cold waters around Japan (Frost 1989), however, they exhibit different vertical distribution patterns and life histories (Yamaguchi and Shiga 1997, Yamaguchi et al. 1998). *Pseudocalanus newmani* accounts for most of the *Pseudocalanus* copepods that appear in the Sanriku coastal area, while only small numbers of *P. minutus* have been observed (Tsuda and Nemoto 1990). Despite this fact, no studies have clarified the geographical and temporal changes in the occurrence of *P. newmani* and *P. minutus* in the Sanriku coastal areas. In this study, I analyzed zooplankton samples from the nearshore and offshore areas of the northern and southern parts of Iwate Prefecture during spring to examine the distribution of *P. newmani* and *P. minutus*. In addition, the body lengths of both species were analyzed to clarify the geographical factors that influence the changes in body length.

Materials and methods

Samplings were conducted at the nearshore stations KR-0 and TS-0 (2.8 and 2.1 km off from the coast, respectively), and the offshore stations KR-50 and TS-50 (109 and 95 km off, respectively) aboard the FRV "Iwate-Maru" of the Iwate Fisheries Technology Center in April and May 2012–

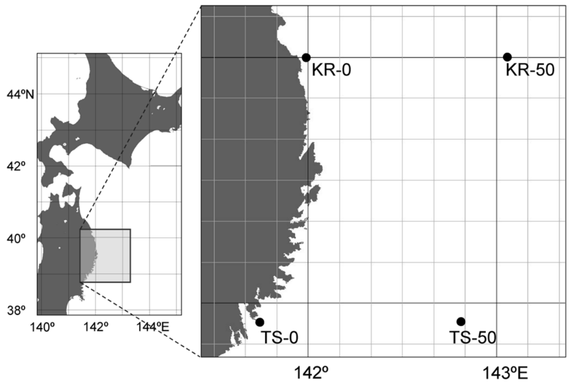

Fig. 1. Sampling stations at nearshore (KR-0 and TS-0) and offshore (KR-50 and TS-50) of Sanriku coastal area.

2014 (Fig. 1). Zooplankton samples were collected with vertical hauls of a remodeled NORPAC net (LNP-net, 45 cm mouth opening, 335 μm mesh, Motoda 1974) from near the bottom (70 m depth) to the surface at KR-0 and TS-0, and 150 m depth to surface at KR-50 and TS-50. The amount of water filtered was measured with a flow meter (Rigo-sha Co., Ltd.). The LNP-net has a cylindrical section of 65 cm under the mouth opening. This net has greater filtration efficiency than the conventional NORPAC net and is often used for fish egg investigation (Goto 1998, and cited therein). The collected samples were immediately preserved in 5% buffered formalin seawater. Water temperature and salinity data were downloaded from the homepage of the Iwate Fisheries Technology Center (2012–2014). Yamaguchi and Shiga (1997) reported that most of the populations of *P. newmani* and *P. minutus* appear at a shallower depth than 50 m at daytime in the spring season (April and July) off Cape Esan, southern Hokkaido, which is adjacent to the present study area. Because of the diurnal vertical migration of *Pseudocalanus* copepods (Yamaguchi et al. 1998), the depth of distribution at night is expected to be shallower. Therefore, assuming that the main distribution depth of both *Pseudocalanus* copepods is 10 m, water mass at that depth was classified into six categories according to Hanawa and Mitsudera (1987).

Adult female *Pseudocalanus* copepods were sorted under a stereo microscope. Copepods were sorted from the entire samples or 1/2 to 1/64 aliquots varied with numerous abundance of the copepods. The sorted adult females were then further identified as *P. newmani* or *P. minutus* according to Frost's (1989) description, i.e., the presence of spines at the posterior end of the ventral margin of the metasome and the shape of the front end of the head. All adult females were photographed using a microscope (SZX16, Olympus Co., Ltd.) equipped with a digital camera (DP-22, Olympus Co., Ltd.). Prosome lengths (PL) were measured to the nearest 0.001 mm using imaging software (CKX-CCSW, Olympus Co., Ltd.).

Differences in abundance and mean PL of both species between the sampling seasons and stations were tested using the Friedman test followed by the Steel–Dwass test, and two-factor ANOVA, respectively. Relationships between PL of both copepods and water temperature in each sampling stations were tested by linear regression analysis. These statistical tests were calculated by the Statcel 4 add-in for Microsoft Excel (OMS Publishing Co., Ltd.). Differences in PL vs. water temperature relationships in each sampling station were tested using ANCOVA with the statistical software R.

Results

Hydrography

During the study period, water temperature and salinity at 10 m depth ranged between 2.6–12.2°C and 32.1–33.9, respectively, at the nearshore stations (KR-0 and TS-0), and 1.04–15.5°C and 32.6–34.4, respectively, at the offshore stations (KR-50 and TS-50, Fig. 2). In 2012, water temperature and salinity were lower than 5.5°C and 33.5, respectively during March and April, which then increased above 9.2°C and 33.6, respectively, after May at the nearshore stations. In the offshore stations, water temperature and salinity were below 5.2°C and 33.6, respectively in March, however, they rose sharply to 9.6–13.2°C and 34.1–34.4, respectively in April.

In 2013, the water temperature and salinity at nearshore stations were 5.3–7.1°C and 33.3–33.8, respectively, during March to April, which was higher than those in 2012. In offshore stations, water temperature and salinity during March to May at northern KR-50 were below 3.9°C and 33.0, respectively, then increased drastically in June (15.5°C and 34.2, respectively). In southern TS-50, water temperature and salinity was low (1.7°C and 33.1) in March, then sharply increased in April (13.2°C and 34.4), and ranged 11.5–15.3°C and 34.1–34.2, respectively, during May to June.

In 2014, the water temperature in March and April was below 4.6°C at the northern nearshore station (KR-0), however, in the southern station (TS-0), the water temperature in March was unseasonably high (8.0°C) and dropped sharply in April (2.6°C). The salinity also decreased drastically from March to April (33.7–32.3). In May and June, the water temperature and salinity in both nearshore stations ranged 7.0–11.0°C and 33.0–33.5, respectively. Similar to the nearshore stations, water temperature in the offshore stations during March and April was below 2.2°C at northern KR-50, however, at southern TS-50, water temperature was unseasonably high (8.9°C) in March, then decreased sharply to 4.2°C in April. The water temperatures in May and June were higher in TS-50 (13.5°C and 10.4°C, respectively) than in KR-50 (6.8°C and 9.5°C, respectively).

Table 1 shows the result of water mass classification performed using water temperature and salinity in 10 m depth at each station according to Hanawa and Mitsudera (1987).

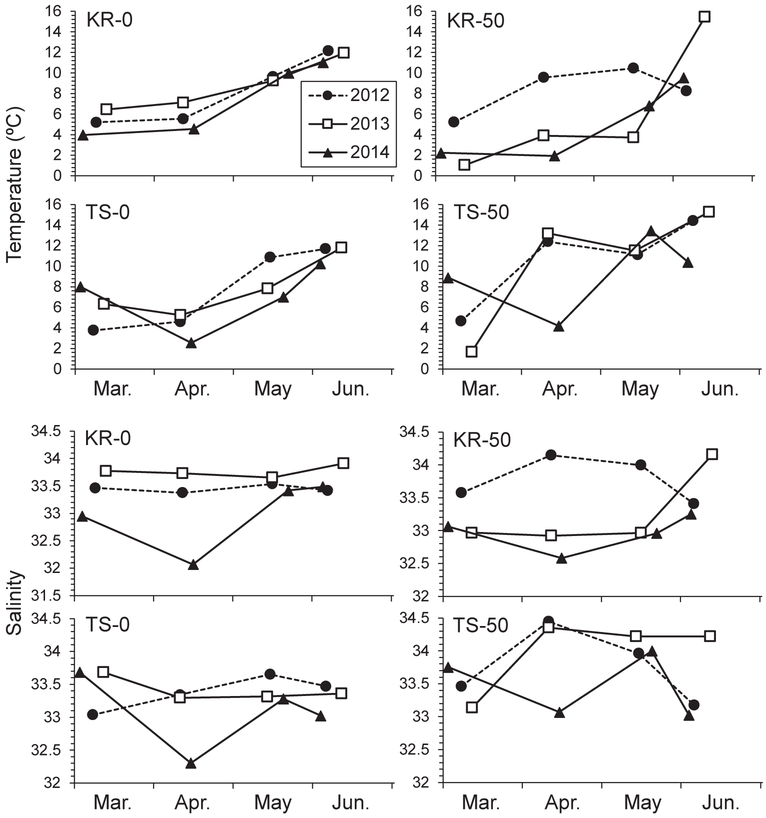

Fig. 2. Changes in water temperature and salinity (10 m depth) at each sampling station during March to June in 2012–2014.

Table 1. Water mass classification performed using water temperature and salinity in 10 m depth at each station according to Hanawa and Mitsudera (1987).

		Station			
		KR-0	KR-50	TS-0	TS-50
2012	Mar.	OW	OW	OW	OW
	Apr.	OW	TW	OW	KW
	May	SW	TW	SW	TW
	Jun.	SW	SW	SW	SW
2013	Mar.	TW	CO	OW	OW
	Apr.	TW	SW	OW	KW
	May	SW	SW	SW	KW
	Jun.	TW	TW	SW	KW
2014	Mar.	SW	OW	SW	TW
	Apr.	SW	CO	SW	OW
	May	SW	SW	SW	TW
	Jun.	SW	SW	SW	SW

OW; Oyashio water, CO; Coastal Oyashio water, SW; surface layer water, TW; Tsugaru Warm Current water, KW; Kuroshio water.

In 2012, the Oyashio water (OW) dominated at all sampling stations in March, but in April, an intrusion of Tsugaru Warm Current water (TW) at KR-50 and Kuroshio water (KW) at TS-50 was observed. In 2013, TW dominated in KR-0 between March and April. During the same period, the intrusion of OW or Coastal Oyashio water (CO) was seen at other stations, however, KW was present in TS-50 in April. In 2014, OW was seen at KR-50 in March and TS-50 in April, and TW was present at TS-50 in March. During this period, the surface layer water (SW) was dominant at other stations. In May and June during the study period, the water mass of all stations was classified as TW or SW.

Pseudocalanus abundance

Over the study period, there was a wide variation in the abundance of *Pseudocalanus newmani* adult females, with a maximum of 286,513 ind. m^{-2} (April 2012) and a minimum of 96 ind. m^{-2} (March 2012, Table 2). The abundance of *P. newmani* tended to increase with time at KR-50 in 2012 (96.2–28,715 ind. m^{-2}) and TS-0 in 2013 (1,976–229,729 ind. m^{-2}), whereas it decreased with time at KR-0 in 2012 (286,513–26,858 ind. m^{-2}), KR-50 in 2013 (11,467–2,282 ind. m^{-2}), and KR-0 in 2014 (194,049–3,834 ind. m^{-2}). Thus, no regularity or pattern was observed in the change of *P. newmani* abundance over time at each sampling site. All sampling sites where the abundance of *P. newmani* exceeded 100,000 ind. m^{-2} were located nearshore (KR-0 and TS-0). By contrast, the maximum abundance at offshore stations was less than 28,715 ind. m^{-2} (at KR-50 in 2012). No significant differences in *P. newmani* abundance were observed between sampling times, but its abundance differed significantly between sampling sites (Friedman test, Table 2). A subsequent Steel–Dwass test confirmed significant differences in the

Table 2. *Pseudocalanus newmani*.

		Abundance (ind. m^{-2})			
		KR0	KR50	TS0	TS50
2012	Mar.	12171	96	7842	472
	Apr.	286513	553	4375	9838
	May	38450	6805	8895	1240
	Jun.	26858	28715	27904	10940
2013	Mar.	7501	2225	1976	701
	Apr.	54806	11467	115021	395
	May	48967	7386	245379	762
	Jun.	3132	2282	229729	905
2014	Mar.	13693	784	1638	1604
	Apr.	194049	4263	10277	730
	May	29733	1027	2266	4454
	Jun.	3834	11433	6428	19856

Test for differences between sampling times (Friedman test)
χ^2=14.1, χ^2(0.95)=19.7
p=0.222

Test for differences between sampling sites (Friedman test)
χ^2=12.1, χ^2(0.95)=7.81, p<0.01

Steel–Dwass test
KR-0 TS-0 KR-50 TS-50

Comparisons of the abundance between sampling times and sampling stations.

Table 3. *Pseudocalanus minutus*.

		Abundance (ind. m^{-2})			
		KR0	KR50	TS0	TS50
2012	Mar.	191	154	20	344
	Apr.	1610	9	621	444
	May	423	0	31	72
	Jun.	164	1612	176	604
2013	Mar.	77	769	127	117
	Apr.	306	75	880	18
	May	328	556	1252	152
	Jun.	102	717	0	181
2014	Mar.	313	298	0	729
	Apr.	626	679	491	194
	May	469	570	169	716
	Jun.	108	885	1024	1430

Test for differences between sampling times (Friedman test)

χ^2=11.6, χ^2(0.95)=19.7
p=0.222

Test for differences between sampling sites (Friedman test)
χ^2=0.9, χ^2(0.95)=7.81, p=0.825

Comparisons of the abundance between sampling times and sampling stations.

abundance of *P. newmani* between KR-0 and KR-50, KR-0 and TS-0, and TS-0 and TS-50 (p<0.05, Table 2).

There were far fewer *P. minutus* individuals compared to *P. newmani*, with a maximum of 1,612 ind. m^{-2} (in KR-50, June 2012) and then 1,610 ind. m^{-2} (in KR-0, April 2012) (Table 3). *P. minutus* did not occur in May 2012 at KR-50, and June 2013 and March 2014 at TS-0. There were no statistically significant differences in the abundance of *P. minutus* between the sampling times or the sampling sites (Friedman test, Table 3).

Pseudocalanus size distribution

The prosome length (PL) frequency distribution of *Pseudocalanus newmani* and *P. minutus* for each sampling time at each sampling station are displayed in Fig. 3 and Fig. 4, respectively. The PLs of *P. newmani* and *P. minutus* ranged

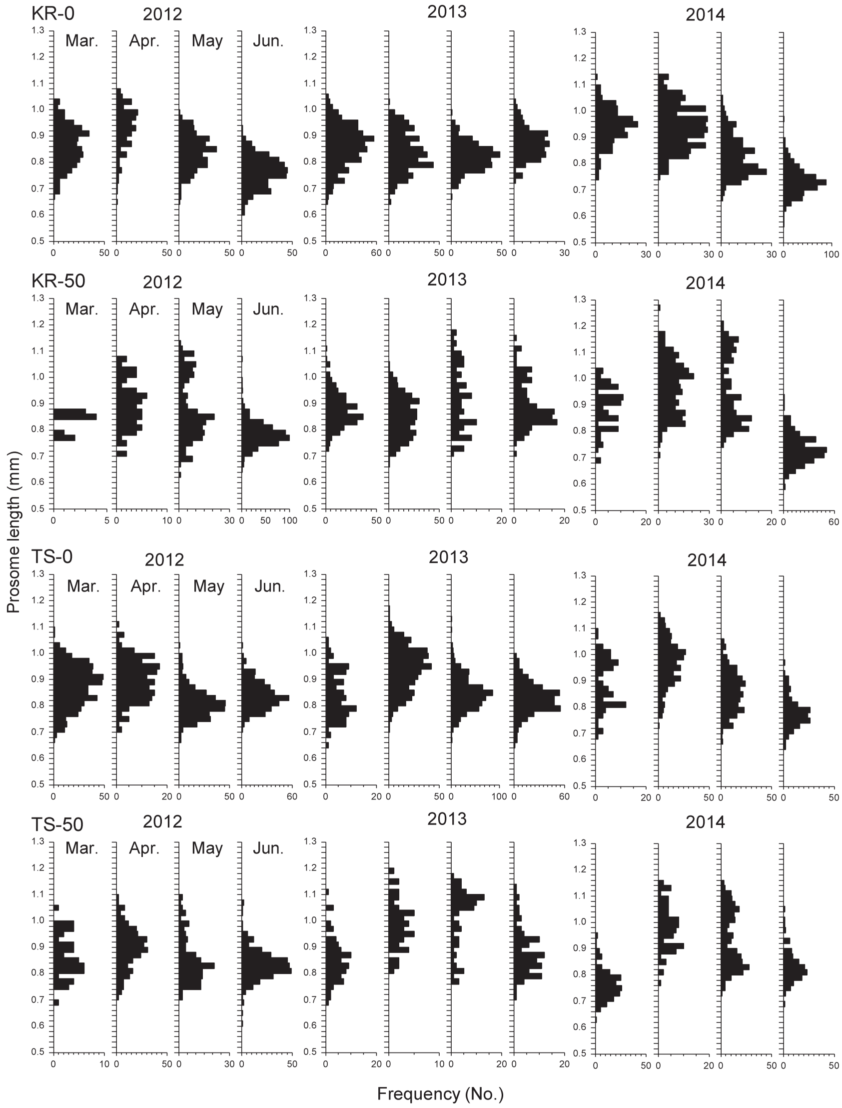

Fig. 3. Changes in prosome length frequency distribution of *Pseudocalanus newmani* at each station during March to June in 2012–2014.

between 0.57 and 1.26 mm and between 0.87 and 1.68 mm, respectively. The mean PLs of both *Psedocalanus* copepods at each collection are shown in Tables 4 and 5. For *P. newmani*, mean PL was significantly varied depending on the sampling time, whereas no statistical difference was observed depending on the sampling site (two-factor ANOVA, Table 4). In contrast, for *P. minutus*, the mean PL was significantly different depending on the sampling times and sites (two-factor ANOVA, Table 5).

In both species, the mean PL tended to increase when water temperature at 10 m depth was low, especially at offshore sampling sites (Tables 4 and 5, and Fig. 2). To confirm this, a simple regression analysis was used to compare the relationships between water temperatures and mean PLs at each sampling site (Fig. 5). The mean PLs of both *Pseudocalanus* copepods significantly increased as water temperature decreased at the nearshore stations (both $p<0.01$, Fig. 5), however, no significant relationship was observed between these two values at the offshore stations (both $p>0.41$, Fig. 5). The slope and intercept of the regression lines were not significantly different between KR-0 and TS-0 for either species (ANCOVA, $p>0.28$, Table 6). Therefore, the data of water temperature and mean PL in KR-0 and TS-0 were combined for each species for regression equations. The equations describing the combined data sets for each station were highly significant for both species ($p< 0.05$, Table 6, Fig. 5).

Discussion

Terazaki (1980) reported that *Pseudocalanus* copepods appear throughout the year in Otsuchi Bay of the central coast of Iwate Prefecture. However, Nishibe et al. (2016) reported that *Pseudocalanus* copepods appear in spring and disappear completely from summer to fall. In the neighboring waters of Okkirai Bay and Ofunato Bay, *Pseudocalanus*

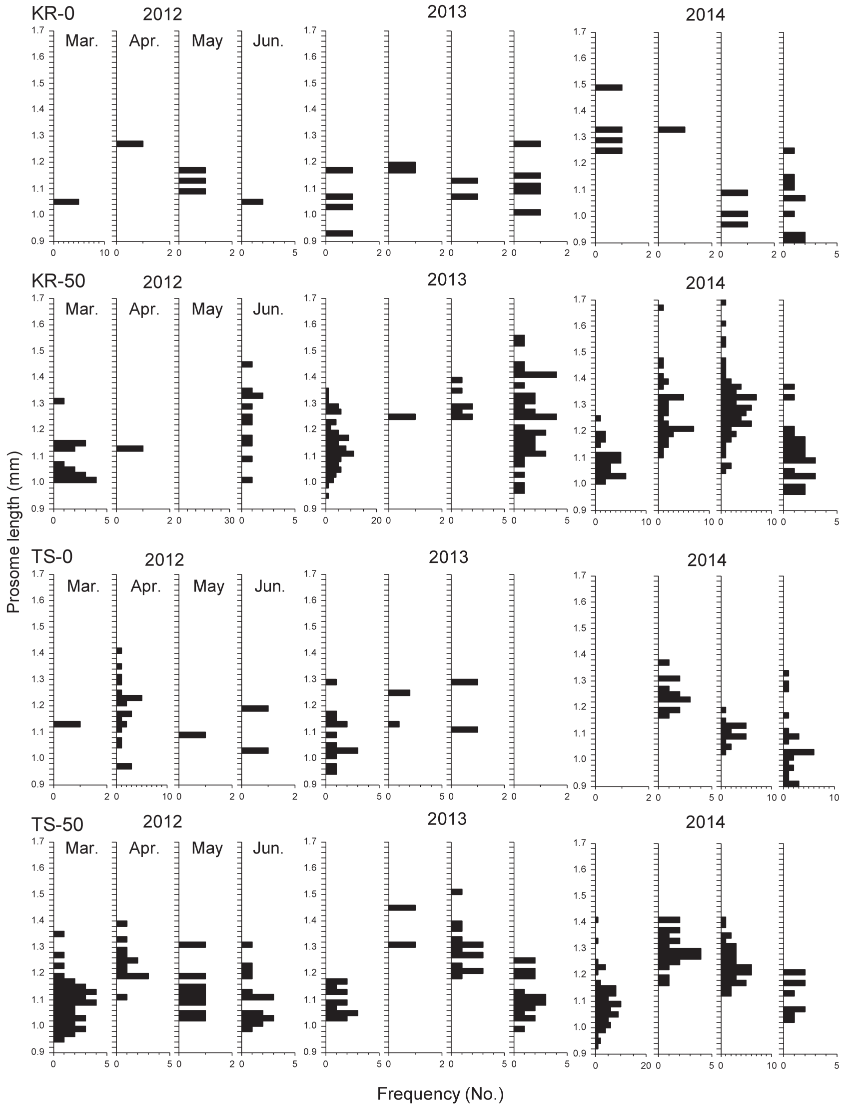

Fig. 4. Changes in prosome length frequency distribution of *Pseudocalanus minutus* at each station during March to June in 2012–2014.

copepods also are absent from summer to winter, then begin to appear in late February to early March (Yamada, unpublished data). The maximum habitable water temperatures for *P. newmani* and *P. minutus* are 15°C and 12°C, respectively (Yamaguchi and Shiga 1997). To avoid high water temperatures, *Pseudocalanus* copepods migrate to deeper layers during the summer to winter in the southwest Hokkaido (Yamaguchi and Shiga 1997) and Toyama Bay (Yamaguchi et al. 1998). In the Sanriku waters, from summer to fall, the water temperature often rises above 20°C through the entire water column in the nearshore area. Concurrently, a warm water core is often formed in the offshore area, and the water temperature rises above 15°C to a depth of 150 m (Iwate Fisheries Technology Center 2012–2014). Therefore, the environmental conditions are not suitable for the habitation of *Pseudocalanus* copepods not only in the nearshore area but also offshore in Sanriku waters. Indeed, *Pseudocalanus* copepods did not appear inside the warm core through the entire water column (0–1000 m), however, appeared at the neighboring Oyashio water mass and the marginal zone of the warm water core (Hattori 1991). *Pseudocalanus* copepods have not been reported to produce diapausing eggs (Mauchline 1998), suggesting that they do not maintain populations in the Sanriku area throughout the year. Instead, it is considered that the seed population of *Pseudocalanus* copepods is transported to the Sanriku area by the inflow of cold water represented by Oyashio and the Coastal Oyashio Current in early spring.

Pseudocalanus are known to be abundant in the Oyashio area (Yamaguchi et al. 2003), and the period when an increase of these copepods in the Sanriku coastal area occurs coincides with an influx of the Oyashio water (Hanawa and Mitsudera 1987). Therefore, the *Psedocalanus* populations in the Sanriku area may also be carried by the Oyashio Current. To confirm this, the abundance of both *Pseudocalanus* copepods at each sampling site were compared between the time when the

Table 4. *Pseudocalanus newmani*.

		Mean prosome length (mm)				
		KR0	KR50	TS0	TS50	
2012	Mar.	0.862	0.832	0.875	0.866	
	Apr.	0.929	0.895	0.899	0.898	
	May	0.839	0.875	0.810	0.848	
	Jun.	0.765	0.784	0.839	0.836	Test for differences between sampling times (two-factor ANOVA)
2013	Mar.	0.863	0.875	0.840	0.853	
	Apr.	0.838	0.851	0.941	0.982	
	May	0.823	0.918	0.847	1.012	
	Jun.	0.870	0.895	0.829	0.882	F=4.65, F(0.95)=2.09 p<0.01
2014	Mar.	0.942	0.891	0.891	0.765	
	Apr.	0.941	0.969	0.969	0.982	
	May	0.829	0.951	0.860	0.932	
	Jun.	0.736	0.732	0.781	0.828	
		Test for differences between sampling sites (two-factor ANOVA) F=1.32, F(0.95)=2.89, p=0.28				

Comparisons of the mean prosome length between sampling times and sampling stations.

Table 5. *Pseudocalanus minutus*.

		Mean prosome length (mm)				
		KR0	KR50	TS0	TS50	
2012	Mar.	1.052	1.080	1.137	1.094	
	Apr.	1.267	1.163	1.178	1.241	
	May	1.131	—	1.096	1.135	
	Jun.	1.053	1.242	1.112	1.099	Test for differences between sampling times (two-factor ANOVA)
2013	Mar.	1.055	1.144	1.079	1.090	
	Apr.	1.175	1.242	1.215	1.384	
	May	1.105	1.298	1.196	1.293	
	Jun.	1.125	1.243	—	1.119	F=6.35, F(0.95)=2.36 p<0.01
2014	Mar.	1.339	1.090	—	1.093	
	Apr.	1.326	1.264	1.248	1.297	
	May	1.021	1.276	1.104	1.239	
	Jun.	1.039	1.110	1.049	1.123	
		Test for differences between sampling sites (two-factor ANOVA) F=0.30, F(0.95)= 3.01, p< 0.05				

Comparisons of the mean prosome length between sampling times and sampling stations.

Table 6. *Pseudocalanus newmani* and *P. minutus*. Result from ANCOVA comparing slope and intercept of water temperature vs. mean PL regression between KR-0 and TS-0.

Species	Result from ANCOVA		Combined simple regression		
	Slope p	Intercept p	a	b	p
P. newmani	0.536	0.659	−0.0152	0.977	<0.01
P. minutus	0.282	0.625	−0.0193	1.288	<0.05

The slope (a), intercept (b) and *p-value* of the simple regression created by combined data of both stations were also shown.

Table 7. *Pseudocalanus newmani* and *P. minutus*.

Species	Station	Abundance (mean±SD)		
		OW & CO	others	*p*-value
P. newmani	KR-0	149342±193990	42102±56453	0.519
	KR-50	1842±1842	8709±9161	0.09
	TS-0	32304±55198	66565±105933	0.497
	TS-50	634±142	5555±6694	0.052
P. minutus	KR-0	900±1003	291±181	0.39
	KR-50	475±296	553±546	0.865
	TS-0	412±407	393±490	0.865
	TS-50	218±115	483±449	0.518

Result from Mann–Whitney's *U*-test comparing abundance between the time when the Oyashio or Coastal Oyashio was dominant (OW & CO) and other water masses existed (other).

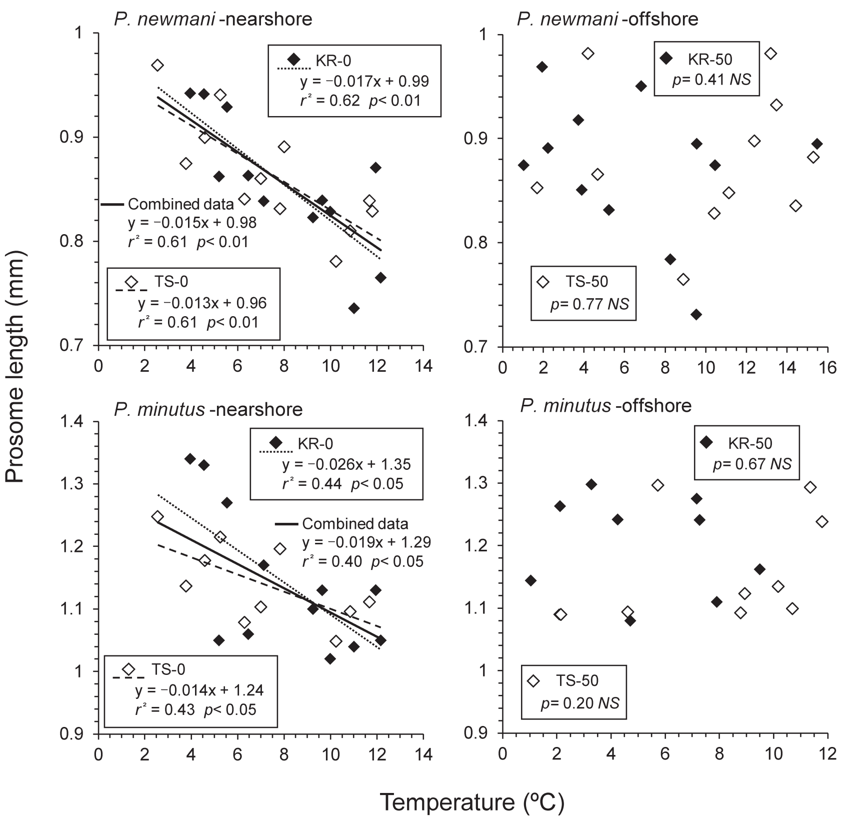

Fig. 5. Relationships between water temperatures and mean prosome length of *Pseudocalanus newmani* (upper panels) and *P. minutus* (lower panels) at the time of each collections in nearshore (KR-0 and TS-0, left panel) and offshore (KR-50 and TS-50, right panel) stations.

Oyashio or Coastal Oyashio Currents was dominant and other water masses existed (Mann-Whitney's *U*-test). As a result, no significant differences were observed between these two periods in the abundance of *Pseudocalanus* copepods at any sampling site (all $p>0.05$, Table 7), suggest that *Pseudocalanus* abundance along the Sanriku area is not affected only by the Oyashio inflow scale. The *Pseudocalanus* samples collected in this study contained a substantial number of adult females carrying eggs. The generation times for both *Pseudocalanus* species are estimated to be 31 to 43 days (Yamaguchi et al. 1998), indicating that the populations are maintained through reproduction in the Sanriku coastal area. Growth and reproduction of copepods are affected by water temperature and cold water carried by the Oyashio Current may delay the growth of *Pseudocalanus* copepods (Yamaguchi et al. 2003). Therefore, it is considered that the abundance of *Pseudocalanus* copepods in the Sanriku coastal area may be affected not only by the Oyashio inflow but also by the subsequent coastal marine environment factors expected to affect the growth and reproduction of *Pseudocalanus* copepods, e.g., water temperature and food availability, etc.

The abundance of *P. minutus* was not significantly different between the nearshore and offshore sampling stations. In contrast, *P. newmani* was significantly more abundant at the nearshore stations compared to the offshore stations in the Sanriku area (Table 2). In the nearshore and inner bay of cold waters, the abundance of *P. newmani* is often very high, ca. 4,000–5,000 ind. m^{-3} (Arima et al. 2014, Kitamura 2018). Kitamura (2018) reported that a reason why *P. newmani* dominated in the spring is that there are few competitors with this copepod because the diversity index (*H*′) of all copepod communities was low (1.3–3.0). In the Sanriku nearshore area, the number of copepod species appearing in early spring was at its lowest around the year (Nishibe et al. 2016), suggesting that fewer competitors are beneficial to the growth and reproduction of *P. newmani*.

In both *Pseudocalanus* species, mean PL of each collection differed significantly depending on sampling times (Tables 4 and 5). Furthermore, water temperature at each collection varied by more than 12°C between sampling times (Fig. 2). Water temperature is the primary factor affecting body size in *Pseudocalanus* copepods (Corkett and McLaren 1978). In general, copepods may attain a greater body size at low temperatures because the stage duration is prolonged in cold water, while growth proceeds at a relatively steady rate (Vidal 1980, Viitasalo et al. 1995). In fact, a negative correlation between *P. newmani* PL and water temperature has been observed in Ishikari Bay, Hokkaido (Arima et al. 2014). In the present study, significant negative correlations were found between mean PL and water temperature in both *Pseudocalanus* copepods in nearshore stations, but not in offshore stations (Fig. 5). Compared to nearshore stations, there were more types of water masses at offshore stations (Table 1). Therefore, *Pseudocalanus* populations with different origins were believed to have been transported to the Sanriku offshore area. Furthermore, due to such frequent changes in water mass, it is possible that the same *Pseudocalanus* populations could not be maintained in the same place. On the other hand, significant negative correlations between both *Pseudocalans* copepods PLs and water temperature were observed at the nearshore stations (Fig. 5), suggesting that the populations of both *Pseudocalanus* copepods consist of a single local population in the nearshore area. These hypotheses are supported by the fact that the PL frequency distributions of *P. newmani* were mostly multimodal in the offshore stations, but were all monomodal in the nearshore stations, except for TS-0 in March 2014 (Fig. 3). As for *P. minutus*, it was not possible to measure the entire PL frequency distributions due to the small number of individuals, however, the differences between the maximum and minimum PL was larger in the offshore stations than in the nearshore stations (Fig. 4), suggesting that multiple populations coexist in the offshore stations.

The PL of *Pseudocalanus newmani* and *P. minutus* in this study ranged between 0.64 to 1.26 mm and 0.97 to 1.68 mm, respectively (Figs. 3 and 4). These ranges had larger maximum PLs for both species compared to those of off Cape Esan (0.79 to 0.95 mm and 1.02 to 1.28 mm, respectively, Yamaguchi and Shiga 1997) and Toyama Bay (0.68 to 0.95 mm and 0.91 to 1.14 mm, respectively, Yamaguchi et al. 1998). In this study, the range of distance from the shore to the sampling sites was between 2.1 km (shortest, TS-0) and 109 km (longest, KR-50), which is considerably wider than the distance off Cape Esan (ca. 34 km) and Toyama Bay (ca. 16 km). The geographically expanded sampling sites allows for the collection of a wider variety of *Pseudocalanus* populations, therefore, it is considered that larger *Pseudocalanus* copepods were collected in the sampling sites of this study.

Because the zooplankton samples used in this study were collected with coarse mesh (335 μm), individuals of all stages of *Pseudocalanus* copepods could not be collected. Furthermore, because the sampling interval was one month, it was impossible to reveal the life histories of *Pseudocalanus* copepods in the Sanriku coastal area during the spring season. The abundance of *Pseudocalanus* copepods in the Sanriku coastal areas varies greatly, especially in the nearshore zone. To clarify the reason behind this, it is essential to investigate the life histories of *Pseudocalanus* copepods in these areas. Therefore, it is necessary to collect zooplankton samples with short intervals using a fine mesh net.

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