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Biochemical composition of *Neocalanus cristatus*(Copepoda; Calanoida) in Oyashio and Kuroshio currents : evidence for southward submergence

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아한대성 요각류, *Neocalanus cristatus*의 화학조성 : 남하침강 증거

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A typical subarctic copepod, *Neocalanus cristatus* copepodite stage V (CV), of three body types, occurred in the mesopelagic layer (500 to 1000m) of the Kuroshio area and Sagami Bay, central Japan. Three types (opaque type with conspicuous amount of lipids and rigid musculatumre, transparent type with poorly developed musculature and no lipids, and intermediate type with conditions between opaque and transparent types) specimen were collected September 1989 to September 1991 in Sagami Bay, and September 2 to 11, 1991 in the Oyashio current, the confluence of the Oyashio and Kuroshio current, and the Kuroshio current including Sagami Bay. First types (transparent) of *N. cristatus* CV were distributed from 0 to 500m in the Oyashio current, from 250 to 700m in the confluence of the Oyashio and Kuroshio currents, and from 500 to 1000m in Kuroshio current and Sagami Bay. Second types (opaque) CV copepodites (50. 0~60. 5%) were distributed from 500 to 1000m in the Oyashio current, from 750 to 1000m in the confluence, the Kuroshio current and Sagami Bay. Epipelagic transparent type CV copepodites from the Oyashio current could not attain the adulthood in Sagami Bay. However, the opaque type and some of the third (intermediate) type CV copepodites originating in mesopelagic water of the north did molt to adult, and they also succeeded in spawning in Sagami Bay around November.

Key words : Calanoida, *Neocalanus*, Chemical composion, distribution,

INTRODUCTION

Biological oceanographers (Furuhashi, 1961a, b; Marumo, 1966) have suggested that Oyashio water sinks as it transports its planktonic inhabitants to the south. Furthermore, Uda (1940, 1949, 1964) proposed that the core of the intermediate water in the Kuroshio region originates from the Oyashio current. A typical subarctic chaetognath, *Sagitta elegans*, is abundant in the intermediate water of Sagami bay at depths exceeding

300m in winter (Marumo, 1966), and a cold-water copepod, *Metridia lucens* is found in the Enshunada off the southern coast of Honshu Island in the Kuroshio current (Furuhashi, 1965). In addition several cold-water copepods have occasionally been found on the west side of the Isu submarine ridge (Omori and Tanaka, 1967)

The southern boundary of *Neocalanus cristatus*, a typical subarctic copepod, has been reported as 28° N, 134° E by Omori (1967), who proposed that reproduction of these cold-water copepods does not occur in pacific waters off central Honshu at depths greater than 400m, where the temperature is lower than 10° C. This species is transported southward in the Oyashio current at a speed of 5.3㎝/s (Omori, 1967), and Yang (1989) has reported the intermediate Oyashio water flow southward at ca. 1㎝/s along the east coast of Boso Peninsula. The reason for this species' failure to reproduce on Sagami Bay, and for its seasonal fluctuation throughout the year and the seasonal variation of its intrusion was clarified by Oh *et al.* (1991).

Body condition for *N. cristatus* stage V (CV) was classified into one of three types (opaque specimens with conspicuous amount of lipids and rigid musculature, transparent specimens with poorly developed musculature and no lipids, and intermediate type specimens with conditions between opaque and transparent types (Ikeda *et al.* 1990).

Oh *et al* (1991) hypothesized two routes of *N. cristatus* in flow into Sagami Bay. The first (transparent type) originates in the surface layer of the subarctic area, this population having no reserve body lipids; the second (opaque) originates in the meso-pelagic layer of the subarctic area. Copepods transported along the former route are CV copepodites in poor nutritional condition; those transported along the latter (less likely) route are CV copepodites and are presumed to be in good physiological condition. They suggested that copepods from the epipelagic source are brought into the bay with inflowing Oyashio water advection, and that those from the meso-pelagic source enter the bay by biological diffusion (including distribution expansion in relation to ontogenetic migration). *N. cristatus* transported from the north, cannot molt to adult stages (except for those originating in meso-pelagic water) due to the adverse environmental condition in Sagami Bay. Instead, they die in the meso-pelagic layer and sink to the bathypelagic layer (1000 to 1400 m). However, the question of whether opaque type CV copepodites originate in the mesopelagic layer of Oyashio current, and whether the opaque type CV copepodites molt to adult and reproduce in Sagami Bay, have remained unanswered.

In the present study, the vertical distribution and difference in chemical composition for three types of *N. cristatus* CV were investigated. The following questions are discussed : two routes of entry of *N. cristatus* throughout Oyashio area to Kuroshio area, the question of whether opaque type CV originate in the meso-pelagic layer of subarctic Oyashio area, whether this species (opaque type) reproduces in this bay.

MATERIALS AND METHODS

Neocalanus cristatus were collectected during crusies of the R. V. "Tansei Maru" and "Hakuho Maru" of the Ocean Research Institute, University of Tokyo at fixed Station P (35°00′ N, 139°20′ E; depth : 1430m) in Sagami Bay from September, 1989 through Septemer, 1992, and were collected during cruise (KT-91-13 : Fig. 1) of R. V. "Tansei

Maru" in Sagami Bay (St. 1), in the Kuroshio current (St. 2), in the mixing zone of the two currents (St. 8, 9), and in the Oyashio current (St. 10, 12 : Fig. 1), using an ORI net (Omori *et al.* 1965) and ORI-VMPS net (Terazaki 1991), September 2-11 September, 1991. The ORI-VMPS net (Mesh size 330 um) was towed vertically (wire speed : 1 m/s) in four water layers : 0-250, 250-500, 500-750, and 750-1000 m, respectively. An ORI net was lowered and recovered at speed of 1 m/s while the ship cruised at 2 knots; 2000 m of wire were paid out. Net depth was estimated from recordings by a T-S depth-distance meter installed on the net. A flow-meter mounted in the mouth of net estimated the volume of water filtered. All zooplankton was preserved in 10% formalin-buffered seawater solution; immediately after collection *N. cristatus* were sorted from the sample.

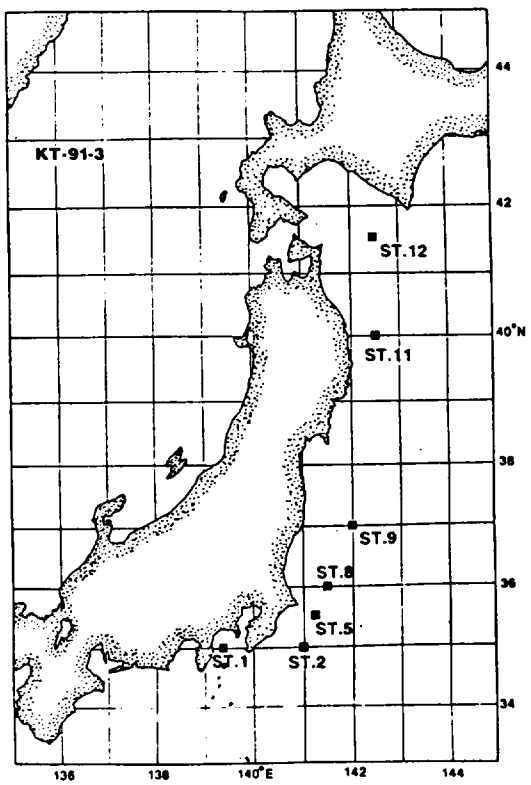

Fig. 1. Sampling stations of *Neocalanus cristatus*.

Body condition for *N. cristatus* CV was classified into one of three types (opaque type specimens with conspicuous amount of lipids and regid musculature, transparent specimens with poorly developed muscula ture and no lipids, and intermediate type specimens with conditions between opaque and transparent types) (Ikeda *et al.*, 1990).

Elemental composition (carbon, nitrogen, hydrogen) and the carbon : nitrogen ratio (C/N ratio) were determined for individual specimens obtained at Sts. P (Oh, *et al.* 1991), 1, 2, 8, 9, 11, and 12 using the Yanagimoto CHN Corder, Type MT-2. The samples were heated at 500°C and combusted at 800°C.

The two water masses, were distinguished by their temperature and salinity signatures; CTD casts were completed during the KT-91 -13 cruise.

RESULTS

The Oyashio current extends as far as St. 11. The mixing of Oyashio and Kuroshio waters is found in the area between St. 8 and St. 9. Sts. 1 and 2 are located in the Kuroshio current (Figs. 1, 2).

The vertical distributions of adult and of the three types of *Neocalanus cristatus* CV are shown in Fig. 3. At St. 12 (located in the Oyashio current), transparent type CV dominated in the 0 to 500m layer (0~250m : 100%; 250~500m : 87%). Opaque type CV copepodites and adults occurred in the 500 to 1000m layer (500~750m : 66.7%, 25.0%, respectively; 750~1000m : 52.9%, 47.1%).

In the Oyashio and Kuroshio confluence (Sts. 8 and 9) the transparent type CV copepodites were distributed from the surface to 750 meters. They were predominant in the 250~500m layer (83.3% in the case of

St. 9). The opaque type CV copepodites were found only at the 750~1000 (61.5% at St. 8; 57.1% at St. 9). Adults were distributed from the 500 to 1000 meters.

At St. 2 (Kuroshio current), transparent type CV copepodites were absent at the surface, but present from 250 to 750m (Fig. 3). Opaque type CV copepodites were found only from 750~1000m (23.8%). Intermediate type CV copepodites and adults were distributed from 500m to 1000m (750~1000m layer : 38.1%). Transparent and intermediate type CV copepodites were distributed from 500m to 1000m at St. 1 (Sagami Bay). A few adult and solid type CV were distributed at the 750~1000m layer only in Sagami Bay. Abundances of *N. cristatus* in Sagami Bay were much lower than those found in either the Kuroshio or Oyashio currents.

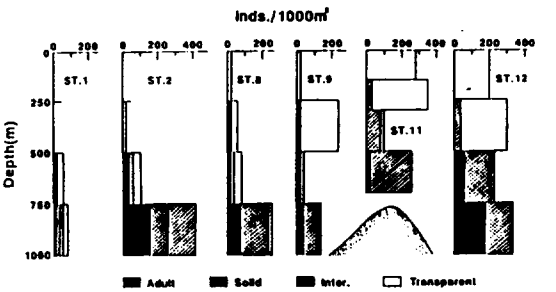

Fig. 3. *Neocalanus cristatus*. Vertical distributions of adult and three type CV (opaque, intermediate and transparent types) specimens at six stations on September on 2 to 11, 1991.

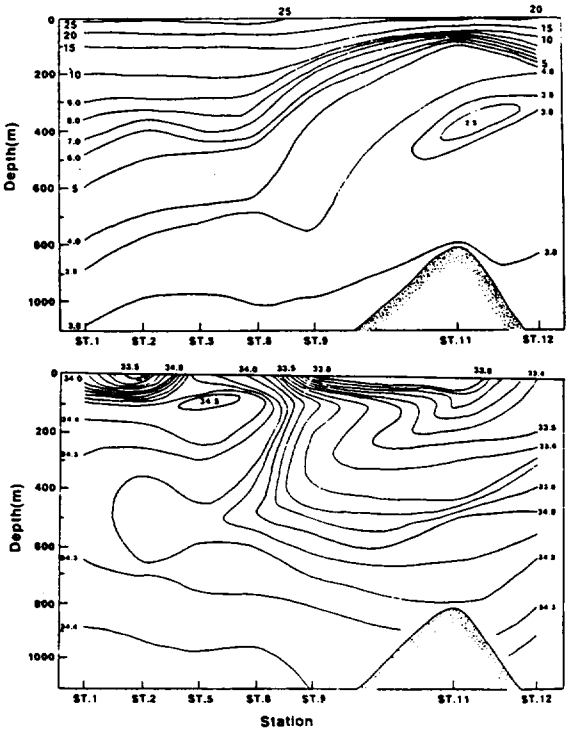

Fig. 2. Vertical profiles of temperature (upper) and salinity (down) observed by the R.V. Tansei Maru in the western North Pacific on September 2 to 11, 1991.

The dry weights and chemical composition of *N. cristatus* occurring in the Sagami Bay and Pacific Ocean off central Honshu Island were examined. Regional variations of carbon, nitrogen and hydrogen and the C/N ratio of *N. cristatus* are shown in Tables 1 and 2.

N. cristatus occurred below the 500m layer at St. 1 (in Sagami Bay). A transparent type of *N. cristatus* CV also occurred at the 500~1000m layer. Carbon contents (% of dry weight) and C/N ratio of the transparent type CV were 46.6~49.2%, 3.2~3.3, and 48.2~48.5%, 4.5~4.8 in intermediate type and 52.4%, 6.3 in opaque type, respectively. Adult of *N. cristatus* occurred at the 750~1000m layer only. The carbon contents and C/N ratio were 52.4%, 5.4 in female, 36.3%, 5.2 in the male.

At St. 2 located in the Kuroshio area, the carbon content of the transparent type CV occurring between the 250 and 750m layers were 38.1~47.3% (C/N ratio : 3.4~3.8). The contents (and C/N ratio) were 45.1~51.3% (4.1~5.1) in the intermediate type, 60.5% (9.6) in solid type, and 48.2~61.4% (4.7~8.0) in adult famales.

Table 1. *Neocalanus cristatus.* **Dry weight (mg per individrals), hydrogen (H), carbon (C), nitrogen (N) and carbon : nitrogen ratio (C/N) of copepodite stage V (CV), female (FCVI) and male (MCVI) sampled by ORI-VMPS net in westhern North Pacific on September 1991.**

Station	Date	Depth (*m*)	Sex (stage)	DW (*mg*/ind.)	% of dry weight			
					H	C	N	C/N
1	3 Sep., 1991	500	CV**	2.24	4.0	48.2	10.6	4.5
		~750	CV*	1.41	4.2	49.2	15.6	3.2
		750	FCVI	3.71	4.4	52.4	9.7	5.4
		~1000	MCVI	4.14	3.5	36.3	7.0	5.2
			CV***	4.97	4.5	52.4	8.3	6.3
			CV**	2.89	4.5	48.5	10.2	4.8
			CV*	1.84	4.3	46.6	14.2	3.3
2	3 Sep., 1991	250 ~500	CV*	2.31	7.7	47.3	12.4	3.8
		500	FCVI	3.00	7.9	48.2	10.3	4.7
		~750	CV**	2.24	3.7	45.1	11.1	4.1
			CV*	0.96	6.9	38.1	11.2	3.4
		750	FCVI	5.33	8.3	61.4	7.7	8.0
		~1000	CV***	7.98	5.8	60.5	6.3	9.6
			CV**	2.23	4.3	51.3	10.0	5.1
8	4 Sep., 1991	0~250	CV*	1.40	9.6	53.4	13.7	3.9
		250	CV**	2.42	8.9	50.5	9.4	5.4
		~500	CV*	1.64	7.3	42.7	11.8	3.6
		500	FCVI	2.99	10.7	64.8	9.0	7.4
		~750	CV**	2.33	6.3	47.8	10.3	5.6
			CV*	1.18	8.3	54.8	12.5	3.7
		750	FCVI	8.03	4.7	58.3	5.9	9.8
		~1000	CV***	8.48	4.1	51.6	6.3	8.2
			CV**	3.87	9.3	51.2	8.8	5.8
9	4 Sep., 1991	0~250	CV*	0.92	4.5	35.7	10.5	3.4
		250	CV**	4.02	6.2	48.2	9.2	5.2
		~500	CV*	1.46	6.5	37.3	12.1	3.1
		500	CV**	4.50	5.9	52.4	10.3	5.0
		~750	CV*	3.53	6.7	43.1	11.4	3.8
		750	FCVI	3.73	9.9	61.6	6.8	9.1
			CV***	9.32	4.7	56.7	6.2	9.1
			CV**	4.73	5.6	53.9	9.0	5.9
11	5 Sep., 1991	0~150	CV*	1.05	5.5	36.2	11.9	3.0
		150	CV**	2.04	8.6	47.8	10.9	4.3
		~300	CV*	1.34	6.5	32.1	10.0	3.2
		300	CV**	1.80	7.8	41.5	11.7	3.5
		~500	CV*	1.25	5.9	33.7	11.0	3.1
		500	CV***	6.78	6.0	52.8	6.9	7.7
		~750	CV**	2.09	7.7	44.0	11.1	4.0
12	6 Sep., 1991	0~250	CV*	1.67	7.4	39.3	11.9	3.3
		250	CV**	1.81	9.2	51.0	12.4	4.1
		~500	CV*	1.52	6.8	40.2	11.3	3.6
		500	FCVI	5.93	7.3	59.3	7.1	8.4
		~750	CV***	8.72	4.9	50.0	6.5	7.7
			CV**	2.75	8.9	49.3	10.9	4.6
		750	FCVI	8.13	5.3	53.6	6.0	8.9
		~1000	CV***	8.14	5.1	59.9	6.2	9.6

* transparent type
** intermediate type
*** opaque type

Table 2. *Neocalanus cristatus.* **Mean dry weight (mg per individrals), hydrogen (H), carbon (C), nitrogen (N) and carbon : nitrogen ratio (C/N) of adult (female : FcVI; male : MCVI) and three types of CV (transparent : T-CV; intermediate : I-CV; opaque type : S-CV) sampled by ORI-VMPS net in western North Pacific on September 2 to 11, 1991.**

Type (Sex)	N	DW (mg/ind.)	% of dry weight			C/N
			H	C	N	
T-CV	15	1.57	6.5	41.4	12.1	3.4
I-CV	15	2.80	6.7	48.7	10.4	4.7
S-CV	7	7.77	5.0	54.8	6.7	8.2
FCVI	8	5.11	7.3	57.5	7.8	7.4
MCVI	2	4.14	3.5	36.3	7.0	5.2

The carbon contents at Sts. 8 and 9 were 37.3~53.4% (3.1~3.9) in transparent, 47.8 ~53.9% (4.6~5.9) in intermediate, 51.6~ 56.7% (8.2~9.1) in opague type, and 58.3~ 64.8% (7.4~9.8) in adult females, respectively.

The dry weight and carbon contents of the transparent type CV occurring at 0~500m at Sts. 11 and 12 were 1.05~1.67mg/ind., and 32.1~40.2%, respectively. Those of the intermediate type collected from the 500~ 750m layer were 1.81~2.75mg/ind. in dry weight and 41.5~51.0% in carbon contents. The C/N ratio was 3.0~3.6 in the transparent type CV, and 3.5~4.6 in the intermediate type.

The seasonal variations of mean dry weight, carbon, nitrogen, hydrogen and C/N ratio are shown Table 3. Mean dry weight per individual of *N. cristatus* CV was 2.64mg (1.11~5.46mg). Females were 2.32mg (September, 1989), 5.12mg (September, 1991), respectively. In the case of females, mean carbon contents were 47.2% (September, 1989) and 49.9% (September, 1990). Mean carbon contents of males were 45.7% (September, 1989), and 48.2% (September, 1991).

In the CV, the mean carbon content was 41.5% (33.5~53.2%). The mean C/N ratios were 5.5 (5.3~5.7) in the famale, 5.7 in the male. In the C/N ratios were higher in summer (3.9~4.4) than winter (2.9~3.2).

In September 1991, the three types of *N. cristatus* CV occurred in Sagami Bay, but the solid type CV did not occur at all seasons. Gravid females and carcasses of the spent female were collected from deep layers of Sagami Bay (Fig. 4).

DISCUSSION

Neocalanus cristatus a typical subarctic copepod, is abundant and is one of the most important constituents of zooplankton biomass in the Bering Sea and the northern North pacific (Omori, 1967; Miller *et al.* 1984). This species performed large-scale ontogenetic vertical migrations (Sekiguchi, 1974). A great number of this species was cofirmed to be transported from north (subarctic area) to south (temperate area). We believe that this large flux of organisms between the subarctic and temperate areas, and between surface and deep layer in the ocean is considerable significance.

Oh *et al.* (1991) reported that two body types (transparent and intermediate) of *N. cristatus* copepodite stage V (CV) occur in Sagami Bay, and suggested that the transparent type CV came from the surface layer of the Oyashio area, and that the inter-

Table 3. *Neocalanus cristatus.* **Seasonal variations of mean dry weight (mg per individrals), hydrogen (H), carbon (C), nitrogen and carbon : nitroge ratio (C/N) of copepodite stage V (CV), and adult female (FCVI) and male (MCVI) sampled by ORI net at fixed station P in Sagami Bay from September 1989 to September 1991.**

Date	N	Sex (stage)	DW (mg/ind.)	% of dry weight			C/N
				H	C	N	
1989. 9	4	FCVI	2.32	4.5	47.2	8.9	5.3
	3	MCVI	3.50	3.9	45.7	8.2	5.6
	12	CV	2.24	5.2	43.2	10.9	4.0
1990. 4	7	CV	1.31	6.3	40.1	12.8	3.3
6	7	CV	4.54	4.8	53.2	13.5	3.9
11	1	CV	1.11	6.3	33.5	11.6	2.9
1991. 2	5	CV	1.20	6.9	38.2	11.9	3.2
9	3	FCVI	5.12	4.3	49.9	8.7	5.7
	3	MCVI	4.98	4.1	48.2	8.5	5.7
	10	CV	5.46	3.3	40.6	9.2	4.4

mediate type CV came from the mesopelagic layer of that same area. In the present study, two routes of inflow are demonstrated by tracing body composition. The solid type CV occurred with other types of CV and adults at the deep layer in Sagami Bay in September.

The vertical distribution of the three types of CV and adult were investigated in each area including Sagami Bay (Fig. 3). The transparent type CV were distributed from 0 ~500m in the Oyashio current (Sts. 11 and 12), in the 0~750m in the mixing area of the Oyashio and Kuroshio currents (Sts. 8 and 9), in the 250~750m layer at Kuroshio area (St. 2), and between 500~1000m in Sagami Bay. On the other hand, the opaque type CV copepodites were distributed from 500 to 1000m in the Oyashio current (St. 12), 750 to 1000m in the mixing area, the Kuroshio current, and in Sagami Bay. It is evident that transparent type CV copepodites collected from Sagami Bay, transported from the north (subarctic Oyashio area) with the inflowing Oyashio current, and adults occurring in this bay, originated from the mesopelagic layer (500 to 1 000m) of the Oyashio area.

Ikeda *et al.* (1990) suggested that among those found in the southern waters of the Japan Sea, Opaque type CV copepodites can be expected to moult to adults, but the fates of the intermediate and, particularly of the transparent type CV copepodites, which occurred at all seasons, are unknown. We could demonstrate moulting to adults by comparing the number of adults (especially gravid females) (Fig. 4-A) and intermediate CV, by discovering the spent females (Fig. 4-B) which occurred in the deep layer in Sagami bay. They may be hatched at the deep layer in this bay, although we could not obtain early copepodite stages. Kidachi and Obata (1971) obtained a few copepodite II and III of *N. plumchrus* in this bay. These should probably be considered to be derived from the deep living gravid females of Sagami Bay rather than from the ones in the earlier stages living in surface water in the Oyashio area; though whether early copepodite stages are removed to another area or die due to poor environmental conditions is unknown.

However, the transparent type CV which

originated in the surface waters of the Oyashio current, probably died in the mesopelagic layer in Sagami Bay. Oh *et al* (1991) reported that *N. cristatus* CV carcasses represented 7.6% of specimens between 500 and 1000m and 35.3% of specimens between 1000 and 1400m being just above sea bottom. It is suggested that many of the carcasses of this species immediately above the sea bottom were drived from copepodites living in the mesopelagic layer of the bay.

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