SOME ASPECTS OF THE DISTRIBUTION OF *CALANUS CRISTATUS* AND *C. PLUMCHRUS* IN THE BERING AND ITS NEIGHBOURING WATERS, WITH REFERENCE TO THE FEEDING OF BALEEN WHALES

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Generally speaking, copepod crustaceans are one of the most important foods for some baleen whales as well as other marine fish. They occupy the most part of the abundance of the zooplanktons in the sea. In the Bering sea and in the northern part of the north Pacific, copepods are one of the most important foods for baleen whales along with euphausiids and fish. Among baleen whales, fin whales usually take *Calanus cristatus* besides euphausiids, and right and sei whales are feeding on *C. plumchrus* favorably (Nemoto, 1959). These selections of their foods are closely related to the feeding apparatus of baleen whales (Tomilin, 1954 : Nemoto, 1959). The distribution of the copepods as a food of baleen whales is examined here from the observation of stomach contents of baleen whales in relation to their feeding.

MATERIALS

The materials treated in this paper have been obtained from the collected samples of stomach contents of baleen whales caught from 1952 to 1961. Plankton samples collected in 150 and 200 meter vertical tows with 45 cm diameter and 0.33 mm net have been also included with other data published by Anraku (1954) and Minoda (1958). The measurements of cephalo-thorax length are only made on the fresh unbroken specimens in plankton net samples or stomachs of baleen whales saved from digestion. Oceanographical materials of the Bering sea and adjacent waters are based on following data.

Data collected by Whales Research Institute.
Data record of oceanographic observations and exploratory fishing. No. 1—5 by Hokkaido University.
Oceanographic data on the northern part of the north Pacific. No. 1—3.

DISTRIBUTION OF FIN AND SEI WHALES

The distribution of baleen whales in the Bering sea and its adjacent waters is considered from the charts of the catch distribution to some extent. As already discussed by Nemoto (1959) sei whales belong to *Ocean denizen type* and comparatively rarely penetrate into the marginal sea. The observation of sei whales has scarcely been recorded in the Bering sea in the whaling these days except some Japanese

records. The number of sei whales found by the whale searching is also very few in the Bering sea in high latitudes (Nemoto, 1959). On the other hand fin whales are considered to be *Ocean* and *Marginal sea denizen* which distribute widely in the Bering sea and even penetrate into the Arctic sea. From the catch statistics in Japanese operations in recent 10 years, 8 main whaling grounds for fin whales have been drawn in the Bering sea and adjacent waters. As illustrated in Fig. 1, the most heavy catch is observed in the north waters of the east Aleutian Islands, where euphausiids *Thysanoessa inermis* and *T. longipes* are very abundant. *Thysanoessa inermis* distributes along the Alaskan continental shelf and *T. longipes* in the off waters of the north waters of the east Aleutian Islands. In this off waters of the said area, *Calanus cristatus* also appears as a food for fin whales (Nemoto, 1959).

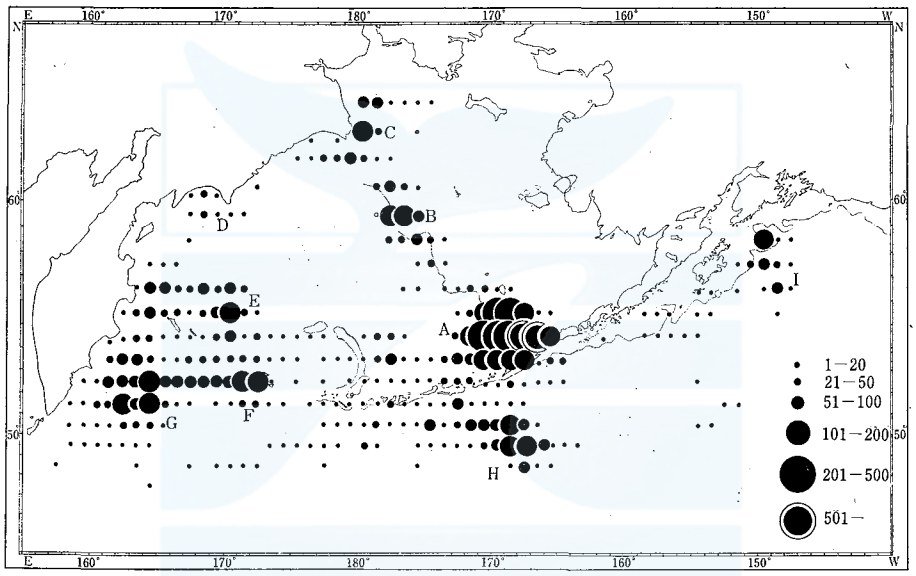

Fig. 1. Distribution of fin whales caught by Japanese whaling from 1952 to 1961.

It has occurred very often in the stomachs of fin whales in 1955 and 1956 seasons, and many fin whlaes have swarmed to feed *Calanus cristatus*. In the northern part of the Bering sea, there have been observed three regions of the concentration of fin whales as illustrated in Fig. 1. Along the Alaskan continental shelf waters, considerable number of fin whales have been taken where Alaska pollack is the food for fin whales (Fig. 1-B.) In other grounds C and D, fin whales sometimes have fed on *Thysanoessa raschii* and caplin which distribute in the waters off cape Navarin (Fig. 1-C). A few catch of fin whales is also observed in Olyutorskiy Bay, where the abundand crop of *Calanus cristatus* for baleen whales was already reported by Brodsky (1950). But fin whales which have been caught by Japanese whaling expeditions in the Olyutorskiy bay in June in 1960 have scarcely taken *Calanus cristatus*. Fin whales caught in Olyutorskiy bay have fed on herring (*Clupea pallassi*) and caplin (*Mallotus catervarieus*). It is safe to say that fin whales feeding in the said areas feed mainly on fish or euphausiids and few occurrences of *Calanus*

cristatus. In the southern Kamtchatka side of the Bering sea, *C. criatatus* is one of the important food for fin whales as illustrated in Fig. 2. In the adjacent waters to Attu Islands (Fig. 1-F), fin whales swarm to feed on *C. cristatus* every year from June to July especially in the late of July. The stage of the *C. cristatus* is copepodite 5 in generall and it coincides with the cycle of it in the waters as established by Heinrich (1957). The considerable part of the copepodite stage 5 *Calanus cristatus* distributes in the surface strata of the north Pacific. (Vinogradov, 1955). In the southern waters of Sagami Bay of Japan, the immature *C. cristatus* also inhabits in the intermediate layers between 300–500 meter and adult specimens are usually found in the depth deeper than 500 m (Tanaka, 1956).

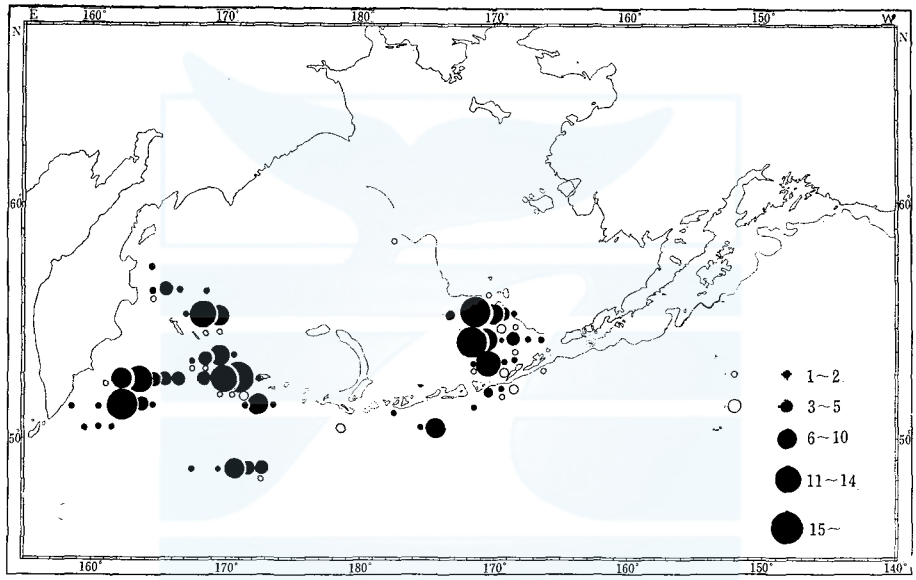

Fig. 2. Distribution of *Calanus cristatus* and *C. plumchrus* in the stomachs of fin whales in the Bering sea and Adjacent waters. Black—*C. cristatus*, Open—*C. plumchrus*.

The swarm of *C. cristatus* is considered to sink to the deeper waters to attain their growth and to spawn. Generally, *C. cristatus* spawn in the waters deeper than 500 m in the Bering sea and adult *C. cristatus* is also found in the deeper waters in Kuril-Kamtchtka region (Vinogradov, 1955). Fin whales can dive as far as about 300 m (Scholander, 1940), and it is considered usual feeding range of the baleen whales do not exeed 300 m. Thus swarms of adult *Calanus cristatus* escape the swallowing of baleen whales. In other two waters, Copepodite 5 stage of *C. cristatus* stay in the upper layer waters later than July. As a second important copepoda, *Calanus plumchrus* occurs in the south waters of the Aleutian Islands from June to August. The occurrence is also observed in July and August in the north waters of the east Aleutian Islands (Fig. 2).

The whaling grounds formed by *Calanus cristatus* extinct as soon as the subsiding of *C. cristatus* to reproduct in the unattainable depth of fin whales. In the ‘ Calanus

year' (Nemoto, 1959), fin whales heavily swarm in the area F and E in Fig. 1 in June and July, however, blue whales usually do not come to the areas by the late of August and September. On the other hand, fin whales have not been attracted by *C. cristatus*, and feeding on the heavy shoals of euphausiids in the waters E, in 'Euphausiid year'. In 1954, many fin whales were feeding in waters along the Alaskan continental shelf but they were feeding in the off waters of the shelf on *Calanus cristatus* in 1955 when euphausiids were rather scarce along the shelf.

The second *Calanus* feeder is the sei whale in the northern part of the North Pacific. Sei whales are the *Ocean denizen* and majority of them come only as far as the Aleutian archipelago. The catch of sei whales, however, usually have been done in the south of the Aleutian Islands as the main herd of sei whales do not penetrate into the Bering sea. As it is shown in Fig. 3, the main concentrations of sei whales catch are observed in the waters off Kamtchatka and along the Aleutian Islands.

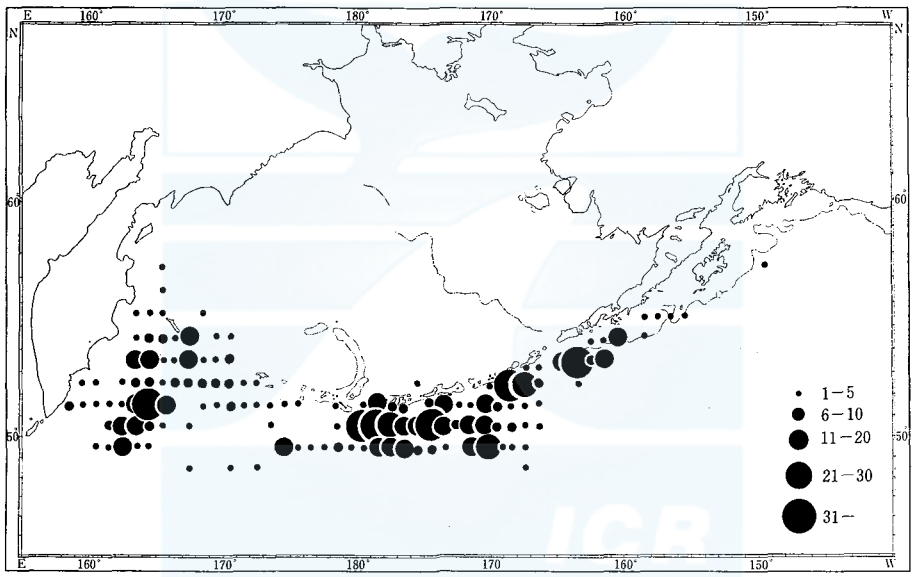

Fig. 3. Distribution of sei whales caught by Japanese whaling from 1952 to 1961.

As a generall tendency, sei whales come to the waters off Kamtchatka in summer when the height of *Calanus plumchrus* is observed (Heinrich, 1957), Heinrich shows two groups of *C. plumchrus* in the waters and sei whales mainly feed the group which attains their copepodite stage 5 in August. But sei whales are already feeding in the south waters of the east Aleutian Islands in June. This also suggests that *C. plumchrus* is abundant in this area in June.

In the stomachs of sei whales, the majority of *Calanus plumchrus* is in copepodite 5, and a few specimens of copepodite 4 are also found among copepodite 5. This differs the case of *Calanus cristatus* found in stomachs of fin whales in which very few copepodite 4 is found in the mass of *Calanus cristatus*.

The food of sei whales in the northern part of the north Pacific is already discussed by Nemoto (1959), and the most sei whales have been feeding on copepods.

The number of sei whales fed on other foods, euphausiids and squids are rather scarce when the data are compared with the one in the adjacent waters to Japan. The destribution of *Calanus* copepoda identified in the stomachs of sei whales are illustrated in Fig. 4. Although the collected number is not so many, the main part of the food *Calanus* is *Calanus plumchrus*. It is suggested these main concentrations of sei whales fairly coincide with the waters where *Calanus plumchrus* are abundant.

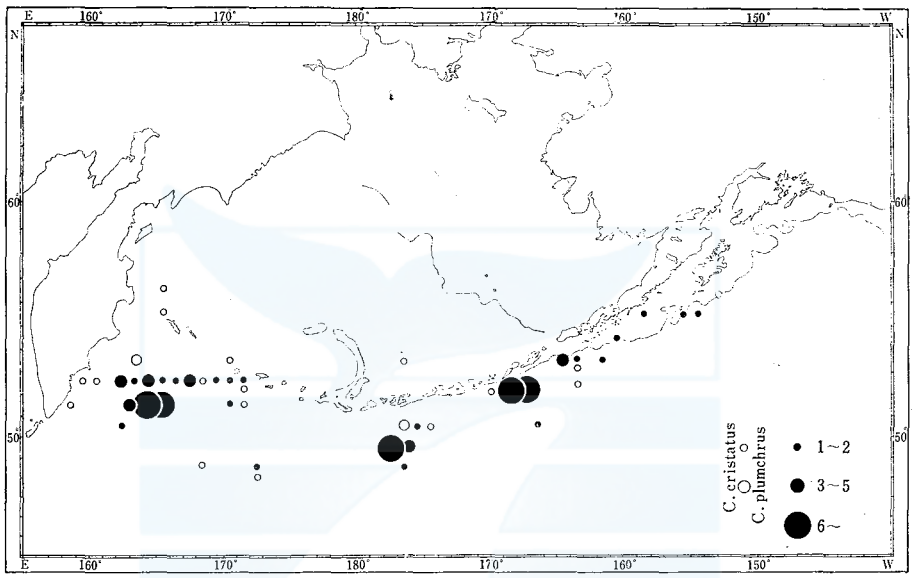

Fig. 4. Distribution of *Calanus cristatus* and *C. plumchrus* in the stomachs of sei whales in the adjacent waters to Aleutian Is. Black—*C. plumchrus* Open—*C. cristatus*.

DISTRIBUTION OF *CALANUS CRISTATUS* AND *C. PLUMCHRUS* IN THE SURFACE STRATA

According to Bogorov & Vinogradov (1960), *Calanus cristatus*, *C. plumchrus* and *Eucalanus bungii* occupy the 80 per cent of biomass of the Kuril-Kamtchatka region. In the surface collecteons of copepods by the vertical plankton net, both *Calanus cristatus* and *C. plumchrus* are found most commonly in the waters investigated. These occurrences of both species show, however, some interesting features as discussed following.

Calanus cristatus found in the stomachs of fin whales usually consists of copepodite stage 5, and adult *C. cristatus* has not been found in the stomachs of baleen whales. The positions where copepodite stage 5 of *C. cristatus* is found in the net collections are plotted in Fig. 5. As it has been considered, *C. cristatus* distributes mainly in the waters which have depth deeper than 500 m and naturally it is found in the deeper waters in the Bering sea. *Calanus cristatus* has not been found in some plankton net towed along the Alaskan continental shelf and Chukchi sea as shown in

Fig. 5. *C. cristatus* has not been collected in the stations within the Alaskan shelf and 5 station in the Siberian side of the Chukchi sea. Of course both areas are little influenced by the Bering sea current which may bring *C. cristatus* from the off water. In the Chukchi sea, Johnson (1956) already reports the occurrences of *C. cristatus* as the visiter from the southern fauna in the Alaskan side of the Chukchi sea. The clear segregation in occurrences of *C. cristatus* in the Chukchi sea is apparently affected by the sea current through the Bering strait and shore waters along the Siberian side.

The number of *Calanus cristatus* in the shallower waters of Chukchi sea is very scarce in the vertical net from the bottom, and adult spectmens have not been collected. The adult *Calanus cristatus* has not been collected by surface plankton nets in other waters of the Bering sea (Anraku, 1954: Minoda, 1958), and it is considered it usually distributes in the waters lower than 500 m.

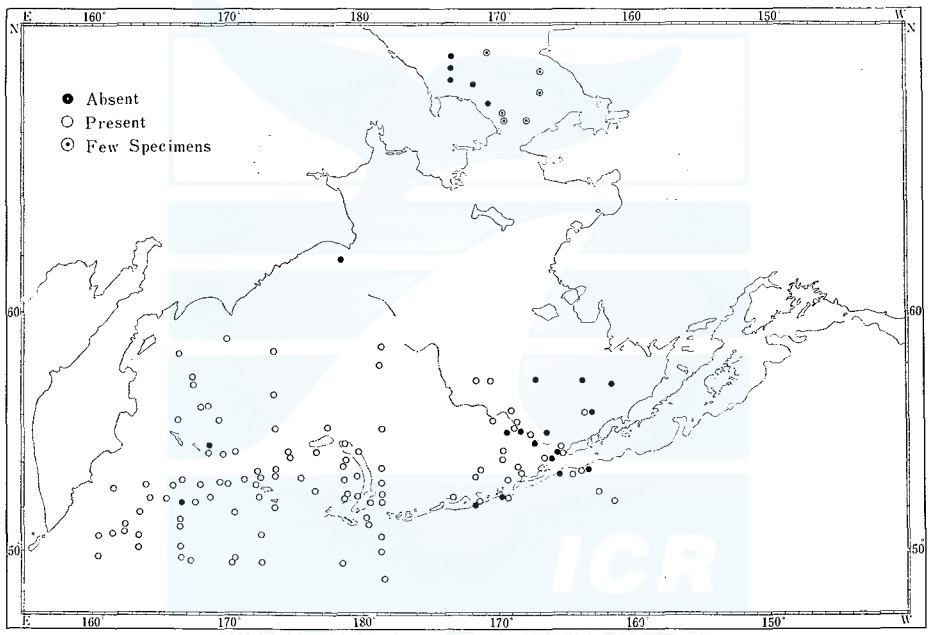

Fig. 5. The occurrences of *Calanus cristatus* in the vertical plankton Net in the surface strata above 150 m and 200 m in the Bering sea and Chukchi sea.

The general distribution layers of the two *Calanus* species are defferent. Copepodite 5 stage of *C. plumchrus* distributes shallower waters than *C. cristatus* (Vinogradov, 1956). This coincides with the swimming depth of fin and sei whales in their usual feeding. (Nemoto, 1959).

The occurrences of *Calanus plumchrus* in the vertical plankton nets towed in surface layer in the Bering sea are plotted in Fig. 6. Both adult and copepodite 5 stage of *C. plumchrus* are more commonly found in the Bering sea and the latter appears in the almost all collections in the investigations. It also occurs in the Chucki sea in several stations. Especially adult *C. plumchrus* is observed in shallow stations

of Chukchi sea and Alaskan shelf as shown in Fig. 6. Adult *Calanus plumchrus* has been found only three net collections towed in stations in the deeper waters off the Alaskan shelf and the west waters, however, it occurs in several shallower stations in Alaskan shelf and Chukchi sea. The adult *Calanus plumchrus* is found in the deep waters of the Bering sea and usually deeper than 200 m (Anraku, 1954). This suggests that *Calanus plumchrus* becomes adult in the shallower waters if it can't subside to deeper waters, although the adult *Calanus plumchrus* spawns like *Calanus cristatus* in the deeper waters. Anraku (1954) reports the adult *Calanus plumchrus* distributes usually in the waters deeper than 150 m or 200 m in the west side of the Bering sea.

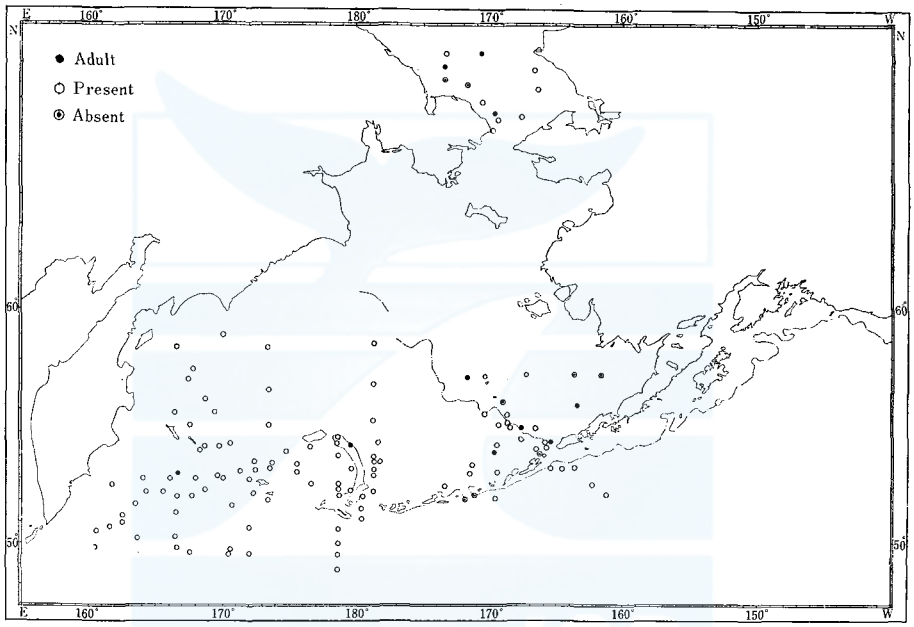

Fig. 6. The occurrences of *Calanus plumchrus* in the vertical plankton net in the surface strata avove 150 m and 200 m in the Bering and Chukchi sea.

In the stomach contents of fin and sei whales caught, there has been no record of adult *Calanus plumchrs* not to say *Calanus cristatus*. It may be reasonable to consider that those baleen whales usually not to feed in the deeper waters where the adult *Calanus plumchrus* and *Calanus cristatus* are reproducing. The number of adult *Calanus plumchrus* sometimes amounts considerable number in the plankton net towed in the Alaskan shelf waters (Minoda, 1958). *Calanus plumchrus* has been collected in almost all stations in the Bering sea as stated above, but it has not occurred in 3 stations along the east Aleutian Islands, 3 stations in the Alaskan continental shelf and 2 stations in the Siberian side of the Chukchi sea. These waters are also shallower and the number of *Calanus plumchrus* is restricted by the environmental conditions.

BODY LENGTH VARIATION

The variations of body length of *Calanus plumchrus* and *C. cristatus* are discussed by Heinrich (1957). The materials collected in Whales Research Institute during 1952 to 1956 are measured, the positions of collections of which are also illustrated in Fig. 7.

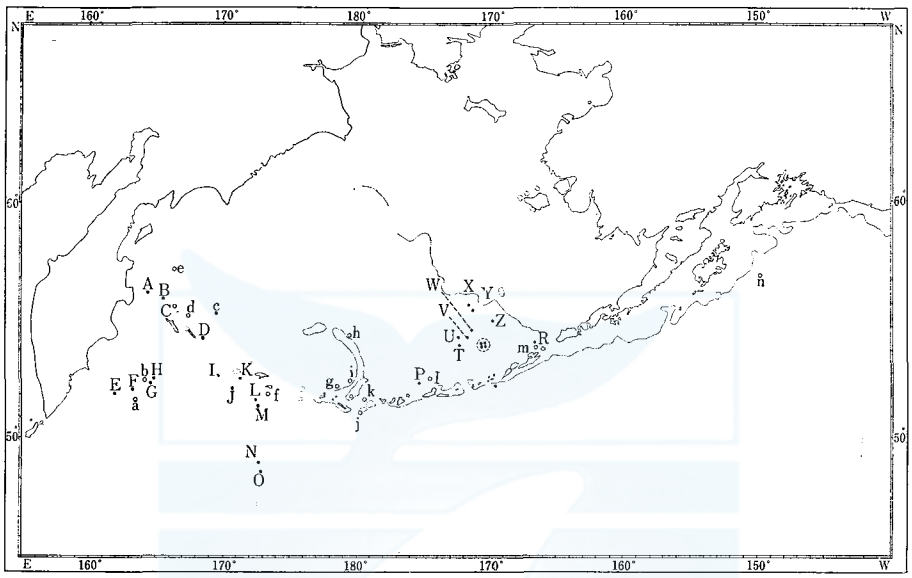

Fig. 7. Stations where *Calanus cristatus* and *C. ptumchrus* have been collected in the Bering sea and adjacent waters to Aleutian islands. Black symbols and capitals—*C. cristatus*, Open symbols and *C. plamchrus*.

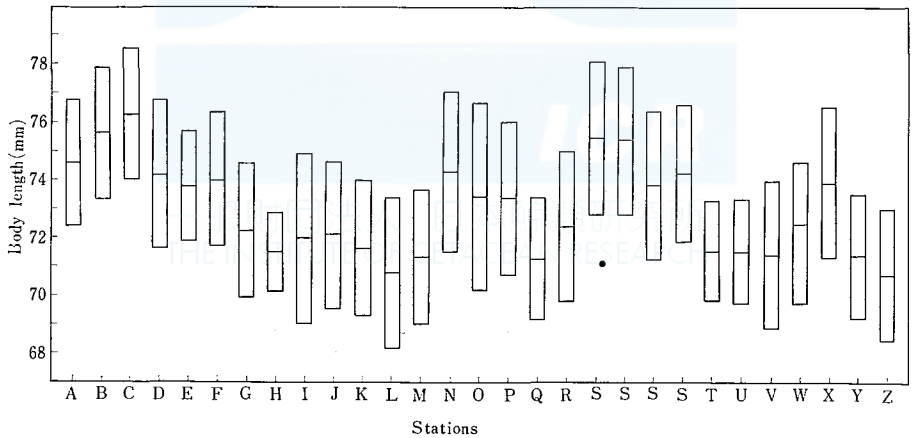

Fig. 8. Cephalothorax length of *C. cristatus* in the Bering sea and djacent waters. Rectangles represent means, plus or minus two standard errors.

The average body length (cephalothorax length) of *Calanus cristatus* in copeopdite stage 5 is plotted in Fig. 8 with two standard deviations. From the figures, it is

suggested that there are 4–5 size groups in the waters around the Aleutian Is. Off Kamtchtka group, South-west Attu Is. group, North-east Aleutian Is. group, and Adjacent waters to Aleutian Is. groups are them. Following points are noticed from the illustration of the body length.

1) *Calanus cristatus* distribution in the off water of Kamtchatka Islands, has the character of cold water form and has larger body length. This may be attributable to the intermedatte cold waters where *Clanus cristatus* develops from naupli to copepodite stage. In the very adjacent waters to stations E and F, the small sized *Calanus cristatus* occurs in G and H stations. This would suggest complicated oceanographic conditions in the waters where the Kamtchtka shore waters, Aleutian current and waters from the south meet one another.

2) From I to M stations, *Calanus cristatus* shows also comparatively smaller values. As it is shown in Fig. 9, the water temperature in J-M waters is higher than the waters A-B, C-D and D-F.

3) The length of *C. cristatus* in N-O waters is larger than the specemens in J-M waters of the north. The reason may be attributable to the fact that those specimens of cold water origin come from Kamtchatkan side

4) *Calanus cristatus* collected in the water Q-R stations has the smaller body length and water temperature is higher as shown in Fig. 9. But station P has a rather larger size *Calanus cristatus* in spite of the lower water temperature than stations Q-R. This reverce correlations should be examined again in the further investigation.

5) In the north waters of the east Aleution Islands stations T-Z, the intermediate cold waters do not so develop. The surface water temperature is also high and this tendency coincides with the small size of *Calanus cristatus* in these waters except stations X and S. It is interesting to note, further, the large sized *Calanus cristatus* specimens are found in the station S and X in the very neighbouring waters. *Calanus cristatus* in station S groups are collected from the stomachs of fin whales caught in the neighbouring waters.

Although plus and minus standard erorrs overlap one another as a series distribution from the west to the east, there are some correlations between the water temperature and body length of *Calanus cristatus*, as it has been established (Wiborg, 1954).

These groups of *Calanus cristatus* constitute fin whales feeding ground from spring to summer. And it has been observed that the prosperity of *Calanus cristatus* in each whaling grounds is different in every season.

When the relation between the body length of *Calanus cristatus* and water temperatures is examined, the water temperatures below 500 m depth do not show so much difference among stations. They are nearly constant values about 3°C at 800 m depth, however, the water temperatures at 300 m depth show lower values at the stations where the larger *Calanus cristatus* has been collected. The water temperaturs at stations A-B. and E-F are lower than the values at J-M and T-X stations. It is more likely that if the development of *Calanus cristatus* affected by the intermediate cold waters in the Bering sea, then it is affected by the slight difference

of water temperatures at 300 m level. The intermediate cold water generally develops in the west waters of the Bering sea especially in the A-B and E-F areas.

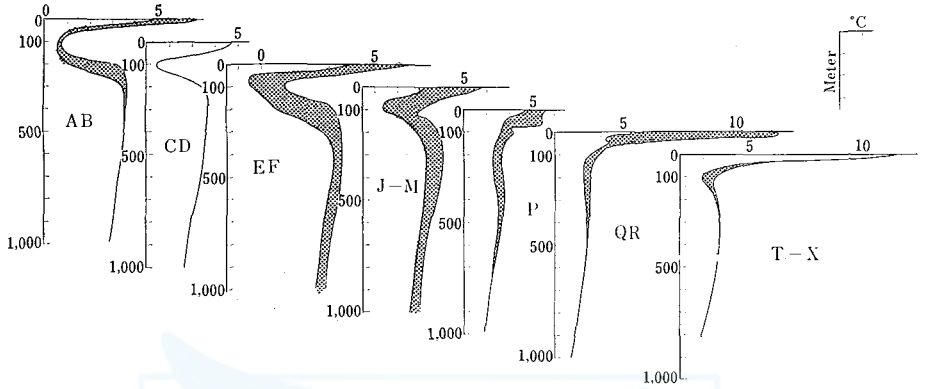

Fig. 9. Water temperature profile in the Bering sea and the adjacent waters. Alphabet shows the position in Fig. 7.

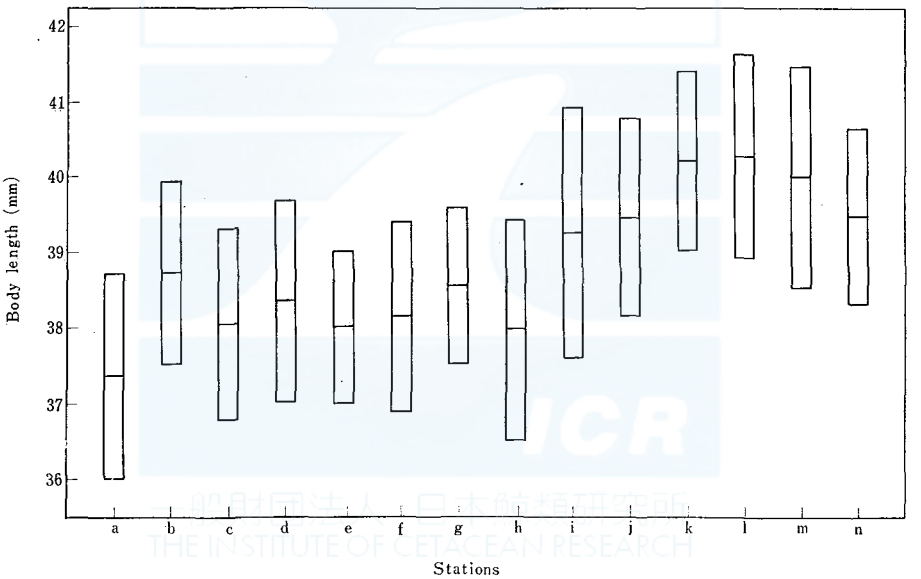

Fig. 10. Cephalothorax body length of *Calanus plumchrus* in the Bering sea and adjacent waters. Rectangles represent means, plus or minus two standard errors.

The body length of *Calanus cristatus* found in J-M stations is smaller than those in C-D stations, although the coldest point of intermediate cold waters is the nearly the same. In the stations Q-R and T-X where the small length *Calanus cristatus* is found, the intermediate cold water does not so develop. Further, the surface water temperature shows 10°C or more. The body length of copepodite stage 5 *Calanus plumchrus* in the collected specimens is illustrated in Fig. 10. The different body size in each *Calanus plumchrus* group is already discussed by Heinrich (1960).

According to his description, the cephalo-thorax length ranging 3.3 and 4.1 mm is obtained in the west Bering sea.

Calanus plumchrus specimens in the adjacent waters to the east Aleutian Islands and Kodiak Is. have rather large body size than the west groups in general. This tendency is attributable to the fact that the *Calanus plumchrus* treated here may be the second group in Heinrich's materials, which attains to their copepodite stage 5 in the summer when the surface water temperature is considered higher. They propagate and distribute in the surface in the western side of the Bering sea and constitute feeding grounds of sei whales in summer.

SWARM OF *CALANUS CRISTATUS* AND *C. PLUMCHRUS*

In the feeding ground of the Bering sea and its neighbouring waters, fin whales like *Calanus cristatus* as their food. But those fed on *Calanus plumchrus* are rather scarce in number when compared with other food taken. On the other hand, sei whales feed usually on *Calanus plumchrus* (Nemoto, 1959). It is reasonable to consider that two *Calanus* copepods have different attractions for fin and sei whales. Some examples of the weight of stomach contents found in fin and sei whales are given in Table 1. This table shows a fairly good correlation between weight of stomach contents and feeding quantity stage observed by naked eyes.

TABLE 1. THE WEIGHT OF COPEPODS CONTENTS IN STOMACHS OF FIN WHALES

Species	Weight	Stage
Calanus cristatus	107 kg	rrr
	87 „	R
	75 „	rrr
	45 „	rr
	30 „	rr
	30 „	rr
	26 „	rr
	18 „	rr
Calanus plumchrus	72 „	R
	64 „	rrr
	25 „	r
	16 „	rr
Metridia lucens	80 „	rrr

Generally speaking, the quantity of *Calanus plumchrus* found in baleen whales is smaller than *Calanus cristatus*, which suggests the patch of *Calanus cristatus* is heavier than that of *Calanus plumchrus* in the sea. Fin whales usually take their food by swallowing method, which needs the food plankton patch to be in suitable density and mass in the sea. Of course, *Calanus plumchrus* also sometimes may make heavy swarms.

From the digestion stage of the stomach contents, it is considered the swarm of *Calanus cristatus* and euphausiids are sometimes swallowed instantaneously or successively in the short period. In the stomachs of baleen whales, *Calanus* copepods

sometimes have been found along with other euphausiid *Thysanoessa longipes*. *Calanus cristatus* is also found with *Thysanoessa inermis* and *Euphausia pacifica*, however, the number of occurrences is far small as given in Table 2. The shore living euphausiids *Thysanoeasa raschii* and *T. spinifera* have scarecely been found with *Calanus cristatus*, It is attributable to the fact that the main distribution of *Calanus cristatus* has been restricted in the region of the sea where the bottom is deep as it is discussed in the former part. *Thysanoessa longipes* is only a off shore euphausiids in the north Pacific, the anual cycle of which has no relation to the shelf or the shallower sea. The possibility of the constituting mingled swarms of *Calanus cristatus* and *Thysanoessa longipes* is also probable.

TABLE 2. MIXED SWARM FORMATION IN *CALANUS* COPEPODS AND EUPHAUSIIDS IN THE BERING SEA AND ADJACENT WATERS

	Thysanoessa			Euphausia pacifica
	longipes	inermis	spinifera	
Calanus cristatus	38	10	—	3
C. plumchrus	3	1	1	—
C. cristatus & C. plumchrus	4	—	—	—

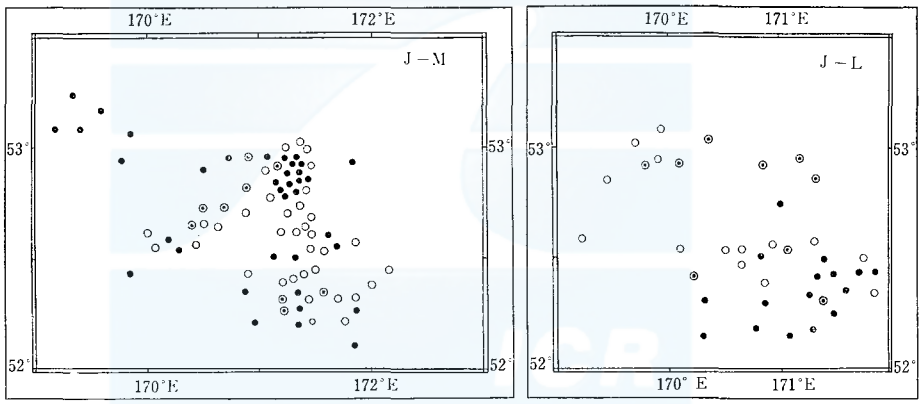

Fig. 11. Distribution of the foods of fin whales in the adjacent waters to Attu Is. in 1953. Black—*Calanus cristatus*, with dot—Euphausiids, Open—Vacant stomach.

On the other hand, few cases of *Calanus plumchrus* have been found in the stomachs of baleen whales as a mingled swarm with other euphausiid as given in Table 2. Only three cases of *Calanus plumchrus* are found in the stomachs of baleen whales along with *Thysanoessa longipes*, and each one case with *Thysanoessa inermis* and *T. spinifera* respectively.

As an example of the distribution of *Calanus cristatus* and euphausiids, the feeding chart of fin whales is given in Fig. 11, which shows the stations where fin whales caught with or without plankton contents in their stomachs in 1953. In the southwest waters of Attu Is. in 1953, the most part of fin whales had been feeding on *Calanus cristatus* by the first in July. In the middle of July, there are cencentrations

of *Calanus cristatus* and euphausiids in certain areas from the distribution of the catch of fin whales with them in their stomachs. *Calanus cristatus* in the waters where the dominant occurrences of *Calanus cristatus* were observed in the middle had extincted in the late of July as shown in Fig. 11. The swarms of *Calanus cristatus* must have subsided down deeper waters for reproduction. The surface water temperature is considered to be the direct reason for the subsiding of *Calanus cristatus* in this case (Nemoto, 1959). The southern groups of *Calanus cristatus* appeared in the same waters still in the late of July as shown in Fig. 11. This would suggest that the subsiding of *Calanus cristatus* occurs successinely by physical condition of *Calanus* and environmental factors.

SUMMARY

1. Based on the data of stomach contents of baleen whales and plankton nets, the distributions of *Calanus cristatus* and *C. plumchrus* are discussed. The probable correlation between the distribution of fin and sei whales in their feeding grounds and the distribution of *Calanus cristatus* and *C. plumchrus* is given. The main concentration of *Calanus cristatus* in spring and summer seasons of the Bering sea coincides with the feeding grounds of fin whales, and *Calanus plumchrus* with sei whales.

2. Adult specimens of both species have not been appeared in the stomachs of baleen whales as their food. Some occurrences of adult *C. plumchrus* in the net collentions are observed maninly in the shallower waters of the Bering and Chukchi seas.

3. The cepharo-thorax body length of two *Calanus* is examieed. The fairly close correlations between water temperature and body length are observed in *Calanus cristatus,* and the related body size groups are found in the neighbouring waters. But the different types of size groups are sometimes found in the very near position in the sea where the sea condition is rather complex.

4. *Calanus cristatus* sometimes may make mingled swarms with euphausiids *Thysanoessa longipes*, or *Calanus cristatus* which often distribuetes in the very near waters to the swarm of *Thysanoessa longipes*.

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