FOOD AND FEEDING ECOLOGY IN THE SOUTHERN SEI WHALE*

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ABSTRACT

The sei whale is an important stock of whales which has currently been hunted in the Antarctic region taking over the decreased catch quotas of fin whale. However, its biology and ecology as a whole are poorly studied being compared with those in another whale species due to relatively recent development in commercial whaling.

This study aims to add some habitual and ecological knowledge on the food and feeding in southern sei whale being based on the materials obtained by the Japanese floating factories and by the research ships through 1967/68 to 1971/72 seasons.

The sei whaling ground is formed throughout the circumpolar seas, but it is centered approximately between 40°S and 50°S under the surface sea temperature of about 8.0～18.0°C, particularly in a zone along the Subtropical Convergence of under 10°C or more in temperature where more than 70% of whales is caught.

A total of 23 species of food organisms was found, of which the following species being arranged with the order of importance consisted main foodstuff of sei whale: *Calanus tonsus*, *Euphausia vallentini*, *Parathemisto gaudichaudii*, *Calanus simillimus*, *Euphausia superba*, *Drepanopus pectinatus*, *Clausocalanus laticeps*, and *Euphausia lucens;* and, the following 7 species were newly known as sei whale food in the Antarctic region: *C. tonsus*, *Cl. laticeps*, *Thysanopoda actifrons*, *E. diomedeae*, *E. lucens*, *Penaeus* sp. and *Scomberesox saurus* though *Penaeus* sp. is still doubtful in identification. However, *C. tonsus* of copepodite V stage was fed by more than 70% of 600 animals examined, and its nutritional importance along with its influence on the formation of whaling ground would be distinct. The food organism changes successionally with the shift in whaling ground from northern extreme along 40°S toward south by following the order of copepods, small sized euphausiids or amphipods, then again euphausiids.

The baleen plates furnished in a row as feeding structure of filtering apparatus are formed by the various sized baleen plates which are furnished with 0.93～1.4 plates/cm, and the figures do not vary with the body length and the sex. The averaged number of bristles on the baleen plate was 45.5 bristles/cm. An example of a total area for the filtering apparatus was 3.59 m^2 in the animal of 14.4 m in body length, and relative ability in filtering the water by a row of baleen plates was considered to be placed somewhere between that in balaenopterid whales other than sei whale and balaenid whales.

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Comparison of the filtering ability in sei whale with others revealed the sei whale to be poor in those ability being 1/5 of the fin whale, and 1/8 of the bolting silk cloth GG54 (0.33 mm mesh aperture, 46% in porosity).

The analysis on the fulness of stomach contents by hours revealed that 20~30% of their amounts reduced within 5~6 hours, from which it is supposed that the sei whale feeds fully once in a day. The amount of stomach contents usually found in fully repleted sei whale was 150~200 kg but was less than 100 kg when they were consisted by *Calanus tonsus*. The daily ration in sei whale was calculated as 4.43% of body weight by using the formulation; Heart weight $\times 100$/body weight $\cdot$ 1/daily ration $\fallingdotseq 0.11$ (const.), then average sized sei whale requires about 900 kg of food daily. The figures both amout of stomach contents and daily ration in sei whale lead to a consideration that the whale would hardly be filled its nutritional requirements by *C. tonsus* food alone, that is, the whales seem to be kept under starvation to some extent in the natural environment.

A possible population density in *C. tonsus* patches being based on both the amount in the stomach and the filtering ability was calculated as approximately $10^3 \sim 10^4$ inds./m^3, and it was proved in this calculation that feeding by skimming type would be much advantageous for sei whale than by swallowing or gulping type feeding. After examining on the net samples of *C. tonsus* patches being composed of similar population structure, it was proved that the population density under patchiness was 2.4×10^4 inds./m^3, which agreed quite well with the figures assessed by the theoretical calculation.

The distribution of whales in connection with the environmental conditions would be understood by a high concentration of phosphate along with the presence of rather deeper layered thermocline where larger standing crops of organisms were found. However, since the swarming of zooplankton into patchiness would be essentially important character as the food of whales, none of organisms which widely occur with larger biomass such as tunicates and chaetognaths induce the concentration of whales. The geographical distribution of *C. tonsus* may essentially be influenced by the physico-chemical conditions of the sea. They may, however, be of no use for considering on the causation of swarming phenomenon of, say, the patchiness of prey organisms since aggregating habits in animal including zooplankton seem to be strongly controlled or released by some less known biological factors such as the density effect under crowding.

CONTENTS

1. Introduction 28
2. Material and method 32
3. Biological observations of whales 34
4. Recent catch and whaling ground of sei whale 36
    4–1. An outline of the whaling ground 36
    4–2. Catch distribution 37
    4–3. Surface sea temperature in sei whaling ground 40
5. Food of sei whale 45
    5–1. Kind of food organisms 46

5–2. Composition of the stomach contents 48
5–3. Geographical distribution of food organisms 53
5–4. Latitudinal change in the distribution of food organisms 56
5–5. Distribution of food organisms by the whaling area 58
6. Distribution of whales, and its relation to physical, chemical and biological environment factors 61
6–1. Distribution of whales and the environmental factors in the Pacific and Antarctic Ocean 61
6–2. Whaling ground of sei whale and the distribution of zooplankton 64
7. Body size of *Calanus tonsus* 72
7–1. Composition of body size in *C. tonsus* population 72
7–2. Discussion 74
7–3. Patchiness of *C. tonsus* and the density effects 76
8. Feeding apparatus of sei whale................................ 77
8–1. Oral cavity 78
8–2. Baleen plates 79
8–3. Bristles on baleen plates 81
8–4. Area of filtering apparatus 82
9. Filtering ability in the row of baleen plates 84
9–1. Porosity in the meshes of filtering apparatus of sei whale 84
9–2. Relative filtering ability in a row of baleen plates 85
10. Amount of the stomach contents and the population density of food organisms 87
10–1. Influence of chasing time to stomach contents 88
10–2. Amount of stomach contents 89
10–3. Daily variation in feeding activity 91
10–4. Possible cause induces a decrease in the fulness of stomach contents 94
10–5. Daily ration in sei whale 96
10–6. Estimation of population density in the food organisms 101
11. Swarms of *Calanus tonsus* Brady 105
11–1. Zooplankton swarms as whales food 106
11–2. Material and method 107
11–3. General hydrology in the investigated region 110
11–4. Shape, color, and size of *C. tonsus* swarms 110
11–5. Distribution of *C. tonsus* swarms 112
11–6. Frequency distribution by hour 115
11–7. Population density in the *C. tonsus* patches 116
11–8. Zooplankton abundance in the back ground waters 118
11–9. Some biological characters in the *C. tonsus* patches 119
11–10. Possible cause of swarming in zooplankton 121
12. General discussion and conclusion 125
Summary 129
Acknowledgments 133
References 134
Appendix 143
Plates 144

1. INTRODUCTION

The way to the modern pelagic whaling from the early North Atlantic whaling in Spitzbergen through those sperm whale whaling by the American ships in the south seas was a story of exploring the unknown seas by mankind who pursued for the undeveloped stock of whales which move in search of rich food concentrations in the vast ocean. In the ecological views it was a activity of mankind to increase the knowledge by the aid of accumulated experiences on the breeding and feeding behavior of whales, since those two are the essentially important factors in controlling the whale movements in the sea.

The famous whaling grounds which are formed during warmer season have been found where rich accumulation of food organisms is expected, or whale movements and the formation of whaling ground were recognized generally as a function of the distribution of food organisms in the sea. For instance, Scoresby (1820) in his cruise to the East Greenland waters early noticed that a " small crustaceans " was fed by the bowhead whale *Balaena mysticetus*, which indicates the whaleman at that time had been interested in whales food in relation to the whale movements although his observation was not biologically tangible. According to Collett (1886), however, the food of sei whale caught in Varangerfjord, Finmark in July 1885 was consisted of *Calanus finmarchicus* and of also *Euphausia inermis*, and they might be an important diet of sei whale in some seasons while fishes were less available as their food. Collett (1912) suggested an importance of the oceanic front as whaling ground where rich planktonic organisms occur due to confront the warm Atlantic and cold Arctic waters, and later Lillie (1915) called the sei and blue whales in the North Atlantic would be a " plankton feeder ". In the North Atlantic the distribution pattern of herring and euphausiids, or and copepods during fishing season closely relates to the movements of baleen whales which feed on those organisms. Concerning with feeding habits of baleen whales, it has been also known that they follow to two different ways to collect the food organisms, say, " skimming " and " swallowing " or " gulping " by boltering the body while feeding, and they are so shy and agile when there are no foodstuff in the stomach (Ingebrigtsen, 1929).

Returning from the 2nd exploring voyage into the southern seas during 1772–1775, Captain J. Cook brought an information that the bulk of pinnipeds and whales were accumulated in the Ross Sea region, and since then the Antarctic region became an indispensable whaling ground after passing several tenth years as heavy sealing places (Fraser, 1964). When C. Darwin made a famous voyage on boad of the H.M.S. " Beagle ", he sighted of many whales in the vicinity of Tierra del Fuego, South America where the surface of the sea was discolored into red-brown by the huge swarming of small crustaceans (Darwin, 1906). At this sight he (Darwin, 1906) thought that those swarming crustaceans must be the food of whales. According to Hinton (1925), Hamilton in his investigations at South Georgia had took note the importance of planktonic " swarming life " as Risting early had pointed out the matter in relation to whales food. It is important to take into account that the movement of whales had been considered as a function of food available there, especially as its distinct distributional pattern of so-called the plankton patchiness (Hardy and Gunther, 1935), and these recognitions of whales and their movements in connection with food organisms must be highly valuated ecologically apart from a qualitative knowledge on the whales food by species. In the investigation on southern whale stocks, much are owe to the works done by the Discovery Committee, especially to its bulk of results having been accumulated, and also to the establishments in methodology for biological examination of whale carcasses (e.g. Kemp *et al*, 1929; Hardy, 1967). In the matter of whales food, the records of the stomach contents by defining the size of food organisms present an important materials for considering geographical distribution of food organisms and their distribution pattern (Mackintosh and Wheeler, 1929; Marr, 1962; Mackintosh, 1973). By examining the stomach contents of blue and fin whales in the South Georgia whaling ground and in Nathal, South Africa, Mackintosh and Wheeler (1929) found only *E. superba* as a pricipal foodstuff, and has long been believed that only above species was the food organisms of southern baleen whales (Harmer, 1928, 1931). However, *E. superba* population which is actually fed by the whales is consisted of both matured adults and small or medium sized immature and adolescent individuals, and they occurred different ways by the places, seasons and by the kind of whale species which prey upon them. By noticing these difference, Norwegian whaleman called them from their experiences as " blue whale krill " for small sized *E. superba* and " fin whale krill " for larger sized one. This would be analogous in the case of *Meganyctiphanes norvegica* and *Thysanoessa inermis* which occur in the Norwegian waters, and they have called them as " stor-krill " and " smaa-krill " respectively. These also suggest that the seasonal movements of whales and their spring run close to their own shore have been considered in connection with the characteristic occurrence of food organisms. Hamilton who conducted biological observations on whale carcasses in 1913–14 season at South Georgia found "shrimp" in the stomachs of fin and humpback whales (Hinton, 1925). It is note worthy that Hamilton clearly separated them from usual krill, and this leads to a supposition that his " shrimp " might had not been larger *E. superba* but Galatheid shrimp such as *Munida gregaria* (Matthews, 1932; Dawbin, 1955; Tabeta and Kanamaru, 1970). In 1913–14 season at South Georgia a total of 90 sei whale was caught (Hinton, 1925). There were, however, no notable biological observations on this species except a mere note as " plankton eating species " since sei whale had less commercial value at that time. The food habits of sei whale have not known well until recent years by reason of little catches as above mentioned (Mackintosh, 1947). During the whaling seasons from 1960/61 to 1964/65 a total of 1223 sei whale was caught at South Georgia whaling ground, and food organisms such as *Parathemisto gaudichaudii*, *Electorona* sp. were newly found in addition to *E. superba* (Brown, 1968). He (Brown, 1968) also mentioned on the feeding habits of sei whale being based on the observations on the stomach contents.

With development of pelagic whaling operation in contrast to declining in principal whale stocks, the whale species commercially hunted for were greatly changed from fin to sei whales after 1964/65 season. This caused also the geographical change and expansion of the whaling ground itself, and the knowledge on the biological characters of sei whale gradually increased in relation to the needs for stock assessment. The kind of food organisms of southern sei whale which known recently in addition to *E. superba* are:- *Euphausia vallentini* (Marr, 1956; Mackintosh, 1960), *E. crystallophias* (Marr, 1956), *Thysanoessa macrura* (Nemoto and Nasu, 1958), *E. recurva*, *E. diomedeae* (Bannister and Baker, 1967), *Parathemisto gaudichaudii* (Nemoto, 1962a), *Calanoides acutus* (Peters, 1955), *Drepanopus pectinatus* (Tanaka, 1964), *Calanus propinquus* and *E. frigida* (Pervushin, 1968), *C. tonsus* (Best, 1967; Kawamura, 1970a), *Clausocalanus laticeps* (Kawamura, 1970a) and so forth.

In this report more several species of food organisms would be added. Among those above mentioned records, one by Best (1967) would be interesting since his materials were obtained in South African waters far outside from the so-called feed-

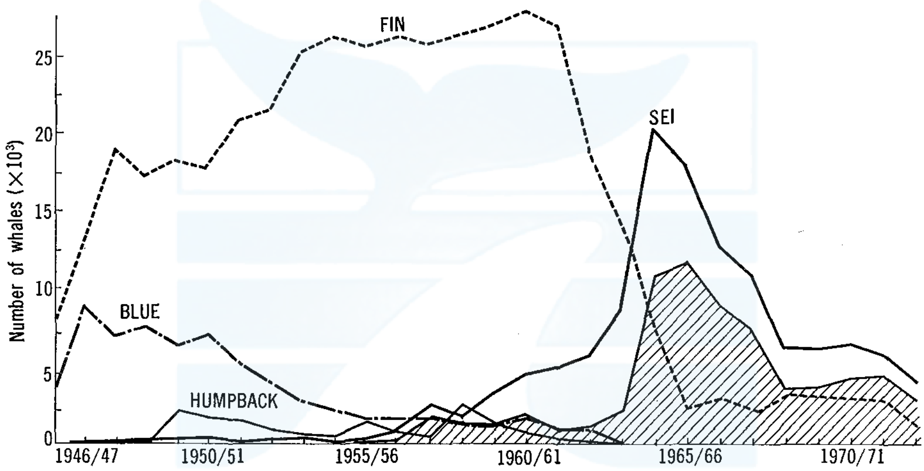

Fig. 1-1. Total catch of fin, blue, humpback, and sei whales in the Antarctic pelagic whaling during the past 28 seasons. Catch of sei whale by the Japanese fleets is shown by the hatched area. Whales taken under special permit after 1966/67 season; 3 humpback whales in 1971/72, 7 blue and 5 humpback whales are excluded.

ing ground in southern oceans. He (Best, 1967) reported a total of more than 44 species of food organisms in sei whale stomachs. Although the principal food was represented by a small number of species such as *Calanus tonsus* and some euphausiids, his result suggests us that sei whale would feed on even the organisms which do not swarm patchily in those temperate waters. Nemoto (1959) early suggested that some copepods would be fed by the sei whale in some place in the Antarctic region, but his suggestion was proved earlier than was expected as I have described above. Recent study on the food and feeding habits of whales tends towards the analysis of both the formation of whaling ground and whale movements along with the distribution of their food organisms (Slepzov, 1955; Nemoto, 1957, 1959; Pervushin, 1968; Kawamura, 1973a), and nutritional physiology based on feeding rate of whales (Klumov, 1961; Sergeant, 1969; Nemoto, 1970; Kawamura, 1970a, 1971a).

Commercially important whale species in the Antatctic region have been blue, fin, sei, humpback, right and minke whales respecitvely. However, recent status of some those stocks are not always kept under hopeful level, and only three of them are currently opened for regal catches. Fig. 1–1 demonstrates the number of catches in the Antarctic by species after 1945/46 season. The figure of the fin whale clearly shows its distinct importance among the total catches but it was took over by the sei whale since 1964/65 seasons. In these figure the history of the Antarctic whaling could be seen in another way as a history of shifts in commercially important species such the circumstances as shown schematically in Fig. 1–2. The

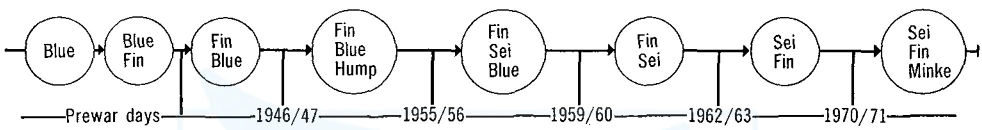

Fig. 1–2. A rough figure showing the change in whale species which have been caught in the Antarctic.

TABLE 1–1. CATCH OF SEI WHALE AMONG TOTAL ANIMALS IN THE PAST 28 ANTARCTIC SEASONS EXPRESSED IN PERCENTAGE FIGURES.

Seasons	Percentage	Seasons	Percentage
1945/46	+	1959/60	8.9
1946/47	+	1960/61	11.1
1947/48	+	1961/62	12.7
1948/49	+	1962/63	18.3
1949/50	0.3	1963/64	28.6
1950/51	1.2	1964/65	63.3
1951/52	0.1	1965/66	71.9
1952/53	0.4	1966/67	61.2
1953/54	0.8	1967/68	68.7
1954/55	0.4	1968/69	50.3
1955/56	0.8	1969/70	49.0
1956/57	2.2	1970/71	50.9
1957/58	6.6	1971/72	47.4
1958/59	3.9	1972/73	39.3

'+' less than 0.1 percent

Discovery Committee aimed to manage and control the Antarctic whale stocks under scientific basis (Kemp *et al*, 1929). In the days of blue and fin whaling, Matthews (1938) noted the forth comming situation that large catch effort would be added onto sei whale in the furture, and stressed the necessity of biological investigation on this species as much as possible. When we consider the present whaling status his anticipation must be greatly valuated. In 1964/65 season the total number of sei whale catch (19874 animals) exceeded that of fin whale, and showed 63.3% among total catch in that season. In 1971/72 season the minke which had not entirely been regarded as commercially exploitable resources turned to some importance for whaling by the pelagic floating factories, and 3000 animals were caught successfully although it was still exploratory whaling. Under these circumstances in the Antarctic whaling as having been mentioned above the purpose and reasons which made me study the sei whale could be summerized as follows:-

1) Food and feeding habits in the animals can be generally recognized as a whole as one of the most important event along with their breeding behavior throughout their life history. The baleen whales are very characteristic in ecological niche through marine food chains where the very primary herbivorous organisms are connected directly with the animals in the highest trophic levels. In connection with these circumstances the sei whale was in need of knowledge about its food and feeding habits and ecology since these factors in general strongly relate to the change of animal population and the movements of whales.

2) Catch of sei whale in enormous numbers began relatively recently, and the biological characters were poorly known particularly in sei whales. There have been done almost no observations and analysis on sei whales food but a brief discusion by Nemoto (1962) since then the main whaling ground in the Antarctic region shifted to further northern waters up to the Subantarctic region.

3) In connection with the shift and vast expansion in the region of main whaling ground, several kind of food organisms began to occur newly in the diet of sei whale (e.g. Kawamura, 1970a).

4) It is hoped to recognize the mechanisms of formation of whaling ground not only by the hydrodynamical process but also biologically through the food conditions of baleen whales.

5) It is expected to make clear the actual distribution characters of planktonic food organisms, especially their uneven distribution in the feeding places through the formation of dense swarms so-called plankton patchiness, which seems to be ultimately responsible for the formation of feeding spot of whales.

6) The knowledge of patchy distribution of some planktonic organisms would be useful for developing the plankton fisheries (e.g. Hempel, 1968; Parsons; 1972).

7) The study of sei whale food is desirable to be conducted while larger number of catch of this species would be expected since the history of shifting the whale species which have been commercially hunted teaches us the importance of properly partinent investigations.

2. MATERIAL AND METHOD

The material used for analytical treatments were obtained from various source, namely, pelagic whaling both in the Antarctic and North Pacific, and some were from land based whaling in the Japanese coastal waters. One of others were obtained in the cruises on board of the research ships. The material can be divided into two principal categories, namely, row material of both whale food and plankton samples, and data in the field chiefly compiled by the Fishery Agency, Ministry of Agriculture and Forestory and by the personnel on the floating factories. Although the material and the method of analysis in particular will be discribed more in detail elsewhere in the following each sections, the principal sources of material obtained are as follows:

The stomach contents of sei whale caught in the Antarctic waters were collected continuously through 1967/68 to 1971/72 seasons by the Japanese floating factories and those materials were treated chiefly for examining the kind of food organisms, their geographical and seasonal distribution. Some results obtained on the material in 1967/68 season concerning to the food habits of sei whale has already been reported by the author (Kawamura, 1970a).

In the seasons of both 1967/68 and 1971/72, I was on boad of the floating factories, " Nisshin Maru " of Taiyo Gyogyo Co. and " Tonan Maru No. 2 " of Nippon Suisan Co. respectively, and engaged in general biological observations of whale carcasses as routine work and also collected the samples of the first stomach contents of sei and fin whales.

In the course of this study I made theoretical estimation on the population density of *Calanus tonsus*, the principal prey crustacean of the sei whale, when it forms the patches being based on both the amount of this organism found in the first stomach and relative filtering ability in the row of baleen plates (Kawamura, 1971a). To prove this result I cruised down into southern waters off Western Australia in 1971/72 season on boad of M.S. " Eihô Maru " of Hôkoku Suisan Co., and made quantitative sampling of *C. tonsus* by spotting its patches in the surface waters. After finishing these investigations, I moved to the F.F. " Tonan Maru No. 2 " as above mentioned when both ships met each other on high seas.

The row materials concerning to examining the relation between the distribution of whales and of their prey zooplankton along with sea conditions were obtained in 1968/69 season by the R.V. " Hakuhô Maru " during her KH 68–4 cruise down to the Antarctic (Ocean Research Institute, University of Tokyo, 1970). With this material a quantitative and qualitative study on the food organisms of sei whale in the Pacific sector of the Antarctic and Subantarctic waters was made, and at the sametime the distribution of sei whale and the occurrence of the DSL in relation to that of physico-chemical elements in the region were discussed. A part of these results were preliminary reported (Kawamura, 1969a; 1970b, c; Kawamura and Kureha, 1970).

Mechanisms of feeding as a function of the structure of filtering apparatus of sei whale and its food habits were also studied. In order to estimate the capacity of oral cavity in sei whale the amount of air used for making afloat the whale carcasses was measured on the whale boat, " Toshi Maru No. 18 " which belongs to the Nisshin Maru fleet of Taiyo Gyogyo Co. in the summer of 1969 when she engaged in the North Pacific whaling operation, and a row of baleen plates was collected too by that fleet to assess its relative filtering ability of the water. Whether or not the whale vomits its stomach contents under continuous chasing was an important matter which have to be clarified when we consider the amount of stomach contents in carcasses, and the observations for this purpose were made by six whale boats, of which each two belonged to K. K. Kyokuyo, Taiyo Gyogyo Co. and Nippon Suisan Co. respectively (Kawamura, 1971a).

To know the daily ration of sei whale theoretically the heart weight which was proposed by Sergeant (1969) as a useful index for this purpose was weighed in 1970/71 Antarctic season at the floating factories, " Tonan Maru No. 2 " and " Nisshin Maru No. 3."

There is bryde's whale *Balaenoptera edeni* Anderson (Olsen, 1913), which is very similar to sei whale dealt in this study though the former has currently been separated clearly as completely different species (Omura, 1966). According to Omura (1966) the bryde's whale distributes in the offshore waters of South Africa, Brazil, Japan and western Australia, and a considerable number of this whale was caught in the north-western North Pacific in recent operations. Japanese whalemen have been noticed some specific differences by calling it as the sei whale of " southern origin " or " southern type " which means the warm water species, but it has not been treated separately in the old catch statistics of Japanese coastal whaling. The bryde's whale are usually found in the warm waters of sea temperature higher than 20°C and its food habits also differs to some extent from the sei whales (Omura and Nemto, 1955). Best (1970), on the other hand, observed two allopatric forms in this species in the South African waters, namely, " inshore " form which distributes in the waters within 20 miles of the coast whereas the " offshore " form is found 50 miles or more from the coast. They differ each other in some biological characters such as external appearance, breeding and feeding habits.

Accordingly, it is supposed to be caught the bryde's whale along with the bulk of sei whale catch especially in the whaling area III in the Antarctic since the sea conditions in that area are much complicated, and sei whale is widely pursued for by the whaling fleets. Of 945 sei whales taken by the Russian fleets in 1972/73 season 5 bryde's whales were included (Intern. Whal. Stat., 1973). However, the morphological and ecological characters of bryde's whale as mentioned above are well known currently by the whalers, and sei whale treated in this study can be considered as *B. borealis* Lesson exclusively.

3. BIOLOGICAL OBSERVATIONS OF WHALES

The Japanese whaling fleets which engage in the Antarctic and North Pacific whaling operate under an obligation to record and collect the materials of every whale carcasses treated after the instructions of whaling inspectors on boad; the actual items and the way of the observations are essentially based on those established by the Discovery Committee (see Mackintosh and Wheeler, 1929). The personnel who engages in this scheme is a governmental whaling inspectors and some deck workers of the whaling company, and the following items are observed: that is, whale species, sex, body length, foetus (body length and sex if present), stomach contents (kind of organisms by rough grouping, the amount of food and freshness), condition of mammaly gland whether lactating in any degree or not, and its thickness), thickness of blubber, weight of both testes, number of corpora albicans and corpora lutea (but they are collected for later examination if counting them on the deck was impossible), collection of the ear plug on every carcasses and the stomach contents about every tenth of carcasses if any food present. In addition to these, the position, date and time of catch and treatment as supplemental data. All these data are compiled in the *seibutsu-chosa-daicho*, a kind of official field note of the Fishery Agency, which can be reffered for statistical analysis.

The data treated in this study other than those obtained on row materials, chiefly based on this field note. The position of catch, however, is not actual but represented by the noon position of the mother ship. Accordingly, the positions of catch may differ to some extent particularly those in the morning and evening. It is, however, recognized empirically that the difference in the position is within tenth miles, and none of those seems to cause any confusion in analysing the data except particular cases such as the catch occurred fairly close to the convergence zone.

It is recognized anatomically and histologically that the stomach of whale is composed of four compartments arranged in series: the first compartment or stomach with no digestive glands, being a kind of dilated sack of the oesophagus origin to the fouth stomach by the extraordinarily developed ampulla (Slijper, 1958a; Hosokawa and Kamiya, 1971). The second and the third stomachs are real gastric compartments provided with digestive glands. Accordingly, the stomach of whale carcasses is usually examined only on the first stomach since the contents remain being undigested for long time and the second or the thrid stomachs are examined only when there was no food remains in the first stomach. In this case, however, the condition of the stomach contents is recorded as " empty " (=0) in the field note above mentioned.

The food conditions of the first stomach in the whaling ground give an important suggestions for whalers to judge whether or not the whaling ground is under suitable sea conditions as long lasting whaling ground. In the observations on the kind of food organisms in the field, the following rough calssifications and abbreviations are adopted as have been described previously by Nemoto (1959) and Kawamura (1970a), namely, ' Calanus ' (Ca), 'Amphipoda ' (Am), ' Euphausia ' (Eu), ' Fish ' (F), ' Squid ' (Sq), ' Munida ' (Mu) and so forth. Since the stomach contents are consisted of so many species of food organisms, it is hard to distinguish all of them after the classifications especially in ' Calanus ' and ' Euphausia ', then both of which actually mean copepods and euphausiids respectively. As for ' Euphausia ' the group is divided into three sizes by the body length; ' Large ' (L) for larger than 5 cm, ' Medium ' (M) for 4–5 cm, and ' Small ' (s) for smaller than 4 cm., and they are recorded by one of a dominant forms in the official record. This definition for classifying the size of euphausiids was supposedly adopted after the way having been employed by the Discovery Committee. In those days there had not been the problems of mixing the food organisms with more than two species since only *E. superba* had consisted of foodstuff in higher latitudes (Mackintosh and Wheeler, 1929). As mentioned before the sei whale is currently the most important species, and they seem to prefer copepods or small sized euphausiids such as *E. vallentini* being found in more northern waters. It may hard to distinguish these kind of small euphausiids from young *E. superba* or from some another euphausiids species expressed as 'Eu-S' in the data record. However, it is possible with considerable preciseness by reffering the result obtained on row food materials to identify the kind of food organisms in those field record. There are no euphausiid species that correspond to the body length of 'L' and 'M' in the northern North Pacific, but the occurrence of 'L' and 'M' of *Euphausia* was recorded in 1969 season, and was proved later by examining the row materials collected that they were a kind of Sergestid shrimp, *Sergestes similis* Hansen (Kawamura, 1970d; Omori *et al*, 1972). This fact suggests that the observations by defining the size as 'L', 'M' and 'S' would be still methodologically efficient for the field work.

One of another items of observations is the fulness of stomach with food against the capacity of stomach itself. This is recorded by five different degrees along with the freshness; these are, 'empty' (0%), 'r' (less than 25%), 'rr' (25~50%), 'rrr' (50~75%) and 'R' (75~100%) respectively. The freshness of food organisms therefore usually corresponds well to the fulness of stomach by its order such as 'R' for 'F', very fresh.

Food organisms as row material were collected on the every tenth of flensed carcasses when the stomach contents were kept under good freshness for the later examination in the laboratory. The collection of row material, however, is also conducted to make the material characteristic in time and space when the kind of food organisms seemed different from others, when the floating factory changed its position, and when the sei whale was caught sporadically during the period of fin whale hunting in higher latitudes. A considerable part of this study is greatly based on the statistical material having been compiled like this way by the Japanese floating factories during 1967/68 to 1971/72 seasons.

TABLE 4-1. THE ANTARCTIC WHALING AREAS ROUND THE SOUTH POLE CAP.

Area	Longitude	Main land and ocean included
I	120°W– 60°W	Eastern Pacific, South America, Folkland Is.
II	60°W– 0°	South Georgia Is., South Sandwich Is.
III	0° – 70°E	Bouvet Is., Marion Is., Crozet Is.
IV	70°E –130°E	Kerguelen Is., Heard Is., Western Tasman Sea
V	130°E –170°W	Tasman Sea, New Zealand
VI	170°W–120°W	Central Pacific

4. RECENT CATCH AND WHALING GROUND OF SEI WHALE

4–1. *An outline of the whaling ground*

The Japanese pelagic whaling in the Antarctic region is operated under the regulations by the IWC's arrangements, by the recommendations under the Antarctic Teaty, and by the measures of Japanese Government. Under these circumstances, four species of baleen whales, *i.e.*, fin, sei, minke and sperm whales are hunted.

The whaling place is found throughout the whole circumpolar seas but it is divided longitudinally into six whaling areas, from I to VI(Table 4–1). These whaling areas were defined being based on the catch statistics of the blue whale for the purpose of clarifying its sub-populations or stock units by the sea areas (Hjort and Ruud, 1932; Mackintosh, 1942). The whaling areas defined thus seem to well represent the stock unit of whales especially in blue and humpback whales whereas they seem rather less convenient for sei and fin whales. It is, however, still con venient to compare the catch statistics of sei whale with those other whale species.

Fig. 4–1 shows the distribution of whaling ground along with the whaling areas where the Japanese floating factories have operated through past five seasons, 1967/68 to 1971/72. In recent whaling with quite larger number of sei whale catch, most of whaling ground is found in the zone along the Subtropical Convergence between 40°S and 50°S, and little number of sei whale is caught along with larger number of fin whale in more higher latitudes, south of 50°S in the areas IV and VI. In the area VI a southerly expansion of the Subtropical Convergence toward higher latitude is very distinct particularly in the east of New Zealand but sea conditions in this area as whaling ground of sei whale do not differ much on the whole from other areas of mid-latitudes. In contrast to those situations the whaling ground close to the pack-ice in the south of 60°S as whaling in 1940's to 1950's when a larger number of blue, fin and humpback whales were caught (e.g. Nishiwaki and Hayashi, 1950; Nishiwaki and Oye, 1951; Mackintosh, 1965; Nasu, 1966). Comparing with those distribution pattern in the whaling grounds, it is clear that the sei whale is caught in the far northern waters north of the Antarctic Convergence, and its whaling ground could be considered as the " Subantarctic " whaling ground instead of the historical "Antarctic " whaling ground.

The whaling activity was most heavily conducted in the areas III, IV, and V throughout the Antarctic whaling grounds, and the areas I, IV in the south of Australia and a part of the area V seems rather less important as sei whaling ground due to a monotonous sea conditions there along with a prevaliling bad weather especially in the area I. Since the bulk of the catch in the southern zone between 45°S and 50°S is consisted of fin whale almost exclusively, and the proportion of sei whale catch among them is so little that the distribution of sei whaling ground in the southern zone does not always represent well the status of sei whale distribution. The center of sei whaling ground can be seen in general close to the northern boundary of the subantarctic region being related to a hydrodynamical upwelling (Nasu, 1966) and the bottom topography.

4–2. *Catch distribution*

Fig. 4–2 shows the number of sei whale caught during 1966/67 to 1968/69 seasons by the Japanese floating factories being arranged in five degree square of both latitude and longitude. The region where the floating factories operated usually correspond to the whaling ground itself, and the latter represents the region where large number of sei whale have been spotted by the scouting boats belonging to the fleet. Accordingly, the whaling ground itself could be considered to agree with the distributions of sei whale with high population density. However, it must be also taken into consideration that there are the case of small catch by artificial reasons due to weather condition, geographical position, and less catch effort on sei whale due to balancing relation with the period of fin whaling. It is clear in Fig. 4–2 and Table 4–2 that the sei whale is caught chiefly in the Sub-antarctic waters between 40°S and 50°S as a whole, and the 5 degree squares with catch more than 100 animals distribute in the narrow zone along both north and south sides of the Subtropical Convergence. The sei whale catch in the south of the Antarctic Convergence is seen in the areas IV to VI but the actual number of catch was relatively small except those in the area IV. The bulk of catch in the area IV is found in 52°–53°S, the northern waters of Heard Island, and a 5

TABLE 4–2. NUMBER OF SEI WHALES CAUGHT AND ITS PERCENTAGE FIGURES (ITALICS) BETWEEN EACH 10 DEGREES OF LATITUDE IN THE ANTARCTIC.

Latitude (S)	66/67		67/68		68/69		69/70		70/71		71/72		72/73	
40°–50°	8775	*71.0*	5114	*49.0*	4178	*72.4*	5112	*87.4*	5644	*91.8*	5329	*97.7*	3633	*94.0*
50°–60°	2270	*18.4*	3373	*33.0*	870	*15.1*	212	*3.6*	186	*3.0*	105	*1.9*	151	*3.9*
60°–70°	1315	*10.6*	1863	*18.0*	722	*12.5*	528	*9.0*	321	*5.2*	21	*0.4*	79	*2.1*

TABLE 4–3. CATCH OF SEI WHALE BY MONTH.

	Whaling season									
	63/64	64/65	65/66	66/67	67/68	68/69	69/70	70/71	71/72	72/73
Dec.	552	1001	3202	3168	1812	2358	2435	2760	2348	1347
Jan.	3204	7116	5701	3615	3351	1779	2055	1958	2098	1681
Feb.	2451	7690	5579	3673	3055	1484	792	875	540	488
Mar.	1867	3870	2923	1880	2113	694	570	520	441	346
Apr.	182	161	153	24	19	—	—	38	28	1
Total	8256	19838	17558	12360	10350	5770	5852	6151	5445	3864

degree squares between 80°–85°E seem to be a particular case. The most distinct trends of northerly shift in the distribution of whaling ground is found in the areas II to IV between Folkland Islands and the Indian Ocean sectors, and the location of these whaling grounds well agree with the mean position of the Subtropical Convergence (Deacon, 1937). The catch of sei whale in such waters as to be considered warm temperate region greatly owe to the formation of feeding place by the dense swarms of *Calanus tonsus* in the surface during mid-December to January, on which the sei whale feed voraciously. The fin whale, on the other hand, usually preferably feeds on euphausiids and supposedly enters into the more higher latitudes in early austral summer. It could, therefore, be considered a habitat segrigation in both fin and sei whales. In those days when blue and fin whales were hunted exclusively, the catch of sei whale in February and March was quite sporadic (Hinton, 1925). However, by examining a long-term catch distribution, it is noticed that

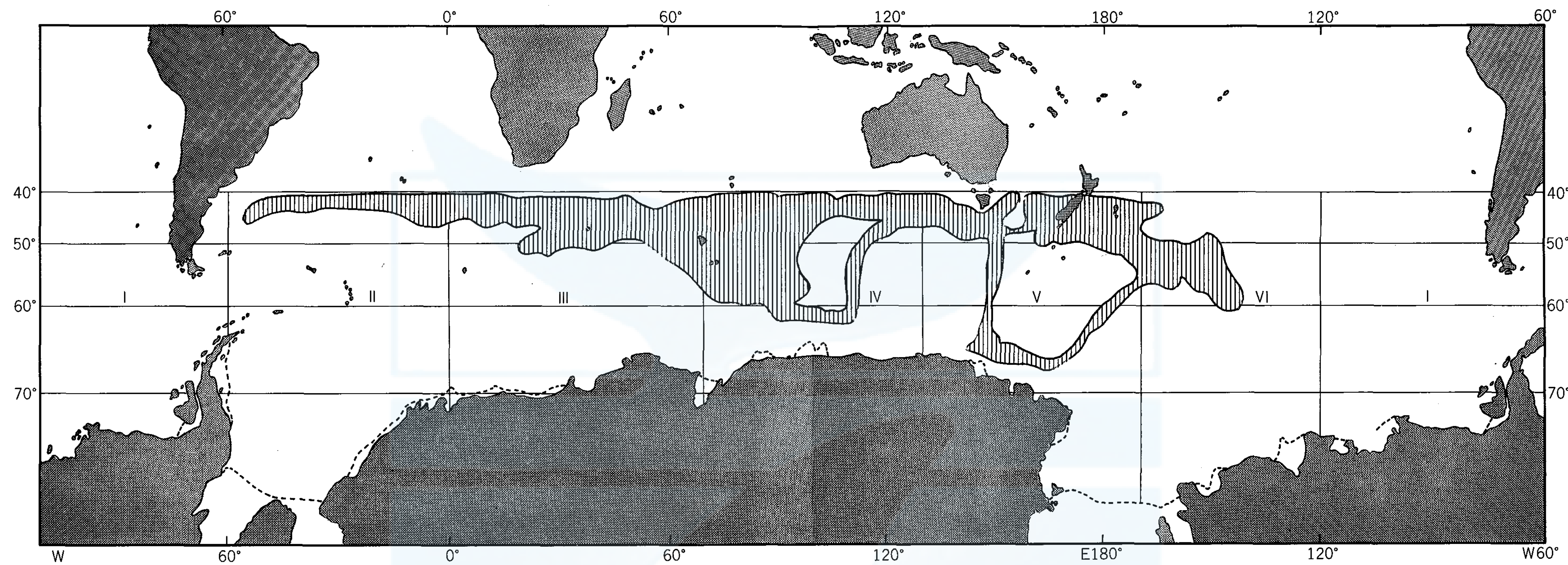

Fig. 4-1. The Antarctic whaling ground occupied by the Japanese floating factories during the seasons from 1967/68 to 1971/72.

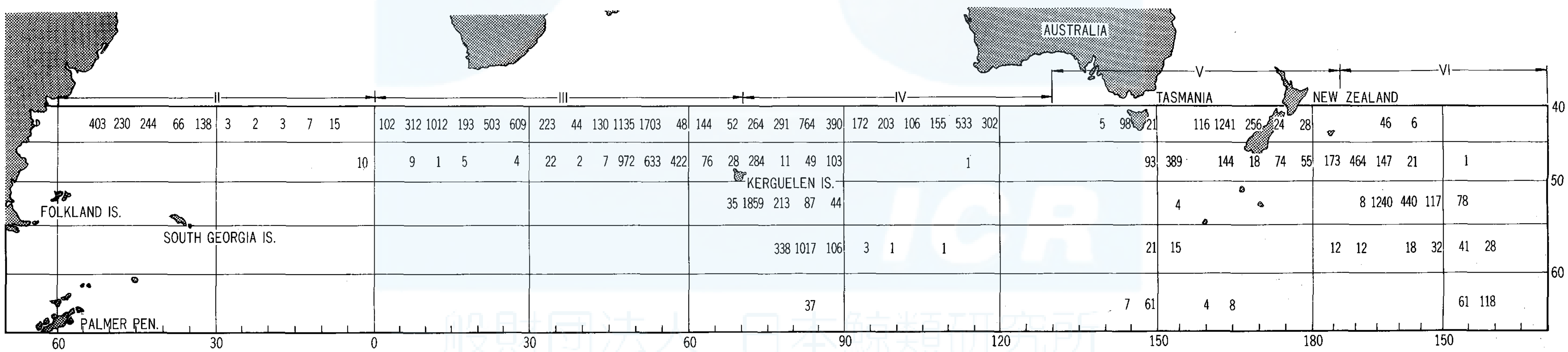

Fig. 4-2. Number of sei whales caught by the Japanese floating factories in every 5 degree squares of the Antarctic whaling ground during the seasons from 1966/67 to 1968/69.

there are some catch of sei whale in higher latitude south of 70°S in the Ross Sea region of the areas V and VI (Kashida, 1972; Omura, 1973).

As season goes by the feeding place formed by *C. tonsus* will fade out due to their wintering migration down to some deeper waters, and the sei whale moves into more colder region where several kind of cold water food organisms of copepods, amphipods and euphausiids occur in swarms. The representative species of those waters are *Calanus simillimus*, *Euphausia vallentini*, *E. superba*, and *Parathemisto gaudichaudii*. In recent whaling operations, however, the whale species of being hunted shifts almost to fin whale in these cold waters after catching such vast number of sei whale in the northern waters as to fill the catch quota for the season. By considering both the number of monthly catch as shown in Table 4–3 and the surface temperature of the whaling ground under about 3°~4°C in March, it is suggested that the region in higher latitudes as above mentioned would be far outside from the usuall distribution range of the sei whale.

The catch of sei whale by pelagic whaling during the seasons of 1931/32 to 1968/69 is shown in Table 4–4 by separating each whaling areas. A fairly little catch

TABLE 4–4. TOTAL CATCH OF SEI WHALE IN SIX WHALING AREAS DURING THE SEASONS FROM 1931/32 TO 1969/70.

Area	Number of animal	Percent
I	3708	3.6
II	42109	40.6
III	20776	20.0
IV	12774	12.4
V	15066	14.5
VI	9207	8.9
Total	103640	100.0

in the areas I and VI would be due to the treatments of total banning of the catch up to 1962, and relatively small in stock size there (IWC, 1969; 1970), and also due to some difficulties in an actual operation by ill weather condition. The most distinct catch is seen in the areas II where one of the most productive regions in the Antarctic, say, South Georgia and Folkland Islands waters, are included. In 1964/65 season, a total of about 2000 sei whale was caught in this area. It has been reported that the cold Weddell Current extends northward distinctly, and this would be responsible along with a complexity in bottom topography for quite high standing stocks of zooplankton which causes high potentials in availability of food organisms for both whales and pinnipeds (Hardy and Gunther, 1935; Ommanney, 1936; Mackintosh, 1934, 1937; Marr, 1962). However, a quite heavy catch in this whaling area might possibly caused a considerable local decline in the population of sei whale, and the catch was actually very poor when two Japanese floating factories operated again in 1969/70 season. This fact suggests a little rcovery in sei whale stock up to today (IWC, 1970), andt herefore the sei whale is caught principally in the whaling areas IV and V in recent operations.

The schematic distribution of sei whale based on the position and the number of catches indicate that there are trends of efficient catch particularly in the regions under some complexity in bottom topography which responsible for arrousing the upwelling under the distinct meandering of the Subtropical Convergence. These general features in distribution patern of sei whale are comparable to those food organisms, that is, the dense swarms or aggregations into the patches in *C. tonsus* (see section 11). Mentioning on the formation of whaling ground in the North Pacific, Nemoto (1957, 1959) and Nasu (1963, 1966) pointed out the close relationships between the distribution of food organisms and the upwelling by various origins and the situation in the Antarctic region seems to be essentially analogous in the structure of whaling ground formation.

4–3. *Surface sea temperature in sei whaling ground*

The distribution of surface sea temperature of sei whaling ground in the areas II-VI during 1969/70 season is demonstrated in Figs. 4–3a∼4–3f, but the

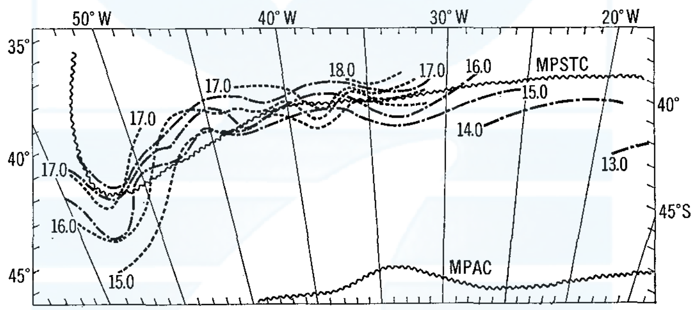

Fig. 4–3a. Surface temperature in the Area II, December, 1969. Solid line indicates the isotherm in the first decade of a month, and dotted and chain lines indicate those in the middle and last respectively. Both MPSTC and MPAC are the mean positions of the Subtropical Convergence and those of the Antarctic Convergence.

general sea conditions in the areas V and VI of the same season has already been reported by Nasu and Masaki (1970). The surface sea temperature treated here was observed at the ship's noon position during the period of whaling operation being measured by electric thermometer which has its sensor on the ship's bottom about 10 meter depth. There are so much measurements of sea temperature in actual operation, but most of them are hardly obtainable for outside use except one as mentioned above.

Fig. 4–3a∼Fig. 4–3f cover the region between Folkland Islands and western Australia, that is, 55°W∼120°E, and this region represents the principal sei whaling groud in recent operations. An outline of the monthly temperature distribution is as follows:

December (*Figs.* 4–3*a*∼4–3*b*): Since the whaling ground of baleen whales is opened in nearly mid December the material treated here covers late half of the month. The sei whaling ground spreads over in latitudinally narrow zones along 40°S, and the temperature of 15°∼18°C occupies exclusively even in the areas II (Fig. 4–3a) and IV (Fig. 4–3b). The whaling ground in Folkland region may be formed by an oceanic front which originates from both the cold Folkland Current and the warm Brazil Current. Accordingly, the coeanic front distinctly extends northward at 50°∼55°W longitudes, and its position agrees in general with the mean position of the Subtropical Convergence in summer (Deacon, 1937). In the whaling ground off southwest Australia the sea temperature principally showed between 14°C and 16°C. The distribution pattern of isotherms does not differ much in general within the same month exept a slight southerly shift about 1° latitude on the whole in late December. This indicates the gradual grow of warming conditions toward south during this month. Discussing on the sea conditions of sei whaling ground in the areas II and VI in 1969/70 season, Nasu and Masaki (1970) concluded that the sei whaling ground in the area II was formed in the waters north of the Antarctic Convergence with temperature higher

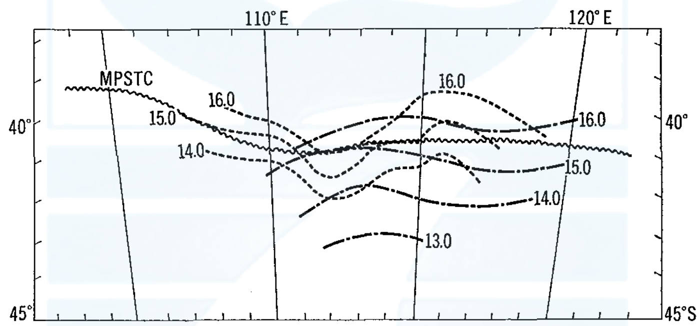

Fig. 4–3b. Surface temperature in the Area IV, December, 1969. Legends as in Fig. 4–3a.

than 4.5°C, but it was found also between 8°C and 10°C in the area VI. A slight temperature differences in the whaling areas also found in the Folkland region and in the southwestern Australia region where the difference was 1°∼2°C in the center of the whaling ground. These suggest that there are some different hydrological conditions for the formation of whaling ground among those areas.

January (*Figs.* 4–3*c*∼4–3*d*): Following to December the whaling was operated through the areas II to IV. In accordance with northerly extension of the Subtropical Convergence beyond 40°S between 10° W and 15°E, the principal whaling ground was covered with 15°∼17°C waters during first half of January in the Folkland region whereas it was 11°∼14°C in the area III. In the area IV there found 14°∼16°C waters close to the Subtropical Convergence zone in January. In the regions south of South Africa between 10°E and 30°E, however, the distribution of sea temperature showed rather complicated features supposedly due to the formation of local fronts, some of which must have been formed by a confronting both the warm Agulhas Current and the cold Benguela Current. These hydro-

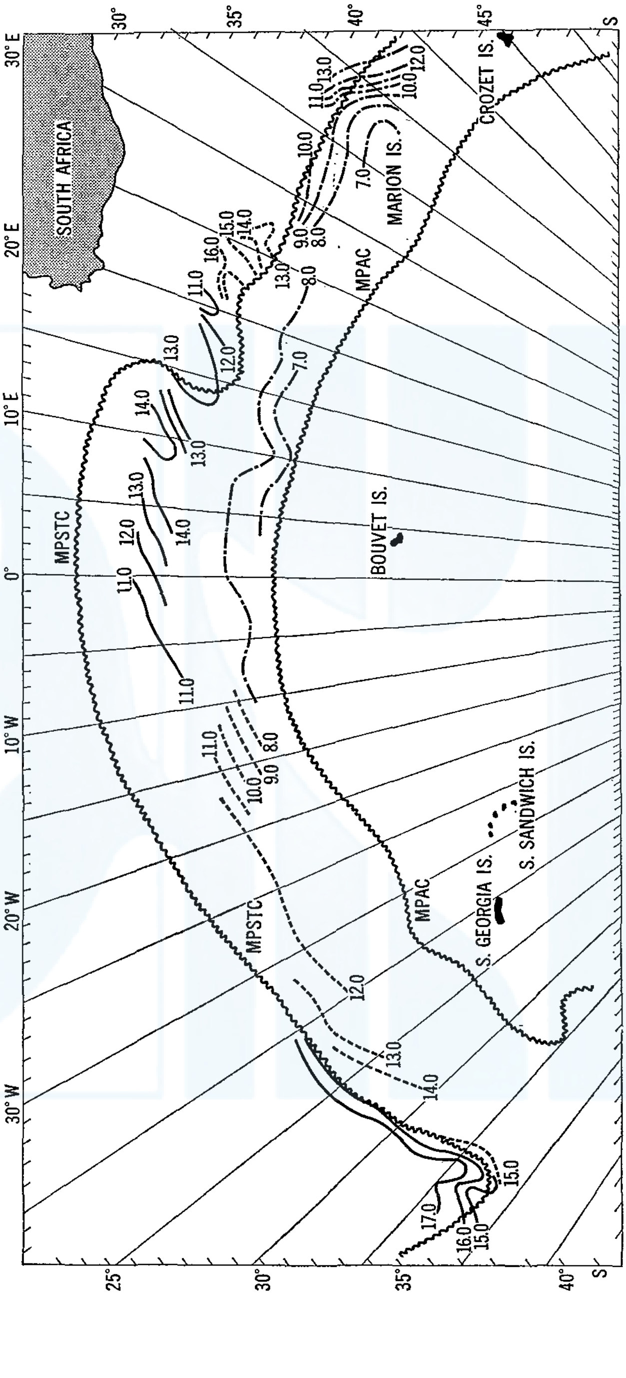

Fig. 4–3c. Surface temperature in the Areas II and III, January, 1970. Legends as in Fig. 4–3a.

logical condition would be responsible for high productivity due to upwelling in the region where forms another fertile whaling ground far outside from those in the Antarctic region especially in the western coast of South Africa (e.g. Best, 1967). By refering the Fig. 4–2 it is noticed that the regions of high density in the catch number of whales in early January are found in relatively warmer waters in the north of the Antarctic Convergence up to 40°S., and the center of heavy catch lies in the zone of temperature above 14°C. The expansion of warmer conditions towards the south is weakened gradually toward late January although there are still slight trends getting warmer as being seen in the behavior of 8°C isotherms at 10°W. However, the temperature of the main whaling ground during January showed 8°∼13°C on the whole.

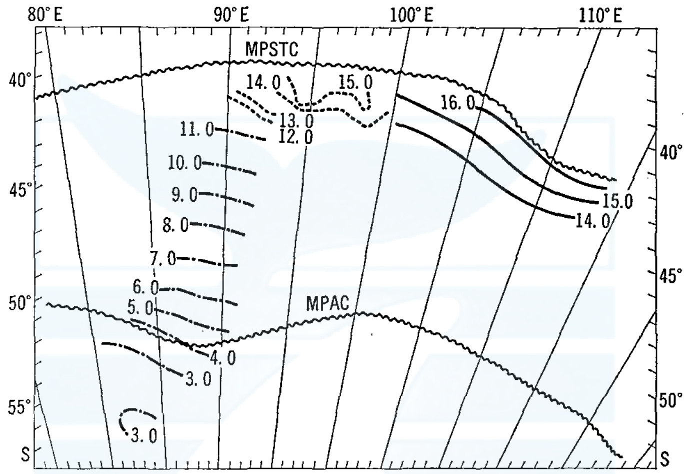

Fig. 4–3d. Surface temperature, January, 1970. Legends as in Fig. 4–3a.

February (*Fig. 4–3e*): There was no whaling activity in the area II in February, but the area II and a part of the area IV where involve Marion, Crozet and Kerguelen Islands has been formed a well staple whaling ground through past several seasons. In contrast to northern positioning of whaling ground close to 40°S during December to January, it is found rather mid to higher latitudes with 45°∼46°S as its center in February. The 7°C isotherms along 35°E was found near to 45°S in late January, and it still continued shifting down to about 47°∼48°S in early February. The southerly shift of the isotherms, however, decreased gradually during mid to late February as observed in the feature of 7∼8°C isotherms at 40°∼50°E and at 60°E, and the sea condition seems as a whole to be in the state of those typical one of mid summer. The whaling ground is found in the temperature of 7°∼10°C, which was slightly colder than that prevailed in preceding month but agreed with the result obtained by Nasu and Masaki (1970).

In view of the kind of food organisms which is responsible for forming principal sei whaling ground, the areas II and VI during December to January would strongly be due to the mass occurrence of copepod, *C. tonsus* whereas more cold water species such as *E. vallentini*, *C. simillimus* and *P. gaudichaudii* are responsible in the areas III and IV. The whaling ground in the area IV along 80°E is usually under very cold sea conditions with temperatures of 4°~6°C, where much fin whales are caught than the sei whale. The principal food organisms are consisted of *E. superba* and *P. gaudichaudii*, but they were replaced to *D. pectinatus* in the slightly northern waters under the temperature of about 7°~9°C.

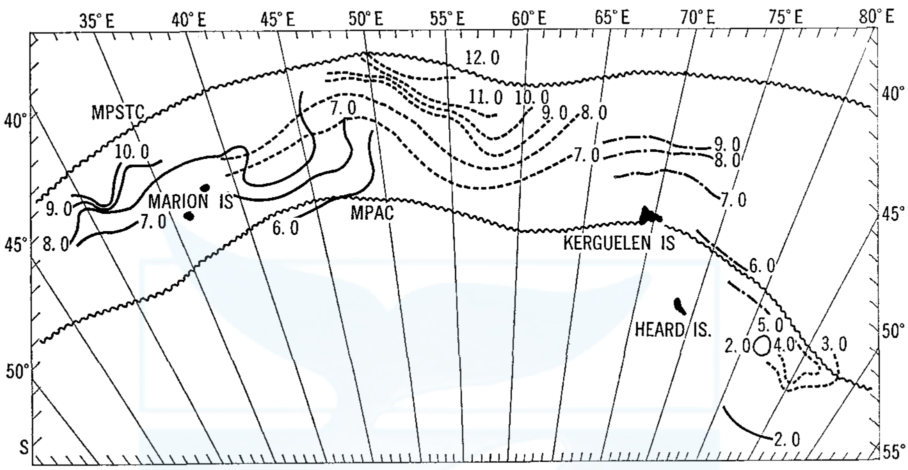

Fig. 4–3e. Surface temperature, February, 1970. Legends as in Fig. 4–3a.

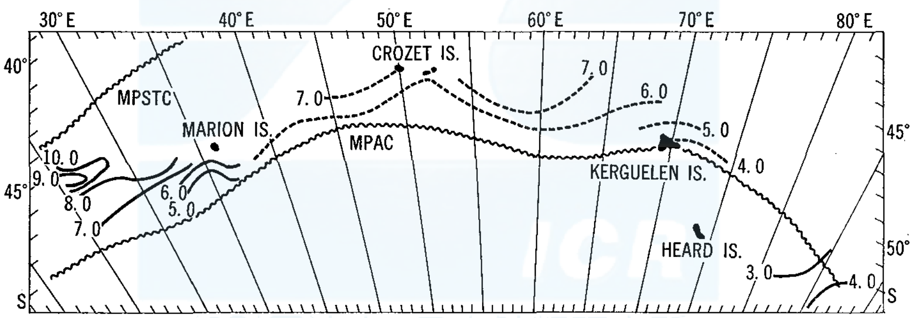

Fig. 4–3f. Surface temperature, March, 1970. Legends as in Fig. 4–3a.

March (*Fig.* 4–3*f*): The catch of sei whale distinctly decreases in March in the recent operations. In the regions of Marion, Crozet and Kerguelen Islands there was a sign of retreating the warm water toward north particularly in the region between 70°~75°E. The sei whaling ground was formed under relatively colder sea conditions of 4°~7°C but the catch of sei whale was very little in contrast to that of fin whale (Table 4–3).

Studying on the food habits of sei and fin whales of the North Pacific Ocean, Nemoto (1957) reported a distinct preference to copepod food in sei whale. In the Antarctic region, on the other hand, the large standing stocks of copepod species is usually found in relatively warmer waters in the north of the Antarctkc Convergence (Kawamura and Hoshiai, 1969; Kawamura 1969b; 1970a, b; Kawamura and Kureha, 1970). Accordingly, the principal sei whaling ground during December to March is found usually in the northern zones of the Subantarctic region, and then it would be hardly expected a bulk of feeding concentrations of sei whale population in the regions south of the Antarctic Convergence even in the midst of austral summer.

5. FOOD OF SEI WHALE

In order to know the kind and distribution of food organisms of sei whale a total of 462 food samples was collected from the first stomach of 462 animals. The 462 food sample is comprised of both the 117 samples collected in 1967/68 season and the 345 in 1969/70. These row material geographically covers for the most Antarctic

TABLE 5-1. FOOD ORGANISMS OF SOUTHERN SEI WHALE CAUGHT DURING 1967/68 TO 1971/72 SEASONS.

COPEPODA	*Calanus simillimus* GIESBRECHT
	Calanus tonsus BRADY
	Clausocalanus laticeps FARRAN
	Drepanopus pectinatus BRADY
AMPHIPODA	*Parathemisto gaudichaudii* GUERIN
	f. *compressa*
	f. *bispinosa*
	f. *intermediate*
EUPHAUSIACEA	*Euphausia superba* DANA
	Euphausia vallentini STEBBING
	Euphausia lucens HANSEN
	Euphausia diomedeae ORTMANN
	Euphausia similis G. O. SARS
	Thysanoessa vicina HANSEN
	Thysanoessa gregaria G. O. SARS
	Thysanopoda actifrons HOLT & TATTERSALL*
FISHES	*Gymnospelus nicholsi* (GILBERT)**
	Myctophum subasperum (GUNTHER)**
	Scomberesox saurus (WALBAUM)
	Notolepis castsi DOLLO**
	Vinciguerria attenuata (COCCO)
	Gonostomatid fishes**
DECAPODA	*Penaeus* sp.***
OTHERS**	*Cleodora sulcata* (PFEFFER)
	Clione antarctica E. A. SMITH
	Eukrohnia hamata (MÖBIUS)

* Although the bipolarity of this species is reported, the occurrence is doubtful.

** The species gathered to feed on amphipods or copepods, and are not important as a staple food of sei whale.

*** Doubtful in identification.

whaling areas, say, the areas II∼VI, and gives us well the general knowledge concerning to the distribution of food organisms within the circumpolar seas exept a sector which involves the eastern Pacific and the Folkland Islands region.

5–1. *Kind of food organisms*

Although the food habits of sei whale in 1967/68 season has been reported previously (Kawamura, 1969b, 1970a, 1971b), some of which were also treated in this report to make the scheme more clear in detail. In the previous repeort (e.g. Kawamura, 1969b), it was pointed out that the sei whale principally feeds on copepods such as *C. tonsus* more preferably than euphausiacea in accordance with the distinct northerly shift in the center of sei whaling ground through recent operations. The kind of food organisms along with those admixed by a chance are enlisted by species in Table 5–1. As having been mentioned above the food organisms in Table 5–1 can be considered to cover the almost all foodstuff of the sei whale which distributes within the circumpolar seas in the south of 40°S. By comparing with the foodstuff known in the northern North Pacific and Bering Sea, (Nemoto, 1957, 1959), Kawamura (1973a) showed that those in the Antarctic region seem to be quite monotonous as a dietary environments for baleen whales, *i.e.*, the Antarctic environment lacks some micronectonic organisms such as the fishes molluscs, and crustaceans like Sergestid shrimp (Omori *et al.*, 1972). Although Nemoto (1962a, b) early reported the newly known food organisms as found in sei whale stomachs, the principal foodstuff of sei whale in the Subantarctic waters is consisted of both copepods and small sized euphausiids, and this fact is far different from the previous recognitions of depending solely on euphausiids. The following species could be considered as newly known food orgnaisms in the Subantarctic and Antarctic regions in addition to those reported previously. They are: *C. tonsus**, *Clausocalanus laticeps*, *Thysanopoda actifrons*, *Euphausia diomedeae*, *E. lucens*, *Penaeus* sp. and *Scomberesox saurus*.

Among those food organisms given in Table 5–1, the following four species might be the most important throughout the Subantarctic waters from their distinct occurrence in the sei whale stomach: *C. tonsus*, *C. simillimus*, *E. vallentini*, and *Parathemisto gaudichaudii*. In addition to these species both *Clausocalanus laticeps* and *Drepanopus pectinatus* could be considered to be particularly important in a local sea regions.

Nemoto (1962a) early suggested that *E. similis* which had not been reported as whales food would be found in the whale stomach when the whaling ground shifted to another place in the future, since *E. similis* forms dense swarms in the surface water. By examining the foodstuff of minke whale, *Balaenoptera bonaerensis* caught in 1967/68 season, I found the occurrence of *E. similis* as food in several number of animals (Ohsumi *et al*, 1970) and again in sei whale caught in 1969/70

* Salinikov (1953, Table 4) described *C. tonsus* as a food of baleen whales in the North Pacific waters. However, it is obvious in the studies by Tanaka (1954, 1956) that Salinikov's *C. tonsus* must be separated from the so-called *C. tonsus*, the endemic species in the southern hemisphere. *C. tonsus* was also reported as sei whale food from the Cape Province, South Africa (Best, 1967) but I enlisted the species again in this report since Cape Province is located at about 33°S being far outside from the Antarctic region proper.

season. These facts strongly suggest that the food organisms of baleen whales would supposedly form the dense swarms or aggregations into patchiness. These results lead to a consideration that the southern saury, *Scomberesox saurus* and *Penaeus* sp., both were found in this study, also seem to form the swarms in the sur-

TABLE 5-2. COMPOSITION OF FOOD ORGANISMS IN THE STOMACHS OF THE SOUTHERN SEI WHALE 1967/68.

Kind of food organisms	No. of whales examined
C. tonsus (CV & Female)	23
C. tonsus (CV)—*P. gaudichaudii* f. *compressa* (Female)	1
C. tonsus (CV)—*P. gauchichaudii* f. *bispinosa* (Female)	1
C. tonsus (CV & Female)—*E. vallentini* (Female & Juvenile)	2
C. tonsus (CV & Female)—*E.* sp. (Furcilia)	2
C. tonsus (CV)—*E. vallentini* (Female)—*E. hamata*	1
C. tonsus (CV)—*P. gaudichaudii* (Female)—*E. vallentini* (Male, Female & Juvenile)	1
C. tonsus (CIV & CV)—*E. hamata*—*Clione antarctica* & *Cleodora sulcata*	1
C. simillimus (CV & Female)	4
C. simillimus (CIV & CV)—*Drepanopus pectinatus* (Juvenile)	3
C. simillimus (CV)—*E. vallentini* (Male, Female & Juvenile)	2
C. simillimus (CV)—*E.* sp. (Male & Furcilia)	1
C. simillimus (CV)—*P. gaudichaudii* f. *compressa* (Male & Female)	2
C. simillimus (CV)—*P. gaudichaudii* f. *bispinosa* (Female)	2
C. simillimus (CV)—*G. nicholsi*	1
C. simillimus (CV)—*P. gaudichaudii* f. *compressa* (Male & Female)—*E. vallentini* (Juvenile)	1
D. pectinatus (Male, Female & Juvenile)	4
D. pectinatus (Juvenile)—*C. simillimus* (CIV, CV & Female)	2
C. laticeps (Female & Juvenile)	2
P. gaudichaudii f. *compressa* (Female)	9
P. gaudichaudii f. *bispinosa* (Female)—f. *compressa* (Female)	18
P. gaudichaudii f. *bispinosa* (Female)—*E. vallentini* (Male & Juvenile)	1
P. gaudichaudii f. *compressa* (Male & Female)—*P. gaudichaudii* f. *bispinosa* (Male & Female)—*E. superba* (Male & Female)	1
P. gaudichaudii f. *compressa* (Female)—*gaudichaudii* f. *bispinosa* (Female)—*E. vallentini* (Male, Female & Juvenile)	1
P. gaudichaudii f. *bispinosa* (Female)—*E. vallentini* (Juvenile)—*C. simillimus* (CV)	1
Euphausia superba (Male, Femal & Juvenile)	14
E. superba (Male, Female & Juvenile)—*Myctophum subasperum* & *Gymnospelum nicholsi*	1
E. vallentini (Male & Female)	10
E. vallentini (Juvenile)—*D. pectinatus* (Juvenile)	1

Degree of dominancy is on decrease from left to right in the left column and the dominant forms of each organisms are shown in parentheses.

Note: CIV—the fourth copepodites, CV—the fifth copepodites.

face waters. A little number of myctophid fishes, chaetognatha, and pteropods were also found as contaminants. They must have been fed by a chance when they gathered in the surface waters in search of their prey organisms such as copepoda and euphausiacea, and have little importance as sei whale food. This kind of mixture not only occur in the mid latitudes but also occur in more higher latitudes.

According to Brown (1968) the sei whale caught in the South Georgian waters had fed on *Electorona subasper* and *E. normani* along with *E. superba*, and he (Brown, 1968) called them as " occasional occurrence ". By discussing the diel vertical distributions of those myctophid fishes, Brown (1968) also supposed that the bulk of sei whale feeds actively in the evening since those fishes usually come up near to the surface in the night. It might, however, rather difficult to know the active feeding time of sei whale like this way since there are also the fact that the sei whale does not seem to feed at any definite time of a day but feed whenever there are a foodstuff available (Kawamura, 1970a).

5–2. *Composition of the stomach contents*

As mentioned before the most important food organisms for sei whale in the Subantarctic and Antarctic waters are *C. tonsus*, *C. simillimus*, *P. gaudichaudii*, *E. vallentini* and *E. superba*, whereas in Saldanha Bay, South Africa there has reported more than fourty five food species; seven euphausiids, twenty of copepoda, six of amphipoda, four of fishes, six of pteropoda and some others such as megalopa larvae, and *Vellella* sp. (Best, 1967). However, there were only 8∼9 species which seemed to be actually indispensable as food of sei whales there. The most of other species might have found as " occasional occurrence ", though

TABLE 5–3. COMPOSITION OF FOOD ORGANISMS IN THE STOMACHS OF THE SOUTHERN SEI AND FIN WHALES, 1969/70.

II \ I	*Calanus tonsus*		*Calanus simillimus*		*Drepanopus pectinatus*		*Euphausia lucens*		*Euphausia vallentini*		*Euphausia superba*		*Euphausia diomedeae*		*Parathemisto gaudichaudii*		*Notolepis castsi*	
	Sei	Fin	Sei	Fin	Sei	Fin	Sei	Fin	Sei	Fin	Sei	Fin	Sei	Fin	Sei	Fin	Sei	Fin
C. tonsus	203*	3													1			
C. simillimus			5**		1													
Th. vicina	2																	
Th. gregaria	1									1								
Th. sp.	1	1																
E. lucens	3						2	1										
E. vallentini	1								10	38								
E. superba											8	8						
E. similis										1								
E. diomedeae														1				
Th. actifrons	1																	
P. gaudichaudii	19		1							1				1	20	2		
Penaeus sp.	4																	
S. saurus	1																	
V. attenuata	1																	
N. castsi																		1

I & II: Order of dominancy.
* Including a mixture with *Pseudochirella* sp. in the Order II.
** Including a mixture with a few individuals of *P. gaudichaudii*, *E. vallentini*, *Th. gregaria* and *E. hamata* in the Order II.

Best (1967) did not give the quantitative data, and they usually recognized as non-swarming species. Consequently, the foodstuff in the South African waters also seems rather monotonous as feeding environment for the sei whale.

The stomach contents of beleen whales are formed essentially with only one species of food organism as many previous works have been stated. In order to know an actual states of stomach contents in the Antarctic sei whale, the results of

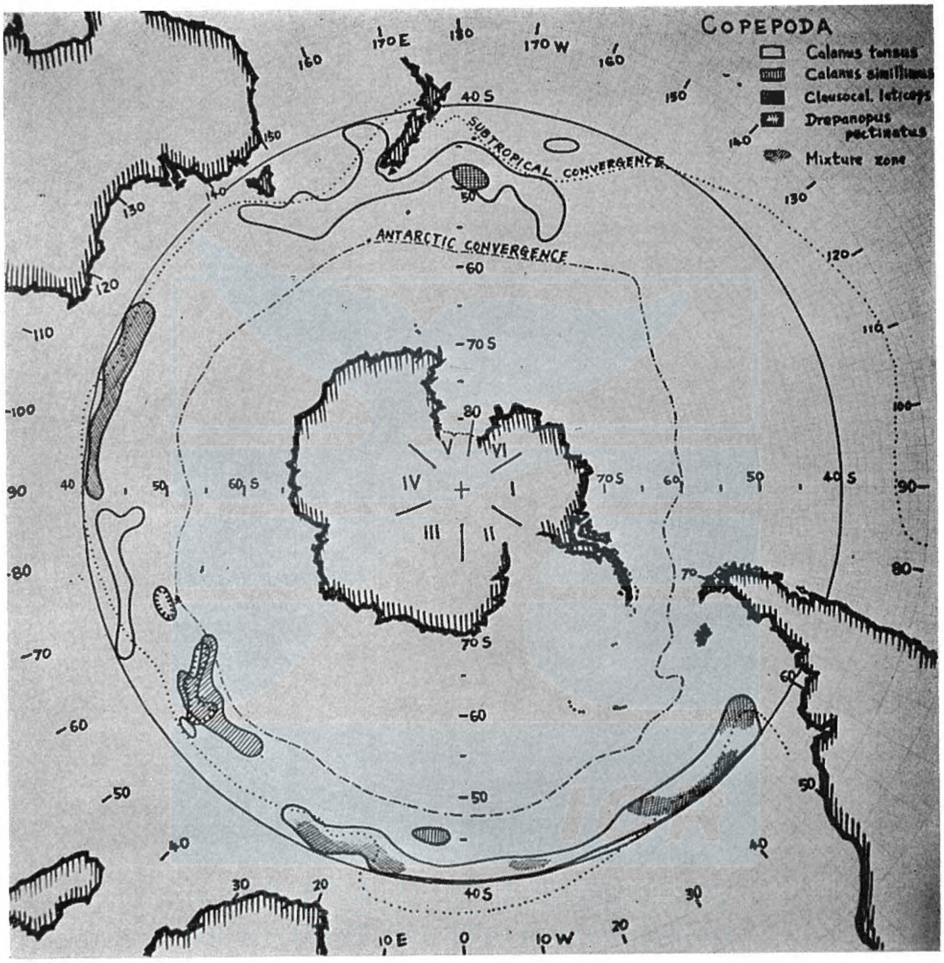

Fig. 5–1. Geographical distribution of the food copepods for sei whale in the Antarctic.

examination on the stomach contents obtained both in 1967/68 and 1969/70 seasons are given in Tables 5–2 and 5–3. It is shown in both tables that the somach contents of sei whale are composed characteristically of monospecific populations particularly in copepods and euphausiids. This fact suggests that the sei whale prey almost exclusively on the swarming organisms. The result in 1967/68 season covers only the whaling areas III and IV. Since there were no distinct differnce being observed in longitudinal expansion of the sea throughout the circumpolar seas, it may be well represented even by the samples obtained in limited whaling areas. In Figs. 5–1, 2 and 5–3 some leading species as sei whale food are indicated on the above right as the figures legend. It is observed in the figures that the geographical distribution of each food species overlaps each other in many regions.

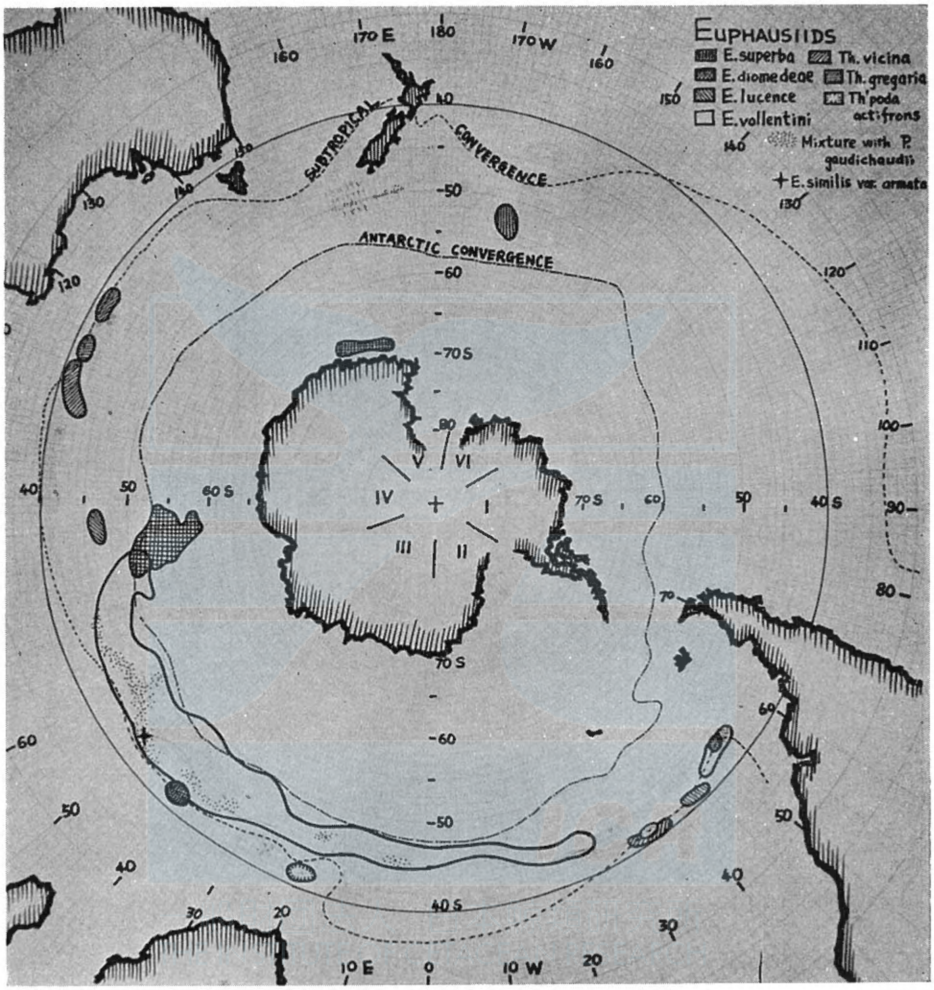

Fig. 5–2. Geographical distribution of the food euphausiids for sei whale in the Antarctic.

However, it does not mean the occurrence under an admixed pouplation but they are a monospecific population being isolated each other. These relationships would be clearly recognized by refering the composition of stomach contents given in Tables 5–2 and 5–3 where most stomach contents were consisted of only one species. The important foodstuff of sei whale are *C. tonsus*, *C. simillimus*, *P. gaudichaudii*, *E. superba* and *E. vallentini*, and each of them forms a monospecific stomach contents themselves although their distribution does not always isolate from each other. Table 5-4 shows a monospecific characters of the stomach contents of sei whale on the basis of five major food organisms. Throughout the areas II to VI as observed in both 1967/68 and 1969/70 seasons, it is clear in the table that a quite few examples of stomach contents had contaminated with one or more numbers of

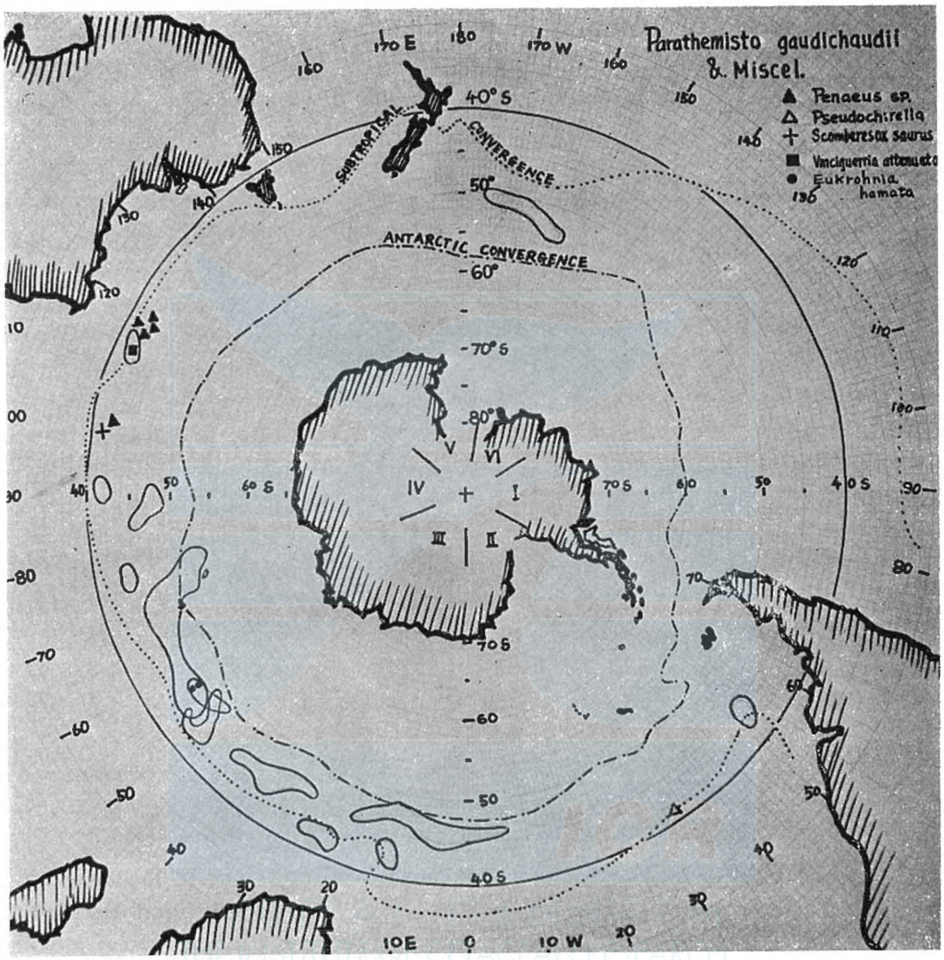

Fig. 5-3. Geographical distribution of the food amphipod, *Parathemisto gaudichaudii*, and other miscellaneous foodstuff for sei whale in the Antarctic.

food species in addition to those constitutes the major body of the stomach contents. These trends are most distinct among the stomach observed when *C. tonsus*, *P. gaudichaudii* and *E. vallentini* constituted the sei whale food where more than 72 percent of stomachs were monospecific. Thus the tables above mentioned show a distinct monotonous composition in the foodstuff of southern sei whale, which leads to a consideration that the sei whale feeds exclusively on the swarm forming organisms. It was also known that the number of species contaminated does not exceed more than two, and they also never exceed the major species in quantity, except when the fishes were contaminated; that is, the food of sei whale usually formed with a species which occurs dominantly in the sea concerned. As far as the individual numbers observed are concerned, the sei whale in the Antarctic waters feed selectively with prefering orders of copepoda—euphaussiid, amphpoda, or both of them—other crustaceans, and then fishes or squids as has been reported in the North Pacific sei whale (Nemoto, 1957; 1959). However, the food preference in sei whale varies to some extent by the case. For instances, they feed chiefly on *E. lucens*, *E. recruva* in the South African waters, and copepods such as *C. tonsus*, *C. carianatus*, *Clausoclanus arcuicornis* f. *major* follow to the former (Bannister and Baker, 1967; Best, 1967). Although the " selection " by the kind of food organisms in baleen whales is still in need of more discussion, there seems to be no other ways to believe it possible by adding more facts observed in the North Atlantic baleen whales where Howell (1930) described the selective feeding habits with the orders

TABLE 5-4. MONOSPECIFIC DEGREE IN THE STOMACH CONTENTS OF SEI WHALE IN FIVE MAJOR SPECIES OF FOOD ORGANISMS.

Species		No. of monospecific samples	No. of mixed samples	No. of species mixed		No. of samples examined	Monospecific samples (%)
				1	2		
Calanus tonsus	1967/68	23	9	6	3	32	71.9
	1969/70	203	34	34	—	237	85.6
Calanus simillimus	1967/68	4	12	11	1	16	25.0
	1969/70	4	2	1	1	6	66.6
Parathemisto gaudichaudii	1967/68	27	4	1	3	31	87.1
	1969/70	20	1	1	—	21	95.2
Euphausia superba	1967/68	14	1	—	1	15	93.4
	1969/70	8	—	—	—	8	100.0
Euphausia vallentini	1967/68	10	1	1	—	11	91.0
	1969/70	10	—	—	—	10	100.0

of small shrimps, anchovy, smelt, and then mackerel. In the Antarctic waters, on the other hand, many sei whale actually feeds on *C. tonsus* at first then *P. gaudichaudii* or *E. vallentini* and finally *E. superba* notwithstanding the fact that there must be exist so rich distribution of *E. superba* in the higher latitudes when they entered into the southern feeding place in early summer. According to my unpublished data the surface swarms of young euphaudiids and amphipods are observed often in the Subantarctic waters of relatively higher latiturdes, but they never found in the stomach contents of sei whales there. They feed exclusively on the adult forms of *E. vallentini* or *P. gaudichaudii*. However, it is still unknown that these are due to the size of food organisms as particles. By examining the sei whale food and feeding in South Georgian waters, Brown (1968) reported a opposite opinion that there were no facts to believe the selective feeding habits in sei whale.

As shown in Table 5–1 the most important food organisms of the sei whale was copepods but an actual feeding habit of sei whale seems slightly more complicated when *Penaeus* sp., *Scomberesox saurus*, and several another organisms occur locally as being found in 1969/70 season. The feeding habits of sei whale can be considered as a whole that they feed on any kind of swarm forming organisms which dominantly occur within their migratory regions. Bannister and Baker (1967) have also been pointed out on this character by examining the feeding of baleen whale at Durban. However, it must be noted that both chaetognatha which does not swarm into so-called patchiness, and tunicates which is not preferable organisms, are avoided at least by sei whale notwithstanding the fact that they usually occur quite abundantly in the feeding place of baleen whales.

5–3. *Geographical distribution of food organisms*

Since considerable large number of sei whale is caught by the floating factories, it is hardly possible to examine or collect the row materials of the somach contents on every carcasses. So the the food samples are usually collected with some intervals in time and space such as every tenth of carcasses, or every shifts in noon position of the fleets. As mentioned in the foregoing section the kind of food organisms are recorded on the every carcasses regardless the collecting samples. By comparing both row and data materials together, it is possible to figure out the general geographical distribution of food organisms. The results are shown in Figs. 5–1 to 5–3, each of which represents the distributions of copepods, amphipods, and euphausiids respectively.

In the overall distributions of copepod food, *Calanus tonsus* not only occurred dominantly in the south of 40°S covering vast circumpolar regions throughout the areas II to VI, but also was fed most frequently in the region. Its occurrence as sei whale food well agrees with the distribution of patches in the surface waters under close relation to the Subtropical Convergence (see also section 11). As has mentioned in the foregoing section, it must be noted that only swarm forming organisms could be fed by the sei whale, *i.e.*, the distribution of *C. tonsus* as described above supposedly present a little different figures from those known as geographical distribution range of this species. The biomass usually found in its patches is maintained such high density as to be hardly comparable to that known in general, and has been considered to be a characteristic niche in the marine ecosystem. Since the whaling in the Antarctic region is opened in the south of 40°S the northern boundary in the distribution of *C. tonsus* in Fig. 5–1 does not show its natural habitat but artificial. The center of rich distribution of *C. tonsus* is usually found in the vicinity of the Subtropical Convergence (e.g. Kawamura and Hoshiai, 1969) but its northern most boundary may extends beyond upto 30°S or thereabouts.

According to Brodskii (1964) *C. tonsus* occurs under the temperature of 5°∼15°C, and its rich occurrence is observed between 8.5°C and 12.3°C off Otago Peninsula, New Zealand (Jillett, 1968). In this study the surface sea temperaure at which *C. tonsus* occurred as food of sei whale during December was between 9.5° and 18.0°C. Judging from feeding percentages by sei whale the most preferable temperaure for this species was supposed to be 9.0°∼13.0°C, and these sea conditions correspond to the Deacons' mean temperature of the Subtropical Convergence during austral summer (Deacon, 1937).

A distinct southerly extension in the distributions of *C. tonsus* down to 55°S between 160° and 170°W longitudes would be comparable to the southerly shift of the Subtropical Convergence. Actually, the Subtropical Convergence at 170°W in 1968/69 season was located in the vicinity of 55°S latitude (Ocean Res. Inst., 1970).

In the plankton communities of South Georgian waters including northeast Weddell Sea and Scotia Sea, *C. tonsus* does not occur (e.g. Mackintosh, 1934; Hardy and Gunther, 1935), since these regions are influcenced under a northward movement by the cold Weddell Current lower than 5.0°C. In general *C. tonsus* distributes abundantly throughout the subantarctic regions so as to be fed by the sei whale under relatively warmer conditions, *i.e.*, 10°∼15°C, and no other kind of organisms which are comparable with *C. tonsus* as whales food were found. In this point of view *C. tonsus* could be considered ecologically most important species being comparable with *C. plumchrus* or *C. finmarchicus* in the northern hemisphere.

Following to *C. tonsus* the secondly important food copepoda is *C. simillimus*. However, as it is seen in the distributions, *C. similliums* occurred in the Indian sector where both Crozet and Kerguelen Islands, and also a part of Atlantic sector are involved. So the occurrence of *C. simillimus* is considered rather local and hardly comparable with that of *C. tonsus* as food of sei whale. This species distributes on the whole in the slightly southern waters than *C. tonsus* with the distribution center between 45° and 50°S. It is note worthy that the distibutions of *C. simillimus* and *C. tonsus* is closely located geographically but never overlaps each other. In contrast to rather earlier occurrence through December to January in *C. tonsus*, *C. simillimus* occurred mostly around February. Accordingly the sea temperature when they occurred was also different: *C. simillimus* food was found under the temperaures of 5.0°∼9.1°C in 1967/68 season. According to the distributions of copepods obtained by the Japanese Antarcic Research Expedition (Kawamura and Hoshiai, 1969), the successive occurrence of *C. tonsus* was replaced with *C. simillumus* at about 45°S in the southern waters of South Africa, when the surface sea conditions were 7.5°C with salinity of 34.07‰. These facts suggest that the lower most temperature for *C. tonsus* distribution may be 7.0°C or thereabout whereas it may be the higher most temperature for *C. simillimus*. Although both *C. tonsus* and *C. simillimus* are the Subantarctic species, the former could be regarded as northern warmer water species while the latter as southern cold water species.

D. pectinatus occurred only in the waters around Kerguelen and Crozet Islands. In the waters in the vicinity of Crozet Islands distribution of this species agreed well with that of *C. simillimus* but not in Kerguelen waters where none of *C. simillimus* occurred at all. Nemoto (1962) also reported *D. pectinatus* as sei whales food only in the waters around Kerguelen Islands. Kerguelen Islands is located on the Kerguelen—Gausberg under water ridges and forms a shallow depth zones which are rarely found in the high seas in the Antarctic region. The characteristic occurrence of *D. pectinatus* as above mentioned may supposedly due to a local hydrological conditions caused by a kind of upwelling of deep waters in the Indian-Atlantic Basin.

Clausocalanus laticeps is one of newly found food species in the Pacific sector of around 180° meridian. Although its distribution area agrees with that of *C. tonsus*, *C. laticeps* occurred as monospecific population without mixing with any other food species. Among the euphausiid species shown in Fig. 5–2, both *E. vallentini* and *E. superba* are the most important species in the feeding percentages and large shares as biomass in a stomach contents. In the mid-latitude zones the euphausiid food represented almost exclusively by *E. vallentini*. Nemoto (1961) added this species in the dietary list of southern baleen whales after finding its occurrence as food of pygmy blue whale, *B. musculus brevicauda* (Ichihara, 1961: Omura *et al*, 1970) in the Kerguelen waters. Mackintosh (1960) had early suggested an ecological importance of *E. vallentini* when there had not been any scientific evidences on the role of this species among marine food-chains. In the areas II and III *E. vallentini* is fed in a narrow zone between 45° and 47°S but in the areas II and IV, the Indian sector, this species was frequently found under admixing with *P. gaudichaudii*. Although the most *E. vallentini* as the case in copepods is usually fed during December, its distribution centered in rather southern waters within the Subantartic zone. A completely isolated occurrence of *E. vallentini* was seen in the southeastern waters off New Zealand. Since its distribution is clearly isolated from that of *C. tonsus*, *E. vallentini* could be considered a typical Subantarctic species, and these facts agree with the result by Nemoto (1962a), in which he suggested that the distribution pattern of *E. vallentini* as whales food seems to agree to some extent with the distributions of shallow zone by continental shelf and under water ridges. In the environs of New Zealand particularty in its eastern regions the continental shelf develops well, which might be responsible both for the upwelling and a local swarming phenomena by *E. vallentini*.

As the whaling season proceeds the sei whaling ground also shift gradually toward south. In accordance with this shift the food organisms of sei whale also changes into *E. superba* which distributes in the waters south of the Antarctic Convergence, a representative of the whales food in the region. However, it seems rather less important as sei whale food since relatively small number of sei whale migrates into the higher latitudes in the south of the Anatrctic Convergence. Other euphausiids species such as *E. lucens*, *E. similis*, *E. diomedeae*, *Thysanoessa vicina*, *Th. gregaria* and *Thysanopoda actifrons*, were also found in slightly northern regions than *E. vallentini* as sei whale food, but their occurrence was quantitatively small and rather sporadic. In this sence they seem less important as sei whales food. According to Nemoto (1957), *Th. macrura* was one of other kind of important species as a food of fin, blue and humpback whales but none of individuals of *Th. macrura* was found in the sei whale stomachs in this study. Nemoto (1957) also had not found its occurrence in sei whale. These facts are characteristic when compared with the case in *E. superba* since *Th. macrura* also distributes in the waters near to ice-pack (Nemoto, and Nasu, 1958). One of a possible explanations is that *Th. macrura* shows rather sporadic and local distributions than *E. superba* in addition to its habitat in higher latitudes.

Parathemisto gaudichaudii, one of the most important food organisms for sei whale which widely distributes in the Subantarctic waters with the center between 45° and 50°S, *i.e.*, relatively southern waters near to the Antarctic Convergence (Fig. 5–3). Accordingly its general features of the distribution resemble with that of *E. vallentini*. However, it would be noticed by comparing the distribution character with *E. vallentini* that the occurrence of *P. gaudichaudii* as food of sei whale is much sporadic, that is, *P. gaudichaudii* forms the patches so as to be fed by the whale but distributes sporadically. *P. gaudichaudii* occurred most distinctly in the Indian sector of the areas III and IV where the bottom topography is complicated by the presence of many islands such as Kerguelen, Crozet, Marion and Heard Islands. So its distribution resembles to that of *E. vallentini*. Although Nemoto (1962) found *P. gaudichaudii* in the stomach contents of fin and pygmy blue whales, this food species would supposedly be preferred much in sei whale from the general selecting feeding habits of baleen whales. The general agreements in the distribution of both *E. vallentini* and *P. gaudichaudii* suggest a possibilities of their co-existing in time and space. Actually they occurred in the food of sei whale by admixing each other in some sea regions of the Indian sector (see Fig. 5–2).

Penaeus sp., *Scomberesox saurus*, *Vinciguerria attenuata* and some other kind of myctophid fishes occurred in relatively larger quantities but were found to be less important since they were considered as the contaminants mixed with the principal food zooplankton populations. Among those above mentioned organisms, Genus *Vinciguerria*, a kind of gonostomatid fishes, would be regarded relatively important since it forms a potential foodstuff of the skip Jack, *Katsuwonus pelamis* at times in the Pacific Ocean (Kubota and Kawamura, 1972).

5–4. *Latitudinal change in the distribution of food organisms*

In 1967/68 season two of four floating factories operated relatively widely through latitudinal zone, and the materials obtained from those two fleets made it possible to analyse the change in geographical distribution of food organisms in terms of the feeding percentages. The general features of latitudinal change in the Indian sector is demonstrated in Fig. 5–4 and those in the Pacific sector along with the Tasman Sea region is in Fig. 5–5. The feeding percentages are expressed by the ratio of the number of animals with food in the first stomach against the total number of animals examined. " Calanus " in the figures does not mean the Genus *Calanus* in taxonomical sence but represent the copepod although most of the case in " Calanus " is represented by *C. tonsus* and *C. simillimus* (Tables 5–2 and 5–3).

In both figures it is noticed clearly that " Calanus " food being represented by *C. tonsus* and *C. simillimus* occurs exclusively in the waters south of 40°S, down to amidst of the Subantarctic region of about 47°S *i.e.*, the northern half of the Subantarctic waters of the main sei whaling ground of the copepod rich waters. Getting closer to southern region of the Subantarctic waters close to 50°S., the representative food organism gradually changes to small-sized euphausiids such as *E. vallentini*, but *P. gaudichaudii* was also fed by the whale in some places under both monospecific composition and mixture with *E. vallentini*. *P. gaudichaudii* increased gradually in the share of occurred food organisms toward the Antarctic Convergence. In the south of the Antarctic Convergence the dominancy of *E. vallentini* in a stomach contents replaced with *P. gaudichaudii* but the latter is again replaced gradually with euphausiids of adult and adolescent forms

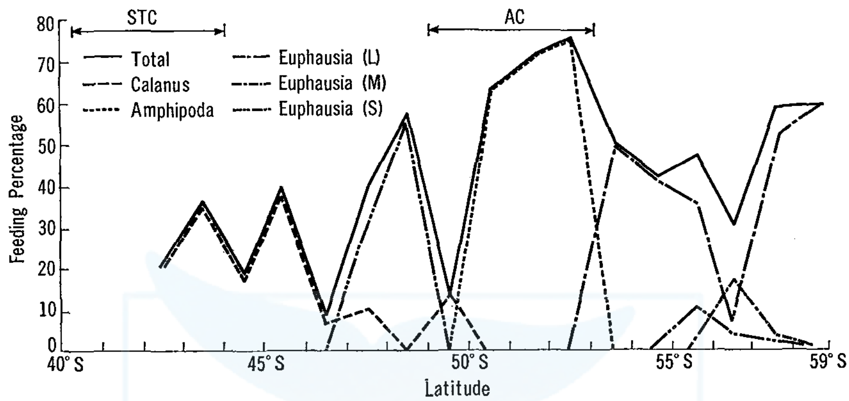

Fig. 5–4. Latitudinal change in the occurrence of food organisms for sei whale in the Indian sector of the Antarctic. STC: Subtropical Convergence, AC: Antarctic Convergence.

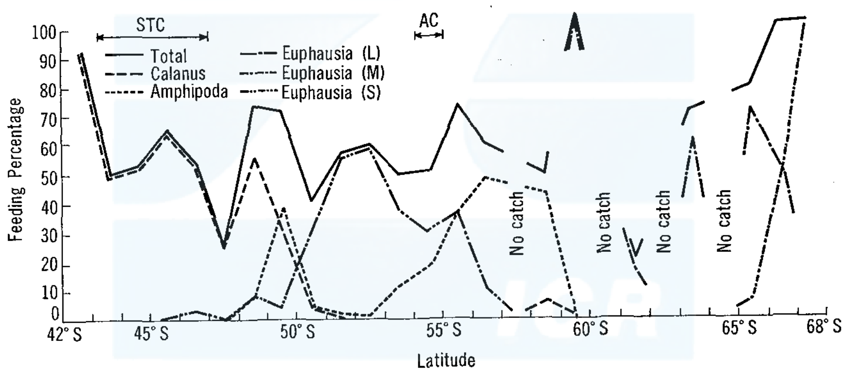

Fig. 5–5. Latitudinal change in the occurrence of food organisms for sei whale in the Pacific sector of the Antarctic and in the Tasman Sea region. STC: Subtropical Convergence, AC: Antarctic Convergence.

of *E. superba*. In the waters south of 65°S 1-year group of *E. superba* occurs sporadically in the stomach of sei whale. Thus the occurrence of the food organisms distinctly changes in latitudinal direction. It is note worthy that these successive changes occur within the narrow zone of about 20° degrees of the latitudes.

The food organisms of sei whale in the waters of the both Subantarctic and Antarctic occurred toward higher latitudes in the order of copepod, euphausiid, amphipod, and then again euphausiid. In the waters north of the Antarctic

Convergence *E. vallentini* was fed more preferably than *P. gaudichaudii* notwithstanding the fact that the former is less abundant than *P. gaudichaudii* in the region, and feeding on *P. gaudichaudii* by the whale was distinctly increased in the south of the Antarctic Convergence (Fig. 5–5). According to Kane (1966), *P. gaudichaudii* distributes most abundantly in the waters around the Antarctic Convergence especially in its northern side. These facts lead to a consideration that the sei whale feeds more preferably on euphausiids than amphipods while the former seems to be less abundant than the latter in the region concerned as a function of selective feeding habits, although it is still unknown whether the food selection is caused by mechanical process or some kind of biologically potential preferance. It may also be possible that the selection of the food organisms in feeding habits would released only when rich food organisms were available in the region. The selective feeding haibts in sei whale also corelate to the distribution pattern of the food organisms whether they form the patchiness or not.

5–5. *Distribution of food organisms by the whaling area*

As mentioned in the foregoing section, the food organisms of sei whale changes one to another in a narrow latitudinal zone. The general circumpolar hydrological conditions in the surface waters of the Antarctic Ocean shows rather monotonous

TABLE 5–5. FEEDING PERCENTAGE (ITALICS) AND ACTUAL NUMBER OF WHALES IN THREE MAJOR FOOD ORGANISM GROUPS BY THE WHALING AREAS III TO VI IN 1967/68 SEASON.

Area & Sector	Kind of food organisms: Calanus	Amphipoda	Euphausiid L	Euphausiid M	Euphausiid S	Unknown***	Empty	Food/Total	No. of inds. Total
Areas III & IV	207*	191	115	23	59	—	919		1518
(Indian Ocean)	*13.64*	*12.58*	*7.58*	*1.52*	*3.89*	—	*60.54*	*39.46*	
Areas IV & V	357**	73	61	17	203	—	537		1248
(Tasman Sea & Pacific Ocean)	*28.61*	*5.85*	*4.89*	*1.36*	*16.27*	—	*43.03*	*56.97*	
Areas V & VI	888	70	—	—	575	9	1008		2550
(Pacific Ocean)	*34.82*	*2.75*	—	—	*22.55*	*0.35*	*39.53*	*60.47*	

* Includes *Drepanopus pectinatus*.
** Includes *Clausocalanus laticeps*.
*** Not examined.

features (Deacon, 1937), that is, the hydrological conditions are less variable by the whaling areas in contrast to those in latitudinal direction. In order to figure out the change in the occurrence of food organisms by the whaling areas, the composition figures were given in Tables 5–5 and 5–6. In the tables the occurrence of food organisms by each whaling areas were expressed in feeding percentages along with the number of animals examined. To make comparison with the case of fin whale its figure was also given in Table 5–6. The kind of food organisms expressed in the tables would be known by refering the foregoing sections. Both large (L) and medium (M) sized euphausiids represents the 1- or 2-year group of

E. superba and small (S) sized one is represented mostly by *E. vallentini* or *E. lucens* in mid-latitudes and by the young *E. superba* in higher latitudes. Only *P. gaudichaudii* corresponds to amphipods (Am).

The feeding percentages in 1967/68 season showed 52.3% on an average and those in 1969/70 was 48.6% through the whaling areas II to VI whereas fin whale showed 58.6%. Their percentage figures suggest that an approximately 50% of sei whale caught in the whaling operations carries food contained stomachs. The feeding percentage of fin whale was slightly higher than that of sei whale. The feeding percentage by the whaling areas in both 1967/68 and 1969/70 seasons varied 39.46∼61.22%, which suggests the different feeding conditions to some extent by the whaling areas. In the feeding percentages by the kind of food organisms, " Calanus " (=copepods) food showed only 13.64% in the Indian sector of the areas III and IV in 1967/68 season while they increased gradually toward the Pacific sector where the feeding percentage attained at 34.82% (Table 5-5). The " Calanus " food through the areas II to IV in 1969/70 season showed a quite high percentage being higher than 60% in the area II whereas they decreased about one half in the areas III and IV.

TABLE 5-6. FEEDING PERCENTAGE (ITALICS) AND ACTUAL NUMBER OF FIN AND SEI WHALES IN FOUR MAJOR FOOD ORGANISM GROUPS BY THE WHALING AREAS II TO IV IN 1969/70 SEASON

Area	Species of whales	Calanus	Amphipoda	Euphausiid L	Euphausiid M	Euphausiid S	Fish*	Unknown**	Empty	Food/Total	No. of inds. Total
II	Sei	675 *60.32*	2 *0.18*	— —	— —	8 *0.71*	— —	— —	434 *38.78*	61.22	1119
	Fin	6 *30.00*	— —	— —	— —	6 *30.00*	— —	— —	8 *40.00*	60.00	20
III	Sei	233 *29.68*	61 *7.77*	— —	— —	42 *5.35*	2 *0.26*	1 *0.13*	446 *56.82*	43.18	785
	Fin	12 *1.10*	4 *0.37*	— —	— —	486 *44.67*	1 *0.09*	— —	585 *53.77*	46.23	1088
IV	Sei	579 *35.76*	47 *2.90*	34 *2.10*	1 *0.06*	6 *0.37*	— —	2 *0.12*	950 *58.67*	41.33	1619
	Fin	9 *1.34*	— —	445 *66.12*	16 *2.38*	18 *2.67*	— —	1 *0.15*	184 *27.34*	72.66	673

* *Notolepis castsi.*

** Not examined.

These results as observed in both seasons suggest that " Calanus " food might be relatively less important in the Indian sector especially in the environs of Crozet Islands. The relatively low feeding percentages of " Calanus " food in these waters well agree with the result obtained by Pervushin who studied on the materials during 1961/63 to 1964/65 seasons (Pervushin, 1968). On the other hand, a relatively high percentages in the areas II of Folkland Island sector and the areas V and VI indicate a potentential importance of " Calanus " food in those regions. However, the " Calanus " food can be regarded potentially important diet for the sei whale whereas they seems less important for the fin whale throughout the whaling areas. The general trends to feed more on euphausiids than copepod in fin whale are clearly seen in Table 5–6.

Although the importance of " Calanus " food for sei whale may be quite evident in general, the fullness of the first stomach with " Calanus " food proved less than 50%, and none of fully repleted stomachs were observed. This fact indicates that the population density in terms of the biomass in " Calanus " food would be less than that in euphausiids and amphipods even when they aggregated densely to show the patchiness. Copepods as food of sei whale have been well known early (*e.g.* Collett, 1886; Ingebrigtsen, 1929; Nemoto, 1957; 1959; Kawamura, 1970a, b) and their more importance for southern sei whale than any other organisms is proved in this study. Accordingly it would be possible that the sei whaling at least in December to January was determined primarily by the distribution of " Calanus " food.

Different from " Calanus " food, amphipods (*P. gaudichaudii*) was fed by 12.58% of sei whale in 1967/68 season and by 7.8% in 1969/70 season. These figures are rather lower when compared with the case of " Calanus " food. Among the whaling areas concerned relatively high feeding percentages were observed in the Indian sector of the areas III and IV in both seasons. However, the feeding percentages in 1969/70 season leveled cosiderably lower than in 1967/68 season as well as having been noticed in " Calanus " food. These phenomena are still not proved yet, but supposedly due to the variation in geographical distribution along with year to year fluctuations in the population size of the food organisms. The low feeding percentages in 1969/70 season also agree with those observed in euphausiids. Since these trends are quite similar through the three kinds of food organisms, it is supposed that they must had not been influenced under the environmental control onto their developmental stages.

Large and medium sized euphausiids, say, *E. superba* had been fed quite little by the sei whale in 1969/70 season. The feeding percentages showed only 2.16% for large sized euphausiid in the area IV whereas it was 7.6% in the Indian sector of 1967/68 season. The latter was the highest feeding percentages through both seasons. In 1967/68 season euphausiids showed relatively higher feeding percentages than copepods and this relationship reversed in 1969/70 season. A relative low feeding percentage in large and medium sized euphausiids supposedly due to the geographical location of main sei whaling ground, and the varations between whaling seasons would be due to the environmental factors which are responsible for the development of young copepods. The sei whale might have fed on *E. superba* when copepods such as *C. tonsus* was poorly available. Studying on the food of baleen whales in the North Pacific, Nemoto (1959) concluded that there must be both *Calanus* rich year and euphausiids rich year in those region. A similar phenomena may be considered in the Antarctic whaling ground.

In small sized euphausiids, however, the general circumstances seem different to some extent. Different from large sized euphausiids the small sized one is chiefly represented by *E. vallentini* and *E. lucens*, and their feeding percentages in the Pacific sector of the areas V and IV showed 22.6%, a relatively high ratio though it decreased gradually toward the west through Tasman Sea, Indian sector and then Atlantic sector respectively. In 1969/70 season the feeding percentages were distinctly low throughout the areas II to IV, and no areal variations were observed. The occurrence of small sized euphausiids may also be related to the abundance of copepods as having been suggested in the large sized euphausiids.

According to Baker (1954) the circumpolar distribution of zooplankton in the Antarctic region shows a monotonous features on the whole through the three oceans whereas they distinctly change in the north-south direction, and both of these circumstances agree well with the general hydrological conditions. The geographical changes in the feeding percentages of sei whale also agree as a whole with the results reported by Baker (1954). A local but distinct occurrence of *C. simillimus* and *P. gaudichaudii* in the sei whale food agrees too with their general distribution patterns, that is, the distribution of food organisms does not differ from that of zooplankton.

6. DISTRIBUTION OF WHALES, AND ITS RELATION TO PHYSICAL, CHEMICAL AND BIOLOGICAL ENVIRONMENT FACTORS

Studying on the food and feeding of sei whale caught in the 1967/68 and 1969/70 seasons, it was considered that the regions where feeding ground is formed in the Subantarctic zone would closely related to the characteristic features in the distribution of food organisms. For instances, the feeding ground being formed by the copepodite V stage of *C. tonsus* during early summer diminishes gradually as to their seasonal vartical migration into the deeper waters (Jillett, 1968), and these environmental changes make the whale move into more higher latitudes in search of another foodstuff such as *C. simillimus*, *E. vallentini* and *P. gaudichaudii*. Thus, the geographical shift in the whaling ground closely relates to the ecological characters in the distribution of food organisms.

6–1. *Distribution of whales and the environmental factors in the Pacific and Antarctic Ocean*

Apart from the biological examination on whale carcasses, the oceanographical investigations along with plankton sampling and whale sighting were made during the KH–68–4 cruise of the R. V. "Hakuho Maru" of the Ocean Research Institute, University of Tokyo, and a part of biological works made in this cruise have already been reported (Kawamura, 1969a, 1970b, c; Kawamura and Kureha, 1970). Leaving Tokyo on November 14, 1968, the research cruise of KH–68–4 was made along two transections, *i.e.*, 170°W from 30°N down to 70°S and 155°E from 38°S to 70°S. The track along 170°W crossed in the midst of main sei whaling ground where one of the Japanese floating factories operated for two successive seasons through 1967/68 and 1968/69 (Ocean Res. Inst., Univ. Tokyo, 1970). A total of 61 oceanographic stations were occupied during the cruise, and the plankton collection from 150 m depth upto the surface was also conducted routinely with the North Pacific standard net, and also several series of divided hauls from great depths with the Petersen type vertical closing net. Of approximately 9,000 miles cruise 2,100 miles of the track was sighted for counting the number of whales and seabirds.

The number and the kind of whales sighted along 170°W were demonstrated in Fig. 6–1 along with the profile of the environmental factors. In general the dis-

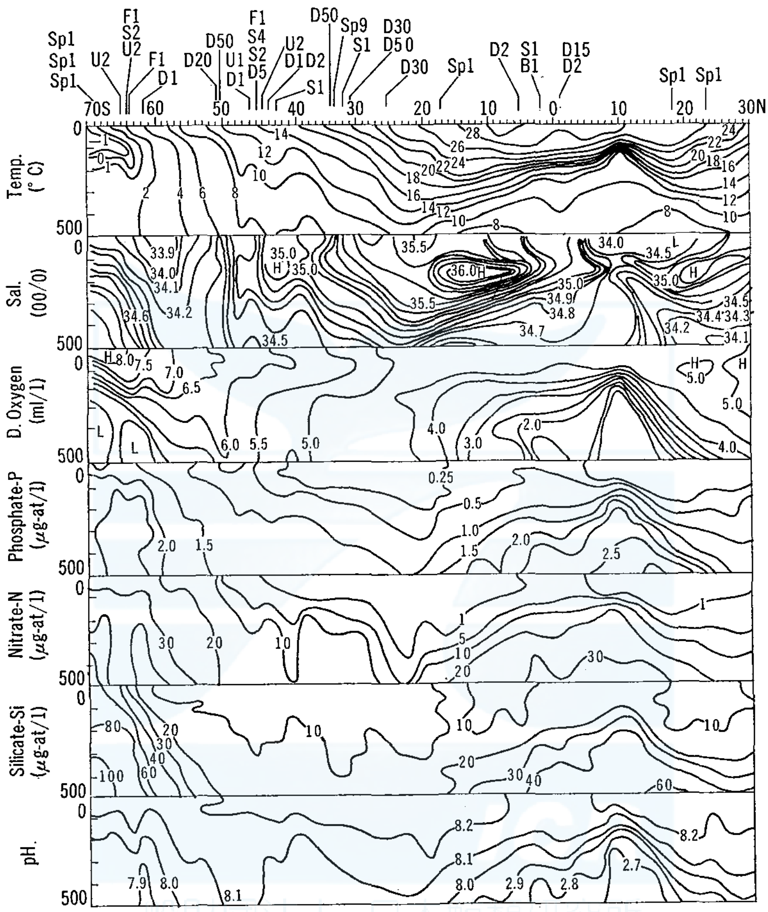

Fig. 6–1. Whales sighted and profile of the environmental factors along 170°W, 30°N～70°S during Nov. 22, 1968 to Jan. 19, 1969. Sp: sperm, B: blue, F: fin, S: sei, D: small toothed, U: unidentified.

tribution of whales shows close relation to the bottom topography in the feeding place (Nemoto, 1957; 1958), but the depth along the track covered by the R. V. "Hakuhô Maru" varied between 2,000 and 3,000 m, and possibly no influences on the distribution of whales. It would be noticed in Fig. 6–1 that the distinct accumulations of whales were found in the south of 30°S especially in the Subantarctic region between 30°S and 50°S. A rather less number of sighted whales between 50°S and 60°S was supposedly due to rough surface of the sea by stormy weather.

An approximate physicochemical conditions in the Subantarctic waters along 170°W were; 10°∼20°C (temperature), 34.5∼35.5‰ (salinity) and 0.25∼0.5 μg-at/l (phosphate) and 5.5 ml/l (dissolved oxygen) respectively. On the characters in chemical properties of the Subantarctic regions, Rochford (1961) demonstrated 35.4‰ of salinity and 0.2∼0.4 μg-at/l in phosphate as its indicators in the waters off Western Australia, and he distinguished the water masses under the names of " south transitions zone ". By taking these results into considerations it would be noticed that relatively denser consentration of whales are located not in the midst of the Subantarctic waters but in rather northerly located transition zone between

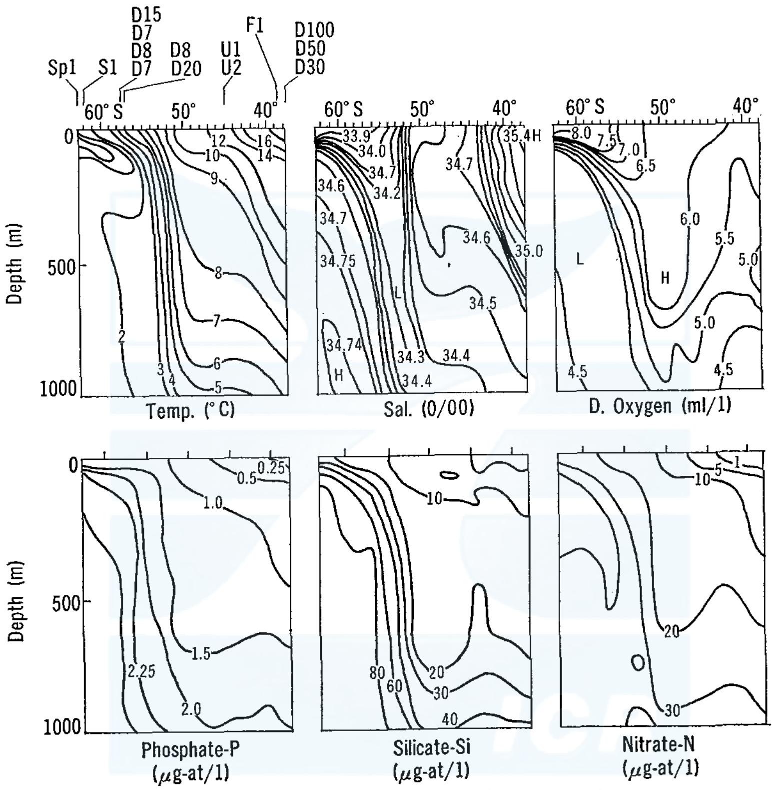

Fig. 6–2. Whales sighted and profile of the environmental factors along 155°E, 63°S∼38°S during Jan. 23 to Feb. 1, 1969. Abbreviations of whale species are as given in Fig. 6–1.

warm and cold waters. As clearly noticed in the distribution pattern of the environmental properties, those transition zone corresponds to the upwelling zone of rich zooplankton standing stocks. In the south of 60°S, the proper of the Antarctic region, a great number of whales distribution was also found.

On the other hand in the Antarctic and the Tasman sea regions along 155°E longitude, the whales were spotted only twice for sei and fin whales, which showed a poor distribution of whales in general (Fig. 6–2). The relationship between the distribution of whales and the environmental factors in this region was less clear than those in 170°W. However, relatively rich distribution of whales was found in the Antarctic and Subantarctic waters, particularly in the transition zone of northern waters.

Apart from the Antarctic regions it was note worthy that there were also distinct accumulations of whales in the region of equatorial divergence between 10°N and 10°S, where a quite high concentrations of zooplanters were found (Fig. 6–3). The zooplankton in this region would possibly be supported by the high primary productivity due to upwelling (Nasu, 1972) which provides a quite rich accumulation of tuna (Sette, 1955). Although it is recognised in general that the baleen whales do not feed much or entirely in the tropical seas (*e.g.* Mackintosh, 1965), but those above mentioned results lead to a consideration that the whales would potentially be in search of foodstuff even in those warmer waters.

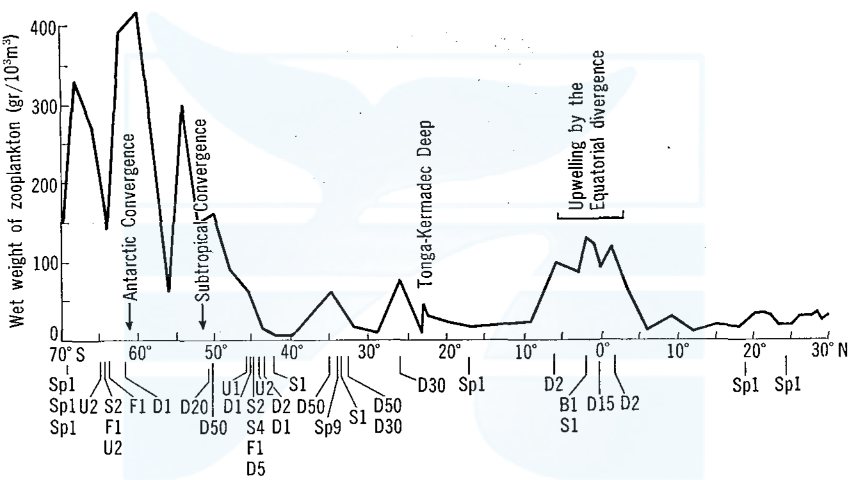

Fig. 6–3. Whales sighted and wet weight of zooplankton in the upper 150 meter of the water column between 30°N and 70°S along 170°W during Nov. 22, 1968 to Jan. 19, 1969. Abbreviations of whale species are as given in Fig. 6–1.

Whales sighted at 40°∼50°S might have been on their migration toward south since most of them were spotted in the early January. According to the catch records in the past 40 years (Omura, 1973), some individuals of the sei whale spotted at higher latitudes in early summer are supposed to be as the stranger from over wintered population.

In summerizing the above mentioned results both baleen and toothed whales distribute in more favourable environments of the sea, where the feeding conditions as having been indicated by the zooplankton abundance would be the most important role not only in the Antarctic region but also in the tropical seas.

6–2. *Whaling ground of sei whale and the distribution of zooplankton*

The whaling grounds of sei whale both in 1967/68 and 1968/69 in the areas V and VI of the Pacific sector were shown schematically in Fig. 6–4, and the distribution of food organisms found in the stomach of sei whale caught in the above mentioned whaling grounds were demonstrated in Fig. 6–5. Black spots on the meridians of 170°W and 155°E in the figures represents the oceanographic observation stations occupied by the R. V. "Hakuhô Maru" during her 1968/69 cruise. The track by the "Hakuhô Maru" crossed over the whaling grounds although the main body of whaling ground in 1968/69 season located somewhat eastward. The mean position of both the Subantatctic and Antarctic Convergences are indicated by the solid lines along with those observed by the R. V. "Hakuhô Maru."

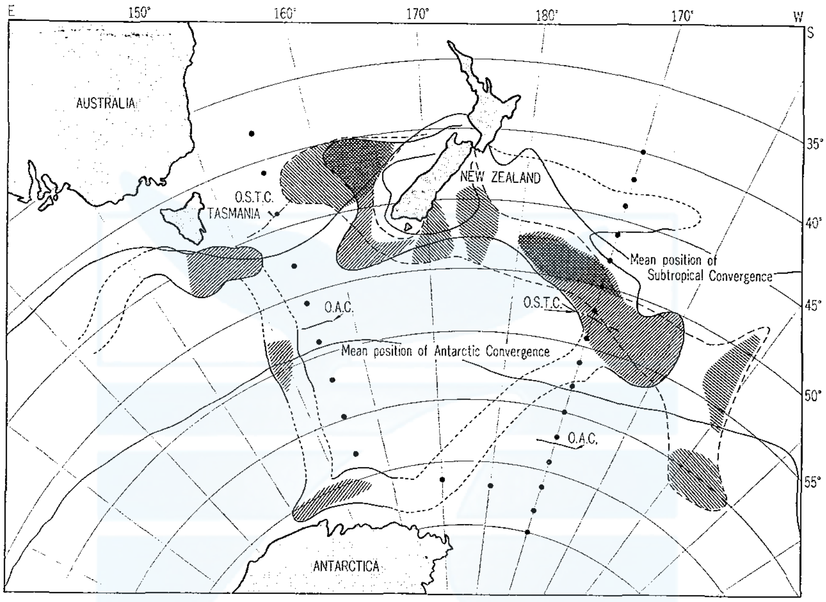

Fig. 6–4. Whaling grounds of sei whale in the Antarctic, Areas V and VI. Shade by hatch indicates the region where the sei whale was heavily catched. Black spot shows the position at which plankton sampling was made by the R. V. Hakuhô Maru during her KH-68-4 Cruise in 1968/69. O.S.T.C., O.A.C.: Observed positions of the Subtropical and Antarctic Convergence.

The whaling ground of sei whale in these regions is formed in the north of the Subantarctic waters with its center along the Subtropical Convergence and its transition zone. These hydrological conditions do not differ much from those in the Folkland region (area II) and the Indian sector (areas III and IV).

The food organisms which occur regularly in the whaling ground around New Zealand are *C. tonsus*, *Clausocalanus laticeps*, *E. vallentini*, *E. superba* and *P. gaudichaudii* among which *E. superba* is found only in the vicinity of Balleny Islands. This species seems less important as sei whale food being compared with other food species. Both *E. vallentini* and *Clausocalanus laticeps* as well as *E. superba* showed local occurrence. In Fig. 6–5 it is considered that the whaling ground of the areas V and VI is largely formed solely by *C. tonsus*.

On the other hand the quantitative distributions of net zooplankton species which were collected by the Norpac net at each stations were demonstrated in Figs. 6–6 to 6–12. In Fig. 6–6 it was observed that the approximate number of individuals of *C. tonsus* population was 10^4 inds./1000 m^3 along the 170°W whereas it was 10^5 inds./1000 m^3 along 155°E. The figures of $10^4 \sim 10^5$ inds./1000 m^3, can be considered quite distinct in abundance as the distribution density of copepods, and are still more higher density than that of *C. tonsus* in New Zealand waters where they showed 0.52∼83.5 inds./m^3 (Jillett, 1968). The general features

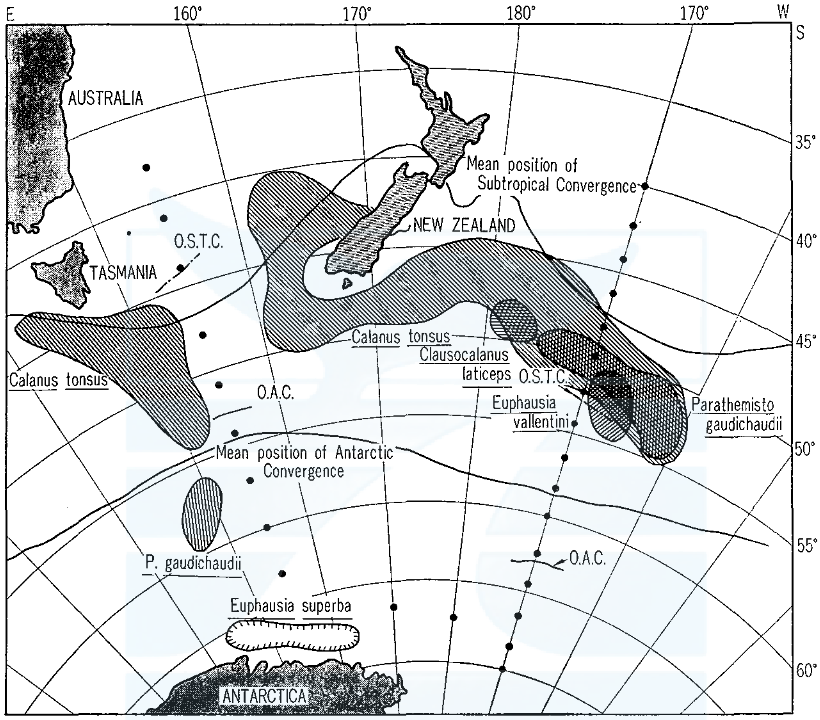

Fig. 6–5. Distribution of the food of sei whale in the Areas V and VI, 1967/68. O.S.T.C., O.A.C.: Observed positions of the Subtropical and Antarctic Convergences.

of the *C. tonsus* distribution in Fig. 6–6 correspond well to the characteristic distribution of whaling ground shifting rather northerly or southerly close to the Antarctic Convergence at 170°W and 155°E respectively.

C. simillimus was one of an important food plankton for sei whale in the Indian sector of the area III, but none in the area V. A considerable number of species, however, occurred in the net samples throughout the Subantarctic region with the individual density of $10^3 \sim 10^5$ inds./1000 m^3 or more (Fig. 6–7). The most *C. simillimus* population occurred was represented by the copepodite stages II and III along with adult forms while *C. tonsus* population was almost exclusively by the copepodite V, that is, the food of sei whale. Accordingly, it would be possible that their life history differs each other. *C. simillimus* is generally recognized as

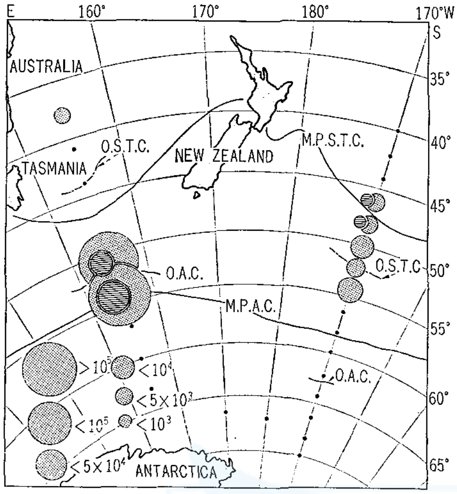

Fig. 6–6. Quantitative distribution of *Calanus tonsus* in the whaling area V, 1968/69. MPSTC: Mean position of the Subtropical Convergence, MPAC: Mean position of the Antarctic Convergence, OSTC: Observed position of the Subtropical Convergence, OAC: Observed position of the Antarctic Convergence. Copepodites under IV are shown by the hatch.

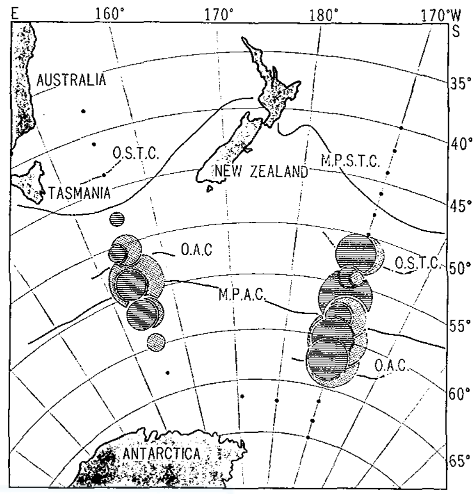

Fig. 6–7. Quantitative distribution of *Calanus simillimus* in the whaling Area V, 1968/69. Legends as in Fig. 6–6.

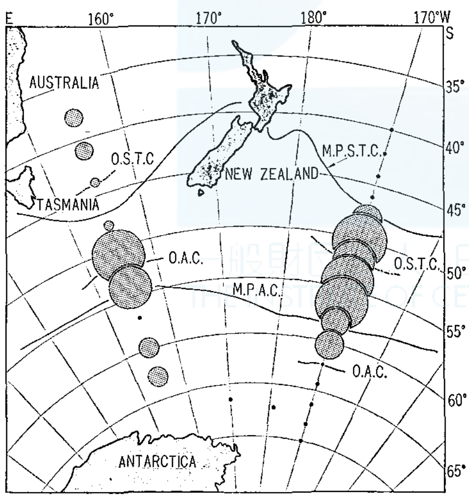

Fig. 6–8. Quantitative distribution of *Clausocalanus laticeps* in the whaling Area V, 1968/69. Legends as in Fig. 6–6.

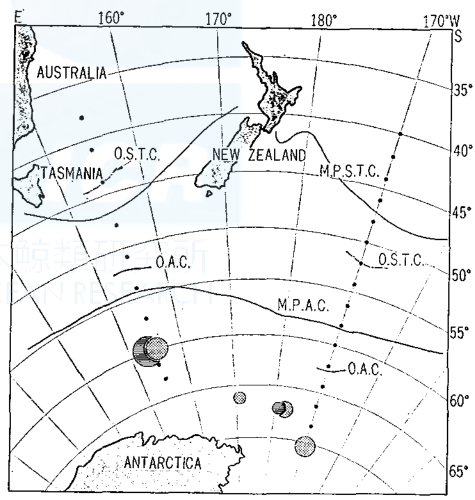

Fig. 6–9. Quantitative distribution of *Calanus propinquus* in the whaling Area V, 1968/69. Legends as in Fig. 6–6.

the Subantarctic species (Hardy and Gunther, 1935, Vervoot, 1951, 1957; Tanaka, 1960; Brodskii, 1964), and the center of distribution in this species were found relatively in the southern waters than *C. tonsus* and does not occur in those transition zone proposed by Rochford (1962).

As it was described by Brodskii (1964), *C. simillimus* distributes in the waters around the Antarctic Convergence being centered between 50°S and 60°S. It was the Kerguelen—Crozet regions of 43°~50°S that *C. simillimus* occurred in the sei whale stomach in late January to mid February. In the environs of Crozet Islands where the surface sea temperature during December to January was 9.0~13.4°C, *C. tonsus* occurred as food of sei whale and it was replaced with *C. simillimus* in the waters of 5.0°~9.1°C. These facts lead to a consideration that *C. tonsus* would be rather northern warm temperate species in contrast to *C. simillimus*. According to Kawamura and Hoshiai (1969) the boundary at which the distributions of both *C. tonsus* and *C. simillimus* replaced one to another was found at 45°S in the area between Cape Town and the Showa Base in Antarctica. The surface sea temperature and the salinity at 45°S were 7.6°C and 34.07‰, respectively. Since *C. simillimus* does not occur under the conditions of low salinity lower than 33.88‰, it would hardly be possible that *C. simillimus* occurs as food of sei whale in the higher latitudes south of 60°S. Accordingly, *C. simillimus* would be fed by the whale in the waters of 45°~50°S where relatively warmer water prevails although its distribution is positioned still southward than the case in *C. tonsus*. Therefore, the distribution pattern of *C. simillimus* is considered to be somewhat similar to that of between *C. propinquus* and *Calanoides acutus*.

As the season goes by the copepodites II and III population of *C. simillimus* in January develops gradually to copepodites III to IV while *C. tonsus* population of copepodite V migrates into deeper waters (Jillett, 1968), and the feeding place for sei whale being formed by this species diminishes gradually. Then *C. simillimus* forms the feeding place following to *C. tonsus* but it is somewhat local phenomenon; none of *C. simillimus* was fed by sei whale in the waters around 155°E while a considerable number of *C. simillimus* occurred in net samples.

It was 1967/68 season that *Clausocalanus laticeps* was recorded first in the food of sei whale (Kawamura, 1970a). This species, as shown in Fig. 6–5 was fed by the whale in the same region as *C. tonsus*, and therefore this species as food of sei whale has not such importance as to *C. tonsus* because of its quite local occurrence. However, *C. laticeps* population occurred under monospecific composition with high population density, and was considered locally important foodstuff for sei whale. *C. laticeps* distributes in the vincinity of the Subtropical Convergence, a slightly northern species, and they occurred abundantly in the Pacific sector proper than in the Tasman Sea region. Although this species distributes upto far north off Australia along the 155°E meridian, the population density showed 5×10^2 inds./1000 m^3 at most. So the biomass of this species in the sea might be rather small due to its body length. As a food of sei whale *C. laticeps* occurred in the waters around Antipodes Island, 50°S, 175°W~180°, and the distribution of this species agreed well with that obtained on the net plankton samples. Therefore, it is supposed that *C. laticeps* forms dense swarms in the surface waters as well as other food species. In the South African waters near Cape Province, *Clausocalanus arcuicornis* was fed by sei whale (Best, 1967). It was proved by this facts that at least genus *Clausocalanus* would swarm into the patches as well as *Calanus* species, and formation of the patchiness would supposedly be the general distribution characters throughout the genus.

Both *Calanus propinquus* and *Calanoides acutus* have not been recorded as the food of baleen whales in the food materials collected by the Japanese floating factories (Nemoto, 1959; 1962a; Kawamura, 1970a). However, Peters (1955) reported *C. acutus* as the food of sei whale during the German whaling operations in 1930's, and later Pervushin (1968) described both *C. propinquus* and *C. acutus* as the food of the baleen whales. According to Ottestad (1932; 1936), *C. acutus* and *C. propinquus* are typically endemic species of the Antarctic waters, and they occurred only within the colder regions in the south of the Antarctic Convergence

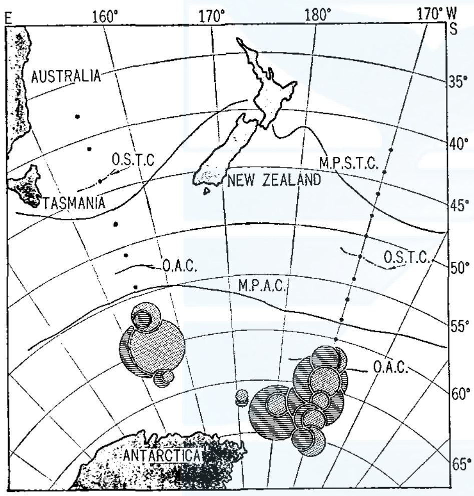

Fig. 6–10. Quantitative distribution of *Calanoides acutus* in the whaling Area V, 1968/69. Legends as in Fig. 6–6.

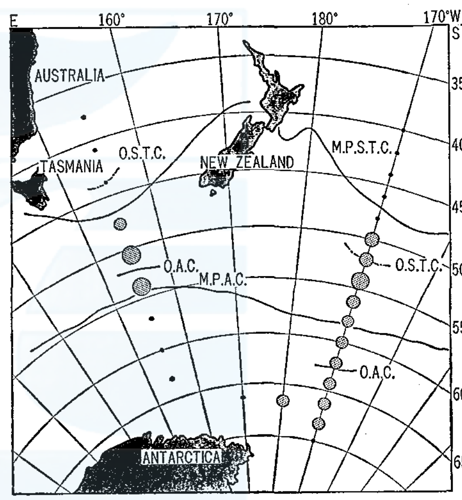

Fig. 6–11. Quantitative distribution of *Parathemisto gaudichaudii* in the whaling Area V, 1968/69. Legends as in Fig. 6–6.

(Figs. 6–9 and 6–10). In many locations these two species occured being accompanied with *Rhincalanus gigas* or dense vegetation of diatoms. Comparing with both species *C. acutus* was more dominant than *C. propinquus* but the former was represented by younger individuals of copepodites II to IV. Since *C. acutus* and *C. propinquus* distribute with a little numbers in the far southern waters apart from the main whaling ground of sei whale, it would be quite possible that none of those two species occur in the diet of sei whale. However, Pervushin (1968) reported their occurrence in the stomach contents of sei whale in the area III of Crozet Islands and its environs although the case might be quite extraordinal. By summerizing the results on the distribution of those two species along with those reported previously (Mackintosh, 1934, 1937; Ottestad, 1932, 1936; Hardy and Gunther, 1935; Vervoot, 1951, 1957; Tanaka, 1960, 1964; Andrews, 1966; Kawamura and Hoshiai, 1969), the northern most boundary in their distribution would on the whole be somewhere between 50° and 60°S except the case in the Indian sector where it was 47°43'S, at 76°48'E (Vervoot, 1957). It seems therefore curious that both *C. acutus* and *C. propinquus* occurred as the food of sei whale in the Crozet Islands regions since the feeding by whale itself essentially requires an abundant distribution so as to form the patches. In this respect both *C. acutus* and *C. propinquus* may possibly be fed to some extent by the baleen whales in some locally limited time and place, but it may also be impossible them to form the staple feeding ground for whales since those two species occur usually by accompanying the thick diatom population of *Thalassiothrix antarctica* along with totally poor standing stocks themselves.

Since *P. gaudichaudii* is provided the strong ability of swimming by its pleiopods (Kane, 1966; Nemoto and Yoo, 1970), many adult forms of this species would have avoided from the net collection. *P. gaudichaudii* population occurred in net samples of this study were excusively consisted of small immatured individuals with body length less than 10 mm. In the Subantarctic waters south of New Zealand Hurley (1961) and Kane (1962) made zooplankton collections, and found that amphipods in those waters were mostly represented by the larval and immatured young individuals. Their net avoidance during net hauling would be obvious.

A relatively small number of *P. gaudichaudii* occurred regularly in the waters between 50° and 60°S along 170°W, where the individual density showed about 10^2 inds./1000 m^3 whereas they showed much poorer but steady density throughout the 155°E. It is supposed that the center of distribution would be around the Antarctic Convergence. The results obtained by Kane (1966) in the area III by R.R.S. "Discovery II" and those by Hurley (1961) and Kane (1962) in the Pacific region agree in general with the present study.

In the row materials of the stomach contents of sei whale the most individuals of *P. gaudichaudii* were represented by the large sized individuals of adult and possibly adolescent forms. This is largely different from the population obtained by the net. However, it was observed that the general characters of the distribution in both populations do not differ much. So it could be said that none of the habitat segrigations are possible in adult and young immature forms.

It has been reported that a little number of *P. gaudichaudii* occurred in the stomach contents of blue and fin whales as an admixture among *E. superba* population (Nemoto, 1959; 1963). However, the importance of *P. gaudichaudii* as food of baleen whales is much increased along with the proportional increase of sei whale in the total catches. In this respect *P. gaudichaudii* seems to be indispensable food for sei whale especially in the Indian sector of the Antarctic (Table 5–4). According to Nemoto (1959) the fin whale in the area V fed exclusively on *E. superba* whereas the bulk of sei whale fed on *P. gaudichaudii*. Following to *C. tonsus*, *P. gaudichaudii* as found in net samples distributed widely through the whaling ground as shown in Fig. 6–5. Since the net avoidance by euphausiids as well as

P. gaudichaudii may also be possible as Fleminger and Clutter (1965) have discussed on this matter, a quantitative treatments on the net samples in this study would be difficult. Fig. 6–12 demonstrates the distribution of euphausiids species occurred in the net samples. The populations of euphausiid were mostly consisted of young individuals of the furcilia stages, and a little number of adult forms. A total of thirteen species of euphausiids was identified, but it was only two or three species that were actually important as food of sei whale, *i.e.*, *E. superba*, *E. vallentini*, and *E. lucens*. In contrast to euphausiid populations in the net samples, those fed by the whale were mostly represented by both adolescent and adult forms. The furcilia and some corresponding individuals were consisted of many species, and therefore, the distribution of furcilia of euphausiids does not seem to have any direct relationship to the formation of feeding ground.

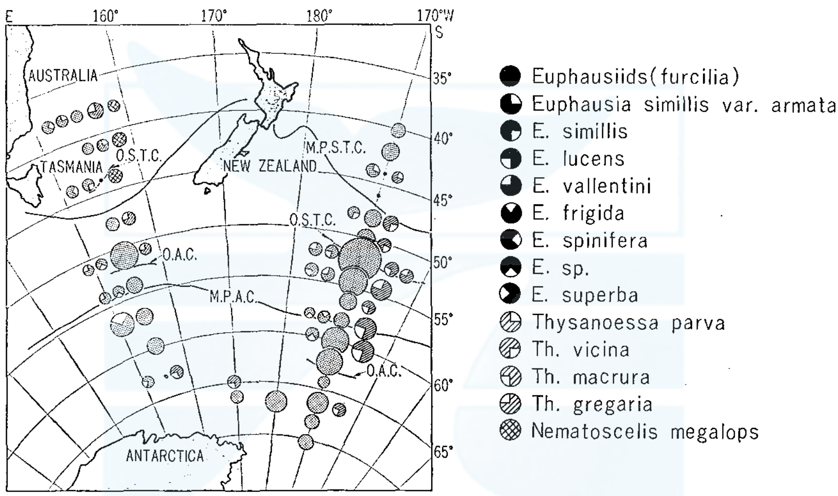

Fig. 6–12. Quantitative distribution of euphausiids in the whaling Area V, 1968/69. Legends as in Fig. 6–6.

E. vallentini, the main euphausiid species occurred at 52°S and 54°S along 170°W longitude, and again at 51°S and 54°S along 155°E. Although the number of individuals occurred was relatively small, the distribution pattern of *E. vallentini* in both whales stomach and net samples agreed well in the region along 170°W. *E. superba* also shown a similar relationships. In *Thysanoessa* populations, *Th. macrura* and *Th. gregaria* were distinct in their individual numbers. The former has been reported as the food of humback and fin whales in the areas I and VI (Nemoto and Nasu, 1958), and they (Nemoto and Nasu, 1958) suggested its importance as whales food particularly in the region of higher latitudes. The occurrence of *Th. macrura* in this study was recorded only in the south of 60°S, and this species may possibly be less important for sei whale which is essentially considered to be copopoda feeder in the mid-latitudes. None of *Th. macrura* was fed by the sei whale in the areas V and VI.

The biomass of euphausiids in terms of the number of individuals in the area

V showed $10^3 \sim 5 \times 10^3$ inds./1000 m^3, and there were no notably distinct differences were found between local regions. As mentioned before the net avoidance by euphausiids would be quite possible, and the euphausiids species as demonstrated in Fig. 6–11 might have been entangled by reason of their dominancy among zooplankters under those circumstances. If so, *E. vallentini* could be considered to have distributed abundantly in the southeast region off New Zealand, and in the Tasman Sea region. Supposing these circumstances the feeding on *E. vallentini* by the sei whale agrees with the general distribution patterns of *E. vallentini*.

In general the distribution of sei whaling ground can be seen as a function of the characteristic distribution of food zooplankters, and these corelations were more clearly observed in copepods. The organisms fed by the sei whale are represented by the patch forming species, and an agreement in the distributions between zooplankton and whaling ground strongly suggests that those food organisms aggregate so as to form the patches to some extent at least in some local regions throughout their geographical distribution range.

7. BODY SIZE OF *CALANUS TONSUS*

In the previous sections it has been discussed and proved that the zooplankters and micronekton as food of baleen whales have to be maintained such high population density as to aggregate into patchiness. This conception would be well recognized by refering to some previous reports (e.g. Collett, 1886; 1911~12; Hinton, 1925; Mackintosh and Wheeler, 1929; Slepzov, 1955; Nemoto, 1957, 1959, 1962a, b; Marr, 1962; Mackintosh, 1973) although non-patch forming organisms would be fed at times when the whales migrate into the region far outside from the so-called feeding ground such as the case in the South African waters.

In the course of microscopic observations on the food organisms some differences in the body size of *C. tonsus* population by the whaling areas were noticed. *C. tonsus*, as has been described previously, is the most important foodstuff for the southern sei whale since it heavily aggregates in the surface waters during the first half of whaling season. In this respect the composition of body size in *C. tonsus* by the whaling areas was discussed in connection with its aggregating habits what it means ecologically.

7–1. *Composition of body size in C. tonsus population*

The materials examined were the stomach contents of sei whales which were caught in 1967/68 and 1969/70 seasons. A total of 5,706 individuals of *C. tonsus* was examined for this purpose, and the results were compiled by separating the month into three decades (Table 7–1). However, the materials were only available during mid December to mid January since the whaling operation for baleen whales is opened on 12th of December thereafter, and also the season for sei whaling lasts for only a month and half to somewhere around mid January due to a fading out of the feeding ground formed by *C. tonsus*.

As shown in Table 7–1 *C. tonsus* of copepodites IV–VI (female) occurred as food of sei whale. Since adult male of this species is usually said as to be mostly in deeper waters (Jillett, 1968), they hardly occur in the surface swarms and consequently, in the population of sei whale food. The body size was measured on the individuals being preserved in good conditions, and they were selected randomly. Then the number of measured individuals through copepodites IV–VI could be considered as to represent the composition of food *C. tonsus* population, and they are represented by the copepodite V stage, since it occupied for 81.9~98.4%, with the average of 89.7% in the whole of *C. tonsus* populations examined.

TABLE 7–1. MONTHLY OCCURRENCE OF *C. TONSUS* BY THE STAGES IN TERMS OF PERCENTAGE FIGURES. THE ACTUAL NUMBER OF INDIVIDUALS EXAMINED IS INDICATED BY PARENTHESES.

Stage	Mid-Dec.	Late-Dec.	Early-Jan.	Mid-Jan.	Total
C IV	1.6 (24)	0.83(20)	1.73(17)	0.62(5)	1.16(66)
C V	81.9 (1222)	88.5 (2135)	96.4 (956)	98.4 (797)	89.7 (5110)
C VI Female	16.5 (247)	10.67(258)	1.87(18)	0.98(7)	9.14(530)
Total	1493	2413	991	809	5706

In 1967/68 season the whaling was mostly operated in the areas III, IV and V, but the area shifted rather westward in 1969/70 season and the areas II, III and IV were occupied. The composition of body size of *C. tonsus* along with the average and the number of individuals were demonstrated by regions in Figs. 7–1 and 7–2, since the overall sea conditions as the habitat of *C. tonsus* are possibly variable by the sea regions (Hempel, 1968). The body size of each copepodite stages was: 2.7~3.0 mm in copepodite IV, 3.2~3.6 mm in copepodite V, and 3.7~4.0 mm in adult female respectively. The composition of body size in copepodite V showed a normal distribution pattern with highest frequency of occurrence at the midst of distribution range through the materials obtained in Folkland region to the east Indian sector region. In the general trends of the variation by the ocean sectors, the distribution range of the body size class widened gradually in the direction from the Atlantic sector toward the Pacific sector, though the most distinct example was in the Western Australian region. The body size of 3.5~3.6 mm usually showed high frequency of occurrence, but in the regions both south of Western Australia and South Africa as indicated by the letter of, D, H, J, K, M and N, the body size of high frequency was found between 3.0 and 3.2 mm. These kind

TABLE 7–2. AVERAGE SIZE OF *C. TONSUS* IN THREE DIFFERENT AREAS IN 1967/68 SEASON. NUMBER OF INDIVIDUALS EXAMINED IS GIVEN IN PARENTHESES.

Area \ Month		Mid-Dec.			Late-Dec.
		III, IV 66°~82°E	V 172°E~163°W	IV 83°~101°E	IV 82°~87°E
	C IV	—	—	—	2.80 (1)
Average size (mm)	C V	3.46 (294)	3.23 (111)	3.38 (78)	3.38 (1335)
	C VI (♀)	3.85 (76)	—	—	3.78 (110)

of difference as a biological character of each swarming *C. tonsus* populations suggests that they might come from a different population as the reproductive units. The pattern of body size composition following to that of the normal distribution lasts for a month or so without any changes within the composition. The female of copepodite VI is considered to follow the similar way as copepodite V although the former is much variable than the latter due to its poor number of materials. The high frequency of the occurence in the adult female was 4.0~4.2 mm and no differences in the body size compositions between the whaling areas were observed. This may possibly be due to their biological character of stopping the feeding activity in the copopodite VI stage as it has been known in *Calanus plumchrus* and *C. cristatus* (Minoda, 1971). In the populations in the Indian sector as indicated by the letters of C and G, the body size of high frequency of occurrence was 3.7~3.8 mm. In general the composition of the body size in the adult female showed the range between 3.4 and 4.8 mm, a rather wider range in the distributions than the case in copepodite V. The variations of this range was most distinct in the Atlantic sector.

TABLE 7-3. AVERAGE SIZE OF *C. TONSUS* IN THREE DIFFERENT AREAS IN 1969/70

Month / Area		Mid-Dec.			
		IV 109°~118°E	II 33°~43°W	II 37°~53°W	IV 110°~118°E
Average size (mm)	C IV	2.72(5)	2.78(2)	—	2.77(9)
	C V	3.13(21)	3.44(23)	3.56(4)	3.19(31)
	C VI (♀)	4.00(5)	4.11(19)	4.21(4)	4.01(15)
Average by month	C IV		2.75		
	C V		3.38		
	C VI (♀)		4.11		

7-2. *Discussion*

Jillett (1968) studied the seasonal distribution of *C. tonsus* in the waters off Otago Peninsula, New Zealand, and found that the *C. tonsus* population in the surface water during the summer was represented by the copepodite V stage. He (Jillett, 1968) also shown that *C. tonsus*, as a biological characters through Calanoida, has two generations annually, and that the copepodites from the second generation of current year mostly occupy the summer population, which must be the food of sei whale in the northern Subantarctic waters. The life history of *C. tonsus* suggests generally that the individual of the copepodite V from two different generations coexists at least during December. One comes from over winterd population and the other from developing population in current year. The coexistence of two size groups of copepodite V from different reproductive sources has been known in *C. finmarchicus* in the North Atlantic waters (Stormer, 1929, Barnes and Barnes, 1953; Colebrook, 1963), and Barnes and Barnes (1953) considered that the difference in size composition would be due to different populations, although there is a possibility of potential male and female.

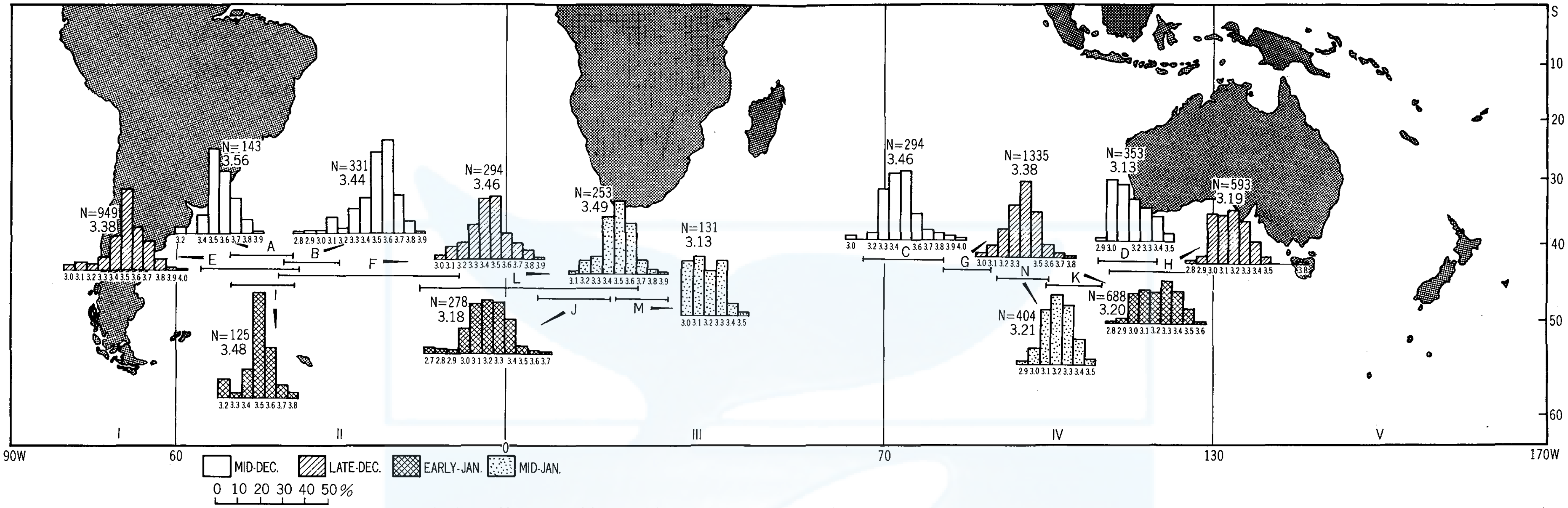

Fig. 7-1. Size composition of *Calanus tonsus* copepodite V in the whaling areas and months in 1969/70 season. Average body length is given above each figures, and an approximate longitudinal range from which samples were collected is shown by the capital A to K.

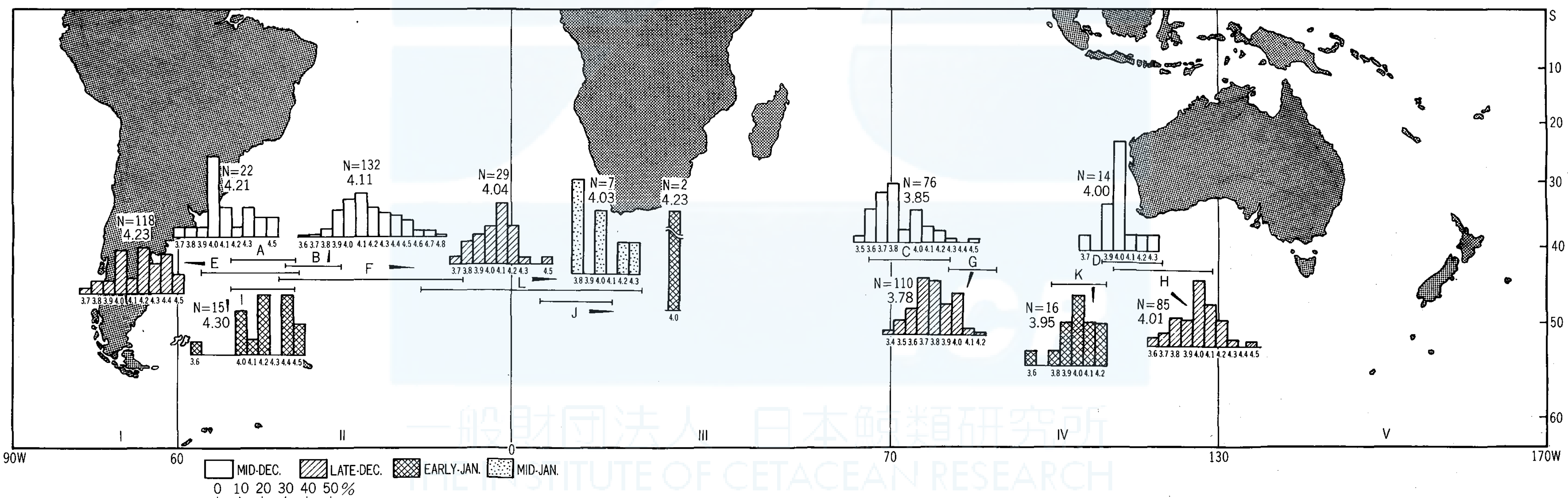

Fig. 7-2. Size composition of *Calanus tonsus* copepodite VI (female) in the whaling areas and months in 1969/70 season. Average body length is given above each figures, and an approximate longitudinal range from which samples were collected is shown by the capital A to K.

In this respects the differences in size composition of *C. tonsus* especially in the copepodite V stage suggest that they should come from the different reproductive populations. It is also suggested as a whole that those different size compositions which are the distinct biological character not as individuals but as the population, would be the result of having been isolated each other. A quite few occurrence of adult male in the surface population of *C. tonsus* is similar to the results by Jillett (1968). Those male occurred sporadically must be newly developed individuals in the current season, which made Jillett (1968) consider a possibility that the second generation would supposedly be due to a result by the parthenogenesis in the over wintered females. The small sized female populations found in the Indian Ocean sector are considered to be the result of different environmental conditions there, or of a complete isolation from the others. It is known in the British waters that a local difference in environmental conditions influences on the size of individuals which form a dominant population in those regions (Marshall and Orr, 1955). The geographical difference in body size in the Antarctic copepods also well known (e.g. Brodskii, 1964). Baker (1954) considered that many

SEASON. NUMBER OF INDIVIDUALS EXAMINED IS GIVEN IN PARENTHESES.

Late-Dec.		Early-Jan.			Mid-Jan.		
II	II	IV	III	II	IV	III	II
8°~46°W	36°~54W	99°~110°E	0°~19°E	40°~51°W	90°~100°E	19°~27°E	14°~52W
—	2.60(1)	2.50(1)	2.89(1)	3.00(2)	—	2.91(3)	2.80(1)
3.46(10)	3.38(31)	3.20(23)	3.18(11)	3.48(5)	3.21(13)	3.13(6)	3.49(10)
4.04(8)	4.23(16)	3.95(7)	4.23(3)	4.30(2)	—	—	4.03(3)
2.69			2.83			2.86	
3.34			3.29			3.28	
4.09			4.16			4.03	

zooplankters would originate from the identical populations of species by species since they show rather monotonous circumpolar distributions. However, as Brodskii (1964) having been demonstrated in *C. tonsus* and other copepod species, there is a distinct geographical differences in the composition of body size as the local populations, and I have also shown these circumstances in the previous section of this report. Mackintosh in his recent report clearly shown that there should be several number of distribution centers under quite high population density in *E. superba* while it shows a typical circumpolar distributions (Mackintosh, 1973). The above mentioned facts indicate that the zooplankton in the Antarctic waters distributes quite unevenly under the general circumstances of circumpolar distributions, and that their occurrence with different body size compositions in various sea regions would perhaps belong to different reproductive populations somewhat likely to a "stock unit".

The largest and the smallest body sizes in female *C. tonsus* measured in this study were 4.8 mm and 3.6 mm respectively, while the former by Brodskii (1964) was 4.25 mm (female) and 3.40 mm (male). Although it is known that the body size both in copepodites V and VI (female) shows latitudinal variations as a whole, the body size seems to differ to some extent between the individuals from sei whale food which have had been formed the patchiness and those taken by the net haul which must supposedly been in a sporadic distribution without forming the patchiness.

7–3. *Patchiness of C. tonsus and the density effects*

The body size of *C. tonsus* in Table 7–4 was based on the row materials which were collected by the net haul along with many other zooplankters. On the other hand, *C. tonsus* being fed by the sei whale as has given in Tables 5–2 and 5–3, occurred as mono specific composition, which suggests that *C. tonsus* population as whales food might possibly have been in an aggregation, to show the patchiness. Both *C. tonsus* populations, mentioned above therefore, can be considered to be ecologically unidentical to show some differences in the size composition and the averaged body size. The food *C. tonsus* population seems rather larger if not entirely in the body size of individuals.

TABLE 7–4. BODY SIZE OF THE SOUTHERN SPECIES, *CALANUS TONSUS* BRADY REPORTED PREVIOUSLY BY THE DIFFERENT WORKERS.

Author	CV	CVI (♀)	CVI (♂)
Brodskii (1964)*		3.40–4.25	3.30–4.15
Tanaka (1956)	3.27–3.47	4.07–4.24**	
		3.66–3.75***	
Tanaka (1960)	3.39–3.69		
Vervoot (1957)		3.69–4.05	

* 3.71 mm on an average.
** Size at higher latitudes.
*** Size at lower latitudes.

The patchiness of zooplankton has been observed but a little. Studying on the food of blue and fin whales in the South Georgian waters, Mackintosh and Wheeler (1929) stated that *E. superba* occurs by a monotonous composition of same year class or same developmental stages since the species forms such patchiness separately as to be fed by the whales. Hardy and Gunther (1935), and Mackintosh (1966) reported the results of their observations on the behavior of *E. superba* under patchy aggregations in Cumberland Bay, South Georgia, and described as " There appeared some guiding ' principle '—almost as if there was some leader in command of the whole ! " (Hardy and Gunther, 1935). Mackintosh (1966) also described later that the patches of *E. superba* moved in a cluster as if they were an amoeba like organisms as a whole, and the patch was quickly reorganized within tens seconds after disturbance. These characters of *E. superba* patches as a kind of animal aggregations strongly suggest their something socialized structure within the patches as the theme having been suggested also by Clutter (1969) in Mysidacea. In general the features of the plankton patches can be comparable though not anologous with the aggregations in the insects such as the reproductive aggregation by male mosquitoes (Kawamura, 1971c). An ecological homology in a plankton patchiness could be imagined by the fact that the empty shells of *E. superba* were collected abundantly in a net haul (Marr, 1962). This indicates that the development of the individuals proceeds simultaneously among almost all members of the patches.

The patchiness of zooplankton can be considered as one of the distinct characters in the distribution of animals. Difference in generations could be responsible for variable body size composition but on the otherhand it should be considered that there must supposedly be some ecological benefits for aggregating into patches through the density effect. For example, it is well known fact in aggregating insects that the population density closely related to their relative growth rate (e.g. Ishida, 1952; Uchida, 1952; Fujita and Uchida, 1952; Takahashi, 1956), in which the density effect would role positively (Chauvin, 1962). In the population of cockroach, *Blatella germanica* the overall growth rate as the unit of population is more enforced quickly by keeping close the intervals between individuals (Ito, 1959; Ishii, 1970). This kind of function by the density effects have also been indicated in Mysidacea population (Clutter, 1969). In the zooplakton population under aggregations, the population density is usually kept quite high; *E. superba* shows one individual per cubic inch (Marr, 1962), and he described them as "jostling one another" under patchiness. Swarming *E. pacifica* shows 1~2 cm of intervals between individuals (Komaki, 1967). These facts leads to a supposition of tactile stimuli, that is, touching each other by the body or by the antennules would possibly occur to some extent during their swimming (Kawamura, 1971c). The differences in body size composition in *C. tonsus* populations could be explained by this kind of density effect through their social behavior, but the scheme will be discussed more in section 11 where the *C. tonsus* patches were treated on the basis of field observations and row materials obtained by net haul.

8. FEEDING APPARATUS OF SEI WHALE

A quite characteristic adaptation in baleen whales is their specialized feeding apparatus to collect a bulk of zooplankton and some micronektons. The baleen plates or whalebone as feeding apparatus has developed in various ways by species in place of the tooth, and no similar feeding structures are found in any of other kind of animals. The baleen plates being arranged in a row on the upper mandible are quite functional for gathering rather scattered foodstuff along with the specialization of oesophagus to form the first stomach which functions as a depositing sac for swallowed foodstuff (Hosokawa and Kamiya, 1971). In this respects a row of baleen plates is indispensable apparatus for the baleen whales actually functions whereas the teeth are not so functional in many toothed whales. When they were lost or heavily damaged by some desease or by an accident, a daily nutritional requirements would hardly be filled. Rice (1961, 1969) reported the rudimentary baleen plates in sei whale due to some microbial desease, and it caused the blubber of the whale quite thin from the insufficient food intake.

The amount of stomach contents under full repletion closely related to feeding habits of whales and to the population density of the food organisms, say, the patchiness of zooplankton. Since the patchiness of food zooplankton hardly be studied by the net haul as has been pointed out by Mackintosh (1966), one of an approaches to studying the plankton patchiness would be found in the stomach contents of baleen whales. In this point of views Klumov (1961), Kawamura (1970b, 1971b), and Omori *et al.*, (1972) reported on the population density of food organisms being based on the stomach contents of whales, and found a hardly believable high population density of zooplankton under the patchiness, which would never be obtained or known by the net haul investigations. In regard to this circumstances it would be necessary to know the ability in filtering the water by a row of baleen plates in sei whale.

8–1. *Oral cavity*

A row of baleen plates furnished on the upper mandible functions in collecting the food organisms. This would be fairly comparable character with the sperm whale whose lower jaw is fully functional against the upper jaw. The baleen plates however would be functional actually with the supplemental aid by the lip on lower mandible. After Ingebrigstsen's suggestion on the feeding habits in baleen whales, Nemoto (1959) described on this scheme under three different feeding types of baleen whales: swallowing or gulping type, skimming type, and the combined both swallowing and skimming. Then the shape of the lip which is characteristic by species closely related to the feeding type above mentioned. Both right and bowhead whales are furnished with so largely developed lips which are indispensable for their feeding by skimming off the food contained water continuously, while

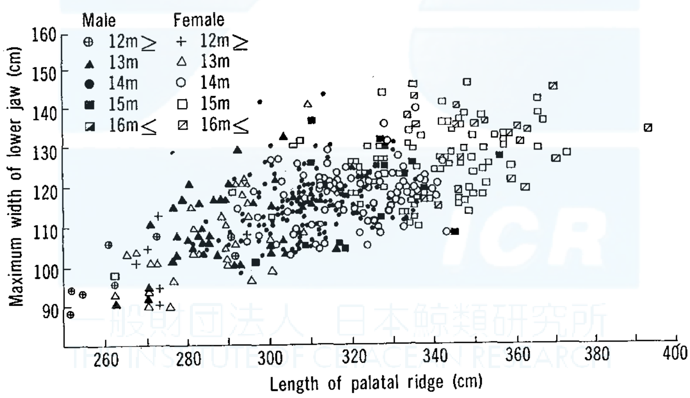

Fig. 8–1. Relationship between the length of upper jaw and the maximum width of lower jaw in sei whale.

balaenopterid whales are furnished with the poorly developed lip since they collect the the foodstuff by swallowing the water although the lip of sei whale relatively well developed among them. In California grey whale, the benthos feeder (Rice and Wholman, 1971), the lip is rather poorly developed. It is worth taking into account that the sei whale follows after both feeding types according to the conditions of the distribution of food organisms.

In this respect the size of both upper and lower jaws were measured in connection with the potential ability in collecting the foodstuff. The relationships between the sizes of upper and lower jaws against the body length of whales are demonstrated in Figs. 8–1 and 8–2. The size of oral cavity varied to some extent among the individuals examined, but it grows larger and larger in accordance with the growth in body length. Dominacy of the female in the size of larger than 330 cm of upper jaw in sei whale and also 470 cm in fin whale is due to their biological character that the female grows much larger than the male, and the former is preferably caught largely than the latter. In bryde's and minke whales the proportional length of the skull is larger in the female than the male (Omura, 1966; Ohsumi *et al.*, 1970). The sei whale which closely relates taxonomically to bryde's whale showed considerable variations in the maximum width of lower jaw against a definit length of the upper jaw, and in a definit width of lower jaw against the upper jaw length. The variations were more distinct in the latter. These variations relating to the size of oral cavity along with the number of baleen plates indicate a manifold character of baleen whales in their feeding mechanisms and in the ability of collecting the foodstuff.

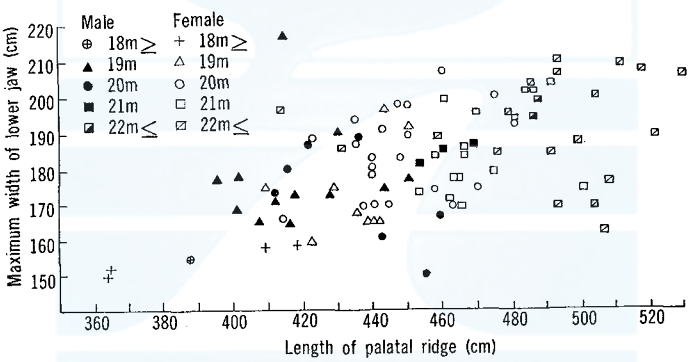

Fig. 8–2. Relationship between the length of upper jaw and the maximun width of lower jaw in fin whale.

8–2. *Baleen plates*

The number of the baleen plates in sei whale varies somewhere between 300 and 350 plates on one side, and two folds of this number of baleen plates functions actually for collecting the food. However, the number of baleen plates varies by the individuals and also by the observer (Williamson, 1973), since they are deformed into a kind of hair-like bristles near at the tip of rostrum and are randomly arranged. The density of the baleen plates furnished in a row varies with the positions of the mouth (Fig. 8–3, Table 8–1). The baleen plates (=bristles or hair) near the rostrum were counted 1.4 plates/cm on average while they were 0.93 plates/cm at their maximum length as indicated by the arrow in Fig. 8–3, and they again showed a high density in the posterior part close to the angle of gape.

The relative ability in filtering the water per unit area of the inner surface of the apparatus is a function of meshes formed by the woven bristles. The meshes are kept so as to show a definite filtering ability at any part of the apparatus, since the overall ability for retaining the foodstuff might greately reduced if the filtering ability was randomly variable by the part of the apparatus due to different mesh sizes in its inner surface.

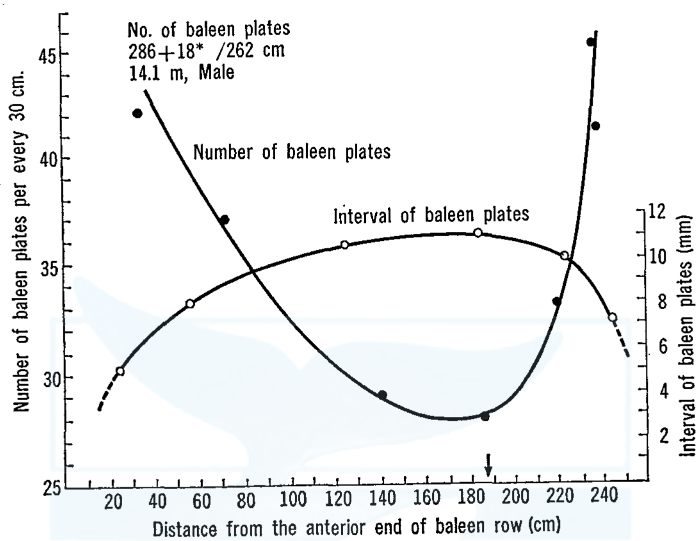

Fig. 8–3. Variation of the number of baleen plates in sei whale. Arrow shows the spot where maximum length of baleen plates was found. (*bristles)

TABLE 8–1. INTERVALS OF EACH BALEEN PLATES AT THEIR MAXIMUM LENGTH IN THE NORTH PACIFIC SEI WHALES.

Body length (m)	Sex	Interval (mm)	Thickness of baleen plate (mm)	Room between baleen plate (mm)
11.6	M	9.20	2.2	7.0
12.3	M	9.78	2.2	7.56
13.2	M	11.60	2.15	9.45
14.1	M	11.11	2.2	8.91
14.3	F	9.29*	1.7*	7.59*
14.4	F	9.40	2.5	6.90

* Measurement on dried material.

The length of each baleen plates is usually measured along their outer margin but it is the length along the inner margin to the base of palatal ridge that actually affects on the total surface area of the filtering apparatus. As shown in Fig. 8–4 the unfolded shape of filtering apparatus varied by the animals along with their body length as a whole. Although the animals examined in Fig. 8–4 were caught in the coastal waters of Japan, those unfolded shape is considered to be the same with the animals throughout the oceans. The position of the maximum width does not coinside with the position of the maximum length of baleen plates, but is found at rather posteriorly of about 66.4~69.5% in the total baleen row length, at which the highest part of the lips of lower jaw is positioned. These general arrangement seems as a whole to function effectively in collecting the foodstuff as much as possible particularly when the whale feeds by skimming the food contained water with its mouth half opened.

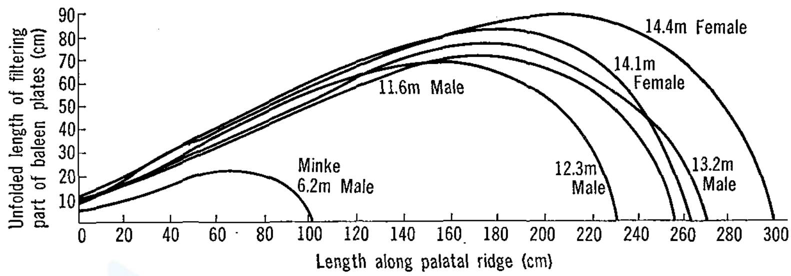

Fig. 8–4. Unfolded figures of the filtering apparatus of sei and minke whales.

8–3. *Bristles on baleen plates*

The bristles furnished on the inner margin of baleen plates form the fine meshed structure as demonstrated in Plate I, and actually retains the foodstuff which have been skimmed off. The inner margin of the baleen plates is furnished with the bristles (Plate I, fig. 1), and the whole surface of filtering apparatus is covered by this meshes although the number of bristles are considerably reduced at the tip of baleen plates (Plate II, fig. 1). Ruud (1940, 1945) examined the baleen plates

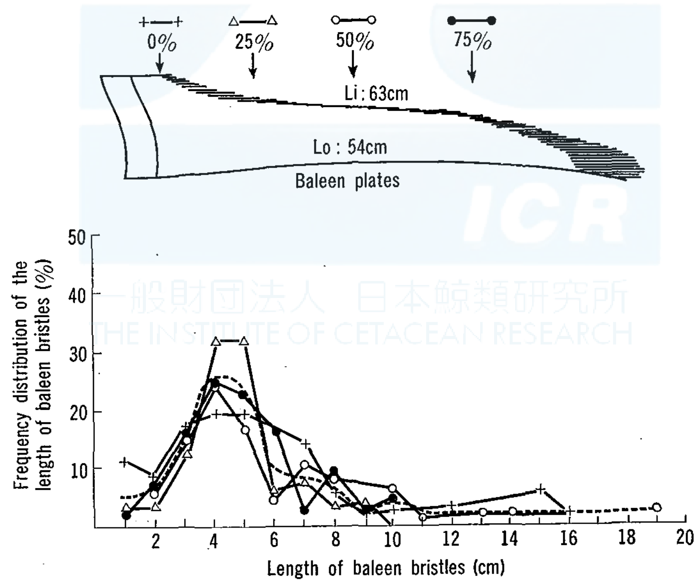

Fig. 8–5. Composition of the length of baleen bristles in 14.3 m sei whale caught in the North Pacific in 1968.

TABLE 8–2. MEASUREMENTS ON THE BALEEN

Location of catch	Body length (m)	Sex	Length of baleen plates* Lo	Li	Lo/Li
N. Pacific	14.3	F	54.0	63.0	1.17
Japan, coastal (off Kinkazan)	13.5	M	42.5	54.0	1.27
,,	12.3	M	43.0	52.0	1.21
,,	11.6	M	44.0	53.0	1.21

* Length along outer edge of baleen plates (Lo), and those along inner edge (Li).
** Diameters of baleen bristles measured at the base (Db), middle (Dm), and at the tip (Dt).

of fin whale in detail and described that they are made of chitinous tissue which is somewhat likely to a kind of fused bandage of many bristles. So the diameter of the birstles do not differ between wet and dried materials.

The length of the bristles varies with the part on the inner margin. Fig. 8–5 shows the frequency of occurrence in the bristles length in a sei whale of 14.3 m, and the actual figures were given in Table 8–2. The number and the length composition of the bristles per unit length along the inner margin showed that relatively longer lengthed bristles were poorly found. The length of the bristles was measured at four parts, and was found that 3∼5 cm long bristles were most dominantly furnished. Accordingly the meshes in the surface of the filtering apparatus are chiefly formed with these length of bristles. It is clearly noticed that the length of the bristles did not show characteristic differences at any part of the inner margin. These suggest that the filtering ability in sei whale would be the same at any part of the apparatus.

Table 8–2 represents relative abundance of the baleen bristles, their length and diameter. Although the triangle shaped baleen plates are well known, the length along the inner margin of baleen plates is longer about 1.2 times than the outside so as to form relatively larger surface of filtering area. The distribution density of the bristles was 50 bristles/cm with the average of 45.5 bristles/cm, and this density does not vary with the sex and the body length of whales. The shape of a bristle itself seems rather slightly tapered: the diameter is larger at its base than the tip. However the variation in diameter is such slight as to make them represent the mean diameter at the mid point of the bristles.

8–4. *Area of filtering apparatus*

The total inner surface area of the filtering apparatus in five animals of different body lenth was measured from the unfolded figures as shown in Fig. 8–4, and the results were given in Table 8–3. However, the filtering area given in Table 8–3 is approximate figures, since an overall shape of the filtering apparatus shows a quite complexed features by the curved surface.

The surface area of the filtering apparatus was 2.37 m^2 in 11.0 m individual and was 3.59 m^2 in 14.4 m individual. Then those areas seem to increase after a geometrical progression (Fig. 8–6). However, it is clearly observed that the surface

PLATES AND BRISTLES OF SEI WHALES.

No. of baleen bristles/cm				Average length of bristles (cm)				Average diameter of baleen bristles (μ)**		
75%	50%	25%	0%	75%	50%	25%	0%	Db	Dm	Dt
44	49	63	36	5.6	6.1	5.2	6.4	250	167	141
	54				4.2			168	108	106
	37				4.4			155	114	93
	42				4.6			157	114	85

TABLE 8-3. AREA OF FILTERING APPARATUS OF SEI AND MINKE WHALES CAUGHT IN THE COASTAL WATERS OF JAPAN, MAY, 1971.

Species of whale	Body length (m)	Sex	Lk* (cm)	Ld* (cm)	Length along outer edge of baleen plates (cm)	Area of filtering apparatus combined both sides (m^2)
Sei	11.6	M	268	256	291	2.37
Sei	12.3	M	236	228	261	2.13
Sei	13.2	M	—	271	330	2.64
Sei	14.1	M	—	262	300	2.89
Sei	14.4	F	—	300	330	3.59
Minke	6.2	M	—	102	114	0.29

* Length of a row of baleen plates along the upper jaw.
** Strait length from the anterior end of baleen plates to the posterior end of them.

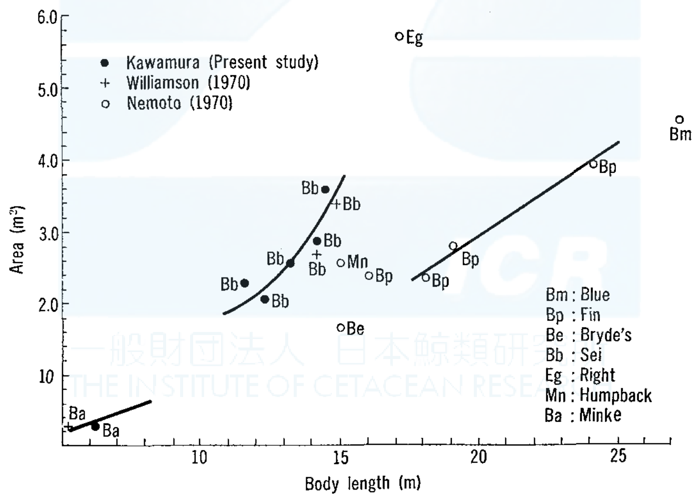

Fig. 8–6. Area of filtering apparatus in baleen whales.

area of filtering apparatus in sei whale is considerably larger in contrast to the body length of animals. These sei whale's characteristics are quite interesting when we compare the feeding habits of both sei and right whales with those of another balaenopterid whales: the former two feed after skimming type with well developed filtering apparatus while the latter feed after swallowing type with poorly developed apparatus. The area of filtering apparatus in sei whale showed moderate figures between right whale and another balaenopterid whales. This fact will be reasonably recogniged by supposing that the sei whale feed after the types of both skimming and swallowing. In balaenopterid whales other than sei whale on the other hand, the area of filtering apparatus changed rather linearly against the body length. In regard to these above mentioned facts it could possibly be considered that the feeding ability of the baleen whales would develop after geometrical progression since the body weight of whales is porportional to cube root of the body length (Nishiwaki, 1950) whereas the food requirement in terms of the daily ration is linearly proportional to the body weight (Sergeant, 1969, Table 4).

9. FILTERING ABILITY IN THE ROW OF BALEEN PLATES

In any types of feeding method the food contained water is pushed outside by the current pressure or by the co-operated functions of oral cavity, ventral grooves, and tongue. In sei whale as mentioned before the foodstuff is collected chiefly by skimming the food contained waters, and the filtering ability in the feeding apparatus may greatly affects on the overall ability for sieving the foodstuff.

9–1. *Porosity in the meshes of filtering apparatus of sei whale*

The porosity, the mesh openings in filtering apparatus in terms of percentages was calculated, and the figures were given in Table 9–1 along with those known

TABLE 9–1. POROSITY OF FILTERING APPARATUS OF SEI WHALE, WHICH IS FORMED BY THE BALEEN BRISTLES. (MEASUREMENTS AT THE MAXIMUM LENGTH OF BALEEN PLATES AND THOSE AT THE MIDDLE PART OF THE BALEEN PLATES ALONG INNER MARGIN).

Body length (m)	Sex	Location of catch	Total length of baleen bristles (mm)	Interval of baleen plates (mm)	Mean diameter of bristles at Dm*** (mm)	Porosity (%) Possible thickness of filtering apparatus (mm)				
						1	2	3	4	5
11.6	M	Japan coastal	1942	9.20	0.114	72.6	86.3	90.87	—	—
12.3	M	„	1111	9.78	0.114	81.97	90.98	93.99	—	—
13.5	M	„	2285	11.60*	0.108	77.0	88.5	92.33	—	—
14.3**	F	N. Pacific pelagic	3000	9.29	0.167	1.0	55.0	70.00	77.5	82.0

* Measurement from 13.2 m, male.
** Measurements on the dried material.
*** Measurements at the middle part of baleen bristles.

in the bolting silk cloth for the comparison. The netting of the filtering apparatus in baleen whales is structured by the following elements: the intervals between each baleen plates (Fig. 8–3), the thickness of bristles in diameter, and the length of the bristles. As the measurements of these elements were given in previous section, the calculation was made by using them (Table 9–1). Since the meshed filtering apparatus in whales is formed with some thickness due to entangled bristles, five cases of the thickness between 1.0 and 5.0 mm were supposed for the calculation. In sei whale, however, the actual thickness is considered about 1.0~2.0 mm (Plate I, fig. 4 and Plate II, fig. 2). The above mentioned thickness along with the intervals increase thicker and wider with the increase in body length although the length of the bristles also grow longer.

The porosity which is usually examined in bolting silk cloth for plankton net (e.g. Anraku and Azeta, 1966) varied between 77.2% and 88.6% by the body length of sei whale concerned. Since the baleen plates and the bristles examined were damaged to some extent due to ill treatment, the actual figures of the porosity would be slightly more lower values. However it is note worthy that the overall figures of the porosity do not seem to vary with the body length, say, the porosity is nearly constant regardless the body length of whales.

By comparing the porosity in ballen plates with that in plankton net, the former showed distinctly larger percentages than the latter (Plate II, fig. 2).

TABLE 9-2. POROSITIES OF JAPAN BOLTING SILK CLOTH COMMONLY USED IN PLANKTON COLLECTION.

Kind of bolting cloth	Mesh aperture (mm)	Open area* (%)
XX 13	0.094	23.0
XX 7	0.193	40.0
GG 54	0.334	46.0
GG 32	0.630	58.0
GG 20	0.926	60.0
Pylen #60	0.350	38.0
Larva net (Cremona+Pylen #60)	—	50.0**

* Data by the Nippon Bolting Cloth Co., Ltd. (S. Ueno pers. com.).
** Anraku and Azeta (1966).

9-2. *Relative filtering ability in a row of baleen plates*

In order to know an actual filtering ability in a row of baleen plates, the filtering ratio was measured experimentary after the similar ways employed in plankton net. The experiment was conducted at the offshore region in Suruga Bay on boad of the R. V. "Tansei Maru" of the Ocean Research Institute, University of Tokyo. The general arrangements of the experimental instrument are shown in Plate III. The dimensions of the instruments were 48.6×23.4×91.0 cm. A flowmeter was mounted on the inside of the instrument at about 1/3 distance posteriorly from the mouth opening. A row of baleen plates was mounted on the bottom of the instrument (Plate III, fig. 2). The slits between the mounted baleen plates and the instruments, which may cause a leakage were filled with 5.0 cm thick of uretan foam (Plate III, figs. 1 and 2). The surface of the filtering apparatus through water passed away in the experiment had an area of about 23.4×54.0 cm. The two 10.0 kg of lead weights were mounted on the both outsides of the instrument, which was towed by bridle. Before experiment a filter made of bolting silk cloth GG 32 (0.63 mm mesh opening, 58% in porosity) was attached on the mouth of the instrument so as to reduce the volume of passing water down to about 1/3.

By this treatment the water entered into the instrument was well filtered off without causing any overflowing. The experiment was conducted in Suruga Bay when the depth was 426 m by towing the instrument vertically from 200 m to the surface at the speed of 1∼1.2 m/second. The volume of water filtered by the row of baleen plates was calculated by the flow-meter's readings.

The results were given in Table 9–3. The relative filtering ability in baleen plates of both sei and fin whales showed rather poor when compared with those in the bolting silk cloth: the ability in sei whale was approximately 1/8 of GG 54 (0.33 mm mesh openings) while the fin whales' was 1/5, and still more, it may be interesting that those relative ability was poorer than the finely meshed XX 13 bolting silk cloth which can retain most of the representative diatoms in the sea. From this experiments it can be safely stated that the filtering ability in sei and fin whales, and possibly in any baleen whales is astonishingly poor than those in the bolting silk cloth. The filtering ability might reduced to some extent by ill treatment in mounting the row of baleen plates on the instrument, and even we take these circumstances into account the results of 1/5∼1/8 against the bolting silk cloth are astonishing enough, that is, the filtering apparatus of baleen whales

TABLE 9–3. FILTERING ABILITY OF THE BALEEN PLATES IN SEI AND FIN WHALES AND THOSE OF JAPAN BOLTING SILK CLOTH.

Exp. No.	Item	No. of flow-meter revolution/200 m	Relative ability
1	Calibration	1842	17.55
2	GG 32	610	5.81
3	GG 32+GG 54	893	8.50
4	GG 32+XX 13	648	6.18
5	GG 32+Sei*	105	1.0
6	GG 32+Fin**	184	1.75

* 14.3 m., female, caught in the North Pacific on July 18, 1969 at 45°–04′ N, 171°–37′ W.

** 16.8 m., female, caught in the North Pacific on August 1, 1969 at 47°–55′ N, 157°–10′ W.

never exceeds in the ability of filtering off the water than in the plankton net.

These results give us some fundamentally important evidences concerning on the scheme of food and feeding habits in baleen whales: that is, there have been two suppositions in connection with the population density of food organisms and the amount of stomach contents acutually found (Klumov, 1961; Kawamura, 1970b). They are: 1) the daily rations of baleen whales would be filled by their extraordinal ability in collecting the foodstuff, and the ability have to be maintained under a quite excellent functions, or 2) the food organisms have to distribute with very high population density of such extent as hardly impossible to know it by means of an ordinal method being employed in plankton samplings by the net.

Those above mentioned results lead to a consideration that the food organisms would distribute under a quite dense population in the sea to fill the daily food requirements of whales rather easily by those poorly developed filtering ability in the row of baleen plates.

10. AMOUNT OF THE STOMACH CONTENTS AND THE POPULATION DENSITY OF FOOD ORGANISMS

The amount of the stomach contents in three species of the baleen whales has been reported previously though it was rather preliminary (Kawamura, 1968b, 1970a). The predator-prey relationships which involve the baleen whales would be a characteristic scheme in the food chains of the sea, since the secondary producer are directly connected with the consumers of the highest level in the ecological niche, that is, the energy flows quite effectively in the economy of the sea. Klumov (1961) made a calculation and described theoretical population density of zooplankton basing on the amount of stomach contents which were actually measured, and he concluded that the food requirement by the whale would hardly be filled fully with the population density of zooplankton being widely found in the sea. After the scheme of Ivlev's "feeding rate" (Ivlev, 1961), Sergeant (1969) confirmed on the daily ammount of food consumed by the whales which has been reported previously would be an appropriate figures, and Kawamura (1970b; 1971b) has discussed on the population density of copepod, *Calanus tonsus* in relation to the amount of this food organism in the first stomach of southern sei whale. Prior to further examination on the population density of food zooplankton, the feeding habits such as feeding cycle, feeding method, amount of stomach contents, speed in digestion, were examined.

Most of whales usually spotted in the whaling ground are considered to be under the movements in search of food, and such whales as being under feeding activity in high seas are rarely sighted even by the whalers who had been engaged in whaling for many years. These fact indicates that the whales feed intermittently within rather shorter hours. Under these circumstances the observations by Ingebrigtsen (1929) on the feeding behavior in North Atlantic sei whale must be an important. According to Ingebrigtsen's observations the sei whale under feeding shows rather dull and only pays a little attention to the surroundings. Far later, Gunther (1949) reported a similar aspects in the southern fin whale, in which he (Gunther, 1949) described that the fin whale continued its feeding without paying any attention to the approaching ship and was easily marked. The whales fully repleted with food also show a similar behavior. When they are under starvation, however, they are quite shy and agile, and can hardly be approached within the shooting distance. The sei whale quickly moves around in the surface with its mouth half opened when they are under feeding (Ingebrigtsen, 1929; Scoresby, 1820; Kawamura, 1972), and it is this occasion that bolting behavior was observed (Andrews, 1909; Gunther, 1949) though the whale sometimes feeds without bolting its body (Millais, 1904–1906). In humpback whale it is also known that the whale makes its food organisms aggregate into dense shoals by moving around them so as to enable feeding himself more effectively (Howell, 1930).

On the other hand, the balaenopterid whales other than sei whale feed by swallowing the food contained water. However, the feeding type employed by the whale is not always fixed but varies with case by case. In the North Pacific relatively larger sized fishes such as the pacific saury, pacific cod, mackerel, sardines and some squids are fed by the baleen whales in addition to the planktonic crustaceans (Nemoto, 1957; Kawamura, 1973a). Feeding by skimming type which seems to be largely employed by sei whale may possibly be less effective against these kind of well swimming food organisms. The sei whale, therefore, is considered to feed by rather combined ways of both skimming and swallowing types, and this supposition would be supported by the following fact: the variation or the change in feeding method is known even in some plankton eating fishes. For example, both biting and filtering types are employed in anchovy by the size of the prey organisms and their population density in the sea (Leong and O'connell, 1969).

The foodstuff swallowed is preserved temporalily in the first stomach, and this kind of function is characteristic in baleen whales among the marine mammals. Studying on the anatomy of the first stomach of whales, Hosokawa and Kamiya (1971) concluded after discussing on its ecological recognition that there might be need to deposit the food as far as the food is available since the whales in their feeding place have been faced the competition with the others for a limited amount of foodstuff.

Under these above mention circumstances, the observations on the amount of food organisms in the first stomch would be an important materials in connection with the feeding habits of whales and the distribution ecology in the food organisms such as their patchiness and the population density. However, Betesheva (1955), Nemoto (1957) and Bannister and Baker (1967) have pointed out that the whales under chasing would possibly vomit their stomach contents supposedly from fatigue after long and continuous chasing. If this occur actually, the amount of the stomach contents which is found in carcasses would be greatly decreased, and therefore, before going further the matter was examined and discussed in the following section.

10–1. *Influence of chasing time to stomach contents*

Prior to further discussion on the amount of food in the first stomach, it was examined and discussed that to what extent the chasing by catcher boast influences on the amount of stomach contents due to vomit. This however have been discussed fully in the previous report (Kawamura, 1970e, 1971a), then I will redescribe here only an abstracts and conclusions by quoting my previous reports.

The duration of chasing time by catcher boats which might influence on the fulness of stomach contents of whales was examined on fin, sei, and sperm whales caught in the northern North Pacific during the summer of 1969. Of 895 whales observed only 28 whales (3.6%) vomited out their stomach contents while being chased and sperm whale vomited most frequently (16.8%) whereas sei and fin whales were 1.1% and 0.78% respecitively (Table 10–1). The diet of the whales concerned was consisted of boarfish, squids, copepods and euphausiids. It was often observed that the whales likely to vomit out more larger sized foodstuff such as boarfish than that of copepods and euphausiids. The amount of stomach contents vomited was negligibly few, and has no significant influences on the amount of stomach contents which have been obtained from carcasses. Most whales (80%)

were caught within 40 minutes of chasing, and the number of whales which would vomit out their stomach contents does not always increase in proportion to the prolongation in the duration of chasing time. There are one possibility left behhind that whales may vomit the stomach contents in the subsurface waters during long restless chasing by catcher boats, since it must be fairly difficult to detect any vomited foodstuff from the boats. The behavior of vomiting a bulk of foodstuff in the subsurface waters, however, presumably causes heavy muscular activity for those whales, and they would not vomit any foodstuff in the subsurface waters since the whales under diving likely to minimize the oxygen consumption as little as possible (Scholander, 1940; Slijper, 1958a).

TABLE 10-1. NUMBER OF WHALES OBSERVED BY SIX CATCHER BOATS WHICH PARTICIPATED IN THE NORTH PACIFIC WHALING OPERATIONS IN 1969.

Floating factory		Kyokuyo Maru No. 3		Tonan Maru		Nisshin Maru		
		Catcher boats participated (day/month)						
Duration of operation		Kyo Maru No. 12 (18/V–25/VII)	Kyo Maru No. 15 (6/V–18/VIII)	Konan Maru No. 25 (19/V–24/VII)	Konan Maru No. 26 (24/V–8/VII)	Toshi Maru No. 17 (16/V–4/VIII)	Toshi Maru No. 18 (17/V–4/VIII)	Total
Sei whale	Vomited	—	—	—	—	1	5	6
	None	22	74	55	102	—	174	427
	Unknown	—	—	15	13	175	6	209
Fin whale	Vomited	—	—	—	—	—	1	1
	None	4	16	25	16	—	24	85
	Unknown	—	—	8	7	28	—	43
Sperm whale	Vomited	—	20	—	—	—	1	21
	None	—	81	—	—	—	23	104

* Sperm whale was not observed expect Kyo Maru No. 15 and Toshi Maru No. 18.

10–2. *Amount of stomach contents*

The amount of the stomach contents was measured on the animals which were appeared to be fully repleted with food. For the measurement in the field a basin of known volume was used to remove the stomach contents completely from the opened stomach, and the amount was calculated by multiplying the number of basin which was required for the complete removal. Since the stomach contents removed by this way contain the water to some extent, the weighing of a basin-full organisms was made after draining away the water. I have reported on the amount of the stomach contents in three southern species of baleen whales (Kawamura, 1970a). It is however, considered necessary to give the results for further discussions, I redescribed here a part of descriptions in the previous report.

In the Antarctic, as I showed in a brief note (Kawamura, 1968b) the amount of stomach contents of 14 sei whales which fed on *Calanus tonsus*, *Parathemisto gaudichaudii*, *Euphausia superba* and *Euphausia vallentini* was measured (Table 10–2). The weighing of stomach contents were carried out on the stomachs being judged as

" full " by eyes, and full data including fin and minke whales were given in *Appendix*. The highest value observed was 228.0 kg of *Parathemisto gaudichaudii*, which was fed by 15.2 m of male, while it was only 68.0 kg in the *Calanus tonsus* food. Nemoto (1962b) mentioned that there was a quite well agreement between the weight and the degree of replation of stomach judged by eyes. However, as shown in *Appendix* there were considerable variations in the case of the Antarctic sei whale. It can be said in general that the whales caught before 0900 hours carry somewhat fresh and large amount of stomach contents, and the proportional weight of water gradually increases toward noon due to digestion.

TABLE 10-2. AN AVERAGE AND THE MAXIMUM AMOUNT OF STOMACH CONTENTS OF SEI AND FIN WHALES CAUGHT IN THE ANTARCTIC OCEAN.

Species of whale	Body length (m)	Sex	No. of whale examined	Average		Maximum	
				Total weight (kg)	Volume (l)	Total weight (kg)	Volume (l)
Sei whale	13.0–13.9	Female	2	171	202	182	204
		Male	0	—	—	—	—
	14.0–14.9	Female	2	118	149	141.3	180
		Male	5	116	140.4	154.6	200
	15.0–15.9	Female	1	152	200	152	200
		Male	3	159.2	208.5	228	312
	16.0–16.9	Female	1	196.5	255	196.5	255
		Male	0	—	—	—	—
Fin whale	18.0–18.9	Female	0	—	—	—	—
		Male	1	301.3	391	301.3	391
	20.0–20.9	Female	1	567	700	567	700
		Male	0	—	—	—	—
	21.0–21.9	Female	0	—	—	—	—
		Male	2	510	700	885	1000
	22.0–22.9	Female	1	133	238	133	238
		Male	0	—	—	—	—

It has long been the obscure mystery or the matter of interest how much the baleen whales take food in a day. According to Nemoto (1959) Collett (1912) early estimated the amount of food taken by the Atlantic blue whale, and showed that they had taken at least 1,000 liters of euphausiids. Betesheva (1954) showed that the North Pacific sei whale can feed 600 kg of squids or 50∼370 kg of *Calanus plumchrus*, while Best (1967) given 59 kg of zooplankton from South African waters, and 175 or 305 kg of krill for Antarctic sei whales (Brown, 1968). There are some more data about this problem which has been accumulated on the whales of northern hemisphere though most of them were on fin whales (e.g. Nishimoto, *et al.*, 1952; Nemoto, 1959; Klumov, 1961). Nemoto (1959) demonstrated that the fin whales of 57 feet in the northern North Pacific fed on 759.0 kg. of Alaska pollack and found a considerable variations in the amount of stomach contents (91.0∼759.0 kg) notwithstanding the fact that the majority of all stomachs concerned were repleted as " full " by eyes. His result also suggests that the weight of stomach contents filled with copepods usually very little than those by fishes or euphausiids.

The highest and averaged amount of stomach contents show that the males of both sei and fin whales likely to feed on much food than the females though feeding percentage seems to be high in the female (Brown, 1968). It is noticed that the stomach is hardly repleted when the whales feed on copepods than fish or euphausiides. This fact leads to a consideration that the larger the size of food organisms, the larger amount of stomach contents is expected. Such a tendency is also shown in the North Pacific fin whales (Nemoto, 1959, Table 24). From my result I may describe the following weights as an approximate amount of stomach contents usually seen in the Antarctic (Table 10-3).

TABLE 10-3. AMOUNT OF FOOD USUALLY FOUND IN THE FIRST STOMACH OF ANTARCTIC BALEEN WHALES.

Species of whale	Kind of food organisms	Amount of food usually found
Sei whale	Copepoda	less than 100 kg
	Amphipoda	150-250 kg
	Euphausiids	150-200 kg
Fin whale	Euphausiids	300-900 kg
Minke whale	Euphausiids	30 kg

By comparing these values with those obtained by other workers (e.g. Klumov, 1961; Brown 1968), the amount of stomach contents of sei whale in the Antarctic does not differ so much from those obtained in the northern North Pacific.

10-3. *Daily variation in feeding activity*

Although the daily variation in feeding activity in terms of the percentage figures is rather well known in fin whales while not in sei whale, and in this point of views Kawamura (1970a) studied on sei whale. Since several facts found in his report are considered to be suggestive on this matter, a section of the results were redescribed: It has been known that the feeding activity of baleen whales in a day in terms of the percentages varies in general with a bimodal curve which has a maxima in the early morning and in the evening (Nemoto, 1957, 1959). One of his results (Nemoto, 1957) suggests that baleen whales somewhat actively feed twice a day in many cases though each patterns of feeding activity are variable with the kind of food partaining to their diurnal vertical movement, seasons, latitudinal positions, or sometimes with the bottom topography of whaling grounds. Sometimes, however, the baleen whales show a evidence suggesting to feed only once a day (Nishiwaki and Ohe, 1951). In any case, it is considered to be quite important to accumulate the evidences on the feeding habit of baleen whales especially of sei whales in relation to estimating the nutritional budget among the food webs in their feeding grounds. However, it is also nesessary to figure out the feeding patterns of baleen whales by theoretical and experimental methods by assuming such a feeding model as Klumov (1961) instituted for this purpose.

The daily change of feeding activities in terms of the percentages of the stomach with food against the whole number of stomach examined is supposed to be affected chiefly by the diurnal vertical migrations of food organisms, because the most of all food organisms listed in Table 5–1 were known as to show a quite distinct diurnal vertical migrations in the South Georgian whaling ground (Mackintosh, 1934, 1937; Hardy and Gunther, 1935; Ommanney, 1936). Accordingly, it is necessary to examine the whales food by the species since each food organisms has their own peculiar migratory patterns in a day. The hourly change in the feeding activity of sei whale in the whaling areas III, IV and V is demonstrated in Fig. 10–1. It is noticed in the figures that a quite high feeding percentages are observed in the early morning, and no distinct recovery occurs in the evening. It is also noticed that the most causative organisms to bring on the daily variation of feeding activity are chiefly responsible in the case when amphipoda, large sized euphausiids or " Calanus " were fed. Medium or small sized euphausiids seems to be fed whenever they are available. The upper and lower extremes of feeding percentages were 57 percent and 28 percent in the areas IV and V, and that in the areas III

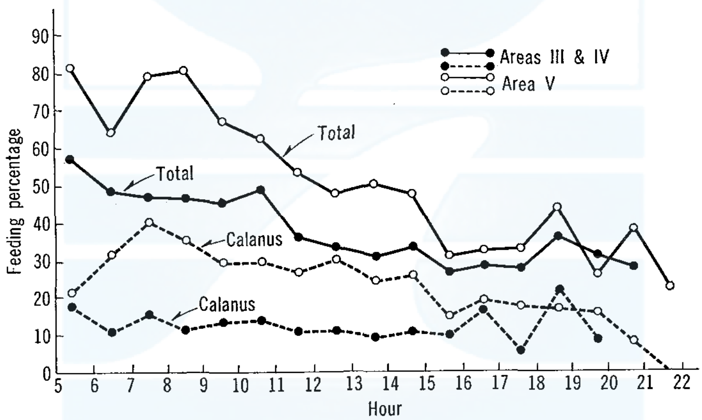

Fig. 10–1. Feeding percentage of sei whale in the whaling Areas III, IV, and V, 1967/68.

and IV were 82 percent and 25 percent respectively. The general trends of feeding activity of sei whale in the Subantactic waters differ considerably from those of fin and sei whales obtained in the northern North Pacific where it varied between 0 to 100 percent in most cases (Nemoto, 1957). This may be attributed partly to the differences of the kind of food organisms taken in both whaling grounds. From the figures, it is naturally considered that the most of sei whales in the Antarctic heavily take a dense population of food once in the morning possibly by ' swallowing ' or ' skimming ', and take a relatively scattered poor population of food organisms by ' skimming ' during the daytime towards the evening, as the manner described by Ingebrigtsen (1929) and Nemoto (1957, 1959).

The components of the " Calanus " food are represented by two dominant species, *Calanus tonsus* and *Calanus simillimus*. In the Indian sector of the Antarctic a considerable number of both *Calanus tonsus* and *Calanus simillimus* occurred as principal food source of sei whale while only *Calanus tonsus* was observed in the Tasman Sea and in the Pacific sector of the Antarctic (area IV and V). Since there are considerable differences in the behaviour of diurnal vertical migration between *Calanus tonsus* and *Calanus similimus* the extent of the repletion of stomach contents by the time was also differed between those two copepod species (Fig. 10–2). Those differences due to diel migratory habits of food organisms have also been known in decapod crustacean, *Sergestes similis* which is locally important food of sei and fin whales in the North Pacific (Omori *et al.*, 1972). In both *Calanus tonsus* and *Calanus simillimus*, the repletion of stomach was relatively small with the quantity of food less than 50 percent during the daytime. It is noticed clearly that the almost fully repleted stomaches (" rrr "~" R ") with *Calanus tonsus* occurred more frequently than *Calanus simillimus*, and the former was fed with a same feeding percentages during the daytime while the bulk of *Calanus simillimus* was exclusively fed only in the evening. This fact would be the result from being exactly followed

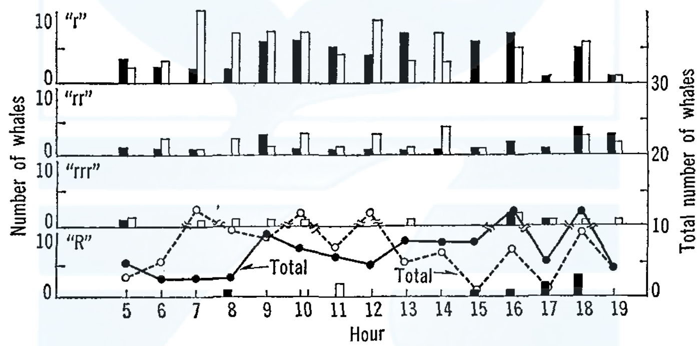

Fig. 10–2. Number of whales fed on *Calanus simillimus* (black colum and solid line), and *C. tonsus* (vacant colum and broken line) by the four different degrees in stomach fulness. Degrees of fulness are as follows: ' r ' less than 25 percent, ' rr ' 25–50 percent, ' rrr ' 50–75 percent, ' R ' 75–100 percent.

to the differences of the migratory habits of both species. According to Hardy and Gunther (1935), *Calanus simillimus* is regarded as one of the quantitatively important copepods in the South Georgian waters, and this species shows a distinct diurnal vertical migration as well as *Drepanopus pectinatus*; the bulk of *Calanus simillimus* population begins upward movement at about 1700 hours in the evening and reachs to 10~20 m depth at 1800 hours. They remain at the surface layer during the night then begin to move into the deep down to about 100 m depth in very early morning, at least 02~03 hours. This behavior leads to a consideration that there would be only a chance for sei whale to feed on *Calanus simillimus* in the evening throughout a day. It is interesting to find that the stomach of " full " occurred very frequently in the evening so as to support the consideration of feeding ' once ' in a day.

Calanus tonsus, on the other hand, is a comparable species to *Calanus plumchrus* in the northern North Pacific, and this species of at least in the copepodite stage V is recognized in general to show no such a distinct diel vertical migration as *Calanus simillimus*. Judging from its hydrological and taxonomical affinities to *Calanus plumchrus* (Tanaka, 1954, 1967; Jillett, 1968), it might presumably be considered that *Calanus tonsus* of 5th copepodite stage does not show any distinct diel-vertical migration. The occurrence of " full " stomachs with *Calanus tonsus* during the daytime suggests a quite well availability of this foodstuff in the surface waters so as to be fed by the sei whale throughout a day.

In summarizing the above mentioned results, it would possibly be said that the sei whale feeds whenever the foodstuff is available within a reasonable spacial range, and therefore its diel feeding pattern so far as it is expressed by the feeding percentages concerned may be different by the kind of migratory habits of its food organisms. Concerning to these food habits of sei whale, a recognition on the ecological means of the first stomach by Hosokawa and Kamiya (1971) as mentioned in the begining of this section would be well understood. Baleen whales in Patagonian waters (Matthews, 1932) and humpback whale in New Zealand waters (Dawbin, 1956) eat but little food, and later, Bannister and Baker (1967) considered that the whales under those circumstances would have to feed whenever there some amount of accumulations of food organisms to fill their nutritional requirements.

10–4. *Possible cause induces a decrease in the fulness of stomach contents*

The number of animals well repleted with food decreased along with the duration of chasing extends over 40 minutes regardless the kind of food organisms (Kawamura, 1971a). The whales with fully repleted stomach were found up to 30 to 40 minutes of chasing time in the morning but they decreased gradually down to less than 10 minutes chasing in the evening. The whales with moderately repleted stomach, on the other hand, were found up to 70 to 80 minutes of chasing time in the morning, then it remarkably prolonged to more than 120 minutes of chasing during midday until it was shortened again in the evening. There observed to present two different kinds of varing patterns in relation to the daily change of the duration of chasing time and the degree of the fulness of stomach. One of possible explanations for those two different patterns would be found in the proceed of digestion, that is, most whales with moderately repleted stomach in midday might have had been fully repleted in the morning, and such whales would shift to those moderately repleted stomach by digestion toward midday (Fig. 10–3). The duration of chasing time which corresponds to the degree of the fulness of stomach seems to be shortened from the morning toward the evening. There observed more or less inversed relationship between the duration of chasing time and the degree of the fulness of first stomach through three different time bands, *i.e.* the more the stomach fully repleted, the more shorter time of chasing is expected. This fact makes us confirm the former observations (Ingebrigtsen, 1929; Nemoto, 1957). So often occurrence of well repleted whales in the morning along with relatively longer duration of chasing time and its hourly change lead to a consideration that the most whales take a bulk of foodstuff once a day in the morning.

The copepod and euphausiid foods were found in the whales which were caught after more or less longer duration of chasing than those fed on squids or boarfish. This may be the result partly due to the vomit, *i.e.* the large sized food organisms likely to be vomited much easier than the smaller one.

It is also supposed from the figures that an approximate time required for the digestion of foods may be estimated. The whales which carry a well repleted stomach were found most frequently in the morning, and consequently they were found being widely scattered up to the duration of 30 to 40 minutes chasing before 0900 hour. However, these whales were greatly decreased in the late afternoon, and they were only found in 10 to 20 minutes chasing after 1500 hour. This must be a result of decrease in the absolute number of whales which are well repleted with food. If it is assumed that the whales with fully repleted stomach could be expected to be caught by the same difficulties throughout the day, the time being

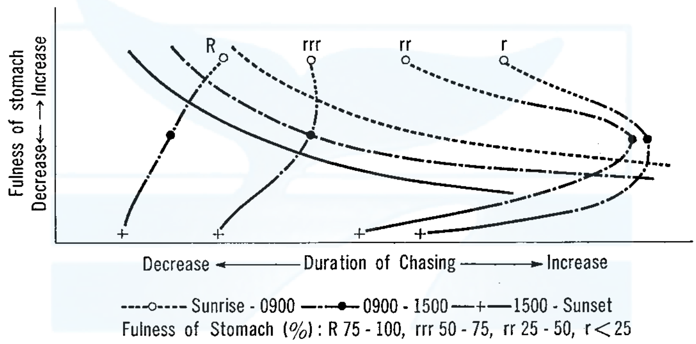

Fig. 10–3. Schematic curves showing regressive tendency of the fulness of stomach contents along with the duration of chasing in three different time bands. Curves with circle and cross by four different degrees of the fulness of stomach show a shift of those degrees toward lesser direction of the fulness with the lapse of time from sunrise to sunset.

required to catch them would give an index for estimating the speed of digestion. The number of whales with fully repleted stomach reduce down to about 70 percent in the first half of day and then to 50 percent in the afternoon; the relative abundance of whale with fully repleted stomach is considered to have decreased down to about half in a day time. In another words, 25 to 30 percent of their stomach contents would be digested within 5 hours or thereabouts, and these whales should be shifted to the stomach conditions of " r " to " rrr " of degrees. The fully repleted stomach with foods would be emptied in this way by the proceed of digestion in the following 14∼15 hours.

It is known in the blue white dolphin (*Stenella caeruleoalba*) and Gill's bottle nosed dolphin (*Tursiops gilli*) which were kept alive in aquarium that their stomachs likely to be emptied within 10 hours or more (Tobayama, personal communication). He (Tobayama) also observed that a small instrument swallowed by mistake was excreted after 17 hours. The digesting speed proposed above for baleen whales as found in this study does not seem unreasonable estimations by taking account of the fact that high feeding rates in percentage figures are usually found twice a day with intervals of 10 to 15 hours.

10–5. *Daily ration in sei whale*

It is interest to know the amount of food required by a whale per day, say, the daily ration. It has long been subjected to determine the daily ration in smaller whales in captivity (e.g. Takahashi, 1961; Tobayama and Tamura, 1964). In larger whales, however, the daily ration has hardly been determined with preciseness although there were some assessment being based on the analysis of the fulness and its daily changes (Nemoto, 1957, 1959; Kawamura, 1970a). However, after examining on the daily rations as function of body weight in small cetaceans, Sergeant (1969) described the following equations which might be applicable to larger whales. Firstly, the feeding rate is defined:

$$\text{Feeding rate} = \frac{\text{Food per diem}}{\text{Body weight}} \times 100 \quad \cdots\cdots\cdots\cdots (1)$$

The feeding rate which was found in smaller cetaceans varied 5.26∼13.67 with 8.26 on average, and the values were somewhat constant regardless the species and the age of animals. Then the following equation was introduced.

$$\frac{\text{Heart weight} \times 100}{\text{Body weight}} \cdot \frac{1}{\text{Feeding rate}} = 0.11 \quad \cdots\cdots\cdots\cdots (2)$$

The heart weight as a factor of the equation was found since its weight well indicates the extent of activity of animals through their metabolisms. According to these formulations Sergeant (1969) concluded that feeding of 2.0∼2.5 tons per day in ordinally sized blue whale would be appropriate, and therefore the whale have to eat fully twice a day. However, the relationships between heart weight and feeding rate in larger whales are still little known when compared with another mammals (Ridgway, 1966; Ridgway and Johnston, 1966). To make the matter more clear I examined the heart weight of sei whales which were caught by the floating factories, "Tonan Maru No. 2" and "Nisshin Maru No. 3" in 1970/71 Antarctic season and the results were given in Tables 10–4 and 10–5. The weight of animals were calculated after the following formulae by Omura (1969), Ohsumi (1969), and Ohsumi *et al.* (1970):

Sei whale $W=0.0016L^{2.43}$
Fin whale $W=0.00024L^{2.9}$
Minke whale $W=0.04655L^{2.31}$

where W is the weight of animals in 10^3 kg, and L is the body length in feet but in meter in minke whale.

The heart weight/body weight in connection with body length and sex did not differ much (Fig. 10–4). The difference in the latter was only $0.16^0/_{00}$, and was almost no difference in the former which was in such body length as to be caught regally by whaling, but some variations by age have been known in smaller cetaceans

(Kleinenberg, 1956; Slijper, 1958b). Table 10–5 was given under combined figures of both sexes, and the following was found in sei whale.

Heart weight/Body weight = 0.00487 ....(3)

Although Sergeant (1969) found the figure 0.00404 in this relation, the above described figure would be considered more appropriate since it was derived from

TABLE 10–4. BODY AND HEART WEIGHTS OF THE ANTARCTIC SEI WHALE BY THE DIFFERENT BODY SIZES.

Body length (m)	Sex	Body weight (ton)	Heart weight (kg)	Heart/Body (‰)	Average	No. of whale examined
12.1	Male	8.94	53.2	5.95	5.95	1
	Female		45.2– 60.0	5.06–6.71	5.89	2
12.4	Male	13.25	41.0– 65.1	3.09–4.91	4.09	4
	Female		58.0– 70.0	4.38–5.28	4.78	4
12.7	Male	—	—	—	—	—
	Female	14.09	62.0– 66.8	4.40–4.74	4.57	2
13.0	Male	14.89	61.2– 86.0	4.11–5.78	4.59	9
	Female		56.0– 75.0	3.76–5.04	4.43	3
13.4	Male	15.72	62.0– 72.0	3.94–4.58	4.22	5
	Female		75.0– 89.0	4.77–5.66	5.22	2
13.6	Male	16.56	70.0– 92.0	4.23–5.56	4.59	4
	Female		74.0– 89.0	4.47–5.37	4.92	4
14.1	Male	17.51	90.0–106.0	5.14–6.05	5.60	2
	Female		76.2–106.0	4.35–6.05	5.43	4
14.3	Male	18.42	68.0– 93.3	3.69–5.07	4.56	7
	Female		86.0–110.0	4.67–5.97	5.06	4
14.5	Male	19.35	86.4– 97.0	4.47–5.01	4.79	3
	Female		83.0– 99.0	4.29–5.12	4.64	5
14.8	Male	20.35	78.5–117.0	3.86–5.75	4.60	6
	Female		90.0–126.0	4.42–6.19	5.10	4
15.1	Male	21.40	97.0–101.0	4.53–4.72	4.66	3
	Female		94.0–126.0	4.39–5.79	5.02	6
15.6	Male	22.40	110.0–114.0	4.91–5.09	5.00	2
	Female		99.0–125.0	4.42–5.58	5.15	3
15.7	Male	23.55	—	—	—	—
	Female		98.0–142.0	4.16–6.03	4.91	10
16.2	Male	24.75	—	—	—	—
	Female		102.5	4.14	4.14	1
8.4*	Male	5.38	21.3	3.96	4.21	1
8.1*	Male	4.96	22.2	4.47		

* Minke whale.

more larger number of materials. Basing on the above described figures, the feeding per diem in sei whale is calculated by the equations (1) and (3) as follows:

Feeding per diem = 0.0443×Body weight ....(4)

Then the daily ration in ordinally sized sei whale can be considered about 4.4% of body weight (Fig. 10–5), and that in fin and minke whales was 0.0407 and 0.384 respectively. The overall figures through baleen whales therefore would be somewhere between 3.8% and 4.4%. These results as a whole agree with those by Klumov (1963) whose figures were 3.0~4.0% though he expressed it by the biomass basis, say, gr.-food/kg-muscle weight of animals. The food per diem demonstrated in Fig. 10–5 shows relatively higher food requirement in sei whale, and it gets lower gradually in fin and then in minke whales. A quite high food

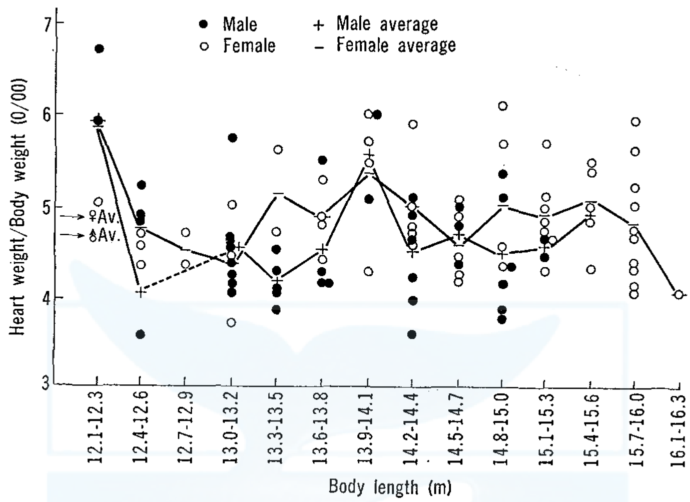

Fig. 10–4. Heart weight and body weight ratios in southern sei whale.

TABLE 10–5. BODY AND HEART WEIGHTS OF THE ANTARCTIC FIN WHALE BY THE DIFFERENT BODY SIZES. BOTH MALE AND FEMALE ARE COMBINED.

Body length (m)	Body weight (ton)	Heart weight (kg)	Heart/Body (‰)	Average	No. of whales examined
17.3	29.33	105.6–156.0	3.60–5.32	4.35	7
17.6	31.05	102.0–193.0	3.29–6.22	4.78	4
17.9	32.45	134.0–150.0	4.13–4.62	4.35	3
18.2	34.20	132.0–205.0	3.86–5.16	4.60	9
18.5	35.85	138.0–185.0	3.85–5.16	4.61	5
18.8	37.54	144.0–200.0	3.84–5.06	4.55	8
19.1	39.30	136.0–179.4	3.46–4.57	4.00	10
19.4	41.25	158.0–224.0	3.83–5.43	4.35	8
19.7	43.25	165.0–220.0	3.82–5.09	4.52	5
20.0	44.99	158.0–239.0	3.51–5.31	4.28	12
20.3	47.25	185.0–245.0	3.92–5.19	4.57	7
20.6	49.20	196.0–280.0	3.98–5.69	5.05	7
20.9	51.40	160.0–258.0	3.11–5.02	4.06	10
21.2	53.60	195.5–278.0	3.65–5.19	4.46	8
21.5	55.7	206.0–350.0	3.70–6.28	5.03	8
21.8	57.9	235.0–258.4	4.06–4.46	4.22	3
22.1	60.8	180.0–330.0	2.96–5.43	4.22	8
22.5	63.2	203.0–379.0	3.21–6.00	4.27	7
22.8	65.4	240.0–375.0	3.67–5.73	4.94	3
23.1	68.1	276.0–343.0	4.05–5.04	4.43	3

requirement in right whale along with similar trends in sei whale indicates that their difference from fin and minke whales would be due to the feeding types; skimming in the former whereas swallowing in the latter.

The amount of the first stomach contents which has been reported in sei whale

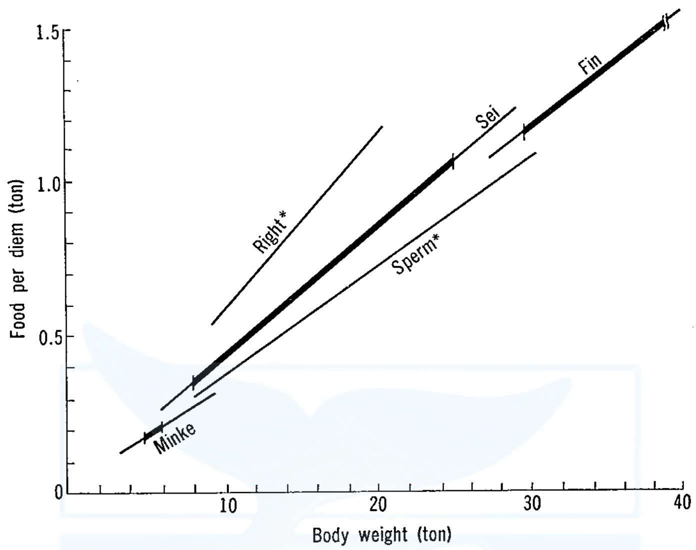

Fig. 10–5. Theoretical amount of food per diem in southern sei, fin and minke whales.

TABLE 10–6. AMOUNT OF STOMACH CONTENTS OF SEI WHALE.

Kind of food	Amount of food (kg)	Locality	Author
Calanus tonsus	54.0	Antarctic	Kawamura (1970)
Parathemisto gaudichaudii	57.6–200.0	Antarctic	,,
Euphausia vallentini	79.1–149.6	Antarctic	,,
Enphausia superba	128.7–149.6	Antarctic	,,
Euphausia superba	175.0–305.0	S. Georgia	Brown (1968)
Zooplankton	59.0	S. Africa	Best (1967)
Calanoida	300.0	N. Pacific	Klumov (1963)
Pacific saury	500.0	N. Pacific	,,
Calanus plumchrus	50.0–370.0	N. Pacific	Betesheva (1954)
Squid	620.0	N. Pacific	,,

is given in Table 10–6. It is observed in the table that the amount of food in the stomach of ordinarily sized animal, *i.e.*, 15∼24 tons of sei whale is 200 kg or thereabout when they feed on planktonic crustaceans. It could also be said as a whole that the amount in the stomach decreases with the size of food organisms, and those amounts actually measured are considerably low when compared with the daily ration. If we follow to the daily ration in sei whale of 18 tons in body weight, the animal requires about 800 kg of food daily, and the stomach of this animal have to be fully repleted three to four times in a day. However, it seems hardly possible for the animal to feed 800 kg of *Calanus* within several hours because *Calanus* remains in the surface only a few hours in the morning and evening. Therefore, the sei whale would have to eat even rather scattered food organisms which might have remained in the surface being apart from the main body of the migrating population. According to Best (1967) the sei whale in South African waters fed zooplankton being consisted of many species, and a considerable number of them were supposed to be non-aggregating species. This fact suggests that the sei whale can

TABLE 10-7. THE HIGHEST NUMBER OF FOOD COPEPODS PER 1000 M³ OF WATER IN THE UPPER 150 METER DEPTH OBTAINED BY THE NORTH PACIFIC STANDARD NET IN THE SOUTHERN WATERS OF CENTRAL PACIFIC AND TASMAN SEA IN 1968/69.

Species		Highest number of individuals by each stages through all stations occupied ($\times 10^3$)	Highest number of individuals in a haul by species ($\times 10^3$)
Calanus tonsus	female	4.53	—
	male	0.51	—
	C V	118.28	12.13
	C IV	249.58	250.58
	C III	39.86	39.86
	C II	2.60	2.60
Calanus simillimus	female	8.10	8.06
	male	6.72	6.72
	C V	60.40	60.44
	C IV	190.73	190.73
	C III	186.69	56.41
	C II	72.30	10.75
Calanoides acutus	female	1.64	1.64
	C V	38.07	35.57
	C IV	51.84	75.63
	C III	103.63	46.09
	C II	51.84	31.07
	C I	89.94	89.94
Calanus propinquus	female	1.17	1.17
	male	0.97	0.39
	C V	4.27	4.27
	C IV	6.95	1.55
	C III	11.45	—
Clausocalanus spp.*	female & male	3179.62	—
Metridia gerlachei	female & copepodites	384.17	—
Rhincalanus gigas	copepodites & C I～C VI	56.41	—

* *Clausocalanus laticeps* & *C. paululus*.

feed even those rather scattered food organisms by skimming type of feeding. It may be considered anyhow that daily ration of about 800 kg would hardly be taken by the sei whale from its filtering ability and the population density of available food organisms.

10–6. *Estimation of population density in the food organisms*

One of the most important food organisms of sei whale in the southern whaling ground is copepods, especially *C. tonsus* and *C. simillimus*. An ecological importance of these two are comparable to *C. cristatus* and *C. plumchrus* in the North Pacific region.

The amount of food organisms in the stomach would be the result of functions of both feeding ability of whales and the population density of food organisms. Studying on the baleen whales in the Fareast seas, Klumov (1961) stated that the amount of stomach contents could not be understood unless the food organisms distribute such high density as to be hardly known by the net sampling in the sea. In the southern sei whaling ground the food organisms distribute with the density as given in Table 10–7 and 10–8. The figures in the tables were obtained by the plankton net hauls through 27 stations in the Tasman Sea and in the Pacific Ocean,

TABLE 10–8. THE HIGHEST NUMBER OF INDIVIDUALS OF EUPHAUSIIDS AND AMPHIPODS PER 1000 M^3 OF WATER IN THE UPPER 150 METER DEPTH OBTAINED BY THE NORTH PACIFIC STANDARD NET IN THE SOUTHERN WATERS OF CENTRAL PACIFIC AND TASMAN SEA IN 1968/69.

Species	Individual number ($\times 10^3$)	Remarks
Euphausia simillis var *armata*	0.26	Immature
Euphausia simillis	0.054	Immature
Euphausia lucens	0.001	female
Euphausia vallentini	2.81	female
Euphausia frigida	1.41	Immature male
,,	1.41	Immature female
Euphausia spinifera	1.11	female
Euphausia superba	0.47	Immature
Euphausia sp.	0.45	Immature
Euphausiids furcilia	59.48	
Thysanoessa parva	0.30	Immature
Thysanoessa vicina	1.09	Immature
Thysanoessa macrura	8.10	Immature
Thysanoessa gregaria	7.80	
Nematoscelis megalops	0.11	female
Parathemisto gaudichaudii	0.21	female, f. *compressa*
,,	0.26	female, f. *intermediate*
,,	3.42	Juvenile

and the population density in each copepod species does not show that of under aggregations. The wet weight of copepods were obtained from the stomach contents which were completely consisted of mono-specific population. On the other hand, the amount of stomach contents was given in *Appendix*. The amount of copepod food was larger in the North Pacific than in the South African and the Antarctic waters. The availability of foodstuff seems in general to be high in the North Pacific.

The quantitative distribution of food zooplankton in the subantarctic waters varied between 15.10 and 426.12 gr./1000 m^3 in wet weight (Kawamura and Kureha, 1970). Since the composition of whales food usually found is monospecific, the highest figures in the poplation density in net haul samples was given by separating each species (Tables 10–7). A distinct occurrence of copepodites IV and V in *C. tonsus*, and adult *Clausocalanus laticeps* agrees with the composition of the stomach contents although *C. simillimus* differed in this respect. Both *C. acutus* and *C. propinquus* showed a quite slight occurrence as none of them were found in the stomach contents. The figures in euphausiids are quantitatively less important due to net avoidance. However, the dominancy of an important food species; *E. vallentini* is indicated. The population density of food organisms was estimated as follows under two feeding types particularly in the case of *C. tonsus*, one of a leading foodstuff in the southern feeding ground:

Swallowing

The 14.4 m sei whale caught in the Antarctic feeds at least 54.0 kg of *C. tonsus* of copepodites IV and V (Table 10–6), and the average body weight of *C. tonsus* is 1.2 mg/individual. (Table 10–9). Accordingly, a total of 54.0 kg. of food *C. tonsus* corresponds to 45×10^6 individuals. In order to obtain this number of *C. tonsus* under the population density of 262.7×10^3 inds./1000 m^3 which was the highest figures actually found (see Table 10–7), a total of 171.2×10^3 m^3 of water have to be filtered off by the whale. The volume of water in a gulp in fin whale is supposed about 6.0 m^3/30 sec. (Klumov, 1961) whereas in average sized sei whale (14.5 m: Intern. Whal. Statistics, 1969) the volume of engulped water would be somewhere between 2.0 and 3.0 m^3/30 sec.

TABLE 10–9. WET BODY WEIGHT OF FOOD COPEPODS COLLECTED FROM THE FIRST STOMACH OF SEI WHALES CAUGHT IN THE INDIAN SECTOR OF THE ANTARCTIC.

Species	Stage	Weight measured (mg)	No. of individual		Body weight (mg)	State of material
			Normal	Damaged*		
Calanus tonsus	C V	200	155	26	1.19	
	C V	200	151	33	1.20	
	C V	1000	595	83	1.57	Moderately digested
	C V+VI female	500	256	105	1.66	Moderately digested
Calanus simillimus	C V	500	541	144	0.82	
	C V+VI female	500	745	226	0.58	
Clausocalanus laticeps	female	20	96	71	0.15	Heavily digested
	female	20	110	75	0.14	Heavily digested
	female	20	186	57	0.09	
Drepanopus pectinatus	female	200	587	358	0.26	Heavily digested
	female	20	139	89	0.11	Moderately digested

* Damaged individuals are supposedly lost their body fluids, and they were regarded as one half of those undamaged individuals in the wet weight.

To examine these figures more clearly the volume of air which was sent into the oral cavity to make the animal afloat was measured (Fig. 10–6), and the average volume of air used in fin and sei whales was 10.4 m³ and 8.95 m³ respectively. In Fig. 10–7 the dots far above from main body would be due to a leakage of air. Since the above mentioned air was pressured 3 to 4 times higher than natural pressure, those amount of air in fin and sei whales could be converted into 2.6∼3.5 m³, and 2.24∼2.98 m³ respectively. It is clear that these figures agree well those above mentioned. Therefore, a total of 54.0 kg. of *C. tonsus* could be obtained in 5.5×10^2 hours, say, 23 days ! As it is noticed in Table 10–6, the amount of the stomach contents in sei whale sometimes attains at 500∼600 kg, and their theoretical daily ration was 800 kg. Then if we assume 300 kg. of copepod food as their possible daily ration since an availablity of copepod food would be considerably poor than

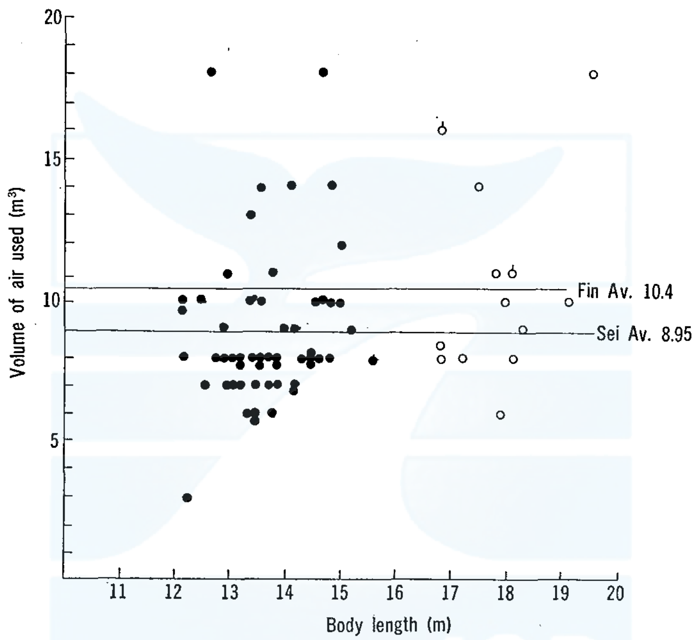

Fig. 10–6. Volume of air used to make afloat the carcasses of sei and fin whales.

the others, a total of 54.0 kg. of stomach contents fills only 1/6 of the daily requirement in sei whale. Accordingly, it could be supposed that the population density of *C. tonsus* under an aggregation must be found somewhere between 3.4×10^7 and 5×10^7 inds./1000 m³ (Fig. 10–7).

According to Minoda (1958) the highest population density found in his study in *C. plumchrus* in the North Pacific was 395×10^3 inds./1000 m³, and later the another case revealed as 631×10^3 inds./1000 m³ (Fac. Fish. Hokkaido Univ., 1963). Comparing these figures with the density of 367.8×10^3 inds./1000 m³ in *C. tonsus*, it is noticed that the population density in both cases agrees quite well while those two are the phenomena in far separated regions each other. These facts indicate that the upper extreme of population density in copepods would be about up to $4\times 10^5\sim 6\times 10^5$ inds./1000 m³ throughout the world seas though rarely found. The estimation described above seems quite high density which may almost unbelievable but it is the patchiness of plankton that gives those high level of the population density.

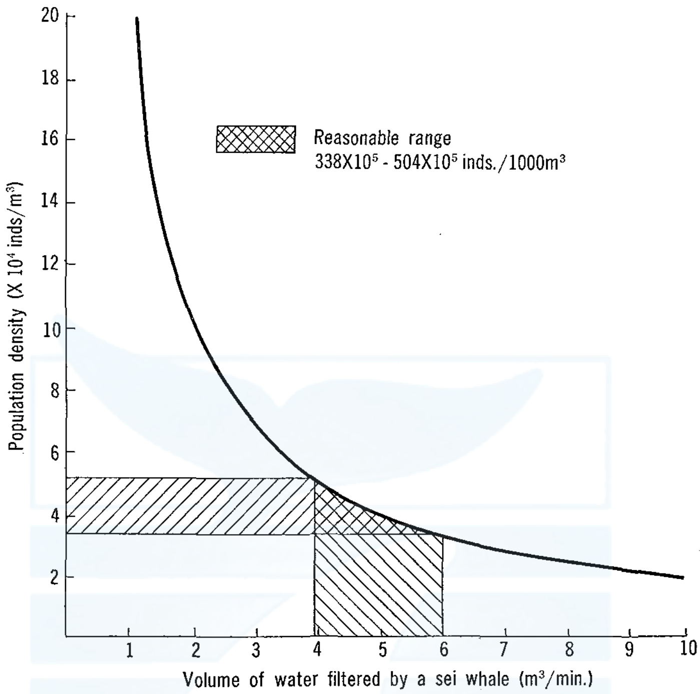

Fig. 10–7. Theoretical estimation of the population density of *Calanus tonsus* patches which fulfill the 54.0 kg of *C. tonsus* within 4 hours.

Skimming

The feeding type actually and most frequently employed by the sei whale is not swallowing but skimming (Scoresby, 1820; Millais, 1904–1906; Ingebrigtsen, 1929). The sei whale collects foodstuff by filtering continuously the food contained sea water with the mouth half opened. The right and bowhead whale feed by skimming exlusively while sei whale does not always but frequently.

As it has examined previously a relative filtering ability in the row of baleen plates in sei whale was 1/2.2 against fin whale (Kawamura, 1971a). A total surface area of the inner surface of filtering apparatus in sei whale was about 3.6 m^2, and the filtering coefficient was 0.167. By these figures a sei whale can filter off 6.0 m^3 of water effectively by swimming for 10 meters. One of possible and acceptable parameters in regard to feeding by skimming would be; 3 knots in swimming speed, 4 hours in feeding duration and a total of 300 kg of food organisms is fed. Then the population density of food organisms which fills enough above mentioned parameters must be 2.13×10^3 gr./1000 m^3, that is, 1.8×10^7 inds./1000 m^3. This figure as the order of density agrees well with the both estimations.

According to Zenkevitch (1963) the biomass of zooplankton standing stock during the summer in the Okhotsk Sea and Bering Sea rarely shows more than 1.0 gr./m^3, and those exceeds 3.0 gr./m^3 would only be found in a limited region of the northern Okhotsk Sea. Kurile region also rarely yields 1.0 gr./m^3 of zooplankton (Klumov, 1961). In the Pacific sector of the Antarctic the biomass of zooplankton was usually between 0.5 and 2.0 gr/m^3, and that more than 2.0 gr/m^3 was rarely found. One of the biomasses of *C. tonsus* in the subantarctic waters ever found was 0.2$\sim$0.5 gr./m^3. (Dolgencov, 1970).

By comparing these figures with those estimations in *C. tonsus*, the biomass or the population density in *C. tonsus* as food of sei whale seems considerable higher numbers than those obtained by the net haul investigations. Those density in food *C. tonsus* would still under estimated since the 300 kg. of stomach contents which was assumed in calculation should be doubled or more. However, it should also be took in account that those extremely dense population would possibly be found only when *C. tonsus* aggregates into the patches. Manteufel (1939) stated 9.0 gr/m^3 of population density in *Calanus* sp., then the biomass of about 21.3 gr/m^3 (1.8×10^4 inds/m^3) in *C. tonsus* population as estimated could be considered quite possible.

The population density of *C. tonsus* required to fill the 300 kg. of stomach contents by swallowing type feeding was $3.4\times10^7\sim5\times10^7$ inds./1000 m^3 whereas it was 1.8×10^7 inds./1000 m^3 in skimming type. Comparing these figures it could be supposed that the feeding by skimming type would be more effective to collect the same amount of foodstuff. The scheme would also support the facts previously known that the sei whale feeds almost always by employing the skimming type feeding in the whaling ground.

11. SWARMS OF *CALANUS TONSUS* BRADY

As has been mentioned in the previous sections, it was strongly suggested that the population density in *C. tonsus* must be maintained at least in such the order of $10^3\sim10^4$ individuals per cubic meter when they swarm into the so-called patches as to be fed by the sei whale (Kawamura, 1971d). However, the population density described above was an estimation being based on the amount of *C. tonsus* in the first stomach of whale carcasses and the filtering ability in a row of baleen plates as a function of feeding in sei whale. The theme therefore, was in need of being substantiated by the further evidence in the field, since the general features of swarming copepods under patchiness along with their population density had been known quite a few, while those swarm forming phenomena in copepods themselves had been known in early 1800's in the North Atlantic waters, and have been relatively well documented (e.g. Marshall and Orr, 1955).

In the following section I will describe some additional evidences on the swarming of *C. tonsus* in the surface waters. *C. tonsus* is a typical endemic species in the Subantarctic waters and considered to be important in a role of marine ecosystems of the southern waters. However, it is still unknown whether there were any socialized relationships among the swarming *C. tonsus* individuals. The swarming *C. tonsus* populations are exclusively consisted of stage V copepodites with a little mixture of adult females. A possible causations of surface swarming behavior may perhaps be similar to those in mysids (Clutter, 1969) though there must be some another pattern-forming agencies in copepods.

An uneven and spatial distribution of plankton species has been well known (e.g. Hardy, 1936a, b; Barnes and Marshall, 1951; Cassie, 1959a, b, c, 1960). However, some recent works (Wiebe, 1970; Kuwabara *et al.*, 1971)on this matter seem to give some confusion in the term of the plankton patchiness: Wiebe (1970), for instance, defined the " patches " or " patchiness " when the overall concentrations of zooplankters under multispecies composition exceeded a central value in a data set, which necessarily induce such a quite much occurrence of the " patches " as about 200 patches per a grid of about 100×100 m squares. These kind of " patchiness " are, however, considered rather usual phenomena as a distribution pattern widely seen in any localities of the sea. On the other hand, the plankton patches under considerations may be something different from those above mentioned, and also may possibly be different from those quite large scaled spacial distribution such as treated by Cushing (1962), but identical to those dense monospecific aggregations into swarms or rafts which by Marr's expression, scattered in a plane keeping 1/3~1/4 miles intervals of " krill-less " sea. As mentioned in the previous sections, the composition of patch forming plankton population is monospecific as known in *Euphausia superba* (e.g. Hardy and Gunther, 1935; Marr, 1955) or in copepod, *Calanus finmarchicus* (Bainbridge, 1952; Kitou, 1956), which make the sea discolored by enormous number of swarming plankton species in the very surface.

11–1. *Zooplankton swarms as whales food*

The swarming organisms as whales food have had been well recognized early among British whalers in those sperm whaling days in the southern seas, and the " Brazil banks ", according to Beale (1839), is " only discolorations of water caused by myriads of animal culæ which perhaps form the sustenance of the common black whale's food; that consisted of " squillæ " and other small animals ", and Beale (1839) also called them as " submarine pastures ". During the cruise on boad of the H.M.S. " Beagle," Darwin (1906) sighted a fairely well discolored waters by a huge number of copepod-like minute organisms, and considered that they must have been the food of whales and seabirds. Apart from recognizing the swarming phenomena of plankton species, Klumov (1961) brought out a subject under ecological considerations concerning to plankton patchiness that the daily food requirements of baleen whales would never be filled by the standing stocks of zoplankton known in the Kurile region even by their uppermost extremes, and concluded that the food zooplankton parhaps be maintained with a density of at least about 1500~2000 mg per cubic meters. An approach to know the population density in whale's food zooplankton involved an important indications, and later Omori *et al* (1972) made an estimation on the population density in swarming

Sergestes similis in the northern North Pacific.

At least the following zooplankton species except copepods have been observed directly as to form a dense swarms or so-called patches apart from those uneven or spatial distributions of plankton species: *Euphausia superba*, *E. crystallorphias* (Marr, 1962), *E. pacifica* and many others (Komaki, 1967), *E. nana*, *E. similis* *Thysanoessa inermis*, *Th. raschii*, *Th. spinifera* (Nemoto, *et al.*, 1969), Mysid, *Metamysidopsis elongata* and *Acanthomysis* sp. (Clutter, 1969), *Mysidium columbiae* (Steven, 1961), Galathea, *Munida gregaria* (Matthews, 1932; Tabata & Kanamaru, 1970), *Pleuroncodes planipes* (Boyd, 1967), macruran, *Sergestes lucens* (Omori, 1969) and *S. similis* (Omori *et al.* 1972). The number of patch forming plankton species would be doubled or more when we take into account the indirect evidences of swarming such as the food of baleen whales, among which amphipods, *Parathemisto gaudichaudii* is distinct. In these patch forming species the population density under swarming is usually maintained quite high, say, 1 ind./inch^3 in *E. superba* (Marr, 1962), 100 crabs/m^2 in Galatheid shrimp, *P. planipes* (Boyd, 1967), or animals swim as close as 1~2 cm one to another in *E. pacifica* (Komaki, 1967). Patchiness in mysids are relatively well known as mentioned before. Recent biosociological study on the swarms of mysids, *M. elongata* and *M. columbiae* (Clutter, 1969) much contributed to our knowledge on the aggregations of zooplankton particularly on swarming mechanisms along with possible but indicative biological cusations of the aggregation agencies such as density or grouping effects, role of sensory organs or underwater vibrations and pheromones (e.g. Laverack, 1962; Horridge, 1966; Ryan, 1966; McLeese, 1973; Dahl *et al.*, 1970a, b).

11–2. *Material and method*

The freezer ship M. S. "Eihô Maru" (1153 ton) which was chartered by the Nippon Suisan Co. Ltd., participated to the Antarctic whaling operation in 1971/72 season, and made a exploratory fishing and scouting for whales on her way down to the whaling ground. During her cruise in the south- to southwestern waters off Western Australia in December 11~26, 1971 when she was engaged in scouting about for sei whales in advance of comming season, many patches of discolored waters by dense aggregations of copepods, *Calanus tonsus* Brady were observed in the surface waters. Japanese whaleman calls them as "Uki-esa", a floating whale's food. The cruise track and the general hydrography are shown in Fig. 11–1. The ship cruised by following up the waters chiefly along the 12.0°~14.0°C isotherms since high concentrations of sei whales are usually expected under these sea conditions by the whaler's experience.

The surface swarms of *C. tonsus* which distributed within the range of about 2 miles of both sides of the ship's track were possible to distinguish by their dark brownish, sometimes blick like reddish discoloration from the surrounding waters, and the plankton sampling was conducted under inducement by the watchers who were on the upper deck, since the margin or the boundary of swarms was hardly visible in closer distance from foredeck. Marr (1962) suggested upon the decrease in detecting ability of the plankton patches when it is partly cloudy weather by

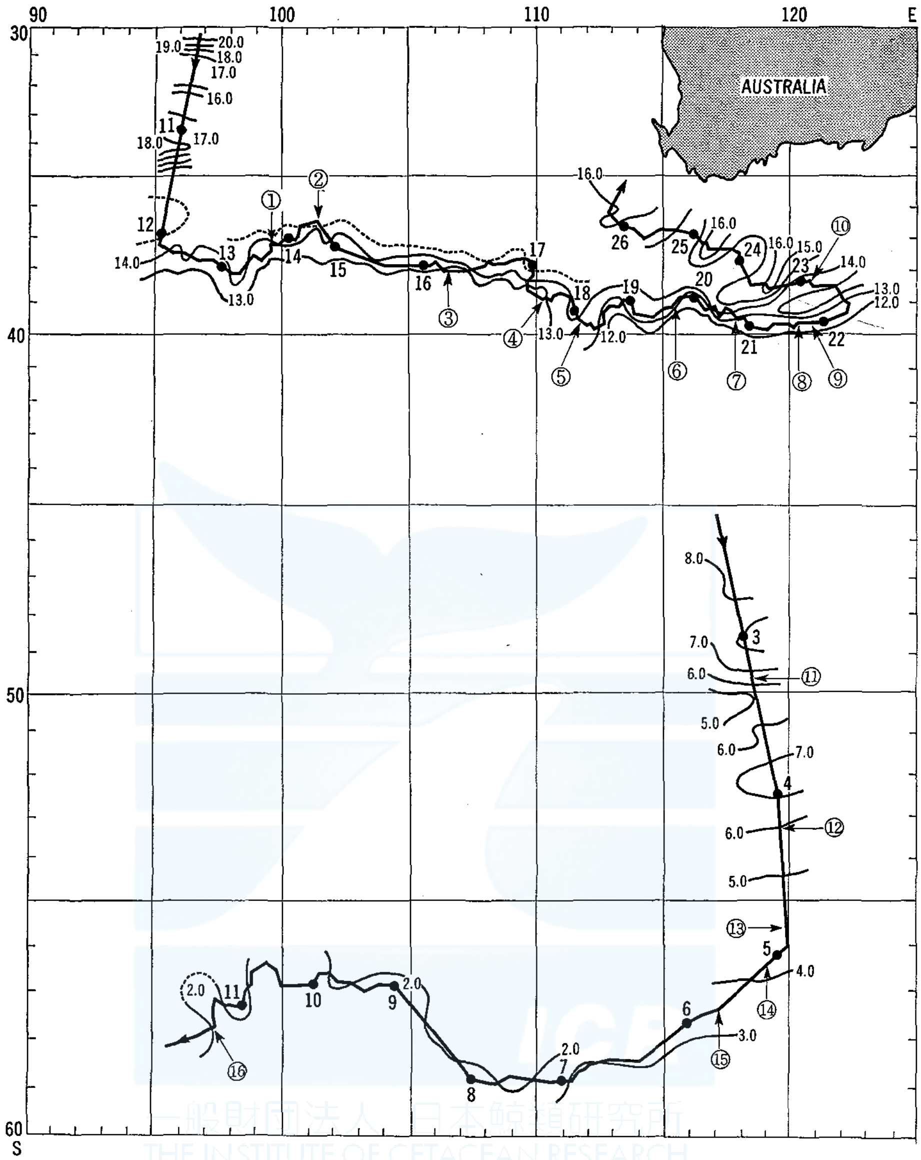

Fig. 11–1. Track of the Eihô-Maru with approximate isotherms along the ships cource during Dec. 11∼26, 1971 and Jan. 2∼11, 1972. Black spot represents the ship's noon position. Numerals with arrow shows the serial number of patches sampled as details are given in Tables 11–3 and 11–5.

confusion with the shades of cloud on the sea surface. However, it was usually over cast or cloudy throughout this investigation, and any hard difficulties in spotting the *C. tonsus* patches were not noticed. The number of surface swarms which occurred along the ship's cource were counted usually by three watchers.

While the ship cruised at the speed of about 10 knots, the shape and an approximate size of *C. tonsus* patches that passing through by the ship's course were also determined as exact as possible by the author on the upper deck. As the eye level at the upper deck was relatively low (ca. 8 meters high above the sea level) there was some difficulties to figure out exact shape of patches which spread out far beyond in the surface waters where large swells and waves prevailed. The shape of patches was determined by observing meandering margin of the patches at least from three different directions, *i.e.* front, side and back as ship passing through by them. The margin of far opposite side from the ship could be sometimes determined when the margin of the patches was on the top or on the slope of swells and waves.

The swarming *C. tonsus* was collected by two kinds of sampler; the high speed underway plankton catcher which was slightly modified from its initial model V (Motoda, 1959): 5.0 cm diameter in mouth opening, 72.7 cm overall length, Japan bolting silk cloth GG 54 netting (ca. 0.33 mm mesh apertures), and the RGS flow-meter was mounted inside the sampler for estimating the volume of water filtered by the sampler. The another one was Petersen type vertical closing net (Kawamura, 1968a), having 70 cm mouth opening with pylen #24 netting (ca. 1.0 mm mesh apertures). The former was used exclusively for estimating the population density itself, and the latter was for the relative abundance and qualitative analysis of swarming population.

Towing of the sampling gear was made usually at the speed about 2∼3 knots by slowing down the ship's speed by keeping some distance before hand from the swarm in question. When the ship seemed to have crossed over the margin of the swarm and positioned inside, the sampling gear was thrown out in the sea. The duration of towing varied from several tenth seconds to several minutes according to the ship's speed and the size of each swarms. In most cases the gear was took in while the net seemed to be still amid of the swarms since the purpose of sampling was focussed chiefly on to know the population density of swarming *C. tonsus* as precicely as possible. Thus, ten samples from *C. tonsus* patches were obtained during December 14 to 23 (see Fig. 11–1). Apart from these sampling on swarms surface tows for ten minutes with under way plankton catcher were made routinely every day, usually at 1000 and 1600 hours (LMT) as far as when there were no surface swarms on the ship's passage. This sampling offered materials to know the standing stocks of copepods and other zooplankters during daytime as the overall plankton population of background waters.

The quantitative treatment on the samples obtained by the underway plankton catcher was made by the flow-meter readings by comparing them with those in calibrations, and 80∼90 percent of filtering coefficient under 2 knot towing was adopted for the samples obtained by Petersen type vertical closing net.

The population density, however, varied considerably even within the identical swarm judged by the pattern of discoloration, and those observed between many other swarms. The underway plankton catcher might have been towed through non-swarming waters more or less, which would make the figures on population density small by dilution. So the results obtained were also variable by the patches and the observed population density of *C. tonsus* must be considered as the " at least " figures.

11–3. *General hydrology in the investigated region*

As shown in Fig. 11–1 the region investigated spreads over between the latitudes of 30°S and 40°S, and between the longitudes of 95°E and 122°E. The ship had not equipped any research instruments, and the depth record of temperature was not known. The general pattern of isotherm distribution was figured out by refering to Rochford (1962) since the data obtained by the "Eihô Maru" was too fragmentary and insufficient to show the overall pattern in temperature distribution. The ship, however, took a cource mainly along the isotherms of about 12.0°∼14.0°C in search for sei whale. The isotherms of these temperature are usually concerned as a bounday between the Subtropical region and the Subantarctic region, say, the Subtropical Convergence. The most of surface swarms of *C. tonsus* were found in this region. The isotherms run for west-east direction roughly parallel to the latitudinal lines although they showed rather complicated features in the waters south of Western Australia where the tongue-like warm waters intrude considerably from the north to make the surface temperature relatively high. According to Rochford (1962) the area in question can be regarded as the South Transision Zone where distinct change in salinity is characteristic.

11–4. *Shape, color, and size of C. tonsus swarms*

As it is shown in Fig. 11–2 the shape of *C. tonsus* patches was manifolds. However, they can be roughly classified into three types of the shape, *i.e.*, meandering stream or streak bands, spindle shape, and quite irregular shape with many tongue-like protorusions. The shape of patches can be said in general that they are different to some extent in their complexity from those previously reported in the patchiness of southern and northern euphausiids (Marr, 1962; Nemoto *et al.* 1969). Some of them were stream like shape being kept very long for several miles as having been called the " plankton stream " (Nemoto, 1962). Most of the patches were formed in the very surface so as to perhaps be easily deformed by the wind and wave actions to show quite irregularity as some figures shown below in Fig. 11–2. It is noticed in the figure that the *C. tonsus* patches keep more or less definite shape when the sea surface conditions were smooth enough under slight wind. Movements of the whole body of patches as suggested in some euphausiids (e.g. Nemoto, *et al.* 1969) were unknown.

Orientation of patches in connection with the relative wind direction and force were: the longer axis of patches against the wind direction kept at the angle of about 90°, or the longer axis kept nearly parallel to the wind direction, and or incoherent by the mixed characters of the two formers. There seem, however, some another causes such as swells, tidal current or even the action by the Langmuir circulations (Langmuir, 1938; Scott *et al.* 1970; George and Edwards, 1973) to be present other than the wind action. The following fact is also note worthy when we consider what causes the plankton patchiness, that is, *C. tonsus* patches kept tightly even in the rough sea conditions such as the wind force 5 which seems rough enough to disturb the swarms. Mentioning on the patchiness of *Euphausia superba*, Hardy (1936b) pointed out that their patches were kept under the sea condition up to at least the wind force 7.

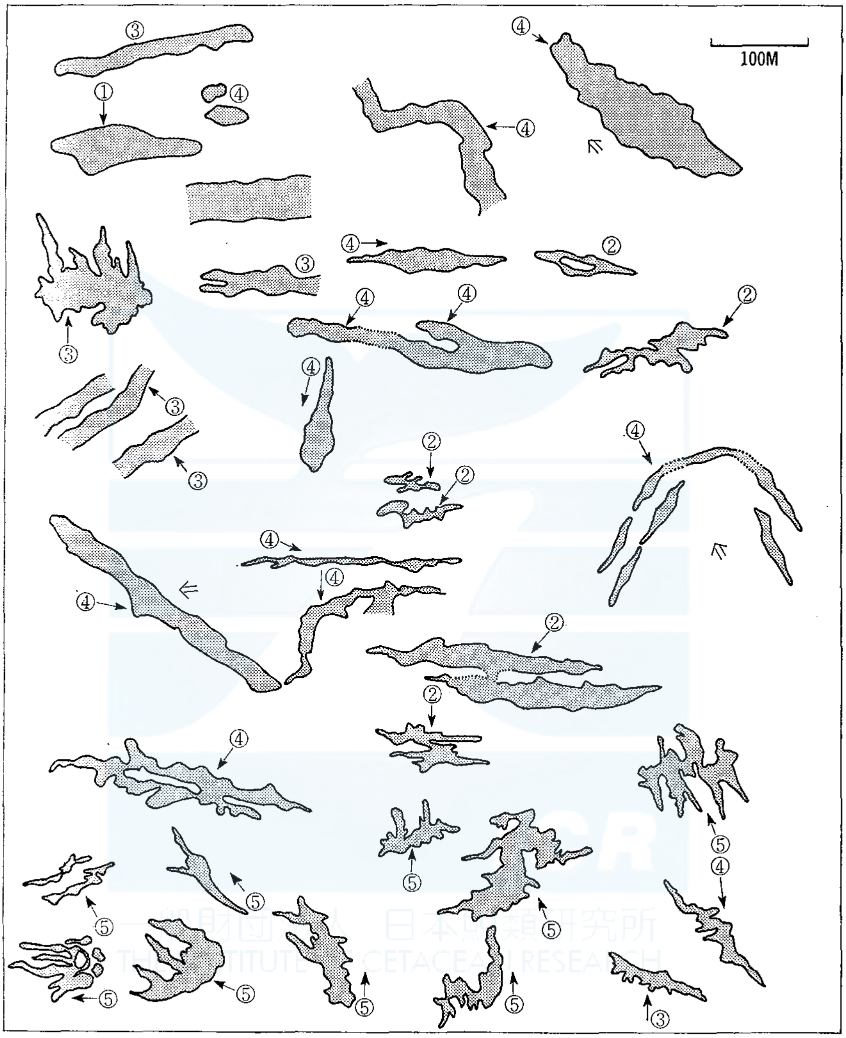

Fig. 11–2. Rough sketches of *Calanus tonsus* patches. Arrows and numeral in the circle show the wind direction and the force.

Sometimes a discoloration of waters by swarming was distinct, but it varied considerably by patch to patch, or by part to part of even in the identical patch. There were void or extremely poorly distributed spots in the midst of the patch through which clear blue water was seen. It is also observed that there were clear water whenever the discolored water was smashed and turned by the ship. This seems to be due to " hop and sink " movements as observed in *C. finmarchicus* swarms (Bainbridge, 1952). He (Bainbridge, 1952) observed it within 12 inch depth, and the above facts suggest that the dense swarms in *Calanus* must be found within very thin layer of the surface. The variations in discoloration character were seemed to be caused maily by the variable change in population density of swarming *C. tonsus*, followed by the character of at what depth the center of swarms is kept in the surface layer.

The distinct difference in the size of *C. tonsus* patches from those of euphausiids was much widely spreading out in the former. Most usual size having been known previously in euphausiids were several tenth meters in diameter (Marr, 1962; Ozawa *et al.* 1967, 1968; Nemoto, *et al.*, 1969), while those in *C. tonsus* were hundred to several hundreds meters in their longer axis. One of the longest sizes under stream like patches showed the length of about several miles. Kitou (1956) also reported 15 miles long patches of *Calanus finmarchicus* in the North Pacific. This kind of difference in size might be caused something by nature of organism itself because the sizes of swarming in patchiness have been known characteristic by the plankton species concerned, *i.e. Parathemisto* and *Salpa* sp. usually show 3 miles wide (Hardy, 1967), and Galathea shows much larger size than *Euphausia superba* (Ozawa *et al.* 1967).

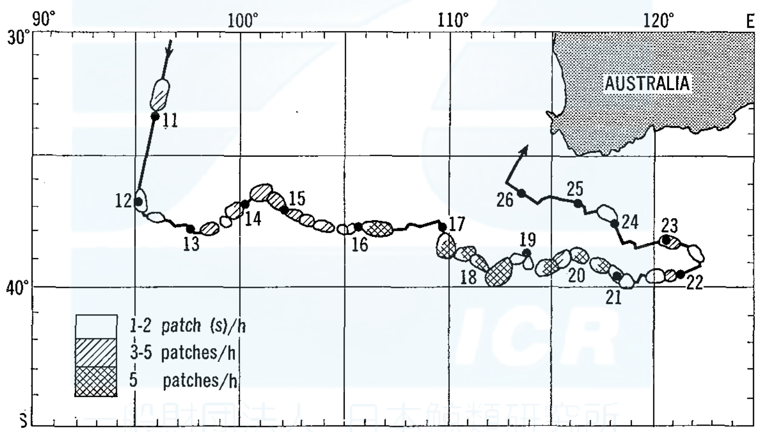

Fig. 11–3. Schematic map showing the distribution of patches of *C. tonsus* during Dec. 11~24, 1971.

11–5. *Distribution of C. tonsus swarms*

The number of patches occurred within about 2 miles of both port and starboad sides along the ship's cource were recorded. As mentioned before the number of patches, however, must be regarded as " at least " or round numbers since the patches of poorly discolored had perhaps been overlooked when they were far enough from the ship to be detected by binoculars.

Fig. 11–3 demonstrates the general features of the occurrence of *C. tonsus* patches which distributed along the ship's track during December 11~24, 1971. The patches occurred every day during that period though the frequency in terms of the number of patches per hour was most distinct during Dec. 16~20 when the sea temperature was in 13.0°~14.0°C. However, a complete absence in some definite region during Dec. 16~17 cannot help to be said curious because any unusual sea conditions in temperature were not observed in the region.

The highest number of patches per hour was recorded between 1600 and 1700 hours on Dec. 16 when it was 21 patches/hr. On the way down to the south after calling Fremantle, Western Australia on Dec. 31, the ship again crossed over the swarm rich area of Dec. 20 at the position between 115° and 116°E longitudes with the time lag of 11 days and 15 hours. The sea temperature was 14.6°C when crossed the previous track. However, none of signs showing the presence of *C. tonsus* swarming were observed in this time.

As it is noticed in the poor occurrence on Dec. 11 and Dec. 24, the *C. tonsus* patches usually do not occur in the region where the sea temperature of high above

TABLE 11-1. SEA TEMPERATURE AND THE NUMBER OF *C. TONSUS* PATCHES OCCURRED.

Sea temperature (°C)	No. of patches
11.0–11.9	4
12.0–12.9	46
13.0–13.9	117
14.0–14.9	49
15.0–15.9	4

16.0°~17.0°C prevails (see Table 11–1). According to Brodskii (1964) and Jillett (1968), *C. tonsus* occurs at the sea temperatures between 5.0°~15.0°C in the southern waters, and both Kawamura and Hoshiai (1969) and Kawamura (1970b) also confirmed those temperature as possible conditions of their habitat. Accordingly the distribution range of *C. tonsus* as a function of sea temperatures concerned would be considered as relatively wide ranged. However, the main body of early summer concentration of sei whale which exclusively feeds on *C. tonsus* patches (Kawamura, 1970a) in the Subantarctic waters is found at the temperature of 10.0°~16.0°C accompanying distinct temperature gradient (Nasu and Masaki, 1970). These fact and Table 11–1 suggest that *C. tonsus* prefers somewhat warmer waters, and its patch would not have been formed much in the waters south of 40°S and in the waters under the temperature of higher than 16.0°C.

To know the relationship between the occurrence of patches and the sea temperature more precisely, Fig. 11–4 was arranged. As mentioned before, *C. tonsus* patches occurred most frequently during Dec. 14~20, and the trends of sea temperature change by hours in connection with the occurrence of patches during those period were distinct; a very frequent occurrence of patches can be expected under the small-scaled variable temperature change. The sea temperature in the figure represents the value measured every hour, but it varied very frequently

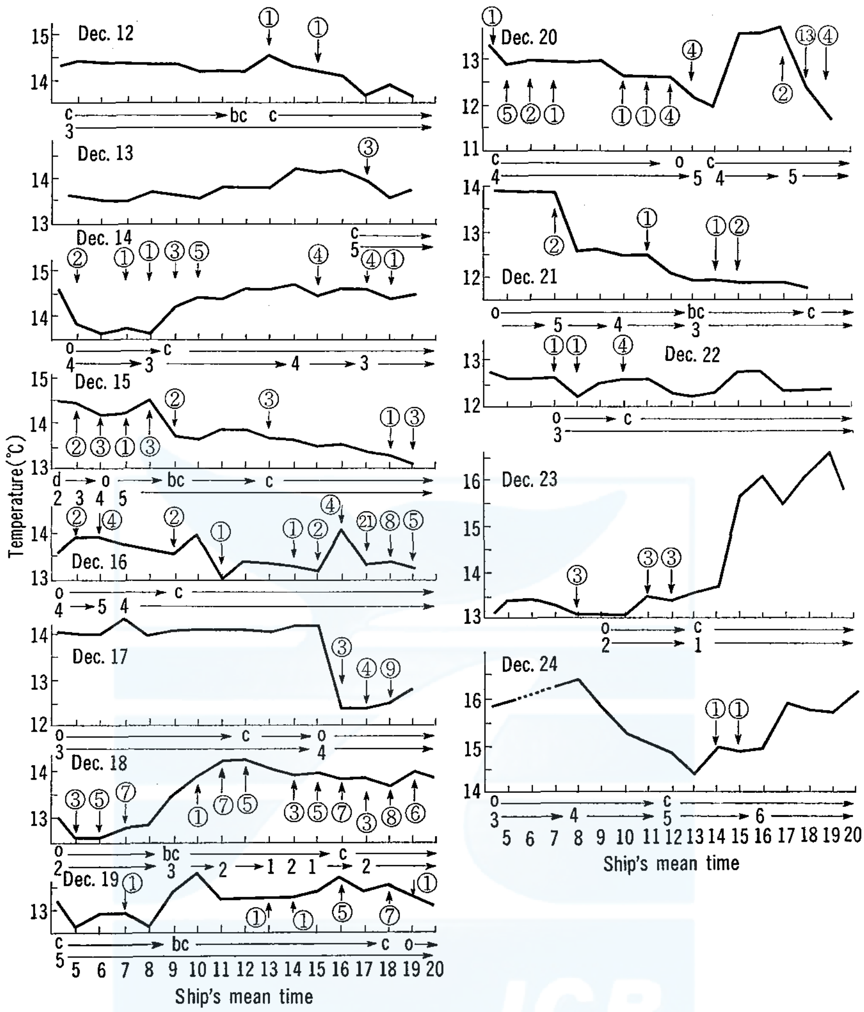

Fig. 11–4. Sea temperature and the occurrence of *C. tonsus* patches along the ship's track during Dec. 12∼24, 1971. Arrow shows the time of occurrece and the numeral encircled shows the total number of patches occurred in every one hour.

TABLE 11-2. TEMPERATURE VARIATION WITHIN VERY SHORT TIME.

Date	Time (SMT)	Temperature change (°C)
Dec. 17	1520–1600	14.5 ∼ 13.3
	1620–1730	14.2 ∼ 12.3
Dec. 18	1300–	Very frequent change within the range of 0.2∼0.3
Dec. 20	1200–1220	12.3 ∼ 14.7 ∼ 12.0
	1350–1640	11.9 ∼ 14.8 ∼ 15.1 ∼ 11.9
	1700–	11.9 ∼ 11.7
Dec. 21	0700–0800	14.8 ∼ 11.9 ∼ 12.4

through hours to hours as an example given in Table 11–2. This suggests that the occurrence of patches would be closely related to the characters of sea temperature distribution especially to the small-scaled local hydrological structures, which something likely to micro-distribution of plankton as demonstrated by Cassie (1959). Poor occurrence of the patches during Dec. 23～24 would be attributed to an unfavourable high temperatures for swarm formation, and those on Dec. 12～13 should be noted as the result of monotonous hydrological conditions possibly due to relatively poor temperature gradient.

The conditions of sea surface in terms of wind force varied from class 1 to 5 throughout the investigation though the most was in the class 3 to 4. During Dec. 16～20, when the patches appeared frequently, the wind of class 4 or 5 prevailed. This fact suggests that *C. tonsus* patches never be dispersed or scattered away at least under these roughness of the sea surface.

11–6. *Frequency distribution by hour*

Fig. 11–5 demonstrates the frequency distribution of *C. tonsus* patches by every observed hour. A total of 220 patches was counted. As far as the figure concerned, the diel variation of occurrence makes us confirm that *C. tonsus* patches which were consisted of almost exclusively by the copepodite stage V likely to move vertically, and a considerable number of patches come up to the very surface in

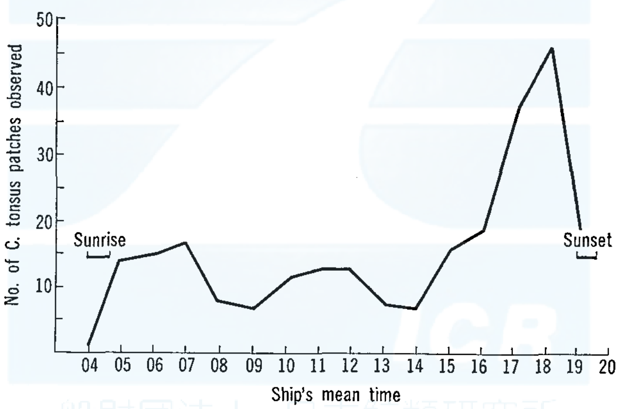

Fig. 11–5. Frequency distribution in the number of *C. tonsus* patches, Dec. 11～24, 1971.

the evening between 1700 and 1800 hours. It is also shown that there are two other peaks in frequency distribution: early morning and daytime, although they are hardly comparable to those found in the evening. By analysing the feeding habits of southern sei whale which feeds on *C. tonsus* exclusively, Kawamura (1970a) considered that *C. tonsus* of copepodite stage V does not make any diel vertical migration. So it seems disagree with the above results each other. It is, however, considered that *C. tonsus* patches move slightly down to such the depth, say, 1 or 2 meters under the surface during daytime as to be hardly detected by eyes but still remaining within the enough depth to be fed by the sei whale. This vertical movements in whale's food can be recognized as "Uki-esa", a floating food and "Soko-esa," a bottom food which were introduced by the Japanese whalers. They are not scattered away but still keeping swarm during daytime since the routine sampling by underway plankton catcher at 1000 and 1600 hours did not show any trends of their dispersal which may cause poor occurrence of *C. tonsus* patches during daytime.

The poor occurrence both in 0800~0900 hours and 1300~1400 hours corresponds to 3~4 hours of the time lag from astronomical twilight at 40°S in December (Japan Maritime Safety Agency, 1971) in the former and 4.7~5.9 hours for the latter. This fact suggests that the light condition in or under the surface varies considerably with both cases, and that the vertical movements of *C. tonsus* patches may possibly not correspond to the light condition. Those small scale movement of patches would also differ from patch to patch themselves. The patches of *E. superba* likely to occur more frequently both in the morning and evening, and those by Galathea are distinct in the daytime (Ozawa *et al.*, 1967). The manifold charactors of movements by the kind of patch forming organisms make us confirm that the behavior of *C. tonsus* patches above mentioned may be, as Cassie (1960) suggested, by some internal behavior patterns within the species.

11–7. *Population density in the C. tonsus patches*

In the study on the food and feeding habits of southern sei whales, it was estimated theoretically that the population density in *C. tonsus* patches have to be maintained at least in the order of 10^4 individuals per cubic meter (Kawamura,

TABLE 11-3. PATCHES OF *CALANUS TONSUS* AND *PARATHEMISTO*

No. of patches	Date	Position		Time (SMT)	Sea temp. (°C)	Weather	Wind direct. & force
		Lat. (S)	Long. (E)				
1	Dec. 14	37–14	99–36	0801–0811	13.6	O	NNW 3
2	Dec. 14	36–26	101–21	1845–1856	14.87	C	NW 3
3	Dec. 16	37–56	106–39	1730	13.54	C	ENE 4
4	Dec. 17	38–37	110–07	1820	13.21	O	ENE 4
5	Dec. 18	39–31	111–56	1556–1558	13.80	C	NNW 1
6	Dec. 20	38–59	115–21	0715	13.49	O	S 4
7	Dec. 21	39–21	117–57	0729–0730	12.13	O	SSE 5
8	Dec. 22	39–36	120–22	0720–0722	12.90	O	SE 3
9	Dec. 22	39–54	120–54	1029–1032	13.10	C	SSE 3
10	Dec. 23	38–19	120–48	1107–1108	13.0	O	ESE 2
11	Jan. 3	49–40	118–35	1906–1916	6.24	BC	NW 4
12	Jan. 4	53–09	119–35	1600	5.60	F	NW 6
13	Jan. 5	55–40	119–57	0740–0744	4.20	F	NNW 3
14	Jan. 5	56–22	118–50	1500–1505	4.00	D	NNE 5
15	Jan. 6	57–17	117–07	0341–0350	3.40	O	SSW 5
16	Jan. 11	57–14	97–03	2029–2035	2.20	R	ENE 5

1) Petersen Type Vertical Closing Net (Kawamura, 1968a).
2) Simple Underway Plankton Catcher (Motoda, 1959).

1971a). One of the purposes of the investigation on *C. tonsus* patches was to get an evidense which directly supports those theoretical estimations.

Table 11–3 presents the details of ten *C. tonsus* patches which were sampled actually, and the quantitative results on the samples were given separately. In the most of sampling in the field, the plankton catcher was towed as to cross over the patches in their short axis. The duration of net towing varied from several tenth seconds to several minutes since individual density varied both vertical and horizontal plane even within the identical patch in addion to the variation of patch sizes. As it will mentioned later, the patches were composed of almost solely by *C. tonsus*, and the number of individuals in a haul was determined by sub-sampling a small fraction of materials such as 1.0 gram or so.

The individual number of *C. tonsus* patches per cubic meter of water varied considerably by the patches: 330 inds./m^3 as the lower extreme and 23,680 inds./m^3 followed by 21,165 inds./m^3 as the upper extremes. So the individual density found in this study was in the range of 10^2 to 10^4 inds./m^3. Some of these figures would not represent an exact density because the sampling method employed in this investigation was in danger of failure in quantitative treatment due to the irregularity of individual distribution within the patch and also due to those variables in vertical section against the definite sampling level in the water. Accordingly the population density within the patches always tends to be under estimated as Fraser (1962) mentioned the difficulty on this matter. The population density of $2\times10^4 \sim 3\times10^4$ mg/m^3, which is equivalent to about $3.8 \sim 5.7\times10^3$ mg dry weight/m^3 (after dry/wet weight ratio of *C. tonsus* by Bradford, 1972) would be

GAUDICHAUDII WHICH WERE SAMPLED BY THE NET.

Kind of net used	Kind of patch organism	Approx. size of patches[3]	No. of individuals per haul	No. of individuals per m^3	Wet weight per haul (mg)	Wet weight per m^3 (mg)
PVCN[1]	*Calanus tonsus*	40×500	144633	670–761[4]	177900	848–937[4]
,,	,,	30×120	146545	623–701[4]	212690	905–1018[4]
SUPC[2]	,,	10×500	4750	23680	5890	29362
,,	,,	10×400	2884	—	4710	—
,,	,,	100×300	16720	21165	27500	34810
,,	,,	10×150	266	3446	—	—
,,	,,	60×500	1525	6277	2990	12305
,,	,,	150×100	5035	8626	9500	16274
,,	,,	6×500	167	330	—	—
,,	,,	100×1000	123	350	—	—
PVCN	*Parathemisto gaudichaudii*	unknown	1688	8–9[4]	5800	27–31[4]
,,	,,	,,	389	36–41[4]	—	—
,,	,,	,,	565	7–8[4]	—	—
,,	,,	,,	353	3–4[4]	—	—
,,	,,	,,	2100	8–9[4]	32300	129–145[4]
,,	,,	,,	4273	3–4[4]	91900	72–81[4]

3) Width×Length (m).

4) Upper and lower extremes of 80% and 90% fiiltering coefficiencies of the PVCN when towed at the speed of 2 knots.

agreeable when compared with the previous estimations of between $3\sim6\times10^4$ inds./m^3 (Kawamura, 1971d), and the result of 9×10^3 mg/m^3 in *Calanus* (Manteufel, 1939). The above results also well agrees to the figure obtained in *Calanus finmarchicus* patches by Kitou (1956), where 8,208 individuals per $0\sim1$ meter haul (ca. 2×10^4 inds./m^3) were recorded.

11–8. *Zooplankton abundance in the back ground waters*

To compare the quite large zooplankton standing stocks maintained by *C. tonsus* patches with those lying in the waters outside from the patches as a back ground, sampling by 15 minutes surface tow with underway plankton catcher was conducted twice a day during Dec. $11\sim26$, and the Petersen type vertical closing net was drifted at times after sunset as supplemental sampling.

Table 11–4 gives the figure that zooplankton standing stocks are very poor during the daytime when only $1\sim2$ individuals per cubic meter of water was found. The area investigated was so barren as a whole only maintaining organisms less than 10 mg/m^3 throughout the investigated period though they increased to about two folds or more in the night; $1\sim60$ mg/m^3. Comparing a poor occurrence both in the number of species and individuals during daytime, most samples in the night showed rather rich zooplankton communities by *C. tonsus* of stages V and VI of female, *Neocalanus gracilis*, *Euphausia lucens*, *E. recurva*, *Ostracods*, *Doliolum* sp. *Salpa* sp. and *Sagitta* sp.

TABLE 11-4. AVERAGED ZOOPLANKTON ABUNDANCE COLLECTED BY UNDERWAY PLANKTON CATCHER IN 15 MINUTES SURFACE TOW DURING DEC. $11\sim26$, 1971.

Organisms	Abundance
Calanus tonsus Copepodite V	0–1 ind./m^3
Micro-calanoida	0–20 ind./m^3
Amphipoda or euphausiacea	0–1 ind./m^3
Doliolum or *Salpa*	0–0.1 gr/m^3

However, in the region concerned to this study it has been known as relatively poor in zooplankton population having been reported less than 25 mg/m^3 (Tranter, 1962), and euphausiids also distribute as poor as in the tropical region of the Indian Ocean (Baker, 1965). The region under consideration can be noted quite characteristic where food rich waters float like a islands or rafts in the ocean which would possibly give a quite different results in the estimation of plankton biomass by sampling condition whether the patch or a part of it were collected or not. Baker (1965) stressed on this matter while he was studying on *Euphausia vallentini*, one of the another important whale's food in the Subantarctic region.

The occurrence of *C. tonsus* patches can be considered to make the region quite characteristic as an ecological environment particularly for the predators in higher trophic levels such as *Scomberesox saurus*, Gonostomatid fishes (Kubota & Kawamura, 1972) in the pelagic waters and basking sharks *Cetorhinus maximus* in offshore waters (Bradford, 1972).

11–9. *Some biological characters in the C. tonsus patches*

The size composition of *C. tonsus* population which formed patches is demonstrated in Fig. 11–6 which was obtained by examining 1152 individuals in all. The size of *C. tonsus* in stage V copepodites through ten patches varied almost within the range of 3.2∼3.3 mm with an average 3.295 mm (N: 1141). There were no stage V copepodites smaller than 2.8 mm and those larger than 3.6 mm. In contrast to dominant occurrence of stage V copepodite (99.2 percent on average) the adult females occurred but very small numbers, 11 out of 1152 individuals. They varied between 3.5 mm and 4.1 mm with an average 3.764 mm, and their size distribution agrees well to that of the populations usually found in 40°S latitude (Brodskii, 1964) where it seems about 3.78 mm as his figures concerned. A fairly

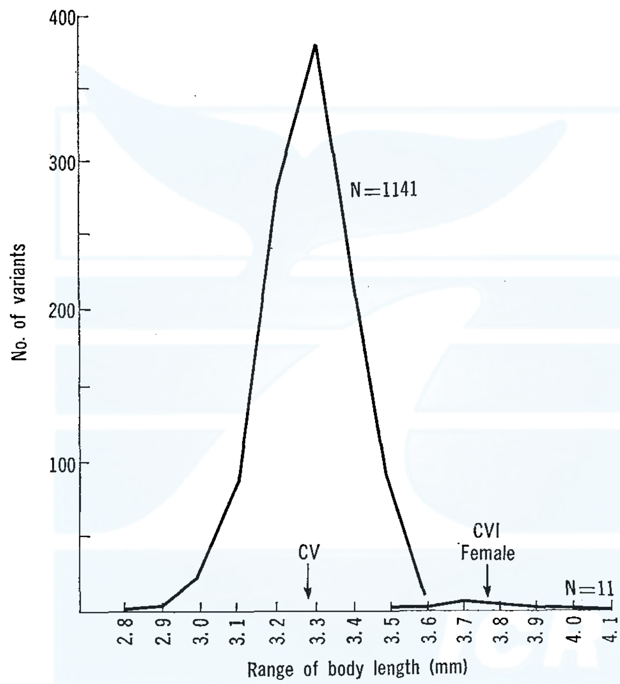

Fig. 11–6. Variability of the body length of *Calanus tonsus* which formed patches.

poor occurrence of adult females among patch forming population agrees to the result on the food analysis in sei whales (Kawamura, 1970a) and it is also similar to net samples obtained in circumpolar waters (e.g. Brodskii, 1964).

However, the size of *C. tonsus* by each patches as numbered 1 to 10 in Table 11–5 shows some interesting facts: the patches of Nos. 1 and 2 were consisted of relatively small sized individuals of 2.8∼3.4 mm with an average 3.18 mm and of 2.9∼3.5 mm with an average 3.28 mm respectively. In contrast to this figures, the patches of Nos. 3 to 10 were consisted of more larger individuals with the size of 3.1∼3.6 mm with an average 3.32 mm. There seems two possible explanations on the differe nce in size distribution of stage V copepodites of *C. tonsus*:

During the austral summer it is known that two generations of *C. tonsus* in stage V copepodites as summer population are present, that is, the individuals of previous year origin and that developed in the current season (Jillett, 1968), and differences in body length composition in the *C. tonsus* patches may be due to this breeding character. One of the anothers also could be considered. According to Brodskii (1964) there are latitudinal difference in body size of *C. tonsus*, and larger individuals are usually found in higher latitudes. So it is possible that the patches of Nos. 1 and 2 were relatively northern water origin accompanying with warm water species of zooplankton (see Table 11–5). These facts suggests that both the patches of Nos. 1 and 2 might have been isolated through their development from others of Nos. 3 to 10, which were possibly the offsprings from the same initial population stock.

TABLE 11–5. BIOLOGICAL CHARACTERS OF *CALANUS TONSUS* PATCHES.

No. of patches	Av. body size (mm)	Av. body weight (mg)	CVI ♀/CV (%)	Range of body size (mm)		Organisms occurred with *C. tonsus* (No. of inds./haul)
				CV	CVI ♀	
1	3.18	1.23	1.65	2.8–3.4	3.7–3.8	*Vellella vellella* (18) Amphipoda (36) *Cavolinia* sp. (1)
2	3.28	1.45	3.22	2.9–3.6	3.6–3.8	*Doliolum* sp. (473) and others*
3	3.34	1.24	0.77	3.1–3.6	4.0	—
4	3.35	1.63	0.87	3.1–3.6	3.8	*Thysanoessa* sp. (1) Amphipoda (2)
5	3.35	1.64	16.23	3.0–3.6	3.5	*Thysanoessa* sp. (7) & juv. (9) *Euphausia* sp. juv. (2)
6	3.28	—	—	3.0–3.5	—	—
7	3.39	1.96	0.78	3.0–3.7	4.1	Amphipoda (1)
8	3.25	1.89	—	3.1–3.5	—	—
9	3.30	—	—	3.1–3.6	—	Copepoda (3) Amphipoda (1)
10	3.27	—	—	3.1–3.5	—	—

* *Diphyes antarctica* (1), *Cavolinia* sp. (1), Combjelly (1), *Cyllopus* ?(1), *Euphausia* sp. juv. (6), Squid (1), and fish larva (1).

The geographical location where the patches Nos. 1 and 2 were collected was in the waters far west from the others, and relative abundance of adult females is large enough to distinguish them from another patches. The zooplankton species entangled along with a bulk of *C. tonsus* seem also to be something different between the patches Nos. 1∼2 and Nos. 3∼10. In the Nos. 1∼2 patches there were found some warm water species such as *Vellella vellella*, *Doliolum* sp. and *Cavolinia* sp. while these species were completely absent in the others. Similar facts showing a different biological characters by patches have been found in the population of *Euphausia superba* (Mackintosh and Wheeler, 1929; Marr, 1962), and these facts seem to be essential characters widely found in zooplankton swarms.

The average body wet weights also varied between 1.23 and 1.96 mg. through Nos. 1 to 10 patches. However, they showed no parallel relationships to the body length as noticed by comparing the patches Nos. 2, 4 and 8. The patch forming individuals must be different in their physiological conditions even in the same developmental stages.

It could be considered as a whole that the patches of *C. tonsus* keep their biological characters each other to some extent, and this means that they do not mingle each other for some long time, and that they are controlled by some biological functions to swarm or aggregate themselves, if not the patches and their biological characters could not be kept so distinctly under the continuous disturbance by strong winds and smashing waves. Marr (1962) mentioned that patches of *Euphausia superba* are maintained for long time through their life span, and rarely found mixed populations with the individuals in different developmental stages among the identical patches. Hardy (1967) also confirmed the similar evidence as a function of strong self-swarming behavior by euphausiids. In the neritic waters, the planktonic larvae of *Balanus* and *Mytilus* sometimes show a dense patchy distribution, but they dispersed over soon after as season proceeds (Raymont, 1963). The patches of euphausiids, or copepods found in the pelagic waters would be considered different in their biological nature such as socialized function through swarming behavior as Steven (1961) and Clutter (1969) confirmed it in the patches of mysid from those swarms by temporal zooplankton species.

11–10. *Possible cause of swarming in zooplankton*

The zooplankton does not evenly distribute throughout its habitat but distribute quite unevenly as has been known by an actual experience in the North Atlantic cod fishing grounds. The swarms or the patches of zooplankton could be seen as one of particularly distinct phenomena of spatial distribution, and those sighted by C. Darwin in the Antarctic region near to Tierra del Fuego might possibly be the plankton patches (Darwin, 1906). The swarming phenomenon in zooplankton has been documented to some extent by Mackintosh and Wheeler (1929) who studied on the food habits in baleen whales, and also by Hardy (1936a, b) in his investigations by the continuous plankton recorder. Hardy (1936a, b) also made it clear that the uneven distribution of zooplankton is not so special phenomenon but rather general characters as a whole, which made him criticise the recognition of even distribution of zooplankton by Hensen (1890). Through his studies on the uneven distribution in plankton population, Hardy (1936a, b) called " patchy distribution " or " patchiness " of plankton when they swarmed densely in a spacially limited region. For example, Hardy (1936a) found patchy distribution of *Salpa longicauda* when they densely swarmed with more than 30~50% larger in their population density to that of the back ground waters. The patchiness as one of a distribution patterns in animals, therfore could be considered a kind of sociality in animals, and Imanishi (1941) called the theme as specific synusia an ultimate pattern of population life as widely found in the insect communities. Imanish (1941) considers these monospecific swarms or aggregations in animal community would be somewhat unusual in their daily life, but the patchy distribution in organisms itself can also be considered rather usual distribution patterns since it is widely found throughout both animal and plant kingdoms.

One of the distinct examples of plankton patchiness is known in *E. superba* and *M. norvegica* populations, and they swarm such densely as to make the sea heavily discolored. It was this discoloration of the sea that has made whalers spot the whales and whaling ground. The *E. superba* population under patchiness is exclusively monospecific composition, and it also clearly formed independently by the individuals in the same developmental stages (Mackintosh, and Wheeler, 1929; Mackintosh, 1973). Therefore, the zooplankton swarming into patches differs in a sence from the patchy or uneven spatial distribution. The latter would be widely found in any kind of plankton communities. The *E. superba* patches are quite important ecologically since they are voraciously fed by the baleen whales while none of *Sagitta* spp. and pteropoda under similar patchiness are fed by the whales. What whales feed exclusively on swarming organisms which form the patches indicates that patch formation would be a staple distribution pattern through the evolutional ages since baleen whales must have adapted to develop specialized apparatus, the baleen or whalebone so as to utilize those patch or aggregation forming organisms.

In the northern North Pacific and Bering Sea, *Sagitta*, *Aglantha* and *Clione* sometimes show a distinctly larger biomass (Hokkaido University, 1962). In the southern seas *Sagitta* spp. also show a patchy distribution (Hardy, 1936a). However, a bulk of occurrence of these organisms is usually accompanied along with many other plankton species to show a complicated zooplankton communities though *Sagitta* occurs with patchiness. More recently, Wiebe (1970) observed on the small scale spatial distribution of zooplankton in detail and he called " patchy distribution " against the plankton biomass of about 2.6~5.1 times larger than the back ground, while Kuwabara *et al.* (1971) definited the patchy distribution as with the biomass larger than the overall median value in a series of samplings. These patchy distribution as definited above however may be similar but different from so-called plankton patches by aggregating or swarming of organisms in view of their community composition.

As it has been mentioned the population density in *C. tonsus* patches was maintained under somewhere between 10^3 and 10^4 inds./m^3. These figures would be larger, approximately several thousands to several tenth thousands times than the back ground waters, and this somewhat similar to the case in *E. superba* (Marr, 1962) and *M. norvegica* (Mackdnald, 1927) where it was larger about 200 to 300 times. Anyhow the zooplankton patches is quite important ecologically in the marine food chains. For instance, a squid, *Nototodarus sloani sloani* which distributes in New Zealand waters feeds on the swarms of both *Nyctiphanes australis* and *P. gaudichaudii*, and *Todarodes pacificus* also feeds on *E. pacifica* (Kawakami *et al.*, 1973; Kawamura, 1974b). These facts suggest an importance of the plankton patches other than the case in baleen whales since the squids supposedly distribute over the world oceans with great quantity.

For the convenience of further discussion on the patches in *C. tonus*, their biologically important characters are given as follows: 1) a horizontal expansion of the patches is at least several hundred meters, 2) the shape is usually recognized with the scale in horizontal plane, *i.e.* stream, round or oval shaped, 3) the patches and its shape firmly maintanined under a rough sea of 8.0∼10.7 m/sec in wind speed and 5 class of waves, 4) patches occur most frequently under the temperature of 13.0∼14.0°C, where distinct temperature gradient prevails, especially in the regions under varying temperature, 5) higher population density of patches is mostly found in the surface waters shallower than 1.0 m but some are in more deeper waters, 6) the population density under patchiness would be $10^3 \sim 10^4$ inds./m^3, 7) the patches are composed of copepodite V though sometimes a little number of copepodite IV and adult female are mixed up, 8) biological characters of patch forming *C. tonsus* population are maintained for long period, 9) occurrence of patches varies with time in a day, 10) patches may show a slight diel vertical movements without any relations to underwater illumination. Among these characters, 3), 7) and 8) strongly indicate that the patches are neither formed by random variation in the distribution nor physical conditions of the water but purely biological causes of internal behavior to aggregate themselves.

Various discussions have been stated on the possible cause to make zooplankton swarm so densely, and the discussion could be divided into three opinions: one of them discussed the phenomenon as being a subject of zooplankton or organism itself, so the environment, have somewhat the secondary importance for it (*e.g.* Gurney, 1924; Russell, 1927; Hardy and Gunther, 1935; Watermann, 1958; Colebrook, 1960a, b), and the other considers an inorganic environments first such as current, circulation of the water, underwater illumination which directly influences on the formation of swarms (Fraser, 1936; Bogorov, 1938; Beklemishev, 1958), and the third is a combinations of the both above mentioned, and Colebrook (1960a, b) considered the surface swarming in *Daphnia hyalina* would supposedly caused by whirling movement of water and swarming behavior of *Daphnia* itself, whereas Russell (1927) insisted the purely biological factors of zooplankton to aggregate themselves after his observations on decapod larva. " Localize didtribution " in *M. norvegica* in the North Atlantic must be due to a seasonal change in an availability of foodstuff along with being chased by predator and with an effect by tidal currents. However, when we consider the biological characteristics of the swarming or patchiness in *E. superba* and *C. tonsus*, it does not seem to be caused by environmental conditions such as the current, upwelling, pack-ice and its melted water but caused primarily only by the subject of those organisms, that is, 1) a monospecific composition of swarming population is maintained for long period (Mackintosh and Wheeler, 1929; Marr, 1962), 2) each patches are composed of individuals in a definite developmental stages but it would possible to occur two kind of patches each of which composed of different developmental stages in the same sea region, 3) orientation of *E. superba* individuals within the patches is almost in the same direction and the patches are quickly reorganized after disturbance (Hardy and Gunther, 1935), and 4) patches are well maintained through even rough weather.

In this study I sighted at many *C. tonsus* patches even when the surface was very rough under the wave class 5, say, 8.0∼10.7 m/sec in wind speed. According to Sakamoto (personal comm.) a theoretical current speed which is possible under the wave height of 1∼5 m would be 62.5∼140 cm/sec. Under these circumstances *C. tonsus* could not maintain those high population density unless they swim actively againt to the current. According to Marshall and Orr (1955) the swimming speed in *Calanus* was 0.42 cm/sec. in long ascent movement, and 1.32 cm/sec. in descent. Still more most *C. tonsus* patches occur in the convergence region where the water sinks to some extent, which would require to make *C. tonsus* move upward to keep their position within the surface layer. However, Jillett (1968) stated that the dense population in *C. tonsus* would be due to an accumulations caused by some current dynamics, and it is in these points that I disagree with his consideration.

If *C. tonsus* forms dense swarms or patches not by a envirommental conditions but by its habits of gathering closely each other into an aggregation, there would be found some physiological and ecological benefits for them as Allee (1938) and Lorenz (1963) discussed beneficial effects in many kind of aggregating animals. The population density in *C. tonsus* patches was approximately $6\times10^3\sim2\times10^4$ inds./m^3 though the figures as plankton biomass still much less than *E. superba*. However, these above mentioned population density would be enough to make the individual under the patchiness touch each other while they jostling one another, and the explanation on the plankton swarming by some factors such as the structual features in a column of water, photo taxis, sensory for polarized light and grazing could not possibly keep the individuals so closely for long time. The antennule in crustaceans functions as a sensory organ (e.g. Dahl *et al.* 1970a, b), and the role of the frontal organ in *Calanus*, and the setae on the antennule themselves would function similarly. The stimulation induced by physical contact while jostling would release the behavior of swimming at least toward the surface (Rudjakov, 1970). Allee (1938), however, considered the absence of any kind of physical contact in copepod aggregations, but also suggested their social habits.

Apart from that above mentioned, one of another possible cause being proposed might be a chemosensory receptors furnished on the antennule although any kind of the receptor had not known yet in *Calanus*. However, its presence in brackish water amphipoda, *Gammarus duebeni* as receptor for sex pheromone (Dahl *et al*, 1970a, b) and in decapod crustacean, *Portunus sanguinolentus* (Ryan, 1966) must function as chemotaxis of a gathering attractant. The swarming in crustaceans particularly under monospecific compositions therefore might possibly benefit as the density or grouping effects in growth speed and shortening the larval period, such as known in a kind of cockroaches (Ishii, 1970; Chauvin, 1967) and in oligochaetes (Brinkhurst *et al*, 1972). According to Ishii (1970) the swarming and settling in a nauplii of *Balanus* sp. are controlled by chemical factors though only settling factor has been known to induce their aggregation and simultaneous settling on the bottom. Stimuli by physical contact through body touch would make copepods ascent toward surface (Rudjakov, 1970), which may explain the occurrence of densely aggregated *C. tonsus* population in the very surface waters. However, since the *C. tonsus* patches were found not only at the surface but also at several meters depth, some another causations to explain these circumstances have to be considered in the future. Bainbridge (1953) indicated the importance of vision and reotactic sence which might explain the animal aggregations, but it would be still in need of examinations to appropriate his indications at least on to *C. tonsus* population and other copepods since visual sence in these organisms is poorly developed. Learning and practising behavior found in the fishes may also be difficult to appropriate on to swarming in zooplankton.

12. GENERAL DISCUSSION AND CONCLUSION

The behavioral patterns of animals in time and space are so complicated features as to hardly be understood even their outlines. However, when we consider a movement of animals in view of the population ecology as a whole, they could be approached to some extent since they were mostly controlled by instinctive behavior of both breeding and feeding as has been pointed out by Elton (1927), and the whales do not differ essentially from another mammals but rather simple due to their seasonal migratory behavior between cold and warm seas. One of the current problems to which the population ecology faces would be to understand the structure and mechanisms of varying animal populations under the natural and artificial factors which affect on their population along with inter-specific factors. Food and feeding habits of animals much influences on the number and size of population through the marine food web. Elton (1927) suggested an importance of study on the prey-predator relationships in connection with the animal populations.

In baleen whales a minute crustacean animals had been known early as the main nutritional sources for the whales (e.g. Scoresby, 1820; Collett, 1929). However, it was until recent years that those food habits were considered from the view points of production ecology in which the secondary producer connected directly with the last consumer, say, a typically simple but effective shift in energy flows. At the sametime, the relationships around food would be an important role on controlling the overall population size of the predators such as, say, catch of anchovata and the population of pelican, whale stocks and the abundance of euphausiids (Kawamura, unpublished data). All these are in need of quantitative treatment in their preypredator relationships. Since the stock of whales is important among all, the study on their food and feeding habits have to be proceeded along with the whales itself.

The sei whale in the Antarctic region distributes along the Subtropical Convergence, and the food organisms in that region are consisted of somewhat simple zooplankton community although the oceanic conditions differ to some extent between the whaling areas. The important food organisms in the southern sei whaling ground are: *Calanus tonsus*, *C. simillimus*, *Parathemisto gaudichaudii*, *Euphausia vallentini*, and *E. superba*. The shift of whaling ground during a season is mostly to the features of the seasonal distribution patterns of food organisms such as disappearance of *C. tonsus* from the surface by its depth migration for wintering. In the formation of whaling ground the patchiness of zooplankton is important among all, since food organisms of whales are restricted in patch forming species. As has been mentioned in the previous sections, the plankton patches as a whole are distinctly characteristic population in general distribution and its movements being differed from the individuals outside the swarms. For example, patches of *E. superba* usually shows diel vertical migrations to some extent (Marr, 1962), while many patches occur in the surface layer throughout the night (Ivanov, 1970). The ecological importance of plankton patches would be understood when we consider their biomass as shown in *C. tonsus* patches where the biomass was $2\times10^4\sim3\times10^4$ mg/m^3 of water while it was only 25 mg/m^3 in the back ground waters. The patches of *C. tonsus* usually found under the temperature of 13.0°∼14.0°C whereas the species itself is known to distribute under wide temperature range of 5.0°∼15.0°C. (Brodskii, 1964). The whaling ground formed by *C. tonsus* therefore could hardly be recongized only by the characters of its general distribution unless the knowledge on the ecological characters of the patches was accompanied. The movements of whale within the feeding ground would be well understood by studying the causations which make the food organisms densely aggregate into the patches.

In the feeding types of baleen whales the filtering apparatus along with its mechanisms and the feeding ability were considerably different in sei whale from those in blue and fin whales. The sei whale can recognized characteristic in this point though all these three belong to balaenopteridae. The baleen plates of sei whale shows rather slim, and its bristles furnished on the inner margin of baleen plates are fine as comparable with those of balaenid whales. The meshes which cover the inner surface of filtering apparatus are quite fine with relatively larger filtering area among balaenopterid whales. In regard to a selective feeding habits in baleen whale (Nemoto, 1959; 1970), the sei whale prefers copepods at first then euphausiids or amphipods in the Antarctic waters though the latter two are replaced one to another by the regions concerned (Best, 1967; Kawamura, 1970a). A preference to copepods in sei whale also found in the North Pacific where *C. cristatus* and *C. plumchrus* are the staple food (Nemoto, 1959; 1957) although they are replaced by fish and euphausiids in more southern waters (Kawamura, 1973a). The food organisms of sei whale took over by *C. finmarchicus* in the North Atlantic (Collett, 1886). A boltering behavior is known well in fin and blue whales (Lillie, 1910; Gunther, 1949) but is less distinct in sei whale. These facts along with the feeding mechanisms, apparatus, and habits lead to a consideration that the sei whale is more closely related to right and bowhead whales. Nemoto (1959; 1970) however, thought the sei whale belongs to blue whale type feeding apart from right and grey whales types. But when the above mentioned circumstances on sei whale feeding are took into account, its feeding type would be rather much similar to that of the right whale.

The over specialization such as elongated teeth in narwhal, *Monodon monoceros* is usually seen to some extent throughout the order cetacea, and the development of the baleen plates could be considered as one of over specialization themselves (Howell, 1930). In this respect the gulping or swallowing type in feeding would be more general throughout many animals while the skimming type as employed in sei and balaenid whales would be an over specialization. As I have assessed in the previous section, the sei whale can collect more abundant foodstuff effectively by skimming the food contained water than swallowing, that is, the sei whale seems to have aquired skimming type feeding as an more advanced habits for collecting the foodstuff in marine biotope.

Marr (1962), Moiseev (1968) and several other workers assessed the stock size of *E. superba* being based on the consumption of *E. superba* by whales. Apart from the whales, Ryther (1969) also made an estimation of *E. superba* production from the view point of production ecology by supposing the energy coefficient of 10, 15, and 20% in the shifts of the trophic level, and criticized the above mentioned method as out of the discussion. Ryther's methodology itself is one of the subject in production ecology. However, it sometimes leads to a confusion or incorrect conclusions unless the biological characteristics such as the dietary habits of prey and predator were took into account. For example, *E. superba*, according to Barkley (1940) and Marr (1962) preferably feeds on diatoms, *Fragilariopsis antarctica*, and as a whole it seems to avoid larger or longer sized diatom and spinous diatomspecies. *E. superba* likely to strongly avoids the water dominated by *Thalssiothrix antarctica* (Kawamura, 1973b; 1974). However, the biological aspects of feeding babits such as food selection are omitted in the method by productivity which involves all of the organic carbon produced. Hasle (1969) reported abundant distribution of *Nitzschia* spp., *Fragilariopsis* and *Chaetoceros* diatoms in the Pacific sector of the Antarctic but they are supposedly less important as food of *E. superba*. This fact supports well a poor distribution of *E. superba* in that region (Mackintosh, 1973). Marr (1962) considered the gaps or voids in phytoplankton abundance between the waters with rich *E. superba* patches and those separating the patches would be due to grazing.

The animals which distribute dominantly with the bulk of biomass and usually in higher trophic levels likely to prey on zooplankton species particularly those aggregate into the patches. These animals, for instance, are anchovata, gonostomatid fishes such as *Viciguerria attenuata*, *Scomberesox saurus*, squids, seabirds, crabeater seal and whales. The role of those animals in the Antarctic ecosystem would be distinct than any other kind of organisms, but none of them studied yet except whales, and therefore the knowledge of food habits in those animals is considered to be strongly in need of further investigations. However, it has been known that the southern blue, humpback, minke and fin whales feed almost exclusively on *E. superba* though the fin whale utilizes copepods to some extent whereas the sei and right whales feed copepods preferably, though the latter feeds much on euphausiids other than *E. superba* and amphipods, *P. gaudichaudii*. When we take into account the ecological niche concerning to those prey organisms in quantitative and qualitative respects, it would be possible to suppose an outline of the structure of the ecosystem in the southern ocean: the organic production in the Antarctic regions proceeds as a whole under relatively lower trophic levels. Accordingly, the role of zooplankton in the southern ecosystem would be hardly comparable importance than that of any other places, and it seem to be almost impossible to understand the ecology such as the movements and the inter specific relationships among those important predators without studying on the swarming habits of their prey organisms.

The swarming habits in zooplankton however have been poorly studied particularly in the biological and ecological knowledge except several observations as an unusual distribution phenomena (e.g. Hardy and Gunther, 1935; Mackintosh, 1967). As it has been stated in the previous section, *E. superba* and *P. gaudichaudii* occur in patchiness which would be formed by the individuals of almost every developmental stages. On the other hand the patches in *C. tonsus*, *E. vallentini*, and supposedly in many another kind of copepods and euphausiids are formed by the individuals of some particular developmental stages such as the copepodite V in *C. tonsus*. The swarming into patches in *E. pacifica* (Komaki and Matsue, 1958; Komaki, 1967), *The. inermis* and *M. norvegica* (Bigelow, 1924; Macdnald, 1927) would be similar to the case in *C. tonsus* and *E. vallentini*.

Marr (1962) discussed on the possible cause which make *E. superba* aggregate so densely but he did not figure out decisive conclusions after examining particularly the effects by animal exclusion and the pack ice, and stated that the patchiness seems to spring from the lifelong habit of this species.

In the patchiness of *C. tonsus*, I have supposed a kind of density effects which would benefit on *C. tonsus* not as an individual but a population to be kept staple, since as mentioned before the aggregating or swarming phenomenon would be the subject of ethological habits in organism itself. However, the surface swarms of Galatheid shrimp, *Munida gregaria* seems to occur under some particular environments such as the depth or the front like structure of the waters (Tabeta and Kanamaru, 1970). *Pleuroncodes planipes* also swarms in the upwelling region accompanying the oxygen minimum layer (Anonymous, 1971). These facts however would possibly be a phenomena which seem as if it were the causation for aggregation or swarms, that is, a kind of pseudo-factor, and the patchiness of zooplankton would be induced purely by biological but still unknown agencies. Komaki (1967) and Kawamura (1971c) have pointed out that the development or occurrence of so-called patches by swarms would hardly be forecasted by the figures of ordinal physico-chemical environmental factors, that is, the swarming of zooplankton differs essentially from the red tides.

Mackintosh (1967) stated on the behavior of *E. superba* patches that each swarming individuals showed a synclonized swimming as if there were some leader particularly in command of the whole. Their behavior as mentioned above would be similar to " following reaction " in fish schools, which was proposed by Crook (1961). In the school of scombid fishes, the distance separating each individuals and the movements of the tail flukes are the important factors to keep the school tightly (Olst and Hunter, 1970). They (Olst and Hunter, 1970) also found that the school was specially well kept tightly when the distance between each fishes were one half of their body length. The population density in the patches of *E. superba* and *E. pacifica* show one individual per cubic inch or thereabouts (Marr, 1962; Komaki, 1967), and these facts make us suppose that the swarming in euphausiids would be similarly understood though the distance between the individuals within the patches must be more important in euphausiids than the fishes since visual sence is poorly developed in the former.

In the population of insects the density effects usually function in controlling the population size (Ito and Kiriya, 1971), but it is also known in some insect species that the density effects would be benefitial for promoting the relative growth rate by shortening the intervals between individuals, in which the density effects make each individuals shorten their larval period being induced by the promoted secretion of the moulting hormone possibly induced by tactile stimuli (Ishii, 1970). The density effects are particularly more strongly functional in the earlier stages of insect species (Chauvin, 1967). This fact indicates something analogy with the case in swarming *C. tonsus* population composed of the copepodites IV and V, and also the case in some temporal plankton species.

On the study of zooplankton patchiness, the followings are particularly hoped to be known in the future: the geographical and the vertical distributions, the seasonal change, change within short time period, population density and its structure, and the causations which trigger the behavior of swarming. In this study a small underwater plankton sampler (Motoda, 1959) was used in collecting *C. tonsus* patches, but the sampling gear seemed to be insufficient for the purpose of quantitative study since population density varied distinctly even within a patch. In this respect the continuous plankton recorder which revealed clearly the uneven distribution of plankton (Hardy, 1936a, b) must be revaluated. Wiborg (1971), on the other hand, found the population density of 4000 inds./1000 m^3 in *Th. inermis* and 5000 inds./m^3 in *Th. raschii* by towing the IKMT, and he (Wiborg, 1971) considered these high population density would be due to their patchiness. Omori (1965) and his colleagues (Omori *et al.*, 1965; Kawaguchi and Marumo, 1967; Kawaguchi, 1973) have successively used the large sized ring net of 160 cm mouth opening for collecting the micronektons, and proved that the net was considerably effective for patchily distributed organisms such as Sergestid shrimps (Omori, 1969; Omori *et al.*, 1972). These facts suggest that the larger sized towing net in its mouth opening would be more successive for collecting the fast moving or very locally swarming organisms.

SUMMARY

1. The food and feeding habits in southern sei whale, *Balaenoptera borealis* Lesson, which was caught during 1967/68 to 1971/72 seasons by the Japanese floating factories were studied. The observations were chiefly focussed on the distributions of prey organisms by species through which the formation of whaling (feeding) ground was considered biologically. One of another focusses was to figure out a comparative structural characteristics of the feeding apparatus along with the dietary habits in sei whale in connection with the patchiness of prey organisms.

2. The sei whaling ground in recent operations is found in the mid latitudes of the circumpolar seas, say, the Subantarctic waters of 40°~50°S, where more

than 70% of sei whale have been caught among all. The formation of sei whaling ground is closely related to the Subtropical Convergence, and the most important areas are the Indian and the western part of the Pacific sectors between 0° and 170°W.

3. The general hydrological conditions of the whaling ground was as follows: the favourable surface sea temperature was somewhere between 14.0°C and 18.0°C during December though it was 8.0°C∼10.0°C by some whaling areas. As season proceeds the whaling ground shifts to higher latitudes where the temperature was 14.0°∼16.0°C in January, 7.0°∼10.0°C in February and then 4.0°C∼7.0°C in March. The isotherm recede toward north with the speed of about 1.0°C/1° lat./month in the region concerned.

4. A total of 23 species or more of food organisms were found in the stomach contents of sei whale, and the following 8 species were most important components: *Calanus tonsus*, *C. simillimus*, *Clausocalanus laticeps*, *Drepanopus pectinatus*, *Parathemisto gaudichaudii*, *Euphausia vallentini*, *E. lucens*, and *E. superba*. There were 7 species of food organisms, *C. tonsus*, *Cl. laticeps*, *Thysanopoda actifrons*, *E. diomedeae*, *E. lucens*, *Penaeus* sp. and *Scomberesox saurus* which were newly known in this study as the sei whales food in the Subantarctic feeding ground though both *E. diomedeae* and *E. lucens* had been known as sei whales food in the South African waters.

5. The composition of the stomach contents was monospecific in more than 72% of the animals examined, and those of mixture with two or more species were rarely found. It was indicated from this fact that sei whale feed on the prey which had so densely swarmed as to form the patchiness. *Doliolum*, *Salpa*, pteropoda and chaetognatha distribute abundantly in the region concerned, but none of them were the important components of the stomach contents. A selective feeding habits by species and size of the prey organisms were also observed in sei whale as has been known in fin whale. The sei whale feeds preferably on crustaceans than any other kind of foodstuff, and copepods were the most important among all. *C. tonsus* of copepodite V stage was the main food species in the southern waters.

6. The distribution of the food organisms changed latitudinally: *C. tonsus*, *C. simillimus* and *Clausocalanus laticeps* were the main composition of the stomach contents throughout the zone between the Subtropical Convergence and about 47°S, although they were took over by *E. vallentini* or *P. gaudichaudii* by the sea regions, and then by *P. gaudichaudii* almost exclusively between 50°S and the Antarctic Convergence. It was only *E. superba* that occurred in the stomach in the southern most whaling ground close to the Antarctica. These geographical change in the composition of stomach contents was a phenomenon which occurred within a narrow zone of 20 degrees in latitudes.

7. In the feeding percentages in terms of the number of animals with food against those examined, 28∼59% of animals in the Indian sector had carried the stomach contents whereas it was 25∼82% in the Pacific sector, and the availability of foodstuff would be considered higher in the Pacific. The scheme above mentioned by species was also varied with the whaling areas, that is, both *C. tonsus* and *E. vallentini* were dominant in the Pacific sector, while *P. gaudichaudii* and *E. superba* were

important food in the Indian sector and in the Tasman Sea area. However, preference to the kind of foodstuff in sei whale was focussed first on copepods and, euphausiids and amphipods were secondarily important. The feeding percentage by the species and seasons revealed that there might be both copepod rich year, and euphausiid or/and amphipod rich year.

8. Sighting investigations revealed that both baleen and toothed whales seem to take food even in the tropical seas, especially where upwelling along with abundant distribution of zooplankton prevails. The region of a relatively dense distribution of whales was indicated particularly by the distribution features of salinity and phosphate.

9. The sei whaling ground agrees on the whole with the abundant distribution of their food organisms particularly of *C. tonsus* and *C. simillimus*. Apart from this however, there was a local but abundant distribution of food organisms such as *D. pectinatus* and *Cl. laticeps*, and the whaling ground formed by these foodstuff hardly be spotted since there was no effective ways left behind to know very local occurrence of the plankton patchiness by plankton net haul.

10. *C. tonsus* population is composed of copepodite stages IV, V, and adult female, but the population is represented by copepodite V since it occupied 89.7 % on average in overall compositions in individual numbers. There were two size compositions of the copepodite V, say, 3.0∼3.2 mm and 3.5∼3.6 mm by the whaling areas, and they were supposed to be the difference due to isolation by breeding stock, and also the difference in generations.

11. The feeding ability in sei whale is a function of the mandible size which grows proportionaly with the body length. However, the filtering structure in feeding mechanism is the row of baleen plates which furnished on the upper jaw with the average density of 1.4 plates/cm near the rostrum and 0.93 plates/cm at the distance of 66.4∼69.5 % posterior from the rostrum where the baleen plates attain at their maximum length. The length of the bristles furnished on the inner margin of the baleen plates varied 3∼5 cm with the averaged density of 45.5 bristles/cm regardless to sex and body legth.

12. The total area of the filtering apparatus in sei whale was 2.37 m^2 in 11.0 m long animal, and 3.59 m^2 in 14.4 m animal. None of sexual variations were observed. The area of filtering apparatus against the body length showed comparatively larger figures in sei whale than the another balanopterid whales though it was still smaller than that in balaenid whales.

13. The calculated porosity of the filtering apparatus varied between 77.2 % and 88.6 %. Comparing with the figure of 46 % in GG54 bolting silk cloth (0.33 mm mesh apertures), the netting in sei whale was considerably coarsely structured but its relative filtering ability was 1/8 of the GG 54 and 1/5 of the fin whales.

14. The number of animals which vomited the stomach contents during chasing against the total animal observed were 6/642, 1/129, and 21/125 in the order of sei, fin, and sperm whales respectively. This fact makes us confirm that the amount of stomach contents found in carcasses shows an actual figures at the moment of animals being killed.

15. By examining the fulness of stomach contents, it was known that 25∼30% of the stomach contents in volume reduces within the following 5∼6 hours supposedly by digestion. This fact leads to a consideration that the stomach of sei whale would be repleted fully once in a day.

16. The amount of stomach contents which were actually found in carcasses was 150∼200 kg, 500∼600 kg, and 30 kg in the order of sei, fin, and minke whales respectively. These amount of food however, seems to be far insufficient as the daily rations of the whales. When *C. tonsus* was fed by sei whale its amount usually found in the stomach does not exceed more than 50∼60 kg. This would be due to a poorer availability as biomass in *C. tonsus* even when they form the densely populated swarms than the case in larger sized prey organisms.

17. Feeding activity in sei whale as indicated by the feeding percentages was high in the morning, but in some case it was unchanged throughout the day. This suggests that many sei whales feed much once in a day, but they have to prey on continuously throughout the day to fill their daily rations particularly when they feed on copepod. The habits of the diel vertical migration in prey organisms also affect on the whale's feeding activity.

18. After the formulations by Sergeant (1969), the theoretical daily rations in 3 species of the baleen whales were calculated as 4.4%, 4.07%, and 3.84% of body weight in the order of sei, fin, and minke whales respectively.

19. The population density in *C. tonsus* patches was assessed being based on the filtering ability, feeding habits, and the amount to stomach contents; and found that *C. tonsus* swarms into patches with the population density of $10^3 \sim 10^4$ inds/m^3. In these calculation it was also indicated that the sei whale can collect the foodstuff more effectively by employing skimming type feeding than the case by swallowing type.

20. A total of 220 patches of *C. tonsus* was investigated, and the following evidences were found: 1) the patches showed spindle-, oval-, and stripe- or stream-shape, of which the former two occurred most frequently, 2) the size was usually somewhere between hundred and several hundreds meters in their longer axis though sometimes it was several miles long in stream-shaped patches, 3) the patch is maintained tightly for long period through rough weather, and each patches are so completely isolated as to keep the overall biological characters as aggregated populations, 4) the patches occurred most frequently along the Subtropical Convergence where the sea temperature was 13.0°∼14.0°C, 5) copepodite V of *C. tonsus* population forms the main body of the patches with slight numbers of adult female, 6) the observed population density in collected samples varied between 330 inds./m^3 and 2.4×10^4 inds./m^3 ($=3 \times 10^4$ mg/m^3). These figures agreed with those assessed theoretically, 7) possible causations of swarming behavior would be the density effects which supposedly benefits to growing larger the population as a functions of stimulation by physical contact of one to another, and then, 8) the formation of patchiness would hardly be explained by the hydrodynamical forces because what makes the organisms swarm or aggregate so densely would be, after Cassie (1960), a internal behavior patterns between individuals of the

same species through a social habits, that is, the subject of organisms themselves.

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Note: References written in Japanese are idicated by parentheses.

APPENDIX. AMOUNT OF FOOD FOUND IN THE FIRST STOMACH OF FIN, SEI AND MINKE WHALES CAUGHT IN THE SOUTHERN OCEAN.

No.	Species of whale	Sex	Body length (m)	Kind of stomach contents	Date of catch	Time of catch (SMT)	Net weight of food (kg)	Water (kg)	Total weight of stomach contents (kg)	Total volume (l)
1	sei	M	14.4	*Calanus*	28/XII/67	1115	54.0	14.0	68.0	66[1)]
2	sei	M	14.1	Amphipoda	6/I/68	0600	136.5	18.1	154.6	171[2)]
3	sei	M	14.2	Amphipoda	15/I/68	0800	73.5	14.5	88.0	109[3)]
4	sei	M	14.6	Amphipoda	30/XII/67	1105	98.0	30.0	128.0	156[1)]
5	sei	M	15.2	Amphipoda	7/I/68	0925	200.0	28.0	228.0	312
6	sei	M	15.1	Amphipoda	15/I/68	1455	57.6	13.8	71.4	93.6
7	sei	M	14.7	Eu-L	21/II/68	1050	142.0	0.0	142.0	200
8	sei	M	15.1	Eu-S	13/I/68	1345	149.6	28.6	178.2	220[4)]
9	sei	F	13.0	Eu-L	23/II/68	0830	149.0	33.0	182.0	200
10	sei	F	13.2	Eu-S	12/I/68	1940	135.6	24.4	160.0	204[4)]
11	sei	F	14.3	Eu-L	22/II/68	0925	128.7	12.6	141.3	180[5)]
12	sei	F	14.7	Eu-S	12/I/68	1745	79.1	15.4	94.5	119
13	sei	F	15.6	Eu-L	23/II/68	0540	148.0	4.0	152.0	200
14	sei	F	16.2	Eu-L,M,S	18/I/68	0855	159.0	37.5	196.5	255
15	fin	M	18.6	Eu-L	21/I/68	1015	273.7	27.6	301.3	391[5)]
16	fin	M	21.0	Eu-L	2/III/68	0820	785.0	100.0	885.0	1000
17	fin	F	20.2	Eu-L	21/II/68	0550	556.5	10.5	567.0	700
18	fin	M	21.1	Eu-L	20/II/68	0640	286.0	28.0	314.0	400[5)]
19	fin	F	22.1	Eu-L	21/I/68	1115	127.4	5.6	133.0	238
20	minke	F	8.0	Eu-L	21/I/68	1805	22.4	4.0	26.4	31.2

Calanus: *Calanus tonsus*, Amphipoda: *Parathemisto gaudichaudii*, Eu-L or -M: *Euphausia supera*, Eu-S: *Euphausia vallentini*.

1) Approximate values, 2) Estimated by the stomach volume averaged on 13 whales, 3) Calculated by the mean weight of a unit volume of amphipod food from four animals, 4) Calculated by the mean weight of a unit volume of small-sized euphausiids taken by #12 animal, and 5) Calculated by the mean weight of a unit volume of large-sized euphausiids taken by six fin whales and one minke whale.

EXPLANATION OF PLATES.

PLATE I

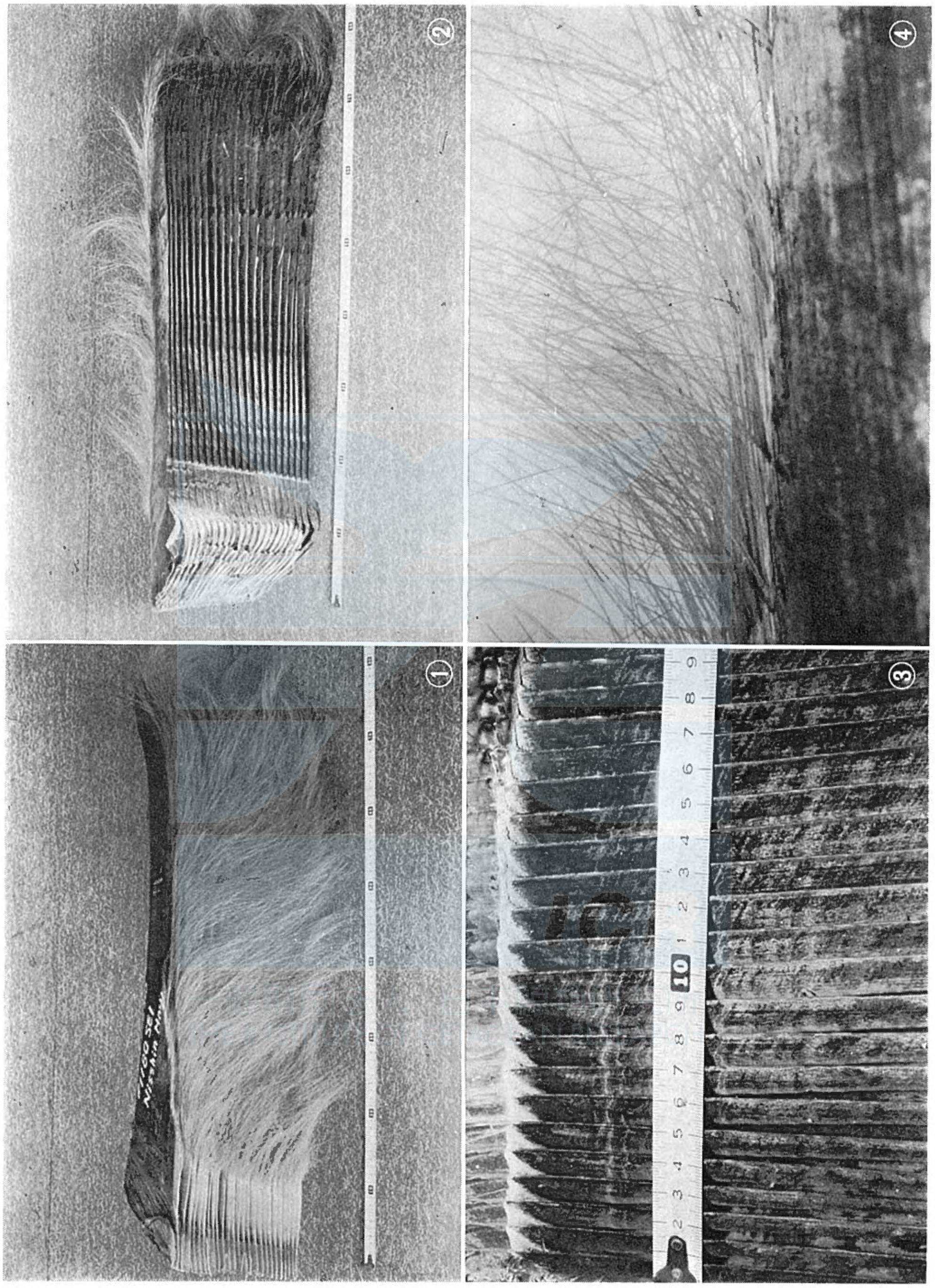
Fig. 1. Inside view of a row of baleen plates in sei whale, female, 14.3 m.
Fig. 2. Same as Fig. 1, but viewed from outside.
Fig. 3. Enlarged view of a row of baleen plates showing the intervals of the plates neibouring with each other.
Fig. 4. Bristles furnished along the inner margin of baleen plate.

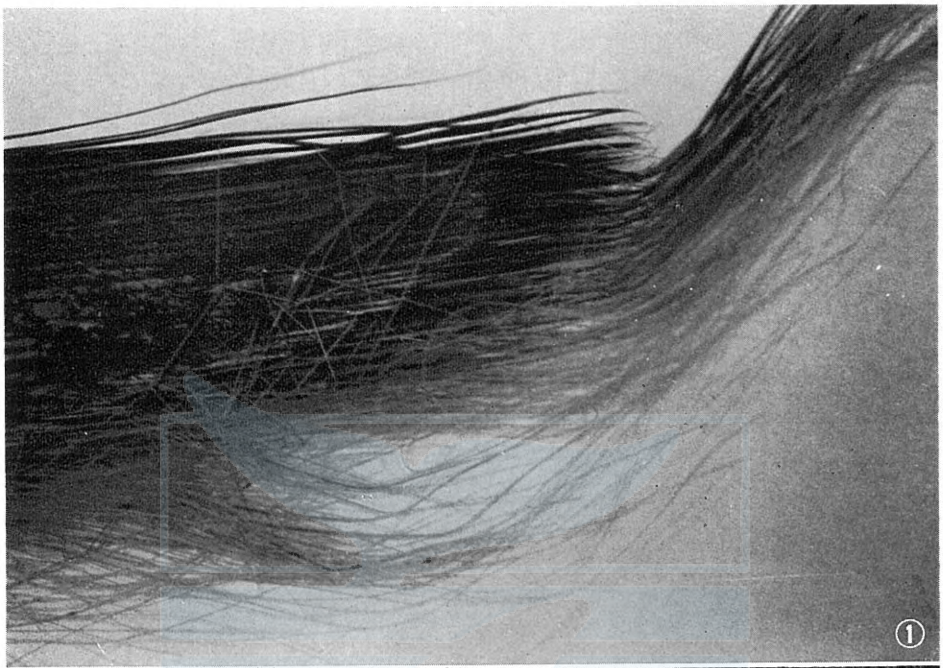
PLATE II

Fig. 1. Bristles at the tip of baleen plate.
Fig. 2. Enlarged view of the filtering meshes formed by the baleen bristles.

PLATE III

Fig. 1. An apparatus for measuring the filtering ability of a row of baleen plates of the sei whale shown in PLATE I.
Fig. 2. Same as Fig. 1, but small fraction of a row of baleen plates is attached on the apparatus.
Fig. 3. Frontal view of the apparatus. Bridles and a flow-meter mounted on the apparatus are shown.
Fig. 4. Flow-meter and the baleen plates attached on the bottom of the apparatus are shown.

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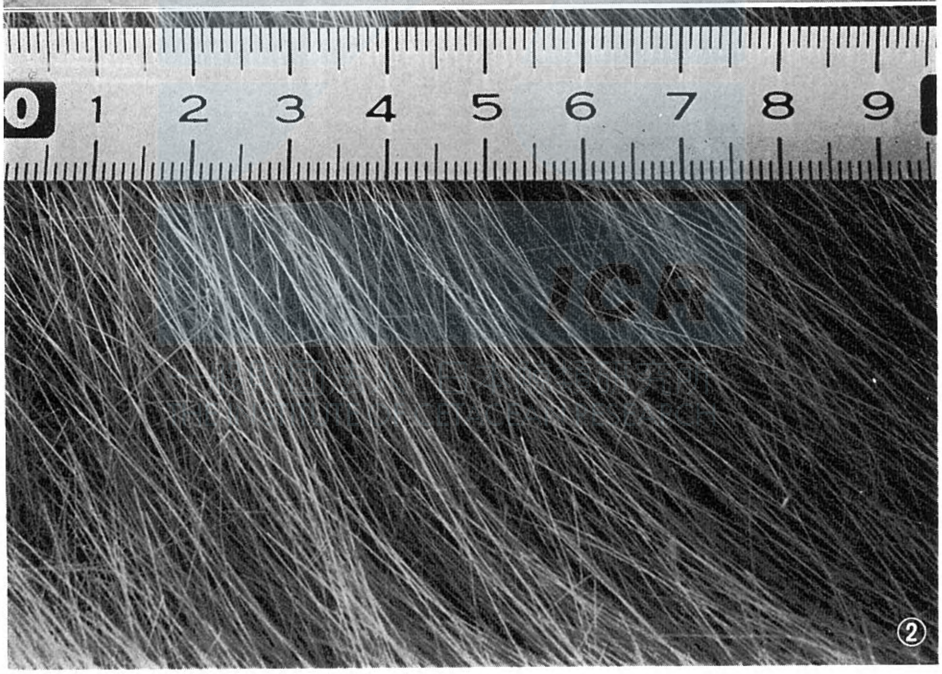
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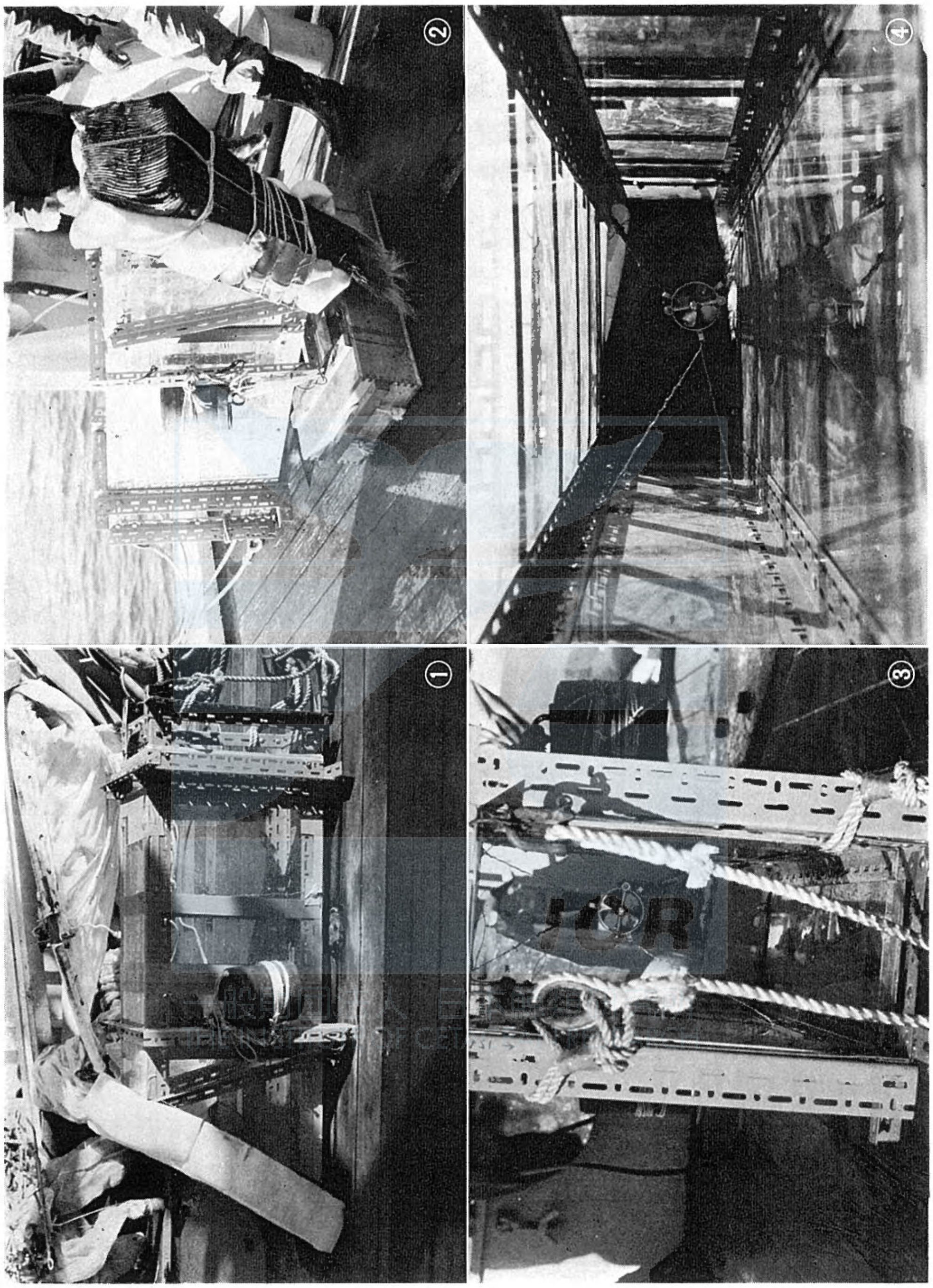
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