INTRODUCTION INTO AYSEN CHILE OF PACIFIC SALMON

No. 14

Seasonal Distributions of Zooplankton in Aysen Fiord and Adjacent Waters, Southern Chile

By

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and

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"INTRODUCTION INTO AYSEN CHILE OF PACIFIC SALMON"

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ABSTRACT

Seasonal changes in biomass and species composition of zooplankton in the waters of Aisén Fiord were examined on the materials collected with a Norpac and MTD nets during the period from 1980 to 1983.

Peaks in zooplankton biomass progressed from the head of the fiord (Ensenada Baja) toward the channel during spring to summer when the released juvenile salmon perform off-shore migration. The highest biomass was reached in the upper layer of the channel basin during summer. Copepoda was the most important group of zooplankton for maintaining high zooplankton biomass in both the fiord and channel, being accompanied with the following groups; cladocerans, barnacle nauplii and cyphonautes larvae in the fiord during spring to summer, and euphausiid eggs, siphonophores and appendicularians in the channel in summer.

The rapid seasonal increase in abundance of *Calanus chilensis* (Copepoda: Calanoida) appeared to be associated with their aggregations which probably result from the water movements acting on stocks during their reproduction periods.

INTRODUCTION

This zooplankton investigation in Aisén Fiord and adjacent waters was undertaken by the Japan International Cooperation Agency (JICA) and the Servicio Nacional de Pesca (SERNAP) from 1980 to 1983, as a part of the project for the introduction of Pacific salmon (*Oncorhynchus keta*) into the Patagonian region, southern Chile. No papers, dealing with seasonal changes in zooplankton of this region, have been published. Recently, Clasing and Chaparro (1983) and Hirakawa (1983, 1984) preliminarily reported the seasonal changes in abundance and species composition of zooplankton in this waters. These informations help fix the period for the release of the juvenile salmon on their feeding conditions, and evaluate if this fiord serves as a migration route for the salmon.

This report synthetically deals with the seasonal distribution of zooplankton and also discusses the relationship between the distributional patterns of zooplankton and hydrographic conditions.

SAMPLING STATIONS AND METHODS

Aisen Fiord (Fig. 1)

Zooplankton were collected at monthly intervals by vertical tows from near the bottom to the surface with a Norpac net (mouth diameter 45 cm, mesh openings 0.33 mm, length in filtering portion 180 cm) at St. A in Ensenada Baja from June 1980 to December 1983 and at St. B in the estuary of Aisén River from May 1980 to December 1981. Samplings at each station from St. 1 to St. 6 in the basin were made once a season by vertical tows from 50 m depth to the surface with the same net from November 1980 to January 1983 (Table 1). In addition to the vertical tows, horizontal tows were simultaneously made with two MTD closing nets (mouth diameter 56 cm, mesh openings 0.33 mm, length in filtering portion 170 cm) for 10 minutes to investigate zooplankton vertical distribution in the upper layer (0 m to 15 m depth) at Sts. 1, 3 and 6 (Hirakawa, 1984).

Moraleda Channel (Fig. 1)

Samples were obtained at monthly intervals at St. C near Pto. Aguirre from April 1980 to October 1982 and once a season at each station from St. 7 to St. 16 (except St. 9) in the basin from November 1980 to January 1983 (Table 1). Vertical tows were made with a Norpac net from near the bottom at St. C and from 50 m depth at the other stations to the surface.

Archipelago region (Fig. 2)

During the cruise of the R/V "Itzumi" in March 1982, zooplankton were collected by vertical tows from 200 m depth (in the bottom depth more than 200 m) or near the bottom (in the bottom depth less than 200 m) to the surface with a Norpac net at nine stations (Vargas, 1983).

All materials were immediately preserved with about 10% formalin sea water on the boards.

RESULTS

Seasonal change in total number of zooplankton at St. A was found to be very similar to those in wet weight and setting volume, their peaks being recorded twice a year; the first in April-May and the second in September-November (Fig. 3). However, the autumn peak in 1983 was not so remarkable as in the other years. Seasonal increases in abundance of zooplankton, in terms of both number individuals and setting volume at Sts. B and C were observed during the period from late winter to summer (Figs. 4 and 5). The abundance during this period was not subject to heavy fluctuations with the rapid increase and decrease found at St. A.

In the upper 50 m depth in the fiord and channel basin, the average zooplankton wet weight for seasons showed the highest value in spring in the fiord (Table 2), but it in summer in the channel (Table 3). In summer, there was the greatest extremes of total number of zooplankton between stations in each basin (Tables 2 and 3). High biomass in the fiord appeared to be built up by the zooplankton and especially by copepods with their major habitats in the below 0 m (Hirakawa, 1984).

In the Archipelago region, total number of individuals and wet weight in zooplankton at Sts. G1, S1 and T2 were higher than the averages for all stations (Fig. 6). This average biomass (264 g. wet wt./10^3 m^3) was higher than those in the western and central Bering Sea (Minoda, 1977) and off the southern coast of Hokkaido (Furuhashi, 1980) in autumn. Therefore, it is estimated that the highest zooplankton biomass in this region was not quantitatively less than in the Bering Sea and northern North Pacific during the high productivity period from spring to early summer.

Of the zooplankton groups listed in Table 4, Copepoda has the maximum number of species, at least 27 species being identified. In these copepod species, the North Pacific coastal calanoid *Centropages abdominalis* Sato (Plates I and II) and the Indo-West Pacific coastal cyclopoid, which is identical with either *Oithona aruensis* **Früchtl** or *O. davisae* **Ferrari** and **Orsi** (S. Nishida, personal communication), were discovered for the first time from Aisén Fiord (Ensenada Baja). The former is new record for the South Pacific and the later for Chilean waters. K. Hirakawa of the present authors will report the detailed morphological descriptions of both species and discuss the history for their occurrences on the following paper. For example, they are presumably being introduced by ships releasing ballast and dilge water, or in the case of fishing boats, water used to maintain live bait (A. Fleminger, personal communication).

Copepods and non-pelagic invertebrate larvae (mostly Balanidae nauplii) occupied high relative abundance during the periods of the seasonal increases of zooplankton at St. A (Fig. 7), St. B (Fig. 8) and St. C (Fig. 9). Additionally, Cladocera and Appendicularia also were major constituents of zooplankton; the former in spring at St. A and the later in late winter and early summer at St. C.

The most abundant group in the upper layer of the fiord and channel basin and the Archipelago region was copepods, accounting for 57.7 - 87.5% of the total number of zooplankton at each season (Table 5). Euphausiid eggs occurred more predominantly next to copepods in summer of the channel, and took the place of the non-pelagic invertebrate larvae as well as Appendicularia-Hydromedusae in the Archipelago region (Table 5). Copepods were abundantly distributed at 10-15 m depth, while non-pelagic invertebrate larvae at the surface in the upper layer of the fiord (Hirakawa, 1984).

Of the five major zooplankters at St. A (Fig. 10), *Paracalanus parvus* occurred more abunantly in spring and autumn in 1981 and 1982. The remains showed the more remarkable annual fluctuations in the seasonal abundance than *P. parvus* and reached their maximum densities for the whole study period in the seasons as mentioned below; *Acartia tonsa* in autumn, *Calanus chilensis* and *Podon leuckarti* in spring or autumn. *Calanus chilensis* restricted its seasonal increase to spring every year. It was indicated that the spring dominance of this species in 1981 appears to be largely associated with the inflow of the high salinity water from the outside bay during its reproduction period (Hirakawa et al., 1983). These four major zooplankters except *C. chilensis* were important to sustain the high zooplankton biomass from spring to summer at St. B, being based on their seasonal increases shown in Fig. 11; *P. parvus* from September to December, *A. tonsa* in February, *P. leuckarti* in October and Balanidae larvae in August. However, *A. tonsa* and *P. leuckarti,* which are representatives in the littoral zone of the fiord, diminished considerably at St. C, and were replaced with the other dominants, *Centropages brachiatus, Drepanopus forcipatus, Oikopleura* spp., Siphonophorae and Cyphonautes larvae. From the seasonal changes in the major zooplankters at St. C (Fig. 12), *P. parvus* and Siphonophorae were more abundant in summer, and *C. brachiatus* and *D. forcipatus* in spring and summer. Although the spring increase of *C. chilensis,* as was found at St. A, was not induced, this species occurred consistently during the long period from summer to autumn. *Oikopleura* spp. occurred more abundantly in late winter and summer, while Balanidae nauplii and Cyphonautes larvae dominated from late winter to early spring. Balanidae nauplii increased explosively in September 1980. *Oikopleura* spp. were the most important foods along with copepods for young Pacific salmon (*Oncorhynchus gorbuscha* and *O. keta*) in the coastal waters of northern British Columbia, Canadá (Manzer, 1969).

In the upper layer of the fiord basin, *P. leuckarti* was not a dominant species but *Calanoides patagoniensis, Drepanopus forcipatus, Metridia lucens* and Cyphonautes larvae newly added to the major zooplankton composition of Sts. A and B. Peaks in abundance of the major zooplankters were developed firstly in spring by *Calanus* copepodids (*C. chilensis* and *C. patagoniensis*) and Balanidae nauplii, and progressed toward autumn on the seasonal succession caused by the summer dominants (*A. tonsa* and Cyphonautes larvae) and the summer-autumn dominant (*P. parvus*) (Fig. 13). The time lag between the seasonal peaks of these zooplankters contributes to maintaining high zooplankton biomass from spring to summer in this basin. Balanidae nauplii, which were prevalent from the fiord waters to St. C, were not predominantly distributed in the upper layer of the channel basin, but were replaced with euphausiid eggs which occurred overwhelmingly at St. 10 in January 1983 (1429 individs./m^3). Most of the major zooplankters of the channel basin shown in Fig. 14 were simultaneously more abundant in summer and therefore had a pattern of the seasonal occurrence which was different form that in the fiord basin.

Of the five major zooplankters dominated from 45°S to 47°S in the Archipelago region, *C. chilensis* (Fig. 15), *P. parvus* (Fig. 16), *Oikopleura* spp. (Fig. 18) and Siphonophorae (Fig. 19) were more abundantly distributed along the shore waters.

DISCUSSION

From the seasonal increase of zooplankton biomass from spring to summer in the fiord, the juvenile salmon may be successfully encountered with the continually rich food preys during off-shore migration, even if the release period in Ensenada Baja was not fixed in a certain month between September and November. Seasonal peaks in biomass shifted westward from Ensenada Baja to Moraleda Channel during warm seasons. In summer, the average zoooplankton biomass in the channel basin was seven times higher than in the fiord basin. The feeding condition of the salmon in the channel, therefore, was found to be more suitable for their growth on the quantity of prey captured. Considering also the regional distribution of zooplankton in the Archipelago region, the seasonal distribution of zooplankton biomass in Aisén Fiord and its environs appears to provide the feeding condition adjusted to the growth of individuals of the released salmon (Fig. 20).

Foskett (1951) mentioned that the juvenile salmon in shore waters changed gradualy their food animals from small to larger kinds with their growth. According to Okada and Taniguchi (1971), the juvenile salmon rapidly changed the largest preys eaten by them from a small-sized group (micro-copepods, young *Parathemisto* spp., decapod larvae, insects) to a large-sized group (adults of euphausiids and *Parathemisto japonica*), growing up to about 55 mm in fork lenght. Most of the major zooplankters throughout the waters investigated from the fiord to the Archipelago region consisted of the small - and medium-sized forms (body length, approx. 0.5 - 3.0 mm). However, the summer dominance of euphausiid eggs in the channel basin suggests that their adults are responsible for supplementing the shortage of the large-sized prey animals in this waters.

Many of the fiords have large rivers discharging into them, usually at the head, and all have some fresh-water inflow. They are estuaries according to the definition of Cameron and Pritchard (1963) and an "estuarine circulation" is presumed to occur. Koyama (1983) reported that the surface layer in the Aisén Fiord basin was mainly covered with the lower saline water (ca. 3-20°/oo) on the fresh-water inflow from Aisén River, showing more marked vertical gradients in salinity. Halocline was established remarkably between the surface and 10 m depth throughout the year. All the surface area from the head to the mouth of the fiord (ca. 60 km) changed seasonally into brakish-water area, i.e., estuary. Consequently, it is assumed that the fresh-water from Aisen River (runoff) flows seaward in the surface layer, entraining salt-water from below and carrying it out the fiord. On a more local scale, Wiborg and Bjrke (1968) have found aggregations of *Calanus*, particularly at the head of fiords or in narrow sounds, which appear to be the result of water movements acting on stocks with preferred vertical distributions.

As suggested from many studies cited by Lasker and Zweifel (1978), zooplankton patchiness, which results in relatively high concentrations of larval anchovy food, is a major factor in the survival of clupeid larvae, although high concentrations alone cannot be the sole criterion for survival.

we must, in future, attempt to clarify the distribution patterns of the large-sized zooplankton by modified sampling methods and investigate their influence on the abundance of the juvenile salmon by feeding experiments.

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Table 1. Data on sampling of zooplankton in Aisén Fiord and Moraleda Channel during the period from November 1980 to January 1983.

			1980		1981											1982											1983	
Area	St. No.	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J
Fiord	1	+																							+			+
	2	+			+			+		+		+																
	3	+																	+			+			+			+
	4	+			+			+		+		+																
	5											+													+			+
	6	+			+					+			+						+			+			+			+
Channel	7	+			+																							
	8	+			+					+			+															
	10	+			+			+		+									+			+			+			+
	11	+																										
	12		+					+																				
	13		+		+			+		+			+															
	14							+		+									+			+			+			+
	15		+																									
	16		+		+			+		+			+															

Table 2. Seasonal averages in total number and wet weight of zooplankton in Aisén Fiord.

Season	Date	No. of station	Total No. / m^3 (Range)	No. of station	g. wet wt./10^3 m^3 (Range)
Spring	Nov. 1980 Sep. and Oct. 1981 Oct. 1982	12	591 (220 - 933)	3	59.0 (16.0 - 118.5)
Summer	Feb. 1981 Jan. 1983	7	766 (113 - 2169)	3	47.4 (19.8 - 73.4)
Autumn	May. 1981 Apr. 1982	4	483 (239 - 1010)	2	33.7 (17.0 - 50.4)
Winter	Jul. 1981 Jul. 1982	5	73 (12 - 200)	2	<1.0

Table 3. Seasonal averages in total number and wet weight of zooplankton in Moraleda Channel.

Season	Date	No. of station	Total No. / m^3 (Range)	No. of station	g wet wt./10^3 m^3 (Range)
Spring	Nov. 1980 Oct. 1981 Oct. 1982	9	418 (220 - 591)	2	113.1 (78.1 - 148.1)
Summer	Dec. 1980 Feb. 1981 Jan. 1983	10	1222 (236 - 3232)	2	345.2 (61.8 - 628.5)
Autumn	May 1981 Apr. 1982	7	298 (89-680)	2	71.7 (16.0 - 127.3)
Winter	Jul. 1981 Jul. 1982	7	116 (28 - 245)	2	ca. 20.0 ($<$ 1-40.0)

Table 4. List of zooplankters found from the samples collected with a Norpac and MTD nets in Aisén Fiord and Moraleda Channel.

COELENTERATA	
Hydroida	
Siphonophorae	
CTENOPHORA	
NEMATODA	
ANNELIDA	Polychaeta larva
ECTOPROCTA (BRYOZOA)	Cyphonautes larva
CHAETO GNATHA	
Sagittoidea	*Sagitta* spp.
ARTHOROPODA	
Crustacea	
Branchiopoda	
Cladocera	*Podon leuckarti*
	Evandne nordmanni
Ostracoda	*Conchoecia* spp.
	Halocypridina sp.
Copepoda	*Calanus chilensis*
	Calanus tenuicornis
	Calanus minor
	Calanoides patagoniensis (= *Calanus patagoniensis*)
	Rhincalanus nasutus
	Paracalanus parvus
	Clausocalanus arcuicornis
	Clausocalanus brevipes
	Drepanopus forcipatus
	Calocalanus styliremis
	Euchaeta sp.
	Aetideus armatus
	Centropages abdominalis
	Centropages brachiatus
	Boeckella titicacae
	Boeckella sp.
	Metridia lucens
	Candacia cheirura
	Acartia tonsa
	unidentified calanoids
	Oithona similis
	? *Oithona aruensis*
	Oithona atlantica
	Oncaea media
	Oncaea venusta
	Corycaeus affinis
	unidentified cyclopoids
	Microsetella norvegica
	Monstrilla sp.
	unidentified harpacticoids
Cirripedia	Balanidae nauplius
	Balanidae cypris
Malacostraca	
Euphausiacea	egg, nauplius, calyptopis and furcilia larvae
Amphipoda	
Hyperiidea	
Gammaridea	
Decapoda	
Macrura	Sergestidae larvae
	unidentified mysis larva
Anomura	unidentified zoea larva
Brachyura	unidentified zoea larva
Isopoda	
Stomatopoda	alima larva
MOLLUSCA	
Gastropoda	
Pelecypoda	umbo larva
ECHINODERMATA	pluteus larva
PROTOCHORDATA	
Appendicularia	*Oikopleura dioica*
	Oikopleura sp.
	Fritillaria sp.
PISCES	egg and larva

Table 5. Seasonal averages in relative abundance of individual numbers over the nine zooplankton groups in Aisén Fiord, Moraleda Channel and the Archipelago region.

Area	Zooplankton	Spring	Summer	Autumn	Winter
Fiord					
	Copepoda	70.1	57.7	79.5	66.7
	Non-pelagic invertebrate larvae	19.6	21.8	15.4	26.8
	Cladocera	4.8	5.8	+	0
	Decapoda larvae	2.4	+	+	0
	Euphausiacea egg and larvae	+	1.5	1.9	0
	Hydromedusae	+	4.9	+	+
	Appendicularia	+	3.5	+	+
	Fish egg and larvae	1.3	+	+	+
	Others	+	3.2	1.6	5.6
Channel					
	Copepoda	73.3	59.3	74.8	87.5
	Non-pelagic invertebrate larvae	11.5	6.1	19.5	6.5
	Cladocera	+	+	0	0
	Decapoda larvae	5.5	1.4	+	+
	Euphausiacea egg and larvae	1.9	15.9	+	+
	Hydromedusae	4.0	10.1	4.0	+
	Appendicularia	1.3	+	+	+
	Fish egg and larvae	2.1	5.5	0	+
	Others	+	+	1.2	4.3
Archipelago region					
	Copepoda		NO DATA	78.1	NO DATA
	Non-pelagic invertebrate larvae			1.9	
	Cladocera			0	
	Decapoda larvae			+	
	Euphausiacea egg and larvae			3.4	
	Hydromedusae			6.8	
	Appendicularia			7.9	
	Fish egg and larvae			+	
	Others			1.5	

+ ; less than 1%

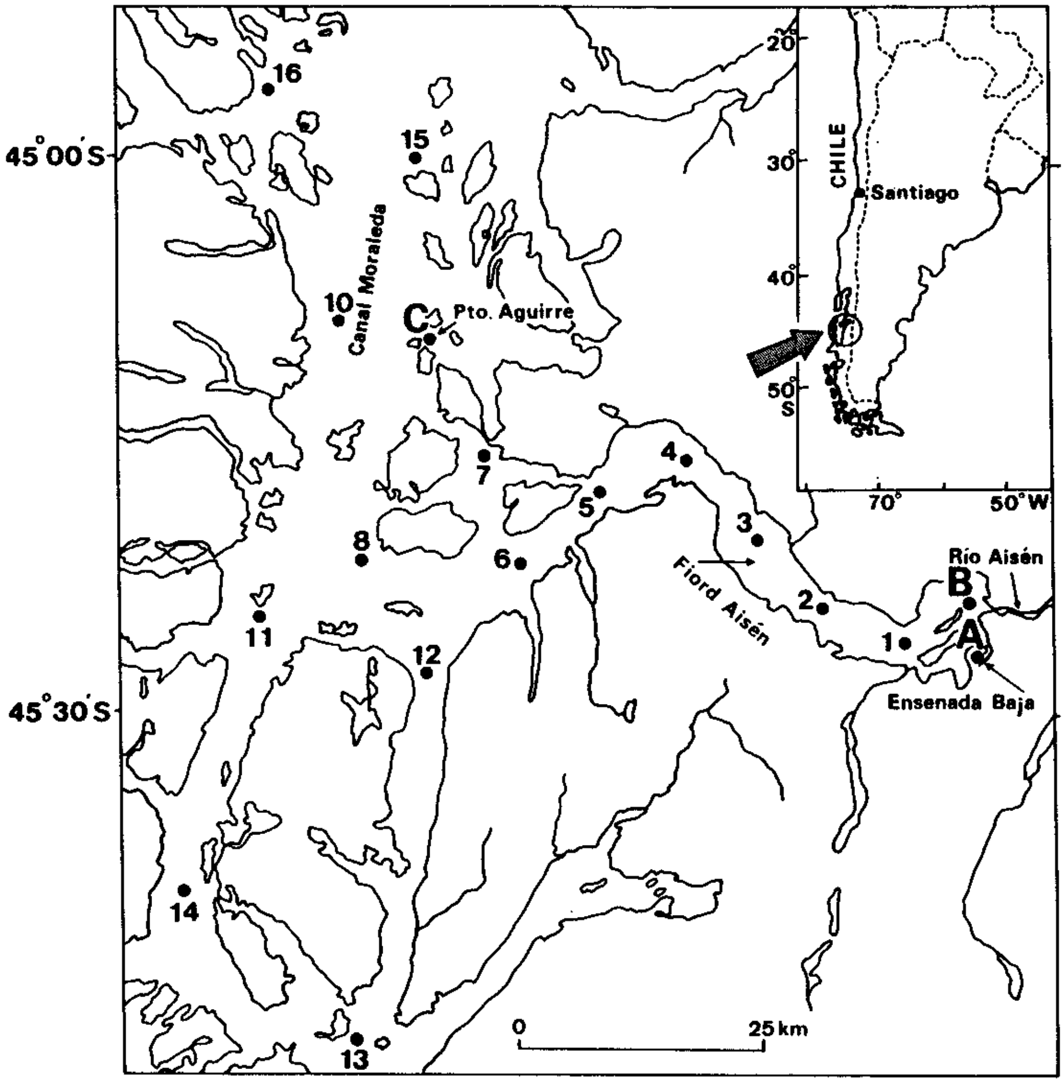


Fig. 1. Location of sampling stations occupied in Aisén Fiord and Moraleda Channel, southern Chile.

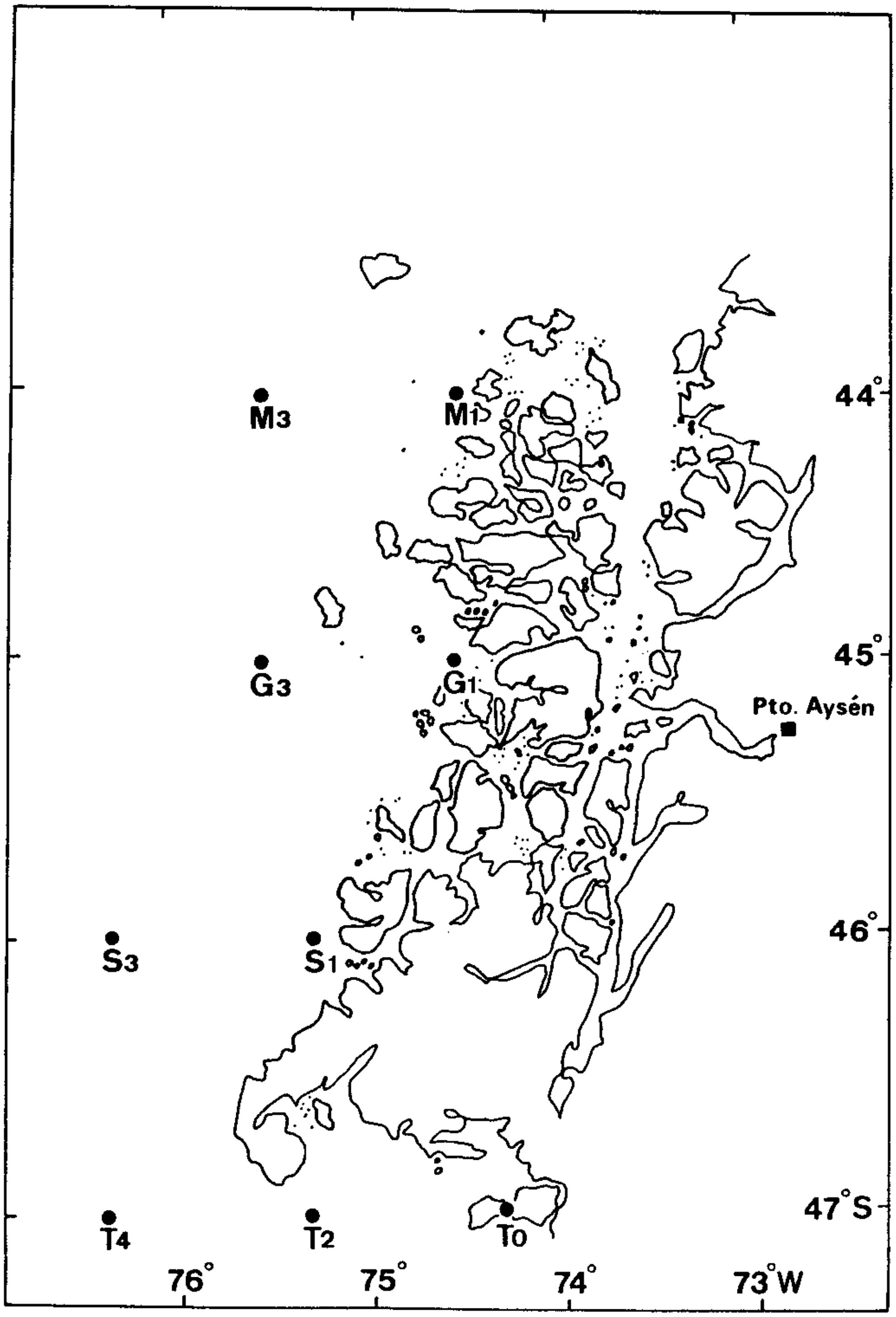


Fig. 2. Location of sampling stations occupied in the Archipelago region in March 1982.

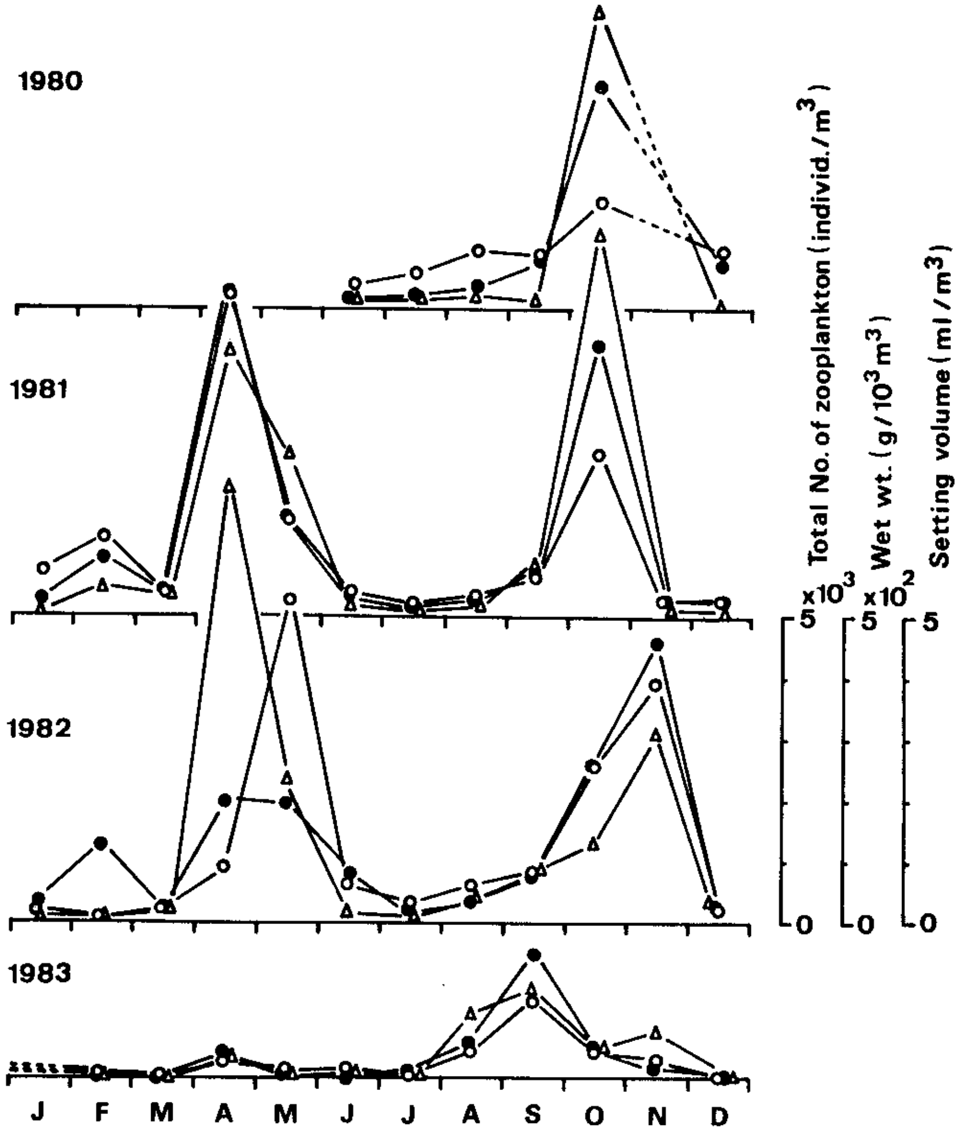


Fig. 3. Seasonal changes in wet weight (solid circle), setting volume (open circle) and total number (open triangle) of zooplankton at St. A during the period from June 1980 to December 1983. Broken line denotes 'No Data'.

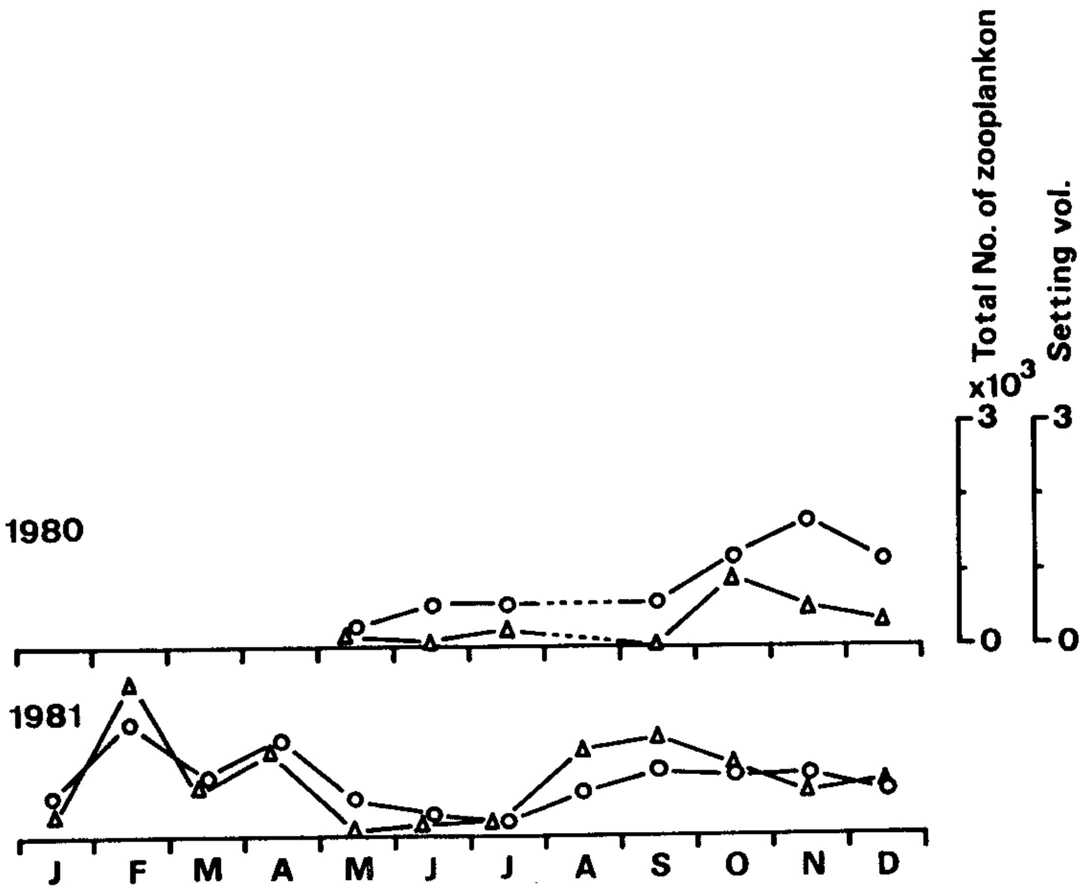


Fig. 4. Seasonal changes in setting volume (open circle) and total number (open triangle) of zooplankton at St. B during the period from May 1980 to December 1981. Broken line denotes 'No Data'. Units as in Fig. 3.

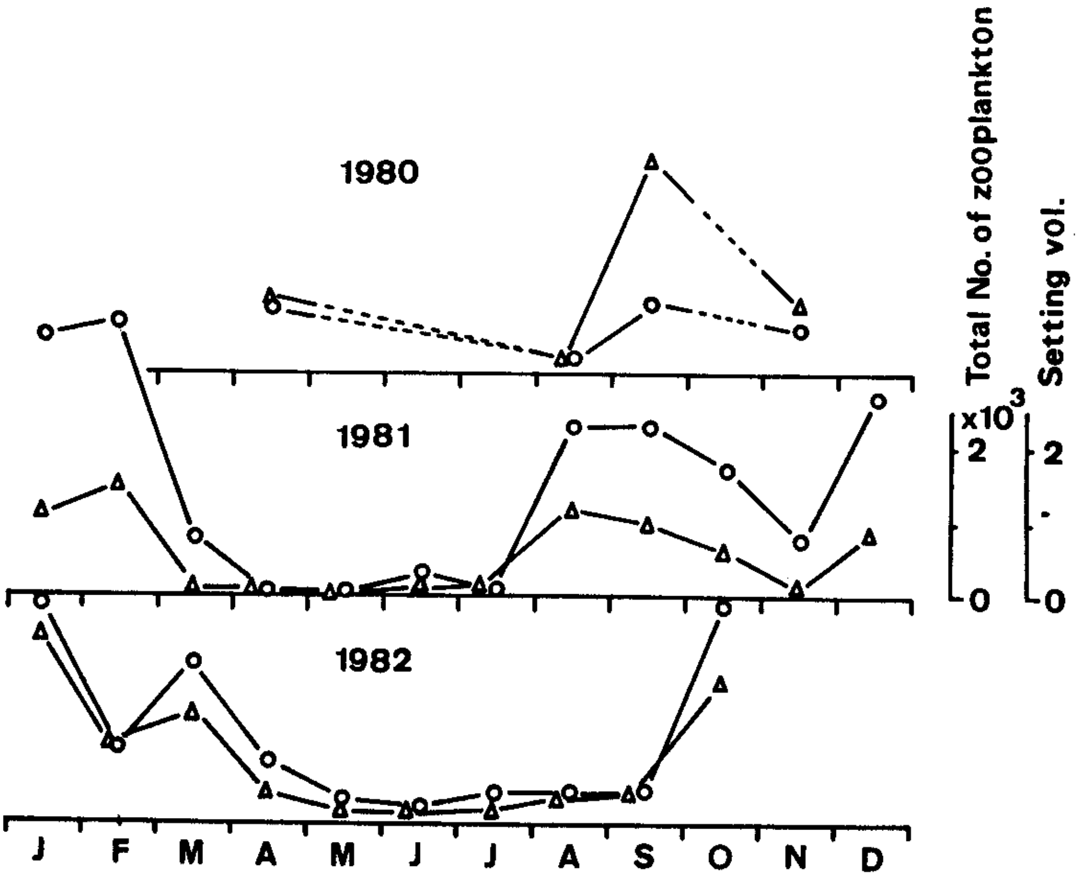


Fig. 5. Seasonal changes in setting volume (open circle) and total number (open triangle) of zooplankton at St. C during the period from April 1980 to October 1982. Broken line denotes 'No Data'. Units as in Fig. 3.

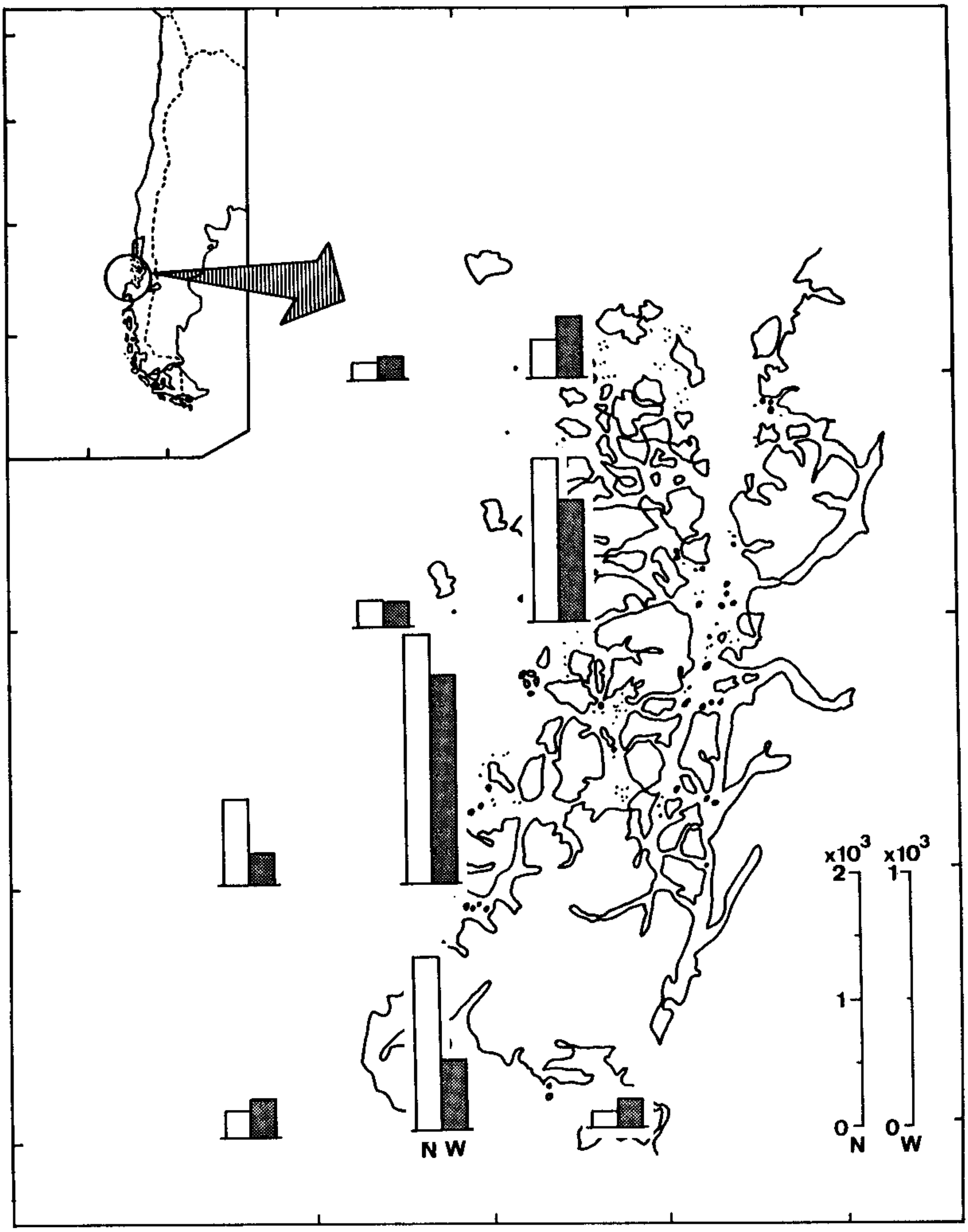


Fig. 6. Distribution in total number (N) and wet weight (W) of zooplankton in the Archipelago region in March 1982.

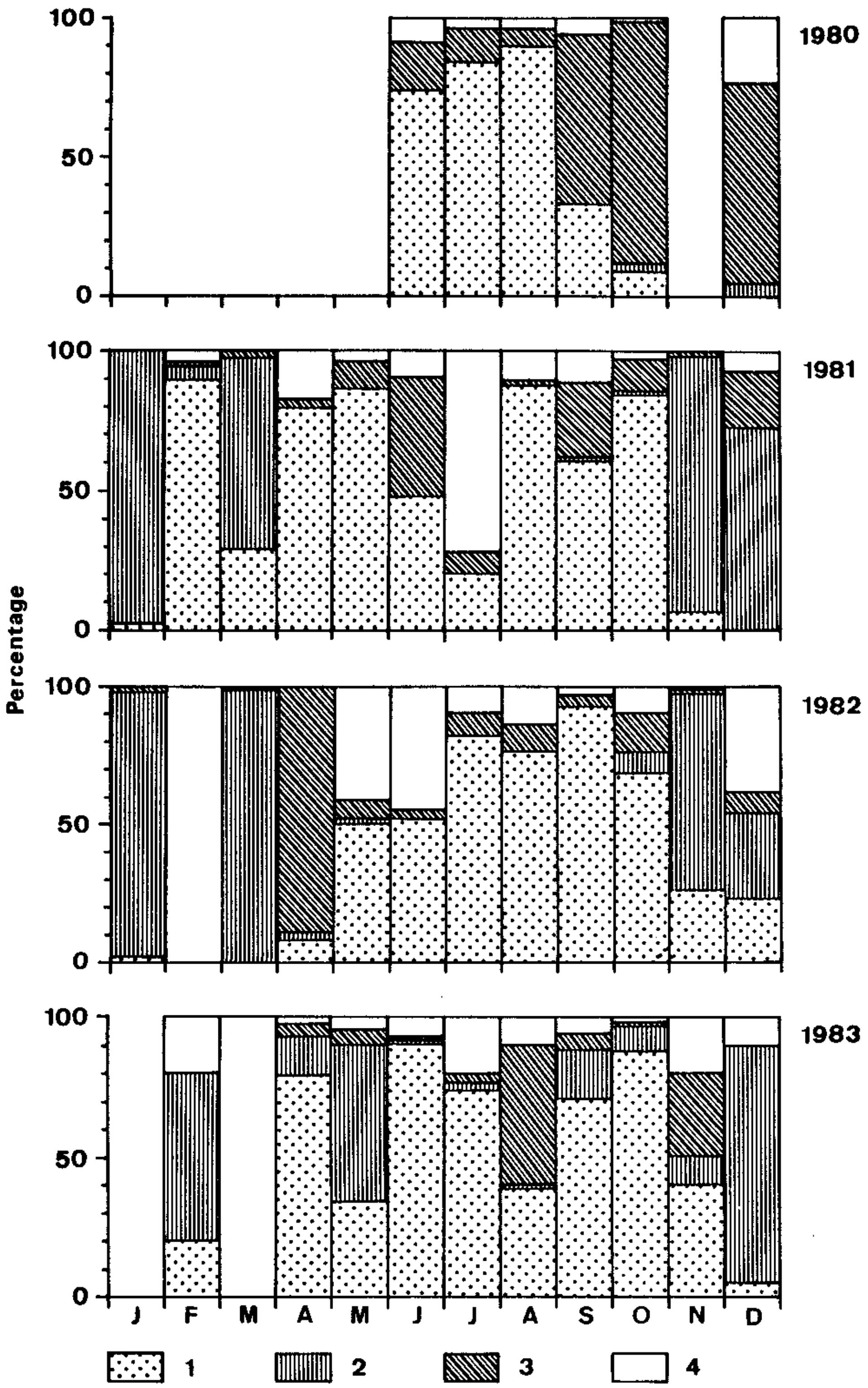


Fig. 7. Seasonal change in relative abundance of individual numbers over the four zooplankton groups at St. A during the period from June 1980 to December 1983. 1. Copepoda, 2. Cladocera, 3. Non-pelagic invertebrate larvae, 4. Others.

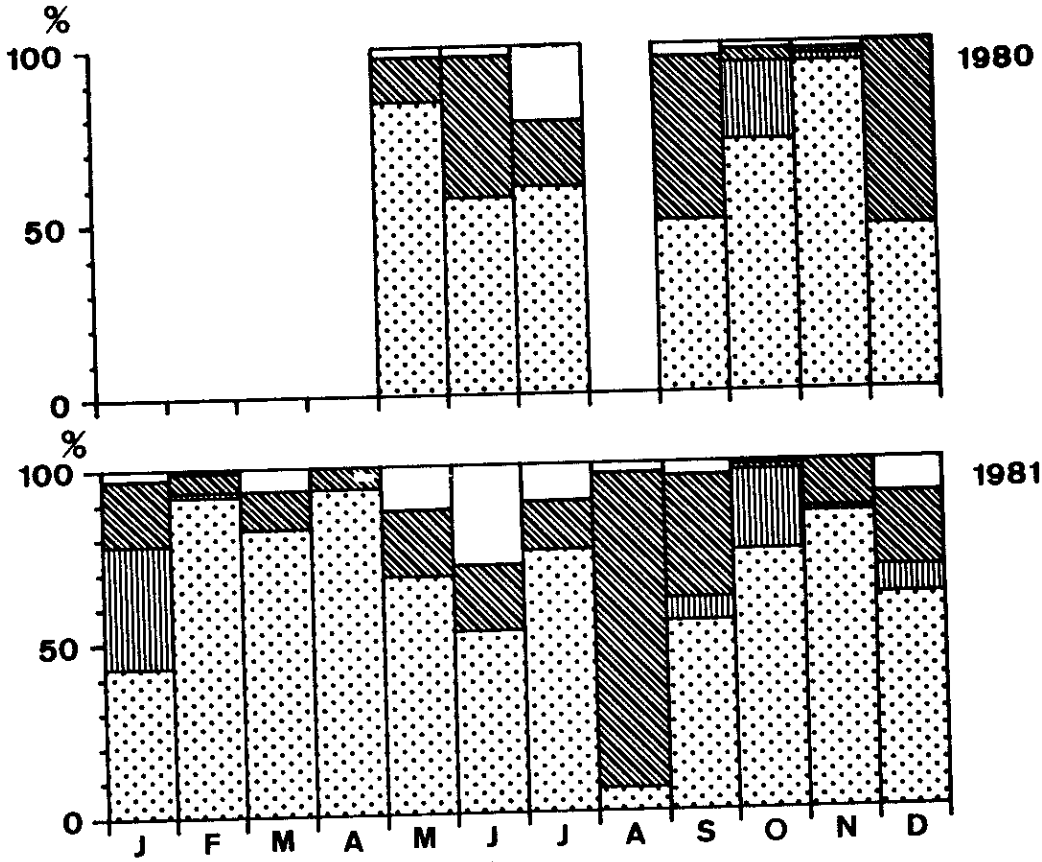


Fig. 8. Seasonal change in relative abundance of individual numbers over the four zooplankton groups at St. B during the period from May 1980 to December 1981. Designs as in Fig. 7.

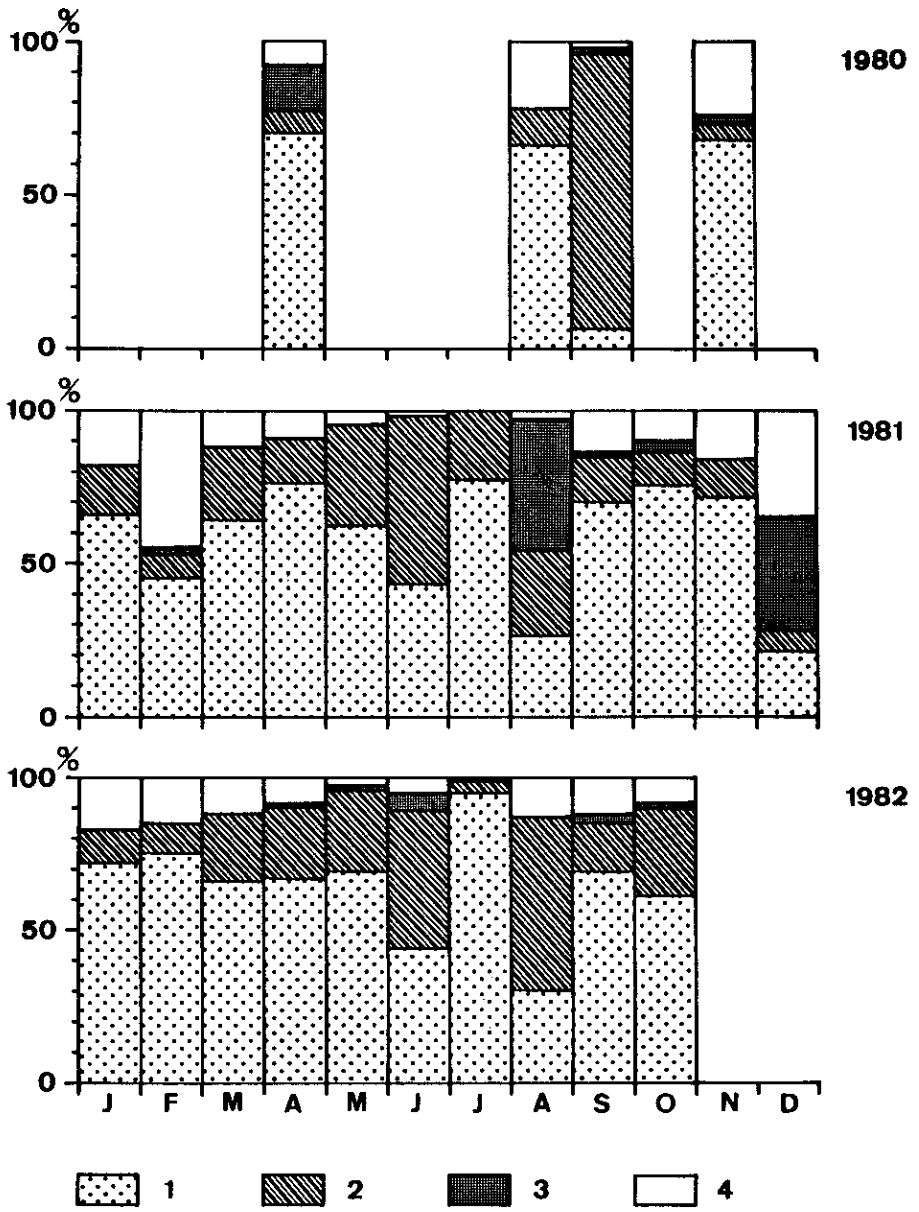


Fig. 9. Seasonal change in relative abundance of individual numbers over the four zooplankton groups at St. C during the period from April 1980 to October 1982. 1. Copepoda, 2. Non-pelagic invertebrate larvae, 3. Appendicularia, 4. Others.

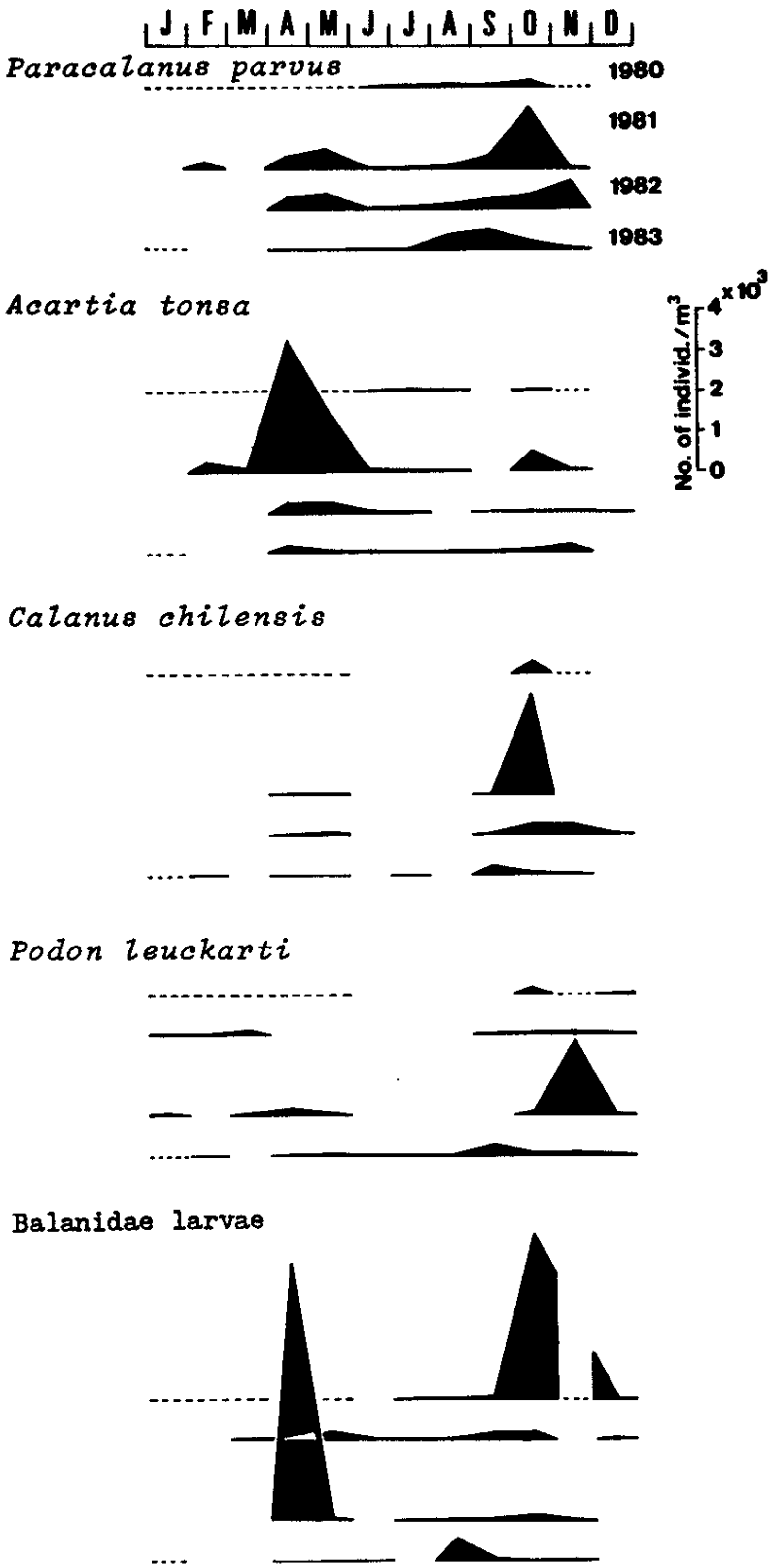


Fig. 10. Seasonal changes in abundance of the five major zooplankters at St. A during the period from June 1980 to December 1983. Broken line denotes 'No Data'.

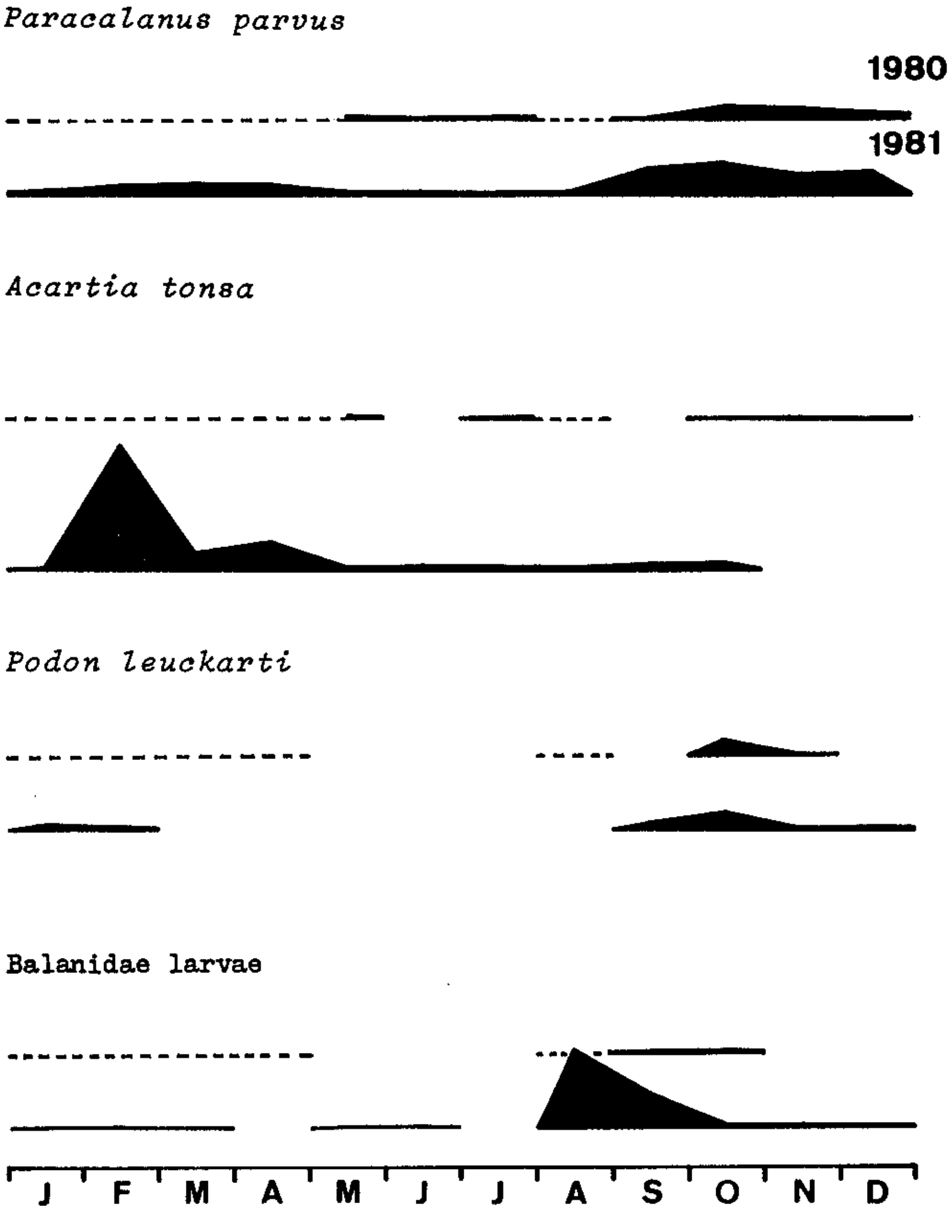


Fig. 11. Seasonal changes in abundance of the four major zooplankters at St. B during the period from May 1980 to December 1981. Broken line denotes 'No Data'. Unit as in Fig. 10.

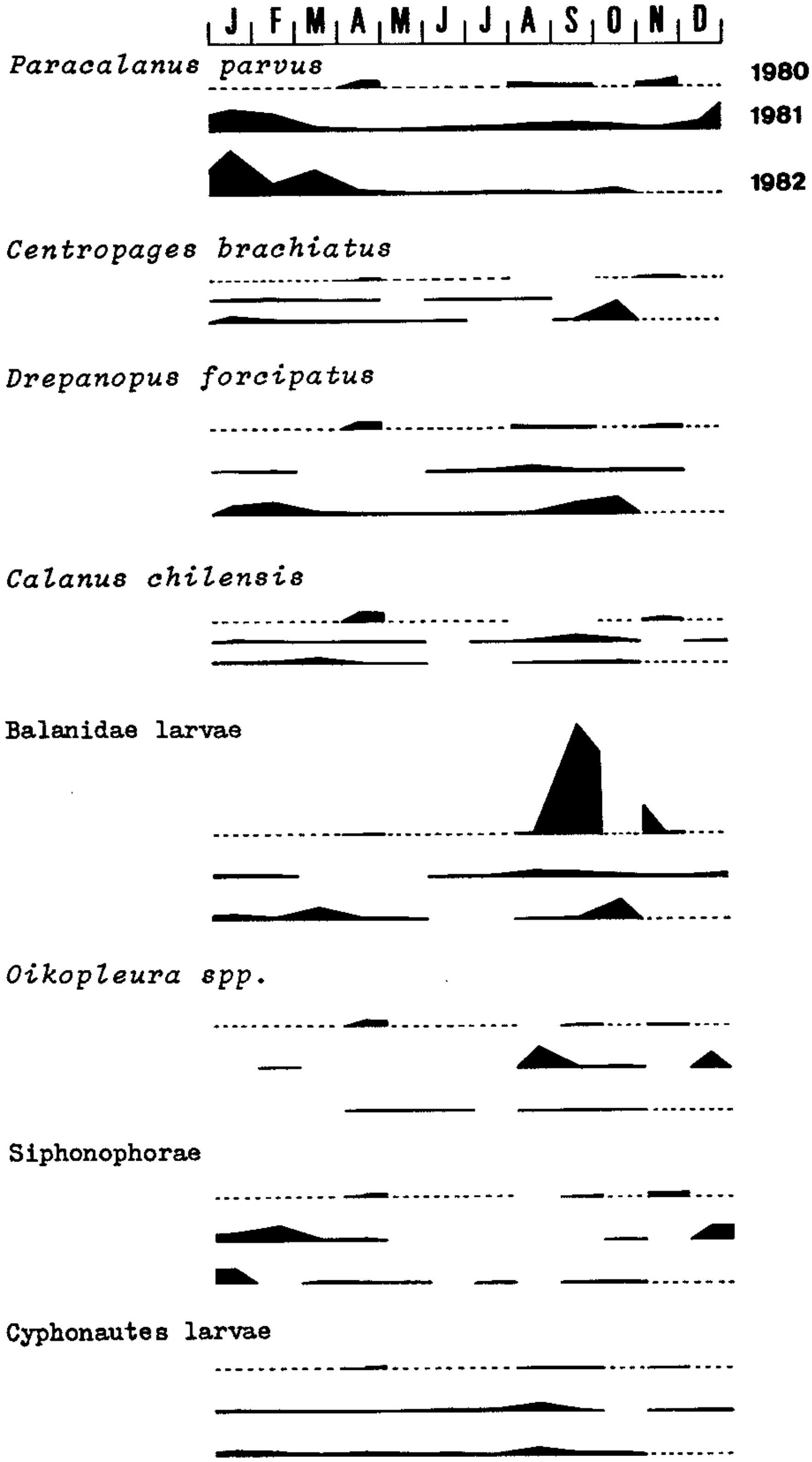


Fig. 12. Seasonal changes in abundance of the eight major zooplankters at St. C during the period from April 1980 to October 1982. Broken line denotes 'No Data'. Unit as in Fig. 10.

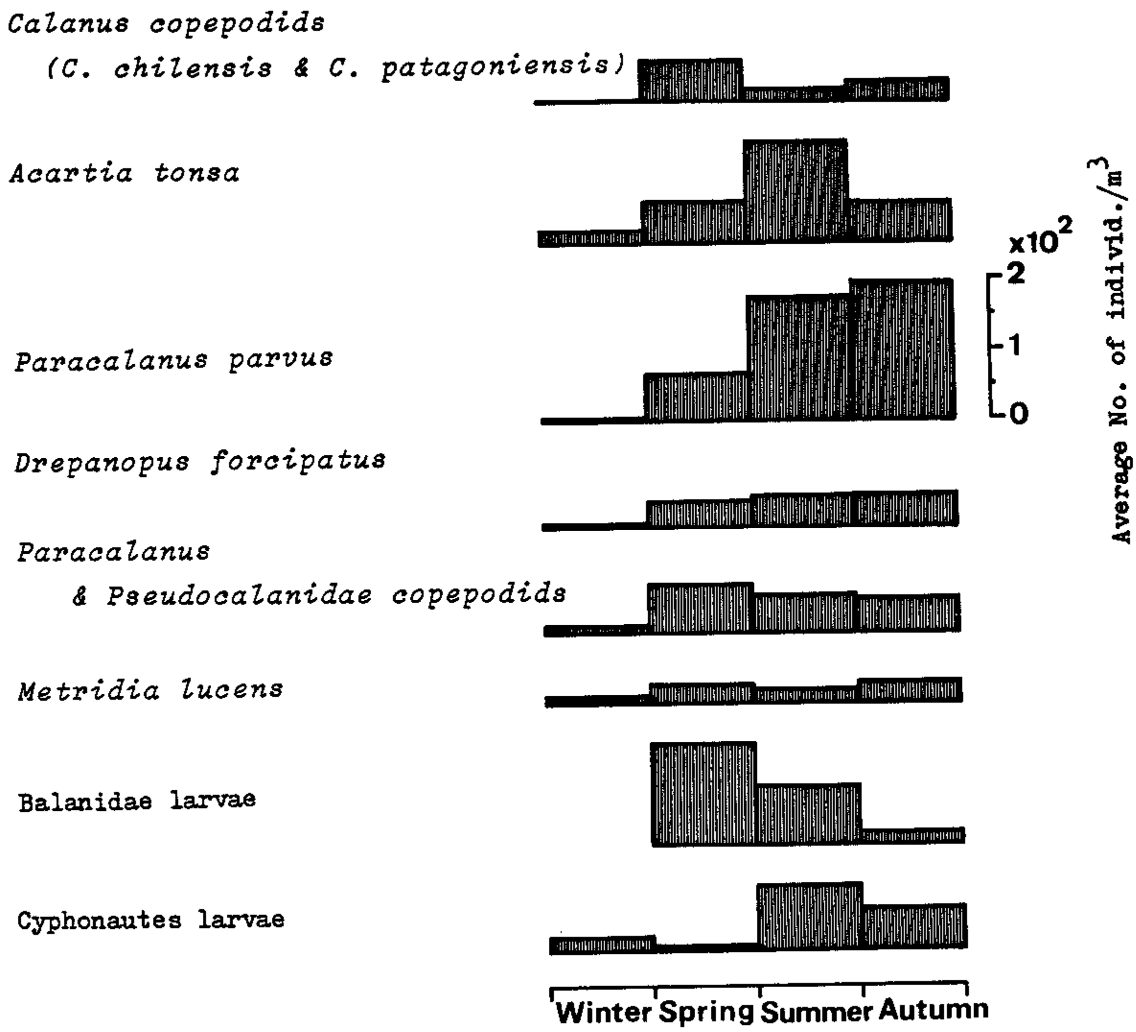


Fig. 13. Seasonal averages in abundance of the eight major zooplankters in Aisén Fiord.

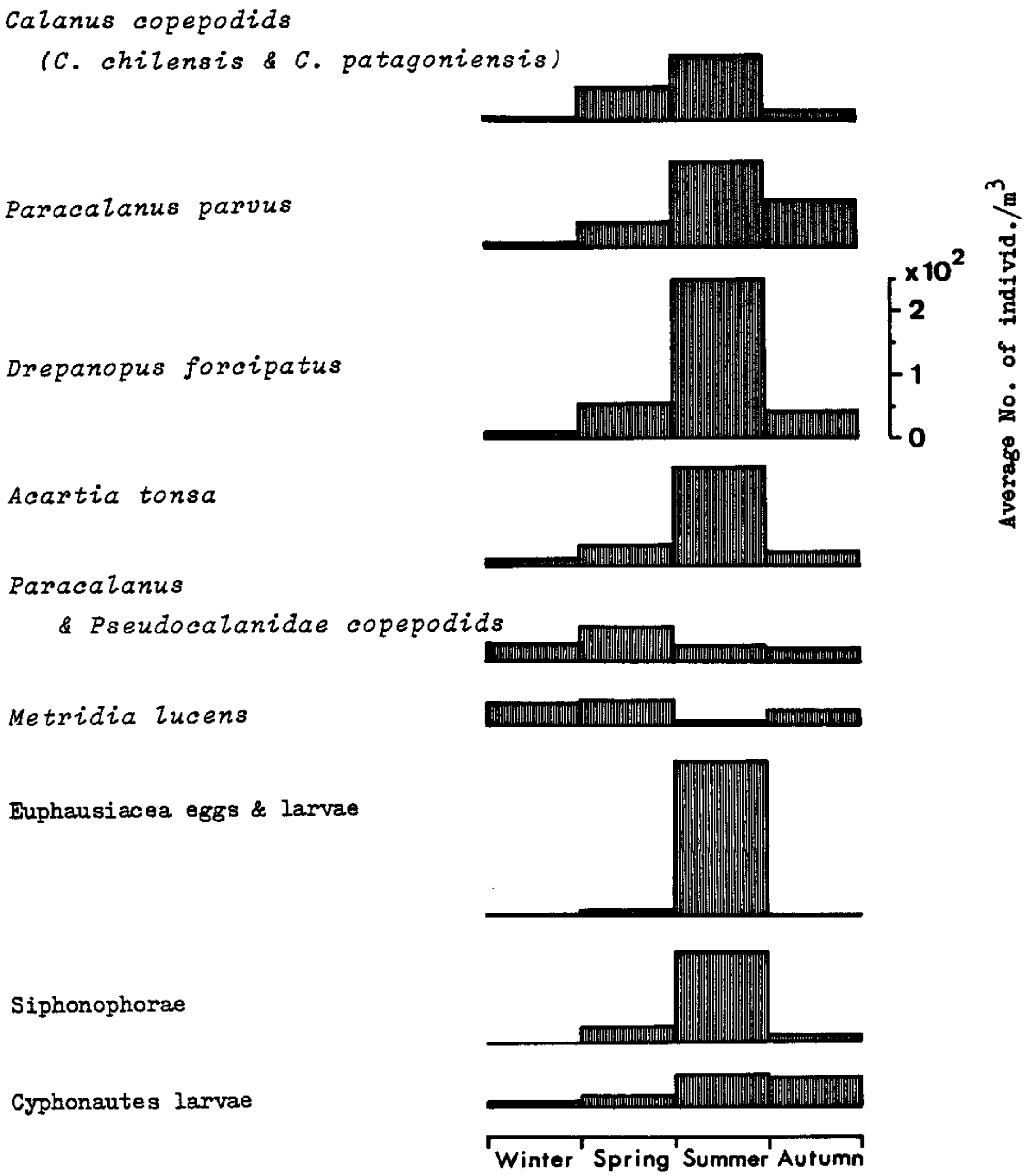


Fig. 14. Seasonal averages in abundance of the nine major zooplankters in Moraleda Channel.

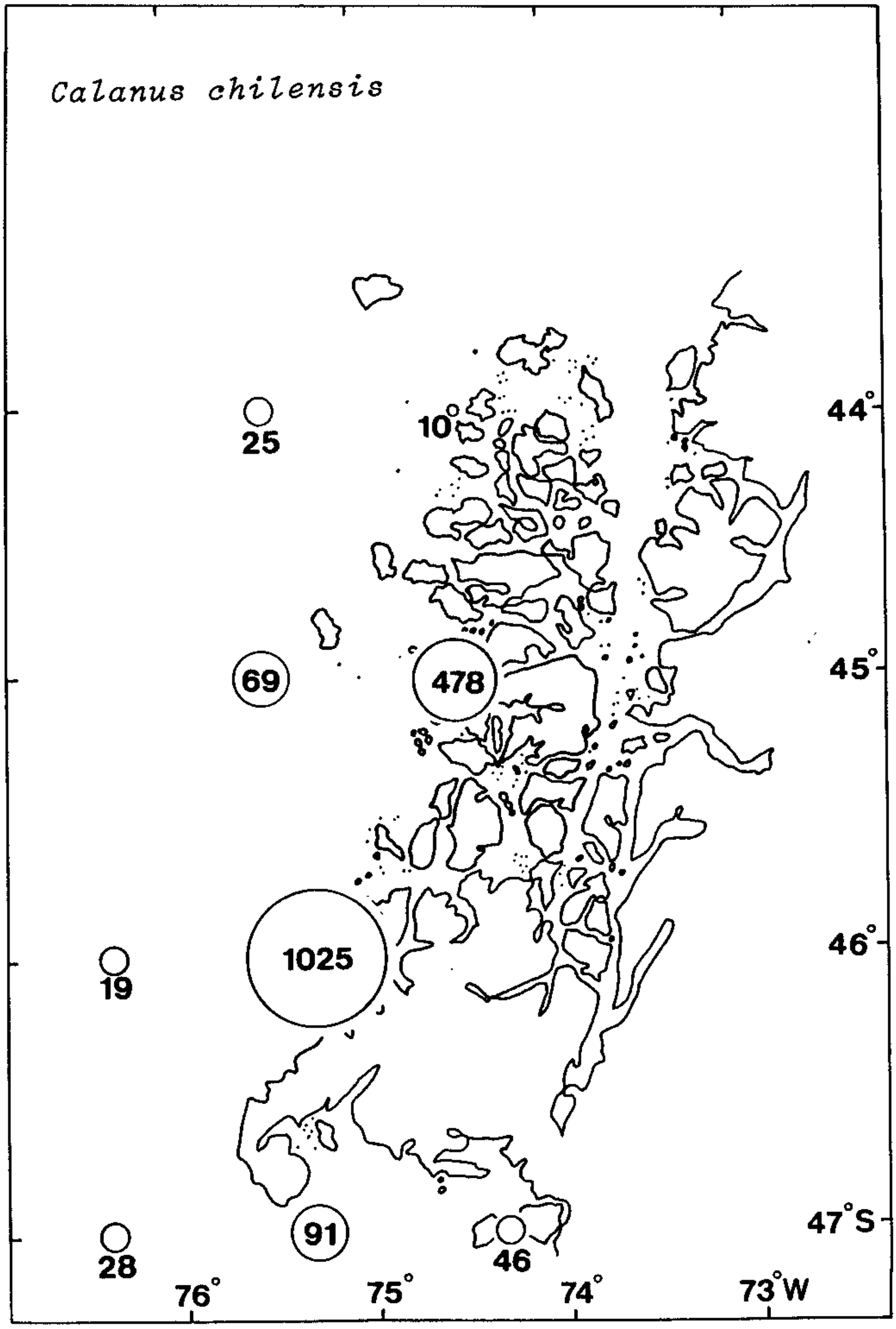


Fig. 15. Distribution of *Calanus chilensis* in the Archipelago region in March 1982. The values in the figure represent the number of individuals per m^3. The areas of the circles correspond roughly to the abundance.

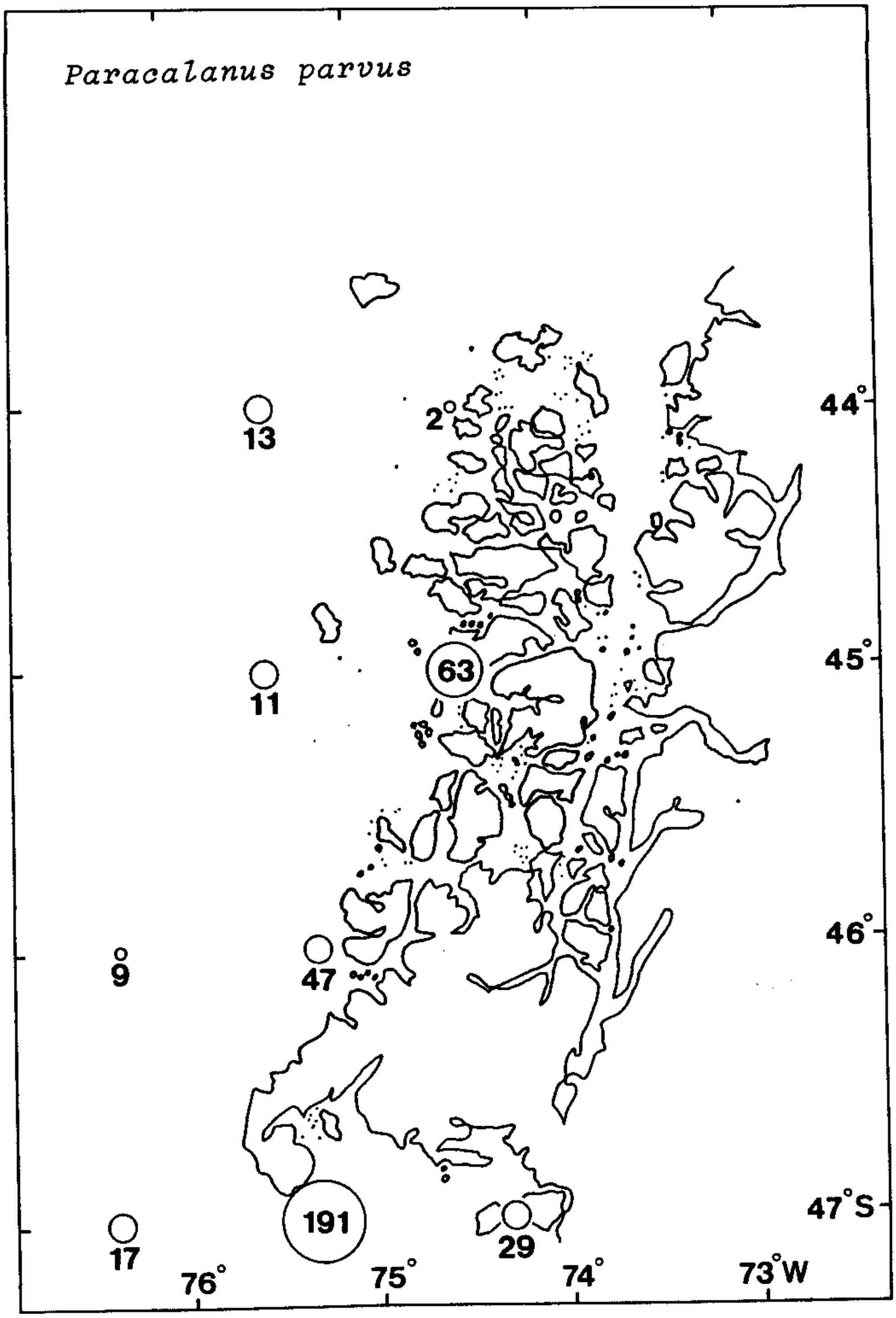


Fig. 16. Distribution of *Paracalanus parvus* in the Archipelago region in march 1982 (for further explanations, see Fig. 15).

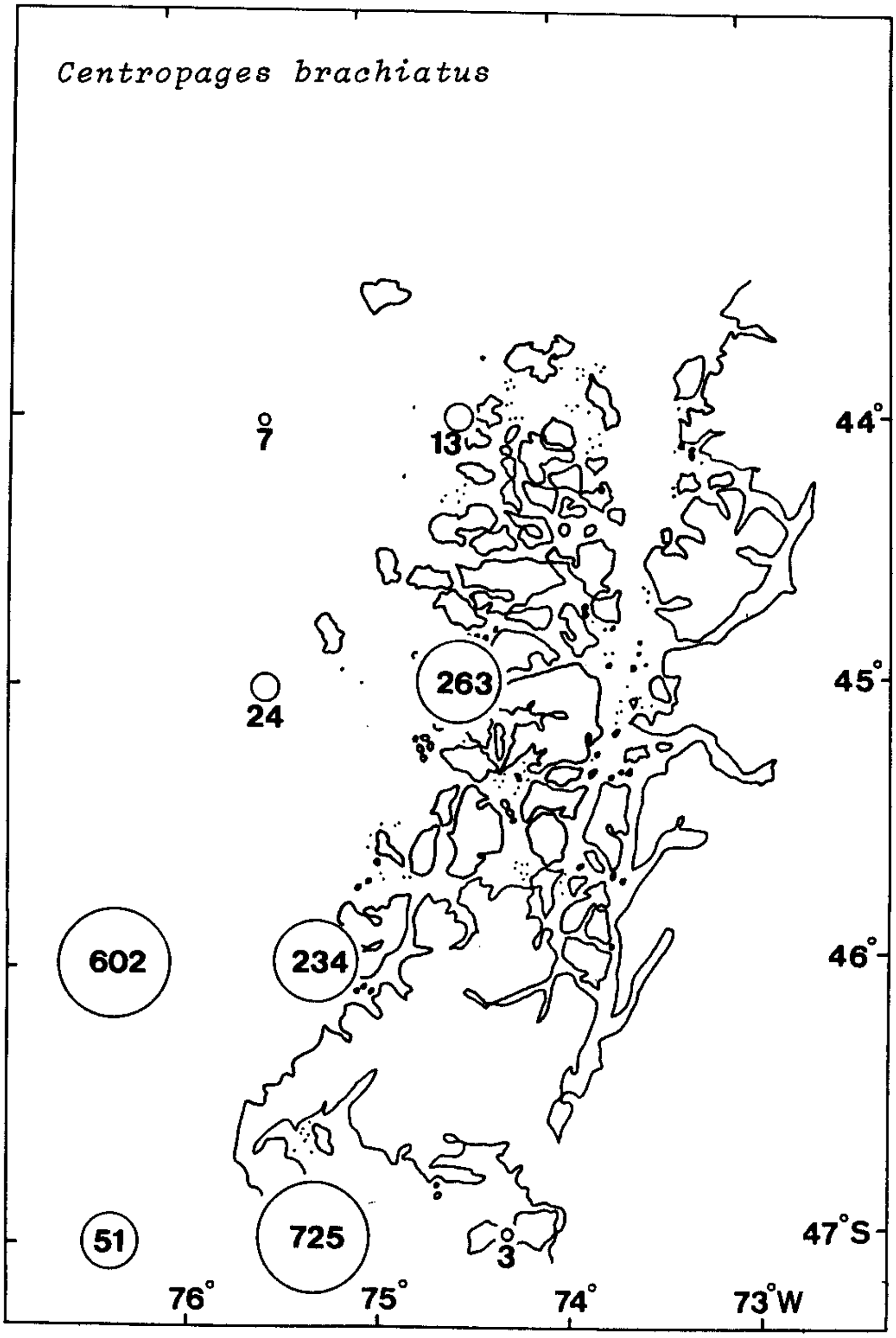


Fig. 17. Diestribution of *Centropages brachiatus* in the Archipelago region in March 1982 (for further explanations, see Fig. 15).

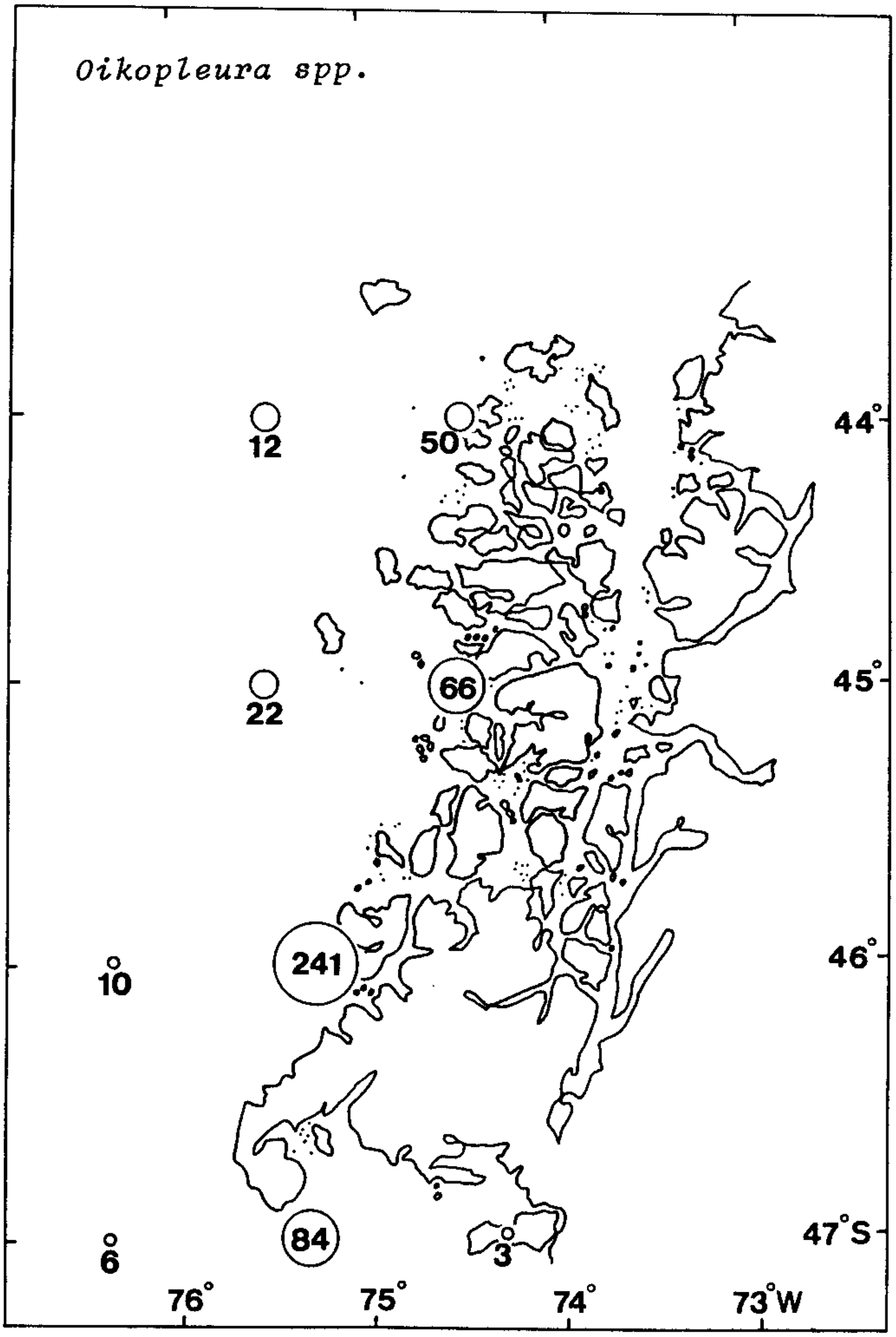


Fig. 18. Distribution of *Oikopleura* spp. in the Archipelago region in March 1982 (for further explanations, see Fig. 15).

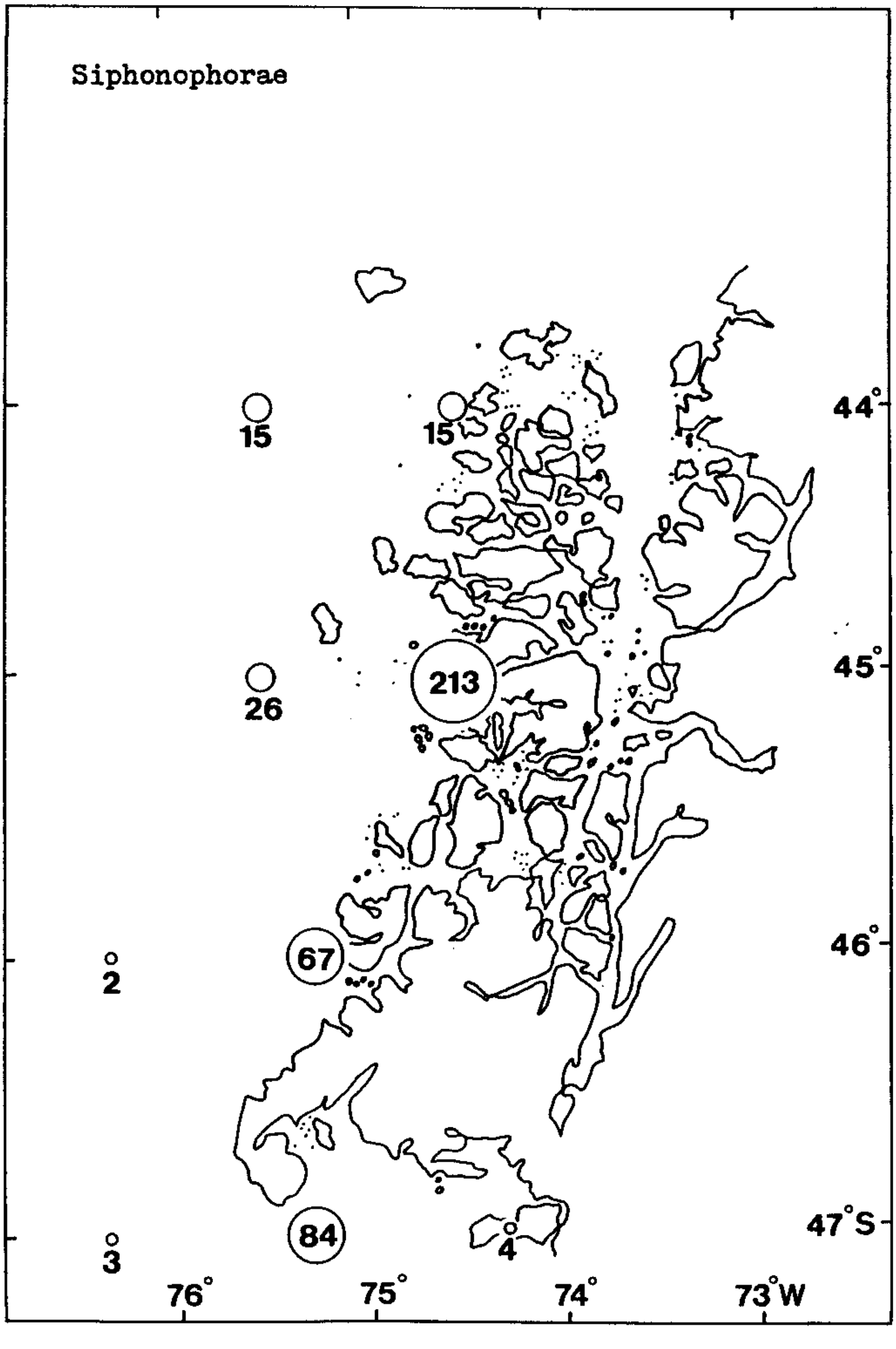


Fig. 19. Distribution of Siphonophorae in the Archipelago region in March 1982 (for further explanations, see Fig. 15).

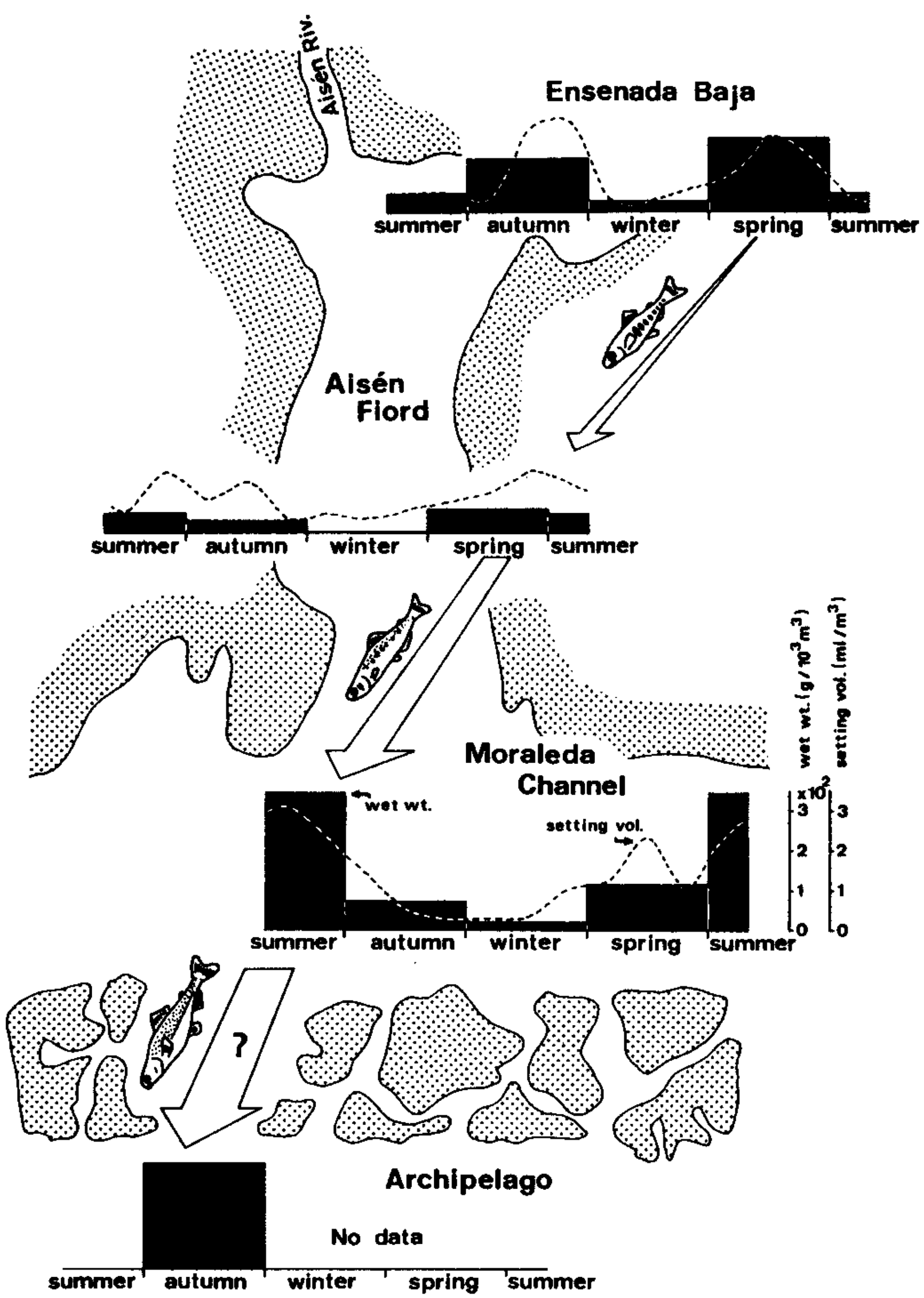
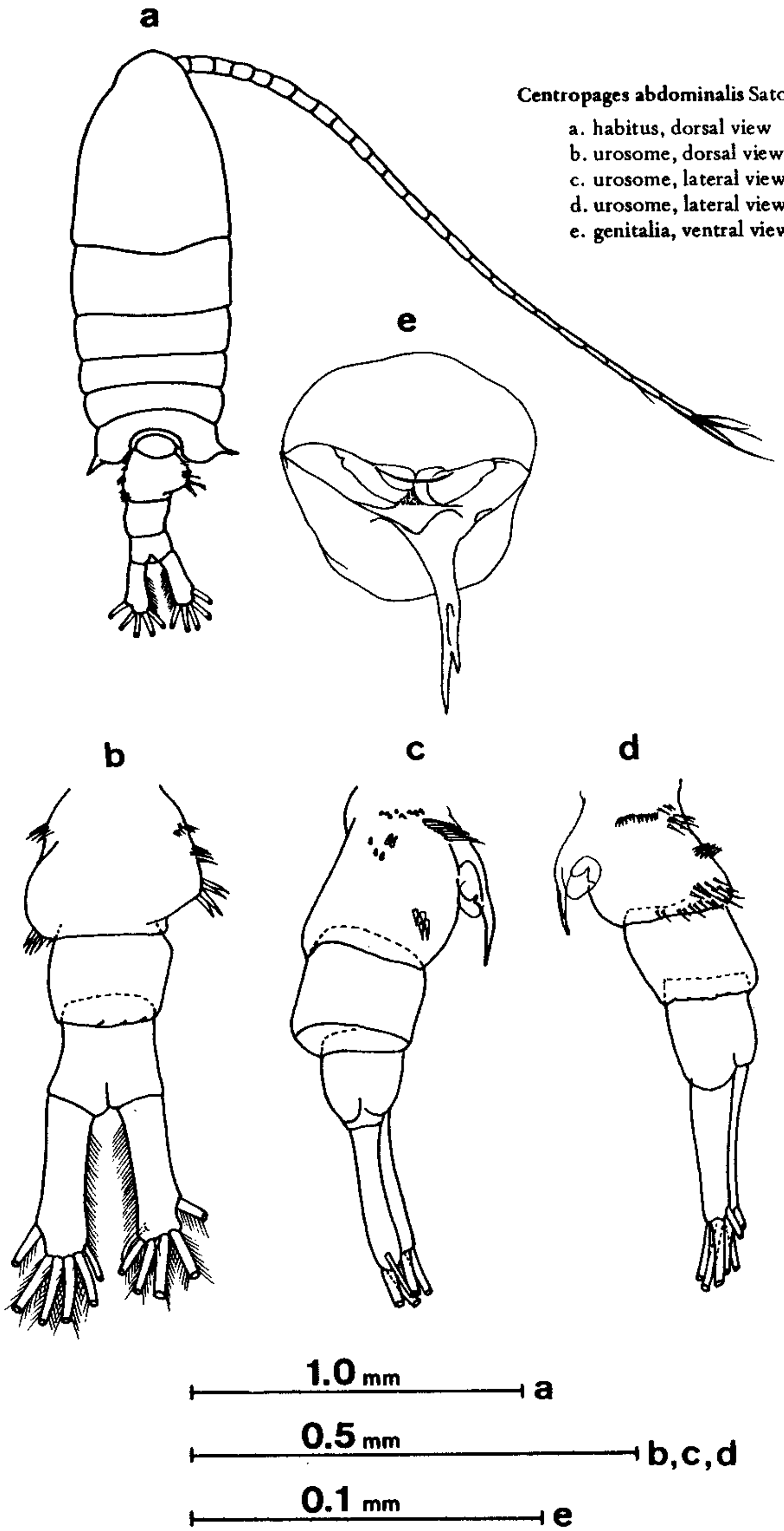


Fig. 20. Schematic diagrams showing the seasonal changes in zooplankton biomass and the migration route for the released juvenile salmon with growth in the waters from Ensenada Baja to the Archipelago region.

PLATE I

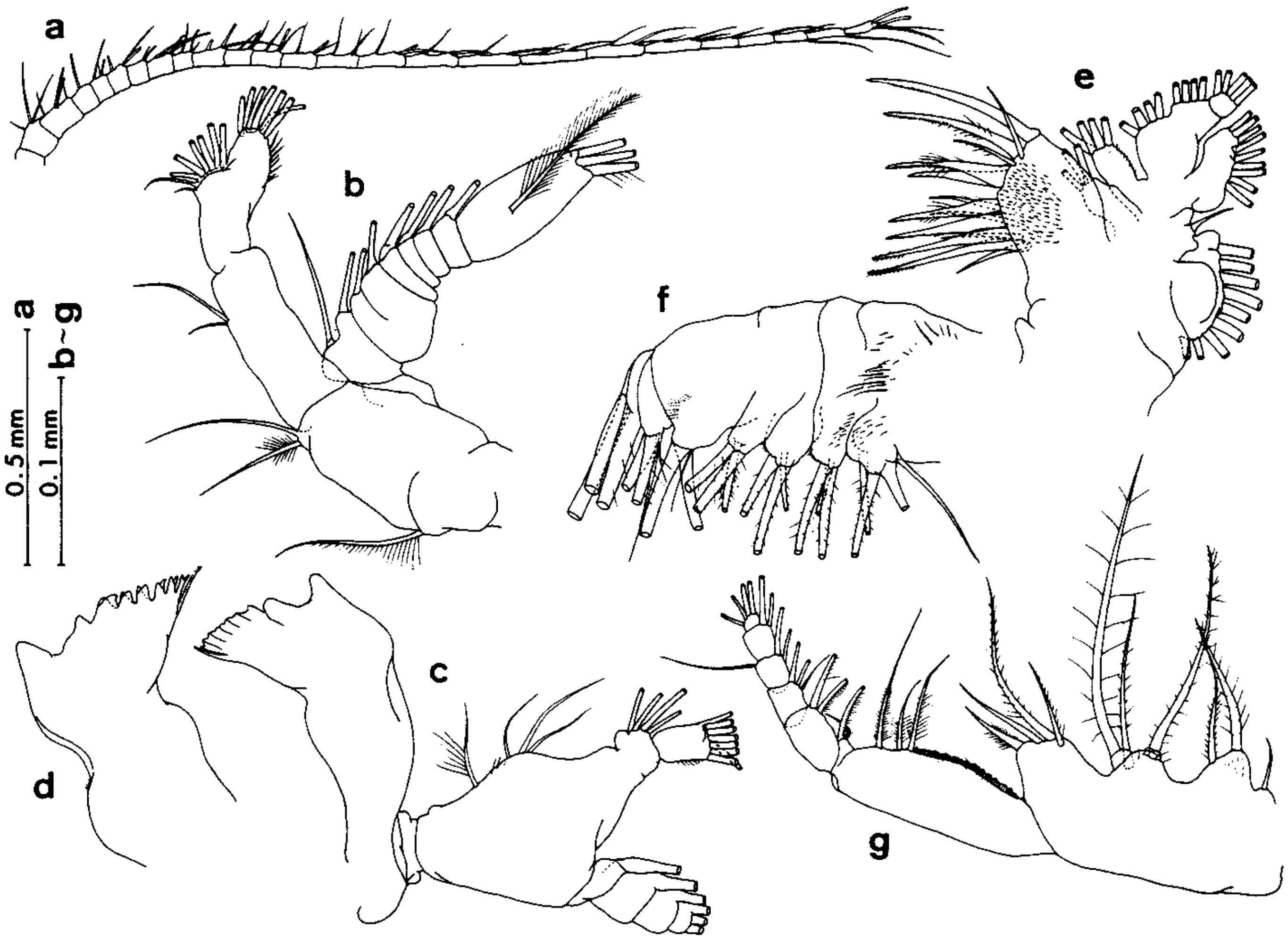
Centropages abdominalis Sato, female

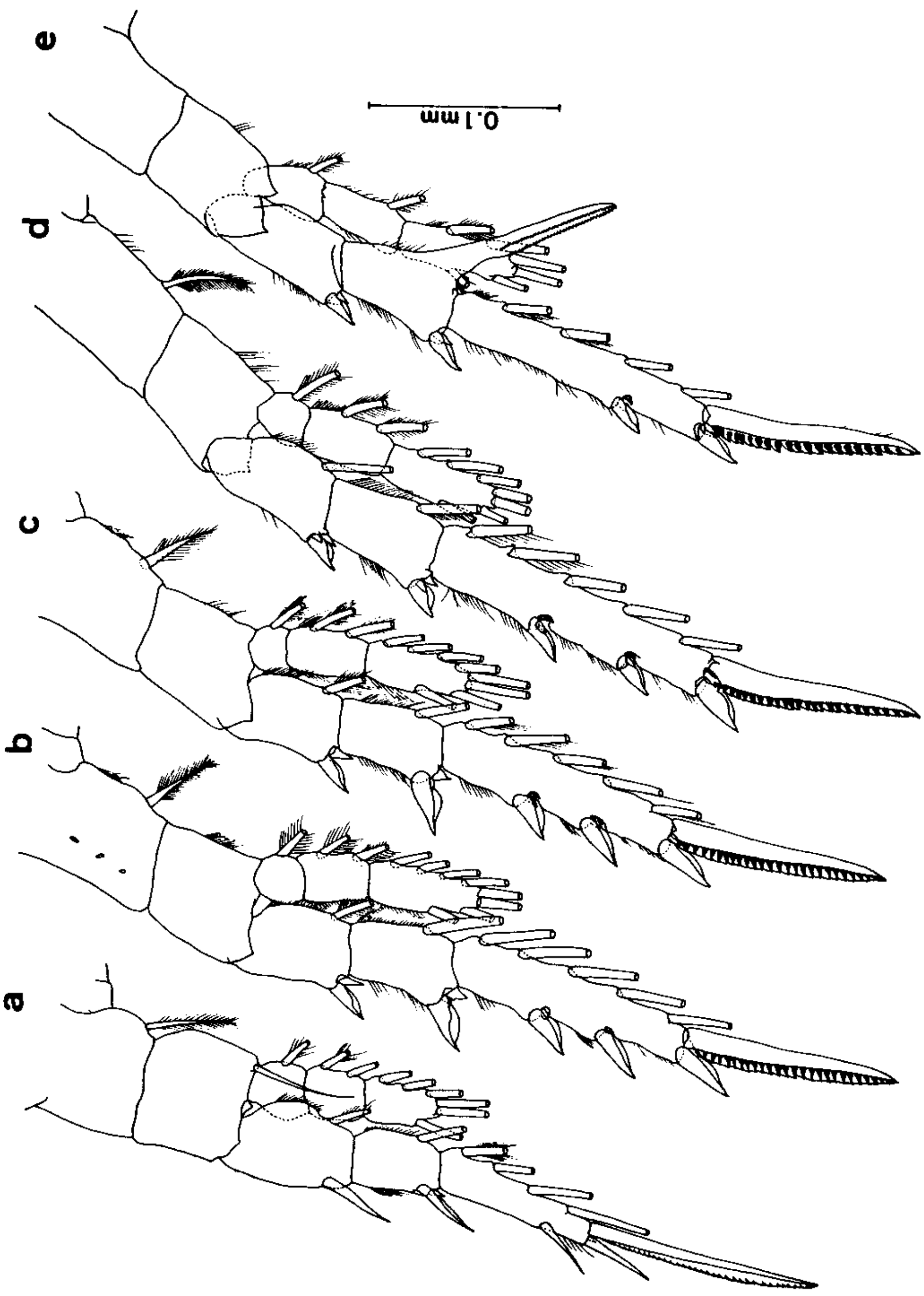
a. habitus, dorsal view
b. urosome, dorsal view
c. urosome, lateral view form right side
d. urosome, lateral view from left side
e. genitalia, ventral view



Centropages abdominalis Sato, female

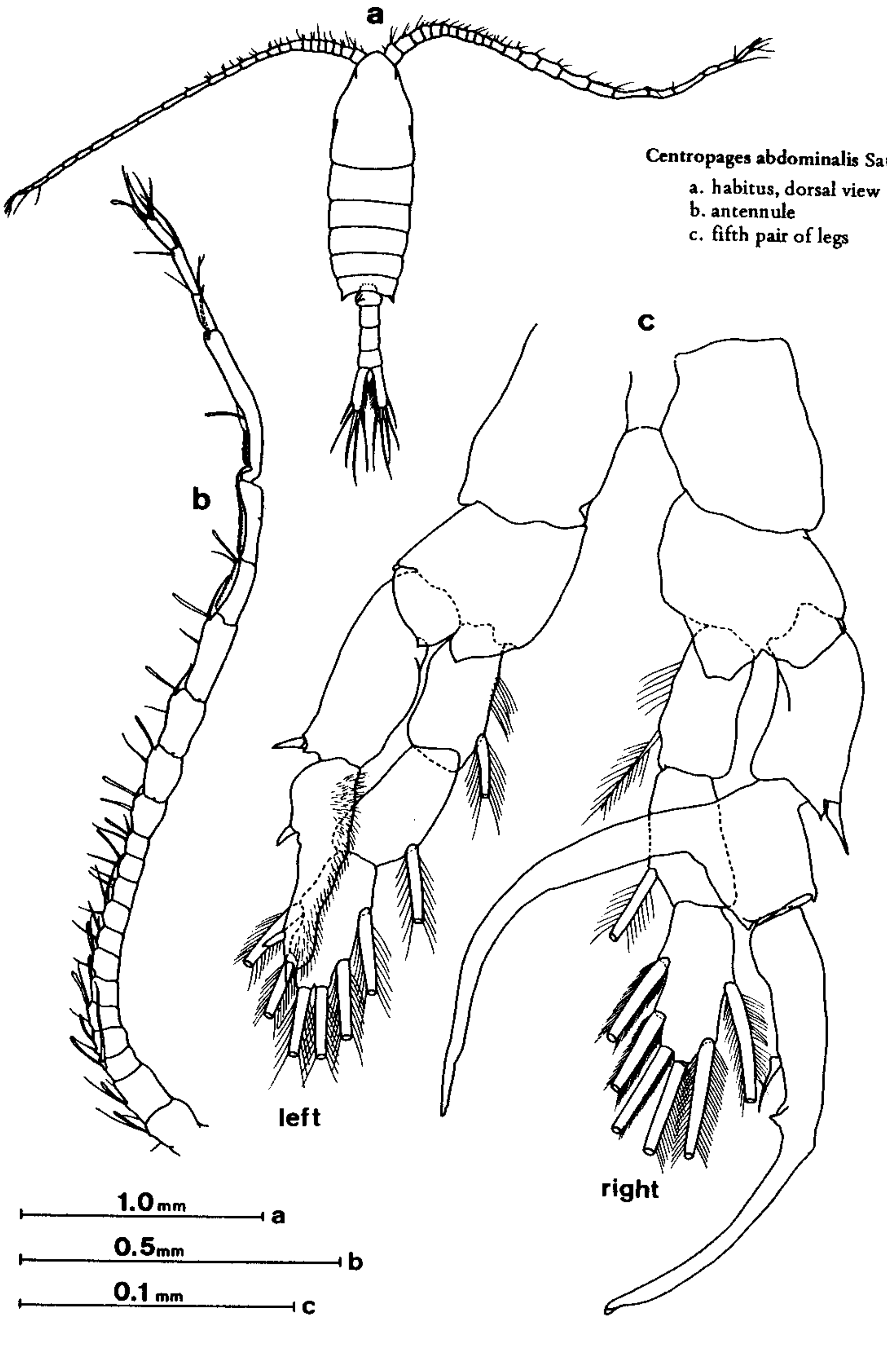
a. antennule
b. antenna
c. mandible
d. cutting edge of mandibular praecoxa
e. maxillule
f. maxilla
g. maxilliped





Centropages abdominalis Sato, female

a. leg 1
b. leg 2
c. leg 3
d. leg 4
e. leg 5



Centropages abdominalis Sato, male
a. habitus, dorsal view
b. antennule
c. fifth pair of legs