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Spatial and Temporal Distribution and Relative Abundance of Pacific Cod *(Gadus macrocephalus)* Larvae in the Western Gulf of Alaska

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Spatial and Temporal Distribution and Relative Abundance of Pacific Cod (*Gadus macrocephalus*) Larvae in the Western Gulf of Alaska

by

William C. Rugen

and

Ann C. Matarese

Resource Assessment and Conservation Engineering Division
Northwest and Alaska Fisheries Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
7600 Sand Point Way Northeast
Bin C15700, Building 4
Seattle, Washington 98115-0070

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INTRODUCTION

The Pacific cod (*Gadus macrocephalus*) is a demersal species of the family Gadidae that inhabits shelf and upper slope waters throughout the North Pacific Ocean. It is most abundant in the Bering Sea, with other commercial concentrations in the northeast Pacific off the coast of British Columbia, in the western Gulf of Alaska between Kodiak Island and Unimak Island, and throughout the Aleutian Islands.

While there has been a fishery for Pacific cod in the northeast Pacific for over 100 years, until the late 1970s, interest in this stock was generally quite limited. However, due to the occurrence of several factors (i.e., institution of the U.S. fisheries conservation zone, the development of a Japanese longline fishery, influx of fishermen from failing crab and shrimp fisheries, and the large year classes of 1977 and 1980), there has been an increase of fishing pressure on the stocks. Because of this, there has also been a considerable increase in scientific interest on Pacific cod. Most studies however, have been directly related to management and have dealt with the adult and juvenile populations (Wespestad et al. 1982, Bakkala et al. 1984, Blackburn 1984, Wespestad et al. 1986) leaving reproductive biology and early life history virtually ignored (e.g. Dunn and Matarese 1987[1/]).

While reproductive biology in other areas of the North Pacific has been studied by Svetovidov (1948), Chyung (1977; as cited in Zhang 1984), and Karp (1982), very little work has been done in the Gulf of Alaska or the eastern Bering Sea. In the Gulf of Alaska, Brown et al. (1984) estimated that 50% of the Pacific cod around Kodiak Island were mature by 45-47 cm (2-3 years old). Although no work has been done on egg production in the western Gulf of Alaska, because of the general north-south cline in egg production values, it is possible to get an idea of production rates for the western Gulf of Alaska from rates in the northwest Pacific (2.5-5 million, Svetovidov 1948) and Washington State (0.66-2.20 million, Karp 1982). Since the latitude of the Gulf of Alaska is between these two areas, fecundity would be expected to be somewhere between 0.66-5 million.

As winter cooling of the inner shelf waters occurs in the western Gulf of Alaska, mature Pacific cod migrate from their shallow, summer feeding grounds (where the temperature ranges from 5-10^{o}C, Robinson 1976) to the outer shelf and upper slope areas to spawn (Wespestad and Shimada 1984). Spawning seems to occur between February and July. The eggs appear to be spawned somewhere below the mixed layer (Alderice and Forrester 1971),

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1/ The caption of Figure 1b of Dunn and Matarese (1987) contains an error. The numbers express catch/1000 m^3 of water filtered not catch/10 m^2 of sea surface. The correct data, expressed as catch/10 m^2, are contained in Appendix Figure 12 of this report.

although Yamamoto and Nishioka (1952) hypothesized that the eggs may be spawned near the surface and then sink. However, because so few eggs are found while sampling the water column, it is most likely that spawning occurs very close to the bottom. Incubation of the eggs, which are demersal and slightly adhesive, most likely occurs on the bottom at depths of 80-290 m and at temperatures of 4-6^{o}C (based on data on adults in spawning condition in Hirschberger and Smith 1983). In the laboratory, Mukhacheva and Zviagina (1960) and Alderdice and Forrester (1971) found incubation to take ~10-30 days. The temperature range of 3-5^{o}C was found to be optimal over a wide range of salinity and dissolved oxygen values (Alderdice and Forrester 1971). Yamamoto and Nishioka (1952) found the highest hatching success at temperatures of 3-6^{o}C; lower temperatures are almost fatal whereas higher temperatures decrease the hatching rate. Newly hatched larvae were found to be 3.27-3.80 mm SL by Mukhacheva and Zviagina (1960), and 4.00-4.42 mm SL by Alderdice and Forrester (1971). Mukhacheva and Zviagina (1960), who described early development, found that the yolk sac was absorbed in 10 days (at 5^{o}C) when the larvae were ~4 mm. Yamamoto and Nishioka (1952) reported the yolk sac was absorbed in 8 days.

Problems with larval identification have inhibited work on Pacific cod larvae, and gadid larvae in general, in the North Pacific. Prior to 1980, larval gadids were identifiable to only the family level. Since 1980 however, descriptions of North Pacific gadid larvae by Matarese et al. (1981), Dunn and Matarese

(1984), and Dunn and Vinter (1984), have made possible work on the distribution and abundance of the larvae of the different species. This report examines spatial and temporal distribution and apparent relative abundance of Pacific cod larvae in the western Gulf of Alaska based on plankton collected by the Northwest and Alaska Fisheries Center (NWAFC) from 1972-1985.

MATERIALS AND METHODS

Study area

Topography of the western Gulf of Alaska is characterized by numerous troughs and shallow banks. The shelf area, as defined by the 200 m isobath, is generally wide (65-175 km) and drops abruptly to depths of 5000-6000 m in the Aleutian Trench.

Offshore near surface circulation (Fig. 1) is dominated by the Alaskan Stream which runs southwesterly and roughly parallel to the shelf break at mean speeds of 50-100 cm/sec (Meunch and Schumacher 1980, Reed et al. 1980). Nearshore, the Alaska Coastal Current (ACC) is the dominant circulation feature. This also flows southwesterly, at mean speeds of 20-70 cm/sec (Schumacher and Reed 1980). Some of the water from the ACC enters the Bering Sea through Unimak Pass (Schumacher and Reed 1983).

Data collection

The National Marine Fisheries Service (NMFS) has conducted ichthyoplankton cruises in the Gulf of Alaska since 1972, either singly or in cooperation with the U.S.S.R.. Early cruises were designed to gather background information to describe seasonal and spatial aspects of fish egg and larvae distributions in the area. However, because of advances in our ability to identify gadid larvae and the growing importance of the walleye pollock (Theragra chalcogramma) fishery, the focus of the investigations shifted in 1981 to the early life history of the walleye pollock. While the focus has shifted to walleye pollock, all larvae continue to be identified to the lowest possible taxon. Since Pacific cod spawn at approximately the same time as walleye pollock (spring), these samples can be used to investigate spatial and temporal patterns of the Pacific cod.

For this report, we considered 30 of these cruises conducted between 1972 and 1985; most (19) took place between April and June. No sampling was done in December, January, or August. A catalog of ichthyoplankton cruises conducted by the Northwest and Alaska Fisheries Center from 1965-1985 can be found in Dunn (1986.)

Ichthyoplankton was collected with standard MARMAP tows (Smith and Richardson 1977) using a 60 cm bongo sampler (Posgay and Marak 1980) equipped with 0.505 mm mesh nets, except on cruises 1PO85 and 2PO85, when a 0.333 mm mesh net was used. Generally, the maximum wire out was 300 m or less, providing a nominal sampling depth of 200 m. On some cruises a 1 meter Tucker trawl and Sameoto neuston sampler were also used, but because so few Pacific cod were collected with these nets, the data are not reported here. Depth distribution of plankton was investigated on cruise 2MF86 using an 8 net MOCNESS discrete depth sampler (Wiebe et al. 1976). This gear collected samples at 15 m intervals from 0-60 m and at various depth intervals between 60 m and 230 m.

Sample processing

The samples were preserved in a 5% buffered formalin solution and sent to the Plankton Sorting Center in Szczecin, Poland. There, the fish were removed, identified to species if possible, and up to 50 individuals per species per station were measured to the nearest 0.1 mm SL. The identifications were verified at the NMFS laboratory in Seattle by Beverly Vinter.

Data analysis

Horizontal abundances are expressed as catch/10 m^2 of sea surface (Smith and Richardson 1977). In order to determine how distribution and relative abundance of larvae changed as the spawning season progressed, the data from all the cruises were combined and then separated into date windows of ~15 days each (Table 2; Figures 2-6).

Vertical abundances are expressed as number/1000 m^3. These values were obtained by dividing the total number of larvae found in a depth interval by the total volume of water sampled in that depth interval, and then multiplying the result by 1000.

Differences in mean lengths between time periods were investigated using predicted means obtained with a maximum likelihood procedure (Dixon 1985). We then used the GT2 method, the Tukey-Kramer method, and the Games and Howell method for multiple comparisons of the predicted mean lengths (Sokal and Rohlf 1981).

Individual cruise maps with station locations and relative abundances of Pacific cod larvae are presented in Appendix Figures 1-13.

RESULTS

Pacific cod larvae were found on 13 of the 30 cruises and only during April, May, and June (Table 1). Of the 1123 stations sampled, 262 contained a total of 1046 Pacific cod larvae. The average number of Pacific cod larvae per positive haul was 3.99. Larvae were found mainly over the shelf in the area between ~146° 00'W and ~168°50'W. Only 8 of the 187 collections seaward of the 200 m isobath contained larvae.

Seasonal distribution

Cod larvae were first collected in early April (1-15). Sampling during this period ranged from the extreme northeast of the study area to just east of the Shumagin Islands (Fig. 2a). Of the 263 stations occupied during this period, 19 stations accounted for a total of 46 larvae. Most of the larvae were found east of Kodiak Island and a few to the south of Kodiak (Fig. 2b). No larvae were found in Shelikof Strait or the adjacent sea valley. The mean length of larvae was 4.3 mm SL and the mean abundance was 13.18/10 m^2 (Table 2).

Sampling in late April (16-30) was conducted mainly between ~150°00'W and Unimak Pass (Fig. 3a). A total of 280 stations was sampled during this period, of which 52 contained a total of 300 larvae. Larvae were found in all areas sampled, except for lower Shelikof Strait and the adjacent sea valley. Heavy concentrations of larvae were found just southwest of Sanak Island, and to the northeast and southwest of Kodiak Island (Fig. 3b). The mean abundance was 33.76/10 m^2 and the mean length was 4.3 mm SL (Table 2).

Only 84 bongo stations were occupied during early May (1-15). Sampling was scattered between the Trinity Islands and the Shumagin Islands and around the north and east sides of Kodiak Island (Fig. 4a). Of these stations, 18 accounted for a total of 122 larvae (Fig. 4b). The only noticeable concentration of larvae was to the northeast of the Shumagin Islands. The mean abundance was 27.01/10 m^2 and the mean length was 4.7 mm SL (Table 2).

Late May (16-31) was the most heavily sampled of the time periods considered. There were 448 bongo stations sampled in the area between ~148°00'W and ~162°00'W, with very heavy sampling in Shelikof Strait and over the adjacent sea valley (Fig. 5a). Pacific cod larvae were abundant in most areas sampled, except for the areas to the east and northeast of Kodiak Island (Fig. 5b). There were 165 stations accounting for 516 larvae, with a mean abundance of 21.81/10 m^2 and a mean length of 8.3 mm SL (Table 2).

Only 48 stations were sampled in early June (1-8), all within the area from the Shumagin Islands to ~168°00 W (Fig. 6a). Just 8 of these stations contained Pacific cod larvae, and most of these were in the vicinity of Unimak Pass (Fig. 6b). A total of 62 larvae were captured, with a mean abundance of 73.00/10 m^2 and a mean length of 8.5 mm SL (Table 2).

Size distribution

The overall size range of Pacific cod larvae was 2.7-15.0 mm SL and the mean was 6.6 mm SL (Table 2). The mean length increased with each biweekly period (except during April), with an unexpectedly large increase from 4.7 mm SL in early May, to 8.3 mm SL in late May. No other consecutive time periods had an increase of greater than 0.4 mm. Samples taken in late May had the greatest size range of any period, 3.7-15.0 mm SL.

The statistical analysis of mean larval lengths showed there was only one instance where the difference between consecutive time periods was significant. The linear equation fitted for the mean length model was:

$$L_{ijkl} = M+Y_i+T_j+S_{k(ij)}+E_{ijkl}$$

where; L_{ijkl}=the length of larva l at station k within time period j and year i

M=the grand mean of all lengths

Y_i=fixed effect of year i

T_j=fixed effect of time period j

$S_{k(ij)}$=random effect of station k within year i and time period j

E_{ijkl}=random error for larva l

Our model for larval lengths is a "mixed" model because the station effect is random and nested within year and time periods. Another complicating problem was unequal sampling in the number of larvae caught at each station and the number of stations sampled within each time period-year combination, hence our data are "unbalanced". These two conditions preclude the use of standard analysis of variance methods. Instead, we used a maximum likelihood method to estimate the effects of year and time period, and the variance components for the station effect and the error term. This analysis assumes that, 1) the larvae sampled are a random sample of larvae at each station, 2) the stations are a random sample of all possible stations in the survey area, 3) the errors (E_{ijkl}) are independent and identically distributed normal random variables with constant variance, and 4) the station effects ($S_{k(ij)}$) are independent and identically distributed normal random variables with constant variance.

With the use of a likelihood ratio test it was determined that the year of sampling, the time period in which the sampling occurred, and the station sampled all have a significant effect (alpha=.05) on the model for the larval length. There was not, however, a significant time period-year interaction effect, hence these two factors are additive.

All three of the multiple comparison tests we used to determine differences of larval lengths between consecutive time periods showed the only significant change (at alpha=.05) occurred between early May and late May. No significant change could be determined within the first three time periods (early April, late April, early May) or the last two time periods (late May, early June).

There are three major problems with the multiple comparison tests we used: 1) The tests we used were developed for classical analysis of variance based on sums of squares and the associated degrees of freedom. We applied the tests to predicted means and estimated variance components obtained via maximum likelihood; 2) Because of irregularity of sampling over years, we have a large number of empty cells in our time period-year combinations. We cannot be sure how this impacts the maximum likelihood estimations; 3) The length data we have are neither normal or homoscedastic (constant variance). Log transformations helped somewhat, but did not entirely correct the problem. Although the same results were obtained with all three methods we used, the Games and Howell method is probably the most valid method because it does not require homoscedasticity.

Vertical distribution

On cruise 2MF86, 16 stations were occupied using the MOCNESS sampler. Sampling was conducted between May 8-18. These stations were located in the southwest end of Shelikof Strait, the adjacent sea valley, and near Sutwik Island. A total of 664 larvae were collected at 10 stations in 22 of the nets (Table 3). Most (~65%) of the larvae were taken between 15-30 m, and almost all (~99%) were found in the upper 45 m (Table 4). There seemed to be a general trend for smaller larvae to be found at greater depths. No larvae larger than 4.1 mm SL were collected deeper than 45 m, whereas the mean length in the 0-15 m interval was 4.7 mm SL. Of the total number of larvae taken by the MOCNESS, 628 were collected at one location sampled twice on consecutive days.

DISCUSSION

Spawning

The distribution of adults in spawning condition (Hirschberger and Smith 1983; Brown et al. 1984) and small larvae (Figs. 2-4) show that the main areas of spawning occur to the northeast and southwest of Kodiak Island and farther to the southwest near the Shumagin Islands and Sanak Island. Brown et al. (1984) found significant proportions of adults in spawning condition to the northeast and southwest of Kodiak Island in 1977-80. Hirschberger and Smith (1983), however, found most of the adults in spawning condition along the shelf break to the southwest of Kodiak (Fig. 7). Our data on early season concentrations of small larvae are similar to the data from Brown et al. (1984), and suggest that the largest amount of spawning occurs to the northeast of Kodiak Island. Smaller spawning concentrations were found to the southwest of Kodiak, near where the high amounts of adults in spawning condition were found (Hirschberger and Smith 1983). We also found evidence of spawning farther to the southwest near Sanak Island and the

Shumagin Islands, areas not sampled by Hirschberger and Smith (1983) or Brown et al. (1984). Because the distribution patterns of small larvae so closely reflect the patterns of spawning adults it could be assumed that there is negligible drift of the developing eggs.

Data from Hirschberger and Smith (1983) suggest that the spawning season runs from February to July; however, our data narrows that time down to a period from early March to mid-May. Our estimate of the spawning season is based on the presence of small, newly hatched larvae, and an estimated incubation period of 20 days. Laboratory studies indicate larvae hatch at lengths of 3.27-4.42 mm SL (Mukhacheva and Zviagina 1960; Alderdice and Forrester 1971). Our estimate of a 20 day incubation period is based on a mean bottom temperature of 5.4°C that Hirschberger and Smith (1983) found in areas with adults in spawning condition. Also, Uchida (1936; as cited in Mukhacheva and Zviagina 1960), found egg development to take 18-20 days in 4.0-5.5°C water in the Gulf of Chin-Ho, Northern Korea. Therefore we suggest that an incubation time of ~20 days is a reasonable assumption in the Gulf of Alaska. Based on the above assumptions and the biweekly size ranges (Table 2) that indicate the first newly hatched larvae are present in early April and the last newly hatched larvae in late May, we conclude that the spawning season generally is from early March to mid-May. Some spawning at low levels may, however, occur prior to and after this period.

Distribution and drift

The major concentration of early larvae is found to the northeast of Kodiak Island and lesser concentrations are found just southwest of Kodiak and around Sanak Island and the Shumagin Islands (Figs. 2b, 3b, 4b). These general patterns remained visible until mid-May, at which time a general dispersal and southwesterly drift, due mainly to the Alaska Coastal Current, had erased the early season concentration patterns (5b, 6b). The concentration of larvae originally found to the northeast of Kodiak is subsequently transported to the southwest, mainly through Shelikof Strait and out over the adjacent sea valley. Prior to this time there is little evidence of any Pacific cod larvae in the Shelikof Strait area and there is no indication that any spawning takes place there. The concentrations of early larvae to the southwest of Kodiak Island and around the Shumagin Islands are transported southwest and roughly parallel to the Alaskan Peninsula. Very few larvae are found seaward of the 200 m isobath, and none seaward of the 2000 m isobath. This indicates that either the prevalent currents are confining the larvae over the shelf area and/or that high mortality occurs to larvae that are transported off the shelf.

From 1972-85, no Pacific cod larvae were found in late June or July; however, cruises during these years sampled mainly around the east and northeast of Kodiak Island, areas that should have very few larvae at this time of year due to southwest drift caused by the Alaska Coastal Current. This was confirmed by sampling conducted in June/July 1987 (unpublished data, NWAFC). Using a midwater frame trawl (Methot 1986) in the area between ~150°00'W and ~164°00'W, 119 Pacific cod larvae were collected. Of these, 113 were found to the southwest of the Trinity Islands, an area rarely sampled at this time of year by earlier cruises. The size range was 12.4-36.0 mm SL and the latest date of collection was July 14.

The data from the MOCNESS shows that Pacific cod larvae rise to the upper 45 m of the water column after hatching. This is suggested by the data taken from two repeated tows made at one location (Table 5). At this location it appears a concentration of newly hatched larvae was sampled. Most of these larvae were quite small, and a definite increase in length can be seen from deep to shallow in the water column, illustrating the ascent of the larvae soon after hatching. Similar behavior was observed by Yamamoto and Nishioka (1952) while rearing Pacific cod larvae in the laboratory. They observed larvae rising to the surface 3 days after hatching. These data are contrary to the hypothesis of Walters (1984), who felt that the larvae would be distributed relatively deep in the water column. Mukhacheva and Zviagina (1960) performed some discrete depth sampling between 0-88 m. They found 18 Pacific cod larvae between 50-88 m, 13 in the 25-50 m interval, and only 4 larvae from 0-25 m. All these larvae, however, were between 10-23 mm.

CONCLUSIONS

Pacific cod larvae are widely distributed over the shelf area in the western Gulf of Alaska. The distribution of small larvae reflects that of known adult spawning concentrations. Most of the small larvae are found in April and early May to the northeast and southwest of Kodiak Island, and around Sanak Island and the Shumagin Islands. By late May, the currents have transported most of the larvae out of the northeast area and to the southwest, mainly through Shelikof Strait and the adjacent sea valley. As spring progresses, the larvae are found progressively farther to the southwest, as a result of drift in the Alaska Coastal Current. Sometime in May, it appears most of the Pacific cod eggs have hatched, and larval dispersion and abundance are at their maximum. At no time are many larvae found seaward of the shelf break. The data on depth distribution shows that the newly hatched larvae rise to the upper 45 m of the water column soon after hatching.

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Table 1.--Data from cruises where Gadus macrocephalus larvae were collected. Cruises are listed chronologically by starting sampling date.

Cruise	Sampling dates	Number of bongo stations	Stations with cod larvae number	Stations with cod larvae percentage	Number of larvae	Catch per 10 m^2	Length (mm SL) mean (range)
1PO85	3/29-4/21/85	154	5	3.2	15	26.55	4.2 (3.6- 5.2)
4DI78	3/20-4/20/78	86	2	2.3	3	6.90	4.7 (4.1- 5.6)
1DA82	4/04-4/23/82	83	8	9.6	81	60.92	4.3 (3.5- 6.0)
1SH84	4/07-5/04/84	179	39	21.8	188	25.06	4.5 (2.9- 9.0)
2SH81	4/16-4/24/81	60	14	23.3	118	48.50	4.2 (2.7- 5.8)
2KE72	4/26-5/09/72	64	11	18.0	40	3.83	4.6 (4.0- 5.8)
3MF81	4/26-5/09/81	79	9	11.4	22	16.60	5.1 (4.0- 6.0)
5TI79	5/16-5/24/79	50	9	18.0	29	22.36	7.4 (5.6- 9.1)
2PO85	5/16-6/08/85	189	63	33.3	178	27.92	8.0 (4.0-11.7)
4MF81	5/20-5/24/81	80	31	38.8	80	18.38	10.0 (4.2-15.0)
3SH81	5/20-5/28/81	57	17	29.8	58	21.38	9.1 (3.7-13.8)
2DA82	5/21-5/31/82	62	23	37.1	160	41.80	7.6 (4.2-12.0)
1CH83	5/21-5/30/83	62	33	53.2	74	11.52	8.0 (5.0-11.5)
Totals		1123	262		1046		
Mean				23.3		--	6.6 (2.7-15.0)

Table 2.--Data on *Gadus macrocephalus* larvae in the western Gulf of Alaska grouped by biweekly intervals, April 1-June 8.

Sampling dates	Number of bongo stations	Stations with cod larvae number	Stations with cod larvae percentage	Number of larvae	Mean number per positive station	Catch per 10 m^2	Length (mm SL) mean (range)
4/01-4/15	263	19	7.2	46	2.42	13.18	4.3 (3.0- 6.0)
4/16-4/30	280	52	18.6	300	5.77	33.76	4.3 (2.7- 4.0)
5/01-5/15	84	18	21.4	122	6.78	27.01	4.7 (3.3- 6.0)
5/16-5/31	448	165	36.8	516	3.13	21.81	8.3 (3.7-15.0)
6/01-6/08	48	8	16.7	62	7.75	73.00	8.5 (5.1-11.7)
Totals	1123	262		1046			
Mean			23.3		3.99	--	6.6 (2.7-15.0)

Table 3.--Vertical distribution of *Gadus macrocephalus* larvae based on MOCNESS sampling during 2MF86 (May 2-19, 1986). At each station 7 or 8 depth intervals were generally sampled. Samples were taken at 15 m intervals from the surface to 60 m, and at various intervals from 60-230 m. Station locations are listed in Appendix Table 1.

Station	Time (GMT)	Depth intervals containing larvae (m)	Numbers of larvae	Numbers per 1000 m^3	Length (mm SL) mean (range)
78	1546	0-15	8	42.6	3.8 (3.0-5.3)
80	0406	0-15	1	9.1	6.4 --
		15-30	1	8.3	4.7 --
95B	0644*	15-30	1	7.2	5.0 --
120	2151	30-45	1	8.8	5.0 --
121	0600	30-45	1	7.7	5.0 --
122	1153	30-45	1	9.6	7.2 --
125A	1740	15-30	1	10.7	-- --
		30-45	2	16.4	6.6 (5.0-8.3)
		100-150	1	2.4	3.1 --
147	0816*	0-15	68	416.9	4.5 (3.9-5.2)
		15-30	369	1958.6	4.1 (3.5-5.1)
		30-45	97	861.4	3.9 (3.1-4.9)
		45-60	3	46.0	4.0 --
		80-100	1	6.1	3.4 --
157	0311	0-15	33	213.6	4.3 (3.4-5.2)
		15-30	54	249.4	4.2 (3.0-5.2)
		30-45	2	11.3	-- --
		45-60	1	9.7	3.1 --
166	2351	0-15	16	188.2	6.3 (3.7-9.8)
		30-45	1	16.8	7.6 --
		45-60	1	11.1	4.1 --

* Sample taken at night.

Table 4.--Summary of data on *Gadus macrocephalus* larvae from MOCNESS sampling on cruise 2MF86.

Depth (m)	Number of tows with cod larvae	Number of cod larvae	Number per 1000 m^3	Length (mm SL) mean (range)
0 - 15	4	118	63.0	4.7 (3.0-9.8)
15 - 30	6	434	236.9	4.1 (3.0-5.2)
30 - 45	7	105	55.0	4.2 (3.1-8.3)
45 - 60	3	5	2.2	3.8 (3.1-4.1)
60 - 80	0	0	0.0	-- --
80 -100	1	1	0.4	3.4 --
100-150	1	1	0.2	3.1 --
150-230	0	0	0.0	-- --
Totals	22	664		
Mean			100	4.2

Table 5.--Depth distribution of *Gadus macrocephalus* larvae from two MOCNESS tows done at one location near Sutwik Island, May 17-18, 1986, cruise 2MF86.

Depth interval (m)	No. of larvae measured	Mean length (mm SL)
0- 15	82	5.0
15- 30	90	4.1
30- 45	50	3.9
45- 60	3	3.7
80-100	1	3.4
Total	229	
Mean		4.4

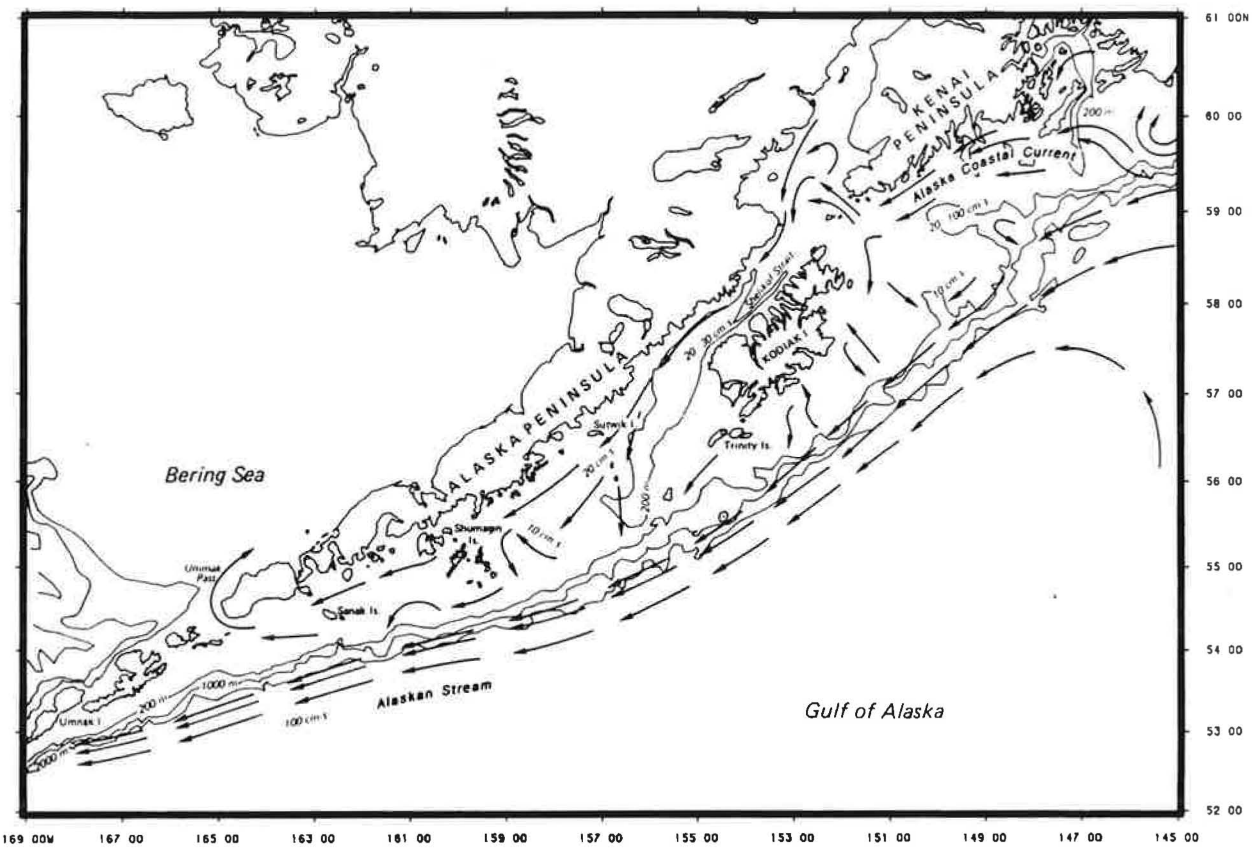


Figure 1. Near surface currents and some geographic and bathygraphic features of the western Gulf of Alaska. Currents based on Reed and Schumacher (1986).

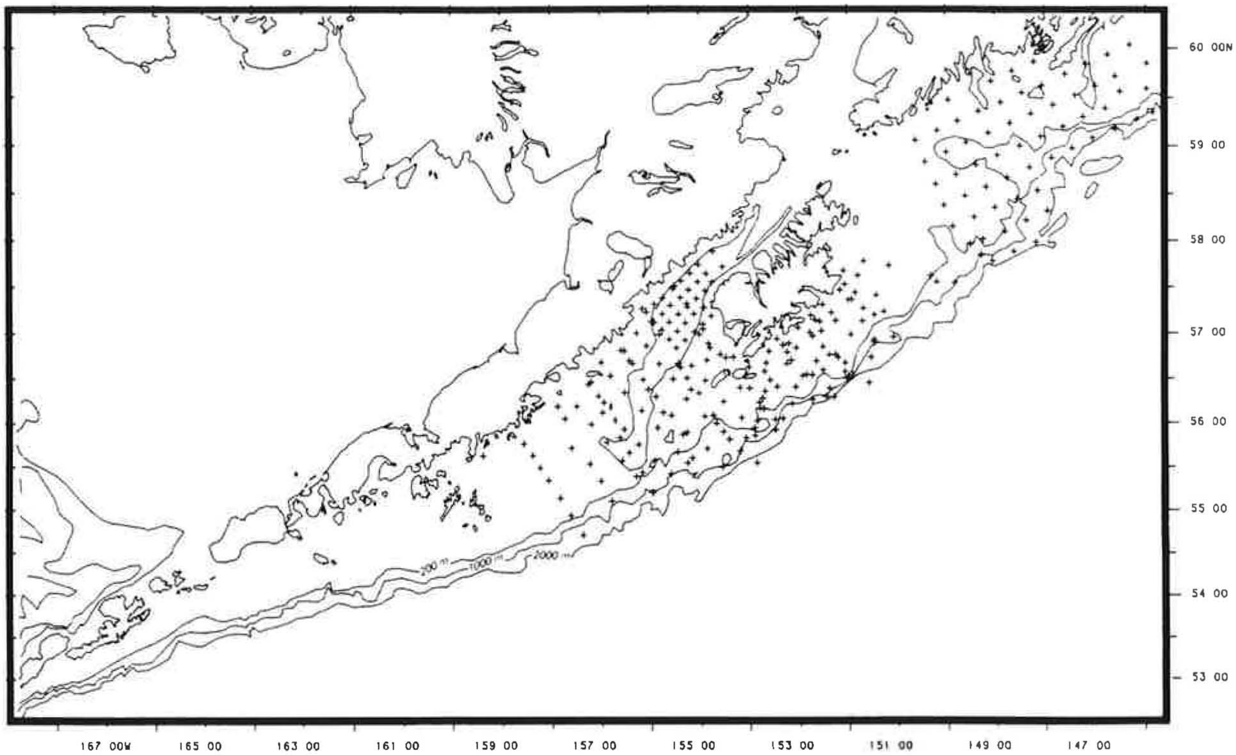


Figure 2a. Location of bongo stations, April 1-15.

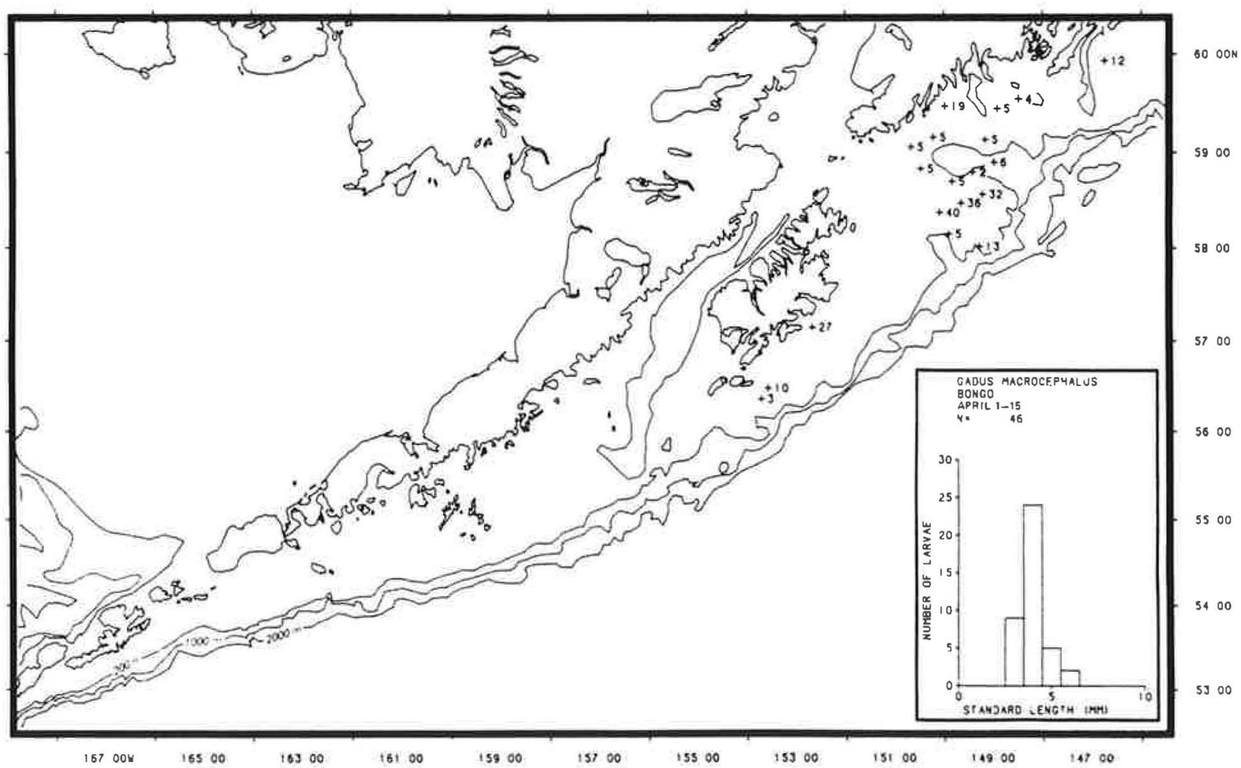


Figure 2b. Catch/$10m^2$ of Pacific cod larvae, April 1-15.

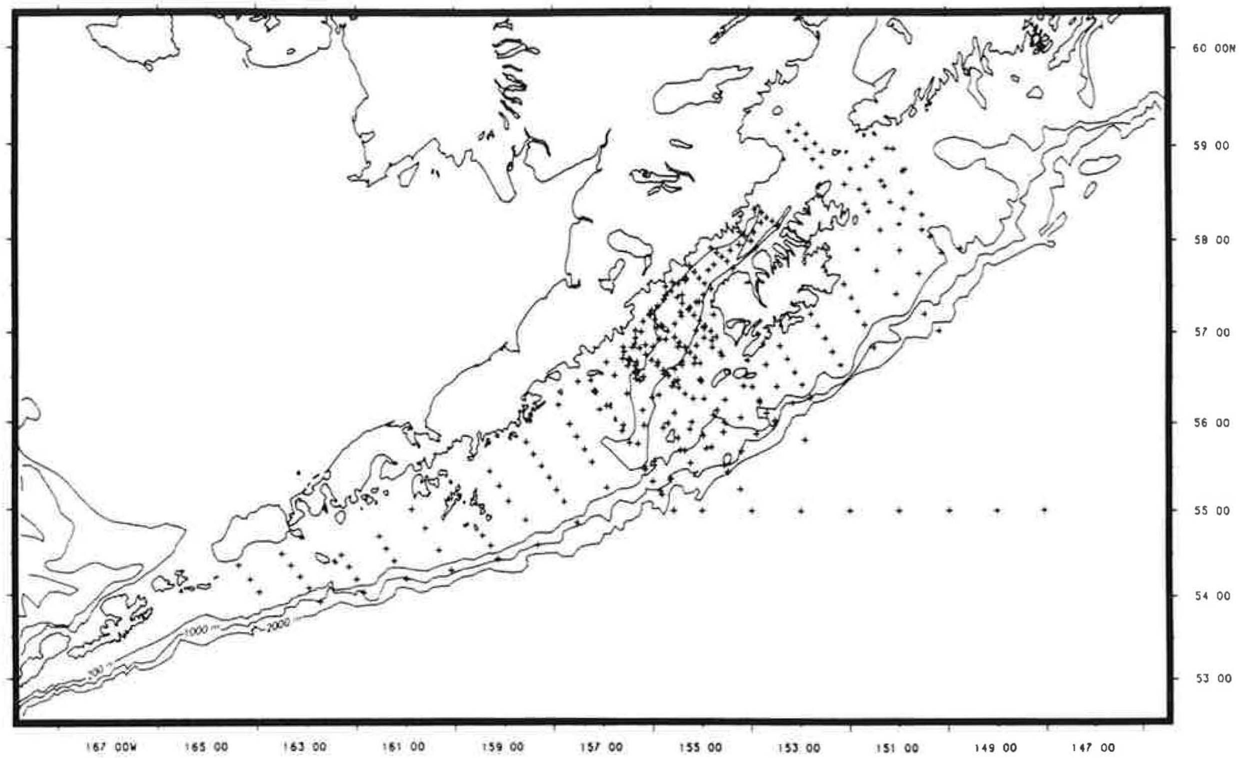


Figure 3a. Location of bongo stations, April 16-30.

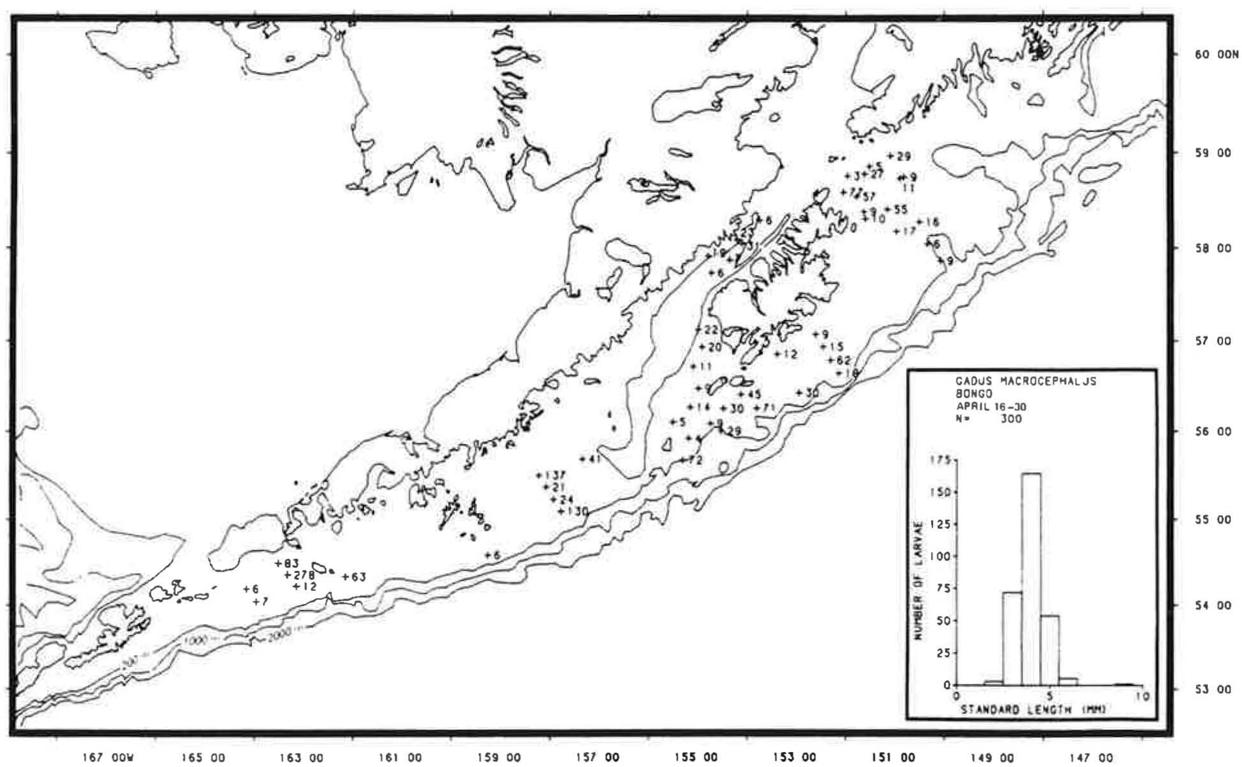


Figure 3b. Catch/10m^2 of Pacific cod larvae, April 16-30.

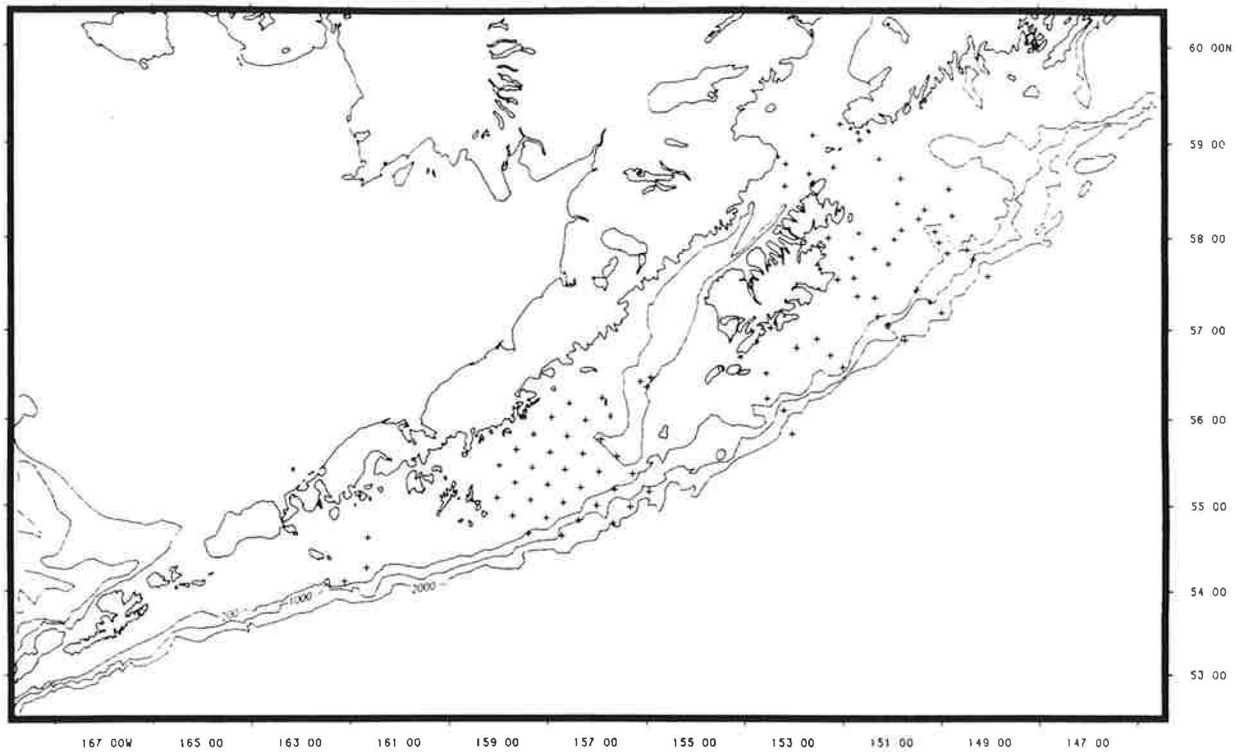


Figure 4a. Location of bongo stations, May 1-15.

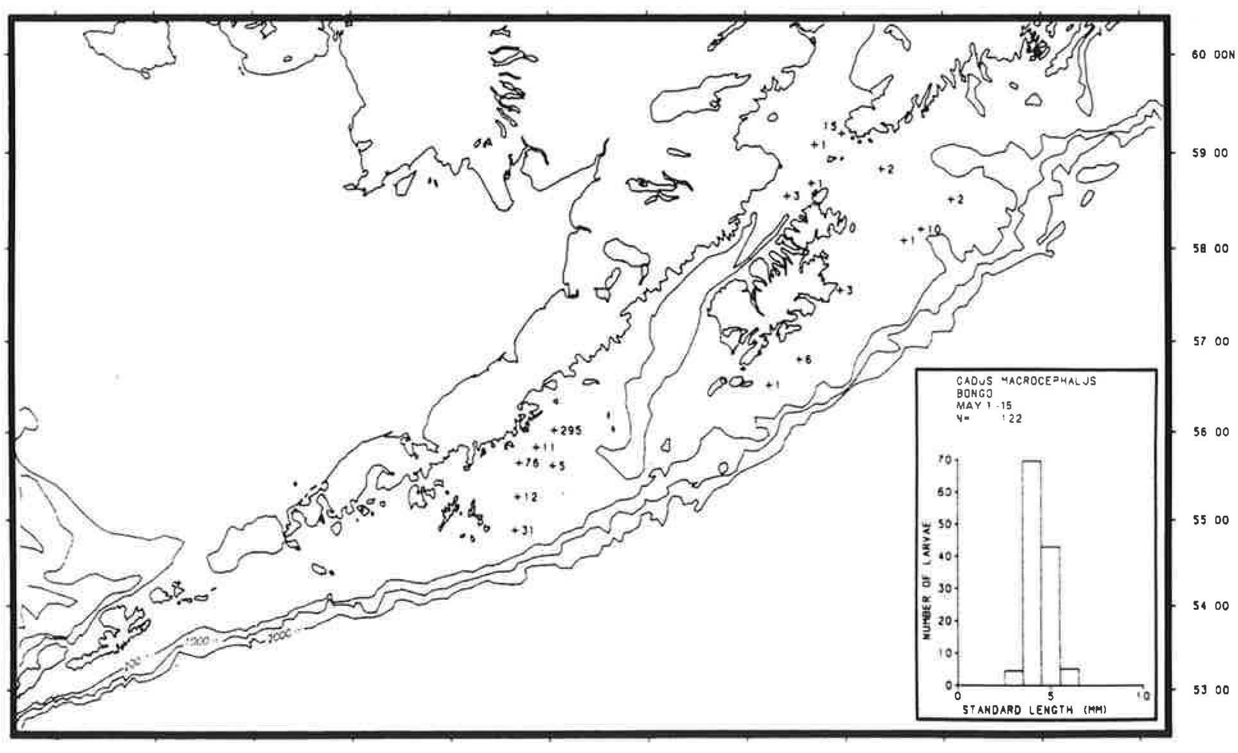


Figure 4b. Catch/$10m^2$ of Pacific cod larvae, May 1-15.

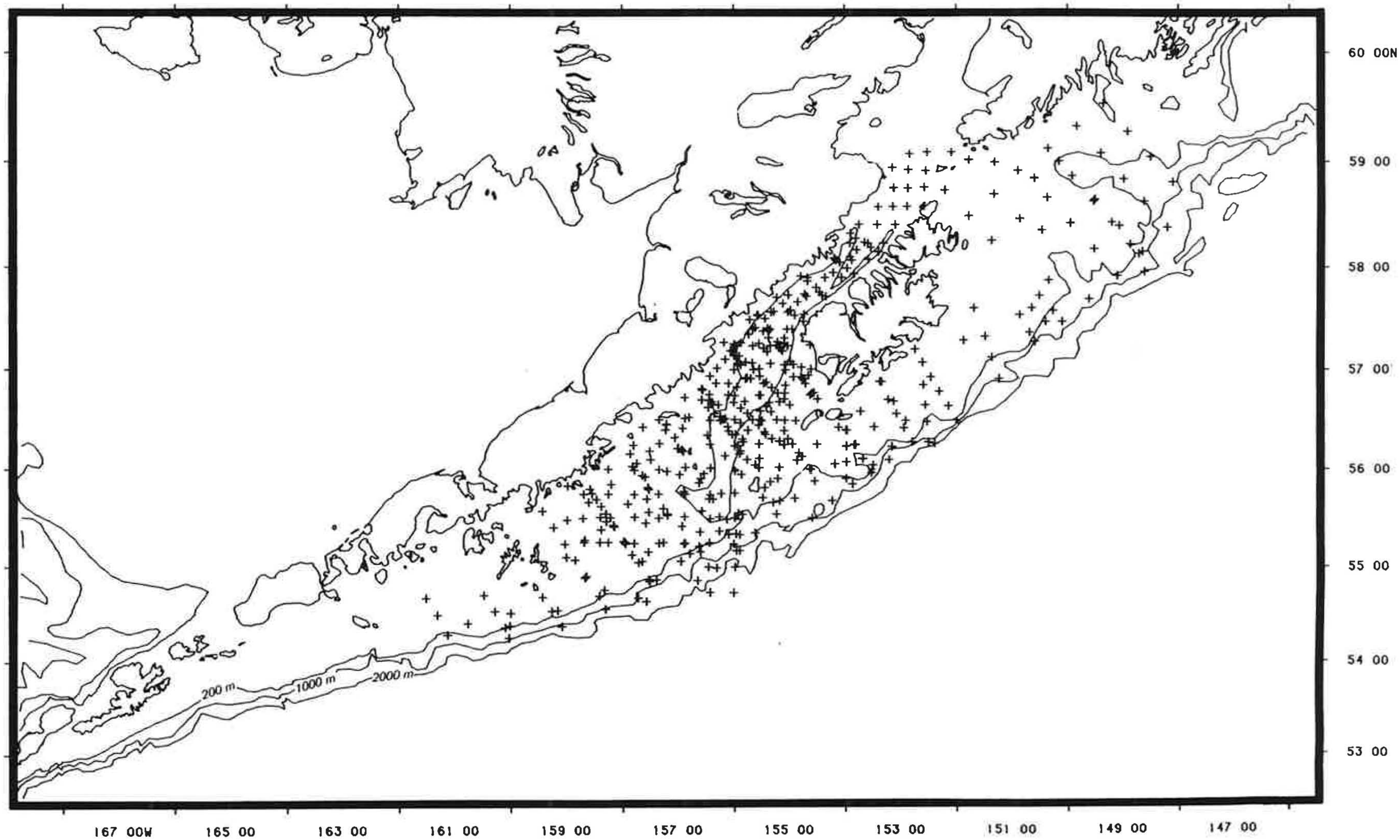


Figure 5a. Location of bongo stations, May 16-31.

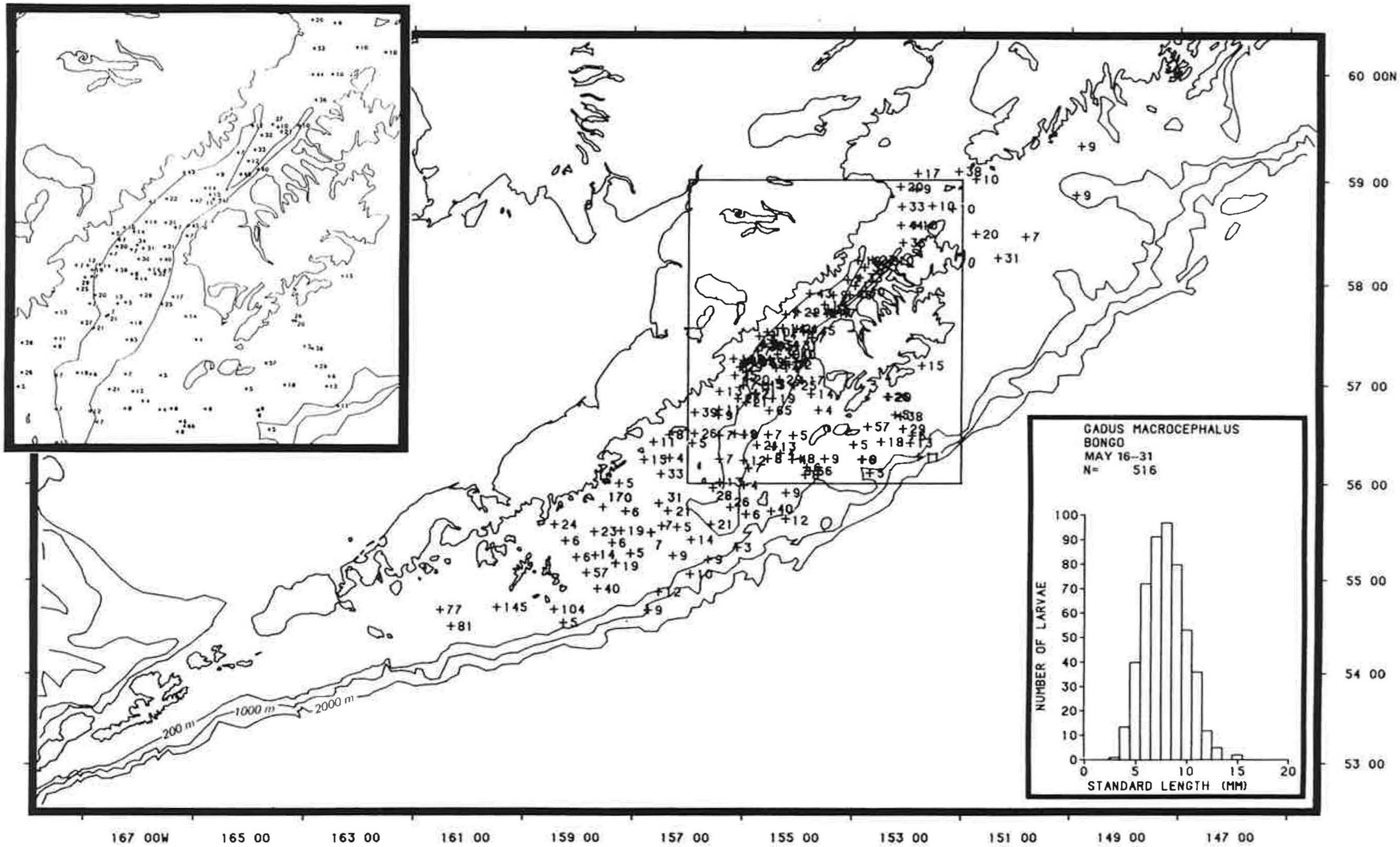


Figure 5b. Catch/10m^2 of Pacific cod larvae, May 16-31. Inset is enlargement of Shelikof Strait area.

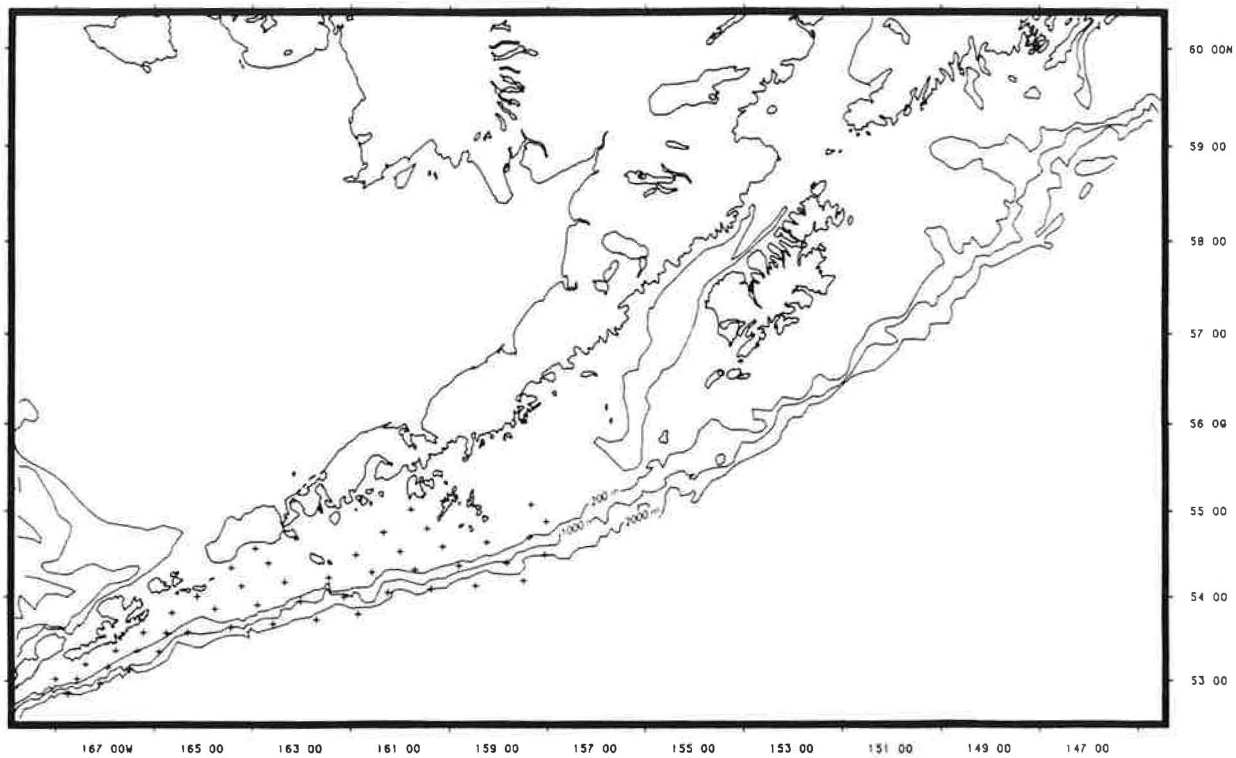


Figure 6a. Location of bongo stations, June 1-8.

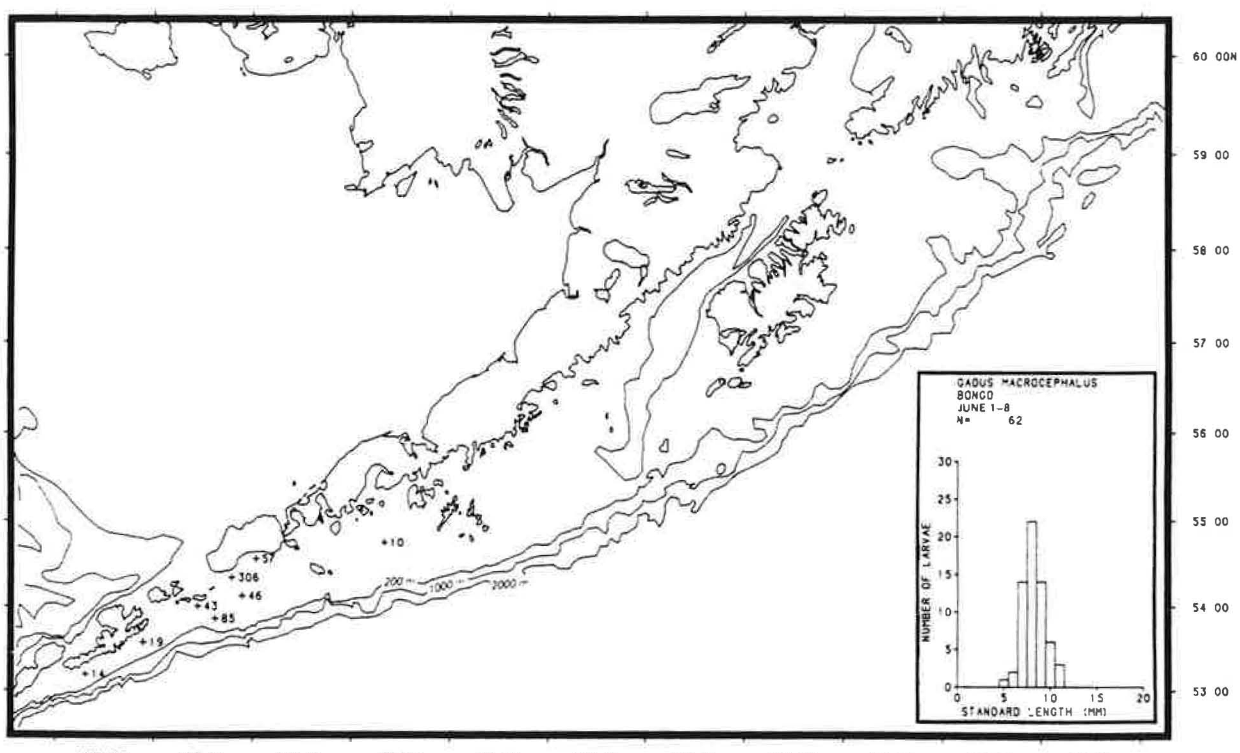


Figure 6b. Catch/10m^2 of Pacific cod larvae, June 1-8.

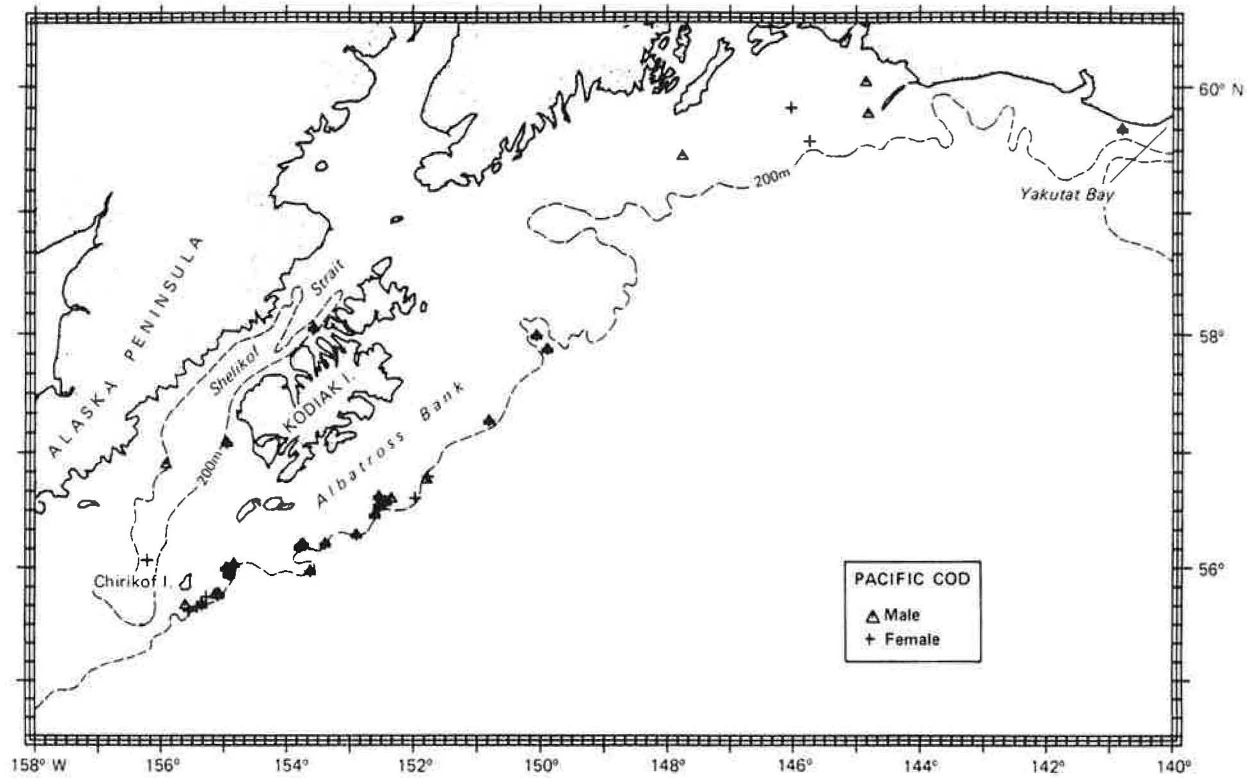
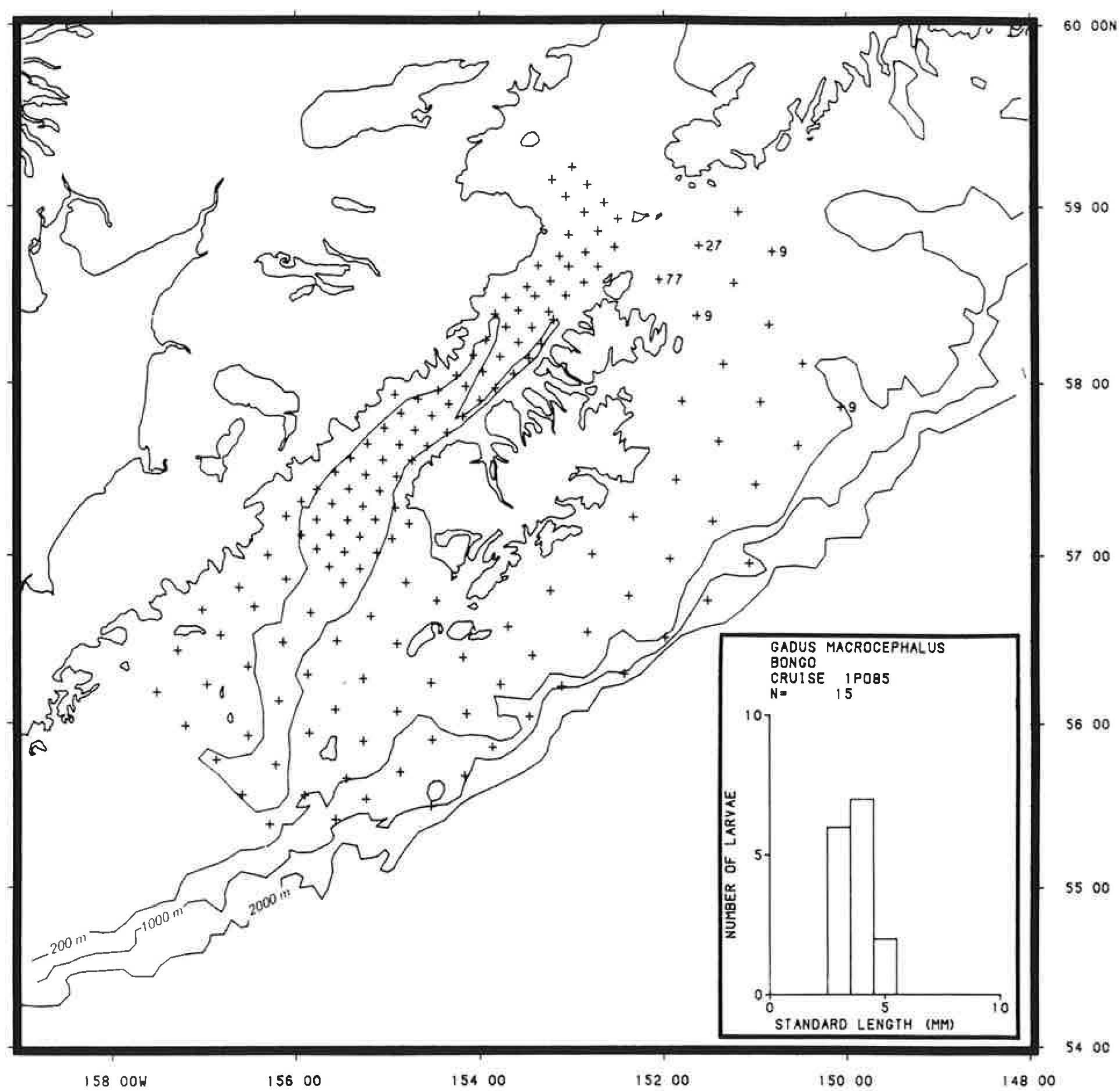


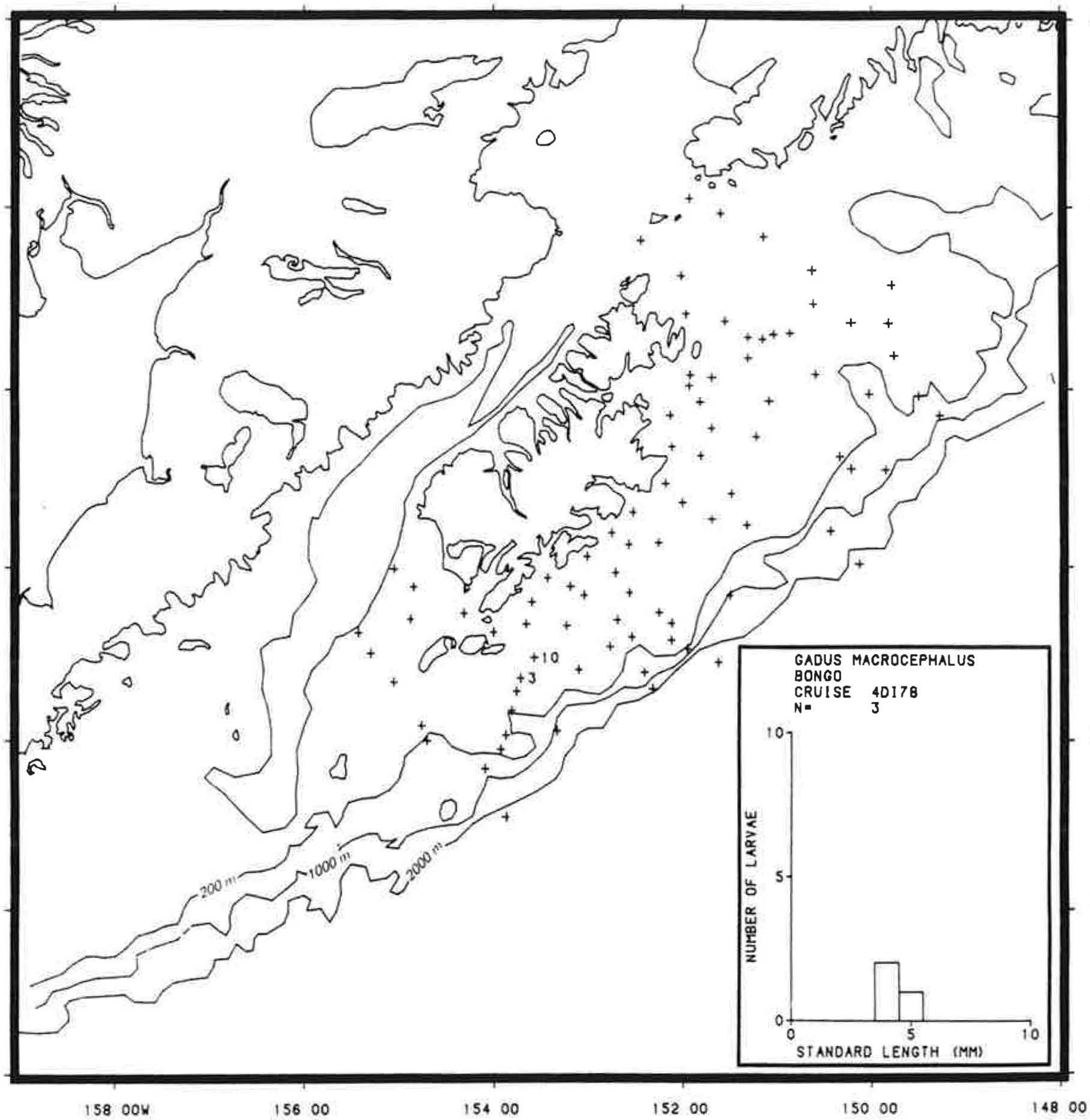
Figure 7. Location where Pacific cod in spawning condition have been observed in the Gulf of Alaska (Hirschberger and Smith 1983).

Appendix Table 1.--Date, time, and location of MOCNESS sampling stations on cruise 2MF86, (May 2-19, 1986).

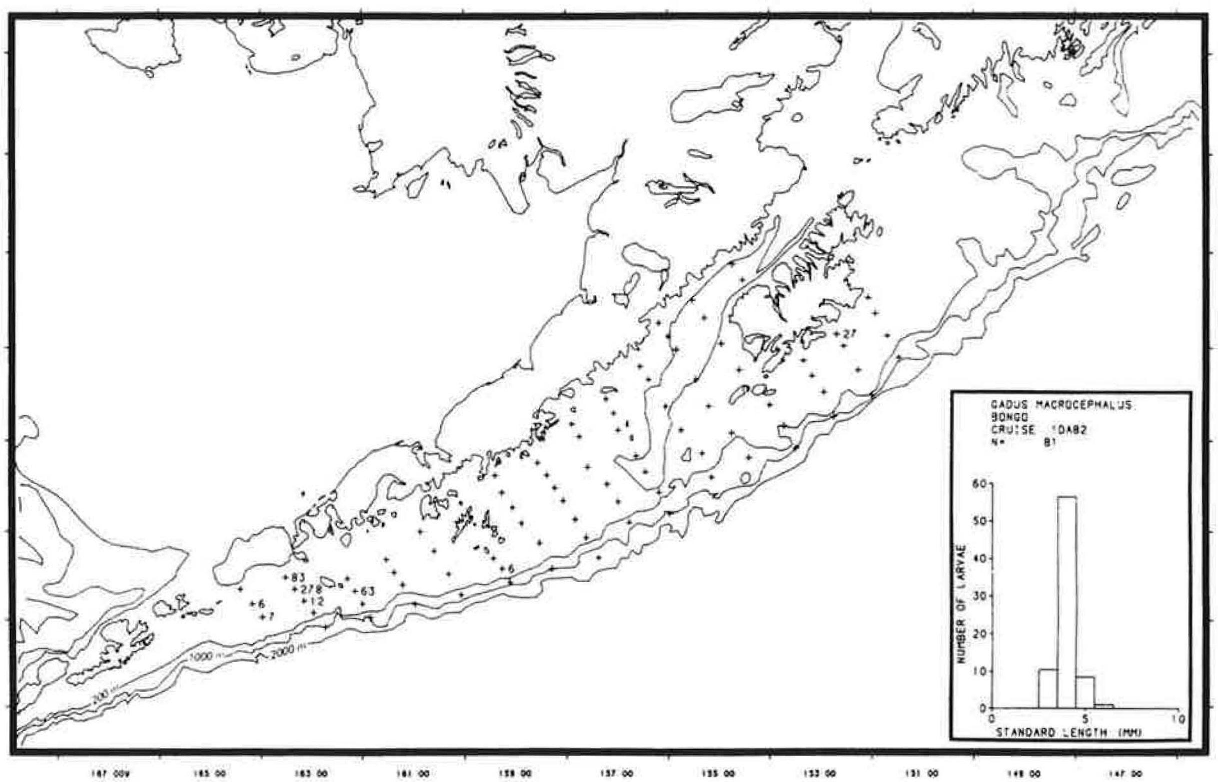
Station	Date	Time (GMT)	Latitude (°N)	Longitude (°W)
78	May 8	1546	56 59.2	155 58.1
79	May 8	2156	57 00.9	155 58.2
80	May 9	0406	57 00.9	155 58.2
81	May 9	0935	57 03.0	155 56.3
91	May 10	1545	57 01.6	155 44.2
93	May 10	2141	56 59.8	155 41.3
95A	May 11	0411	56 55.1	155 37.3
95B	May 11	0644	56 53.9	155 41.3
119	May 13	1810	56 37.3	156 24.2
120	May 13	2151	56 37.3	156 24.2
121	May 16	0600	56 37.3	156 24.2
122	May 15	1153	55 56.8	156 23.0
125A	May 15	1740	55 56.9	156 23.6
147	May 17	0816	56 21.0	156 53.3
157	May 18	0311	56 21.1	156 53.0
166	May 18	2351	57 40.6	155 09.8



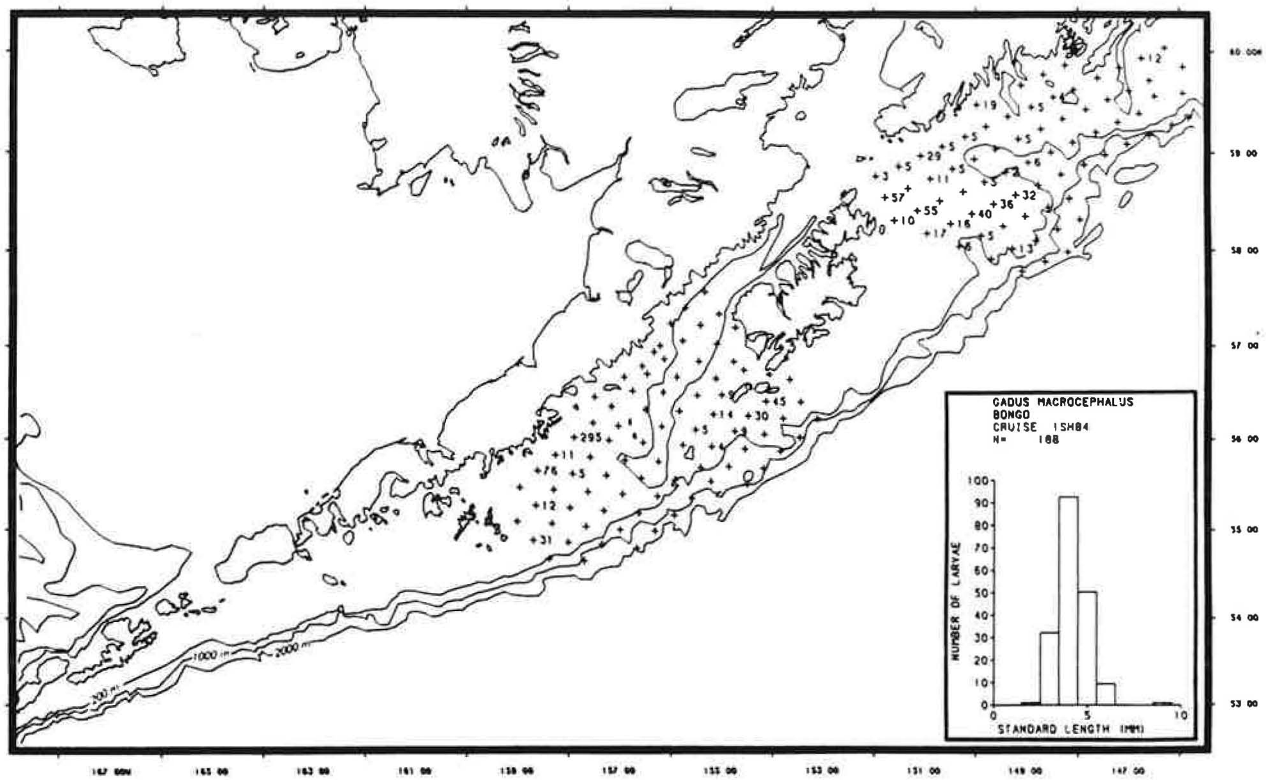
Appendix Figure 1. Station locations and catch/$10m^2$, cruise 1PO85.



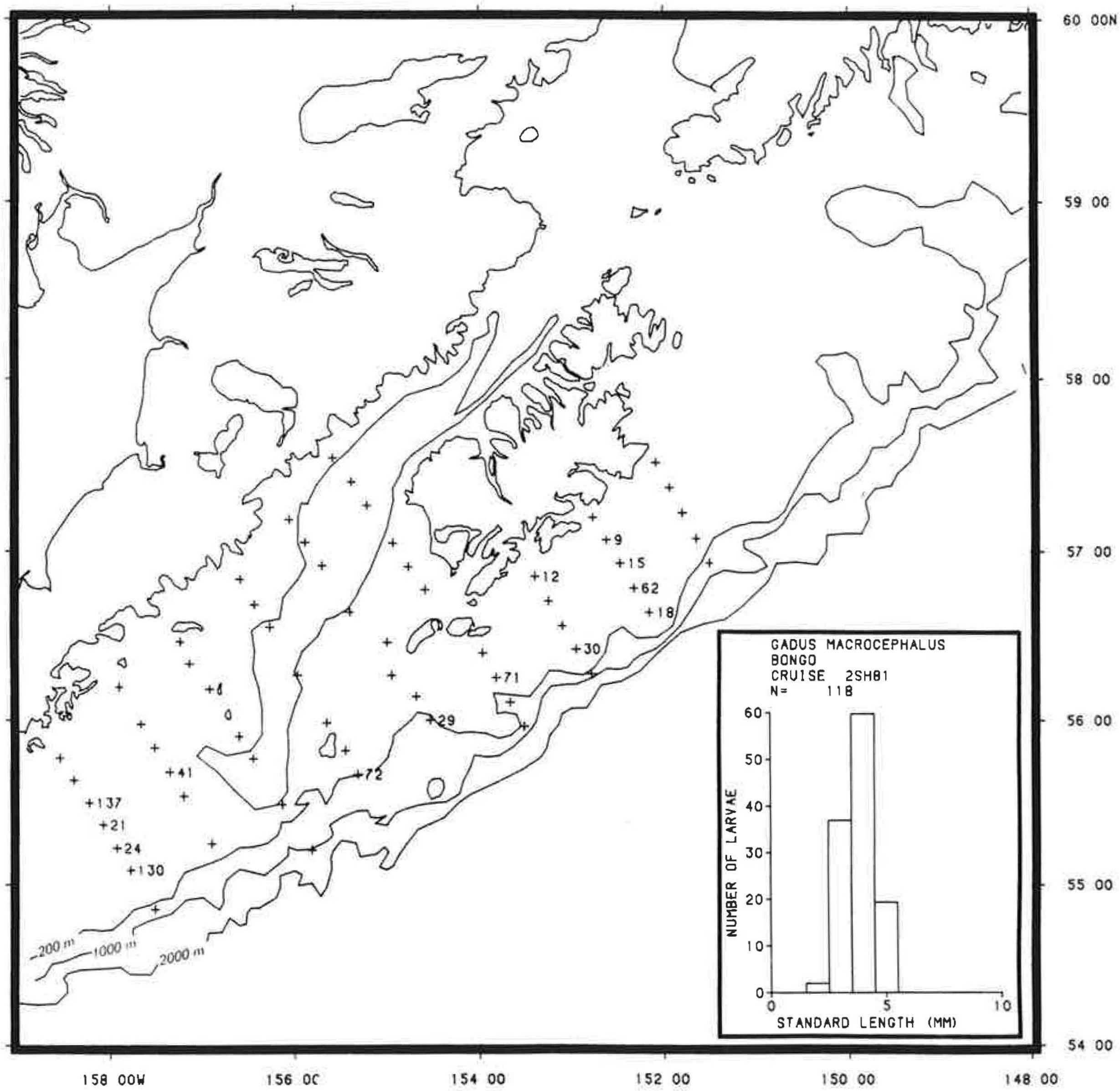
Appendix Figure 2. Station locations and catch/10m^2, cruise 4DI78.



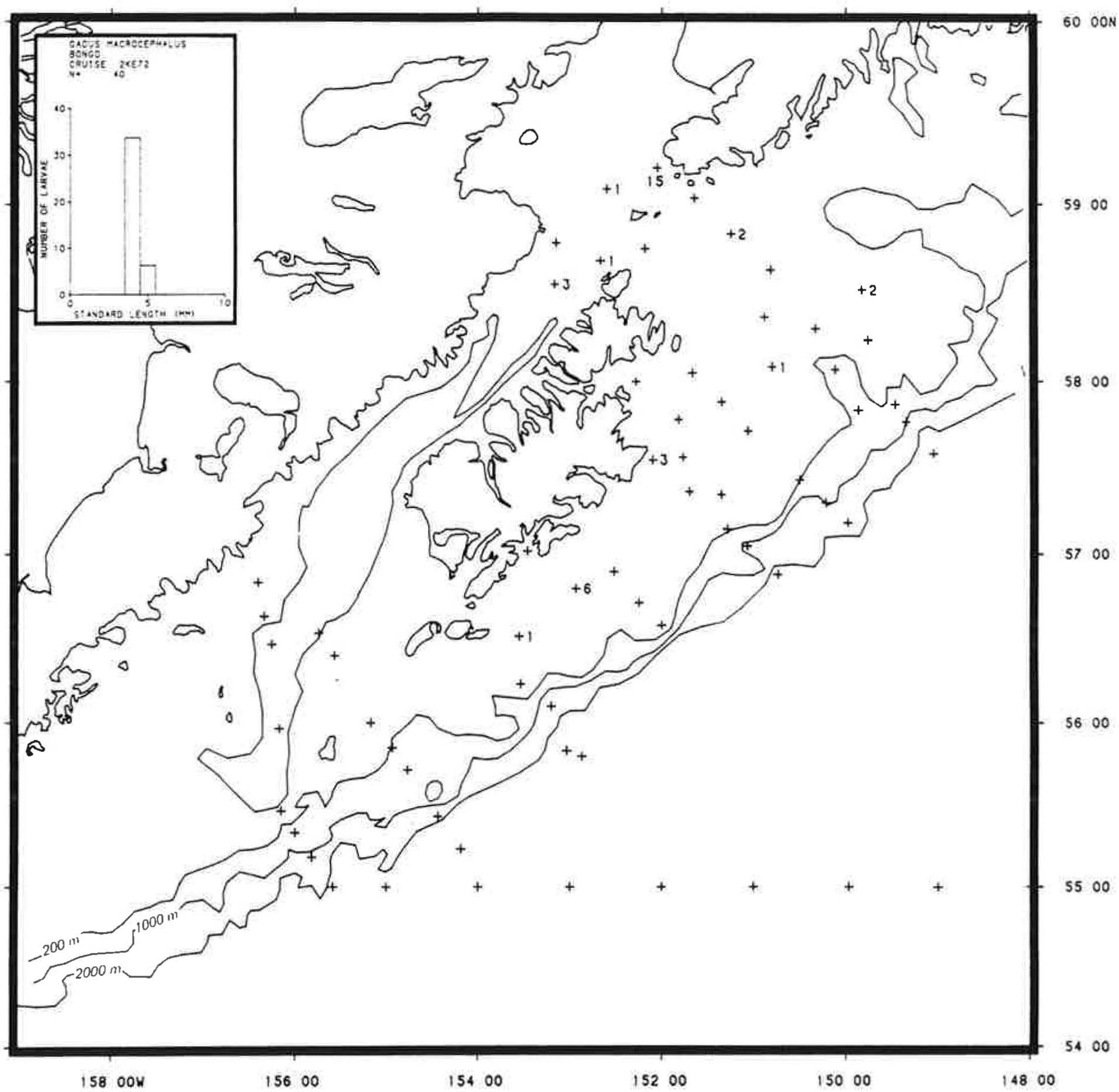
Appendix Figure 3. Station locations and catch/10m^2, cruise 1DA82.



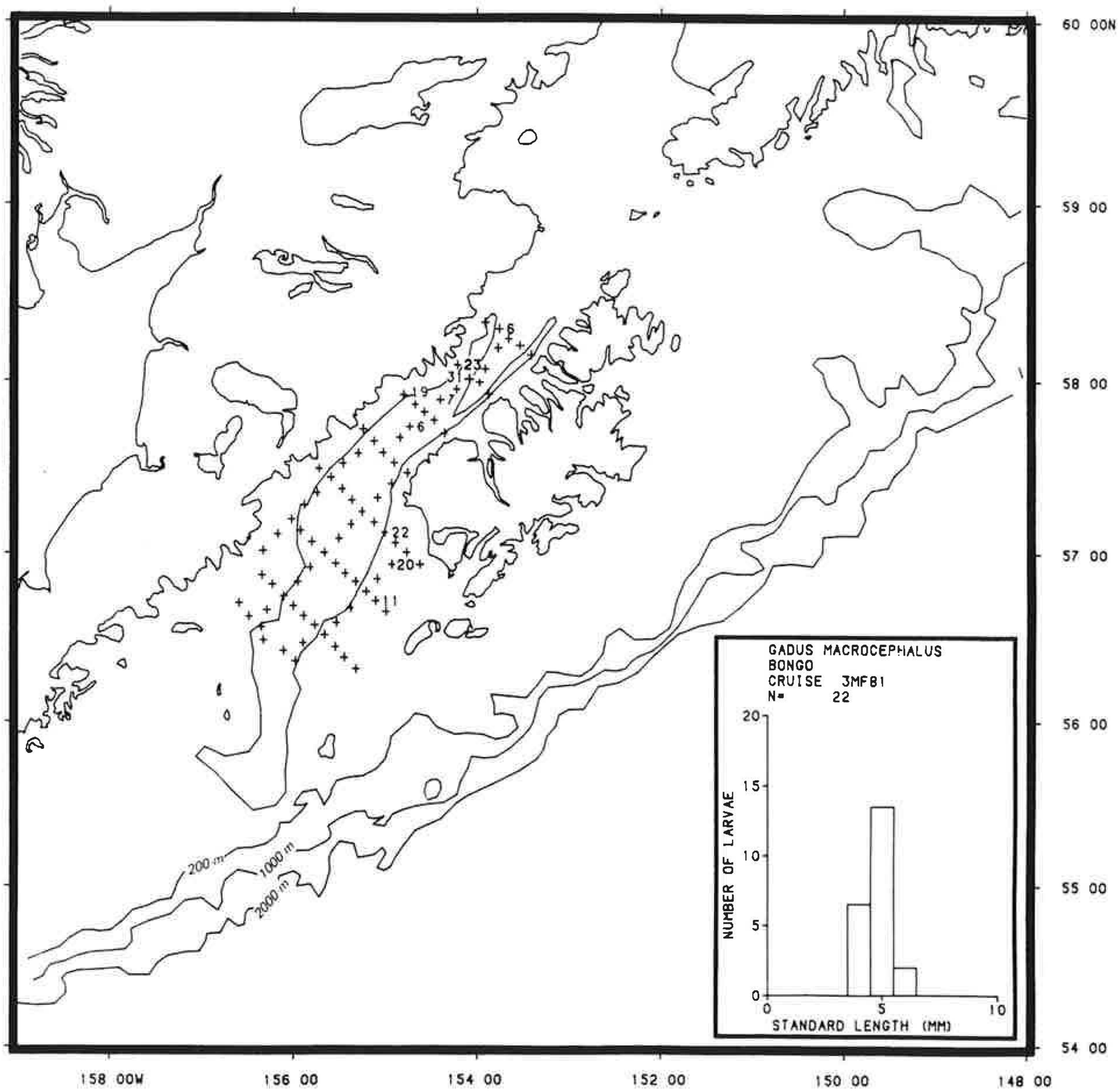
Appendix Figure 4. Station locations and catch/10m^2, cruise 1SH84.



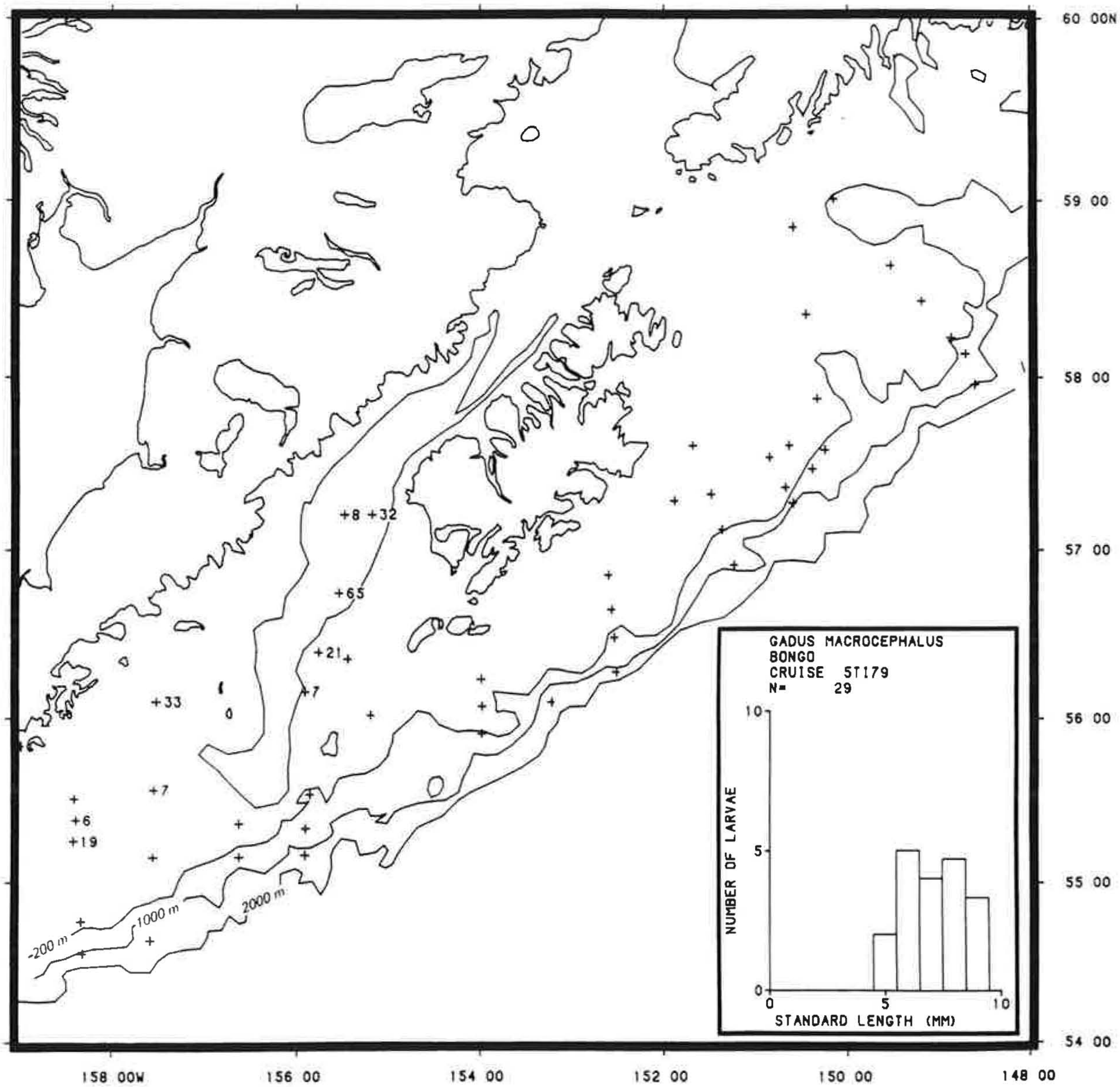
Appendix Figure 5. Station locations and catch/10m^2, cruise 2SH81.



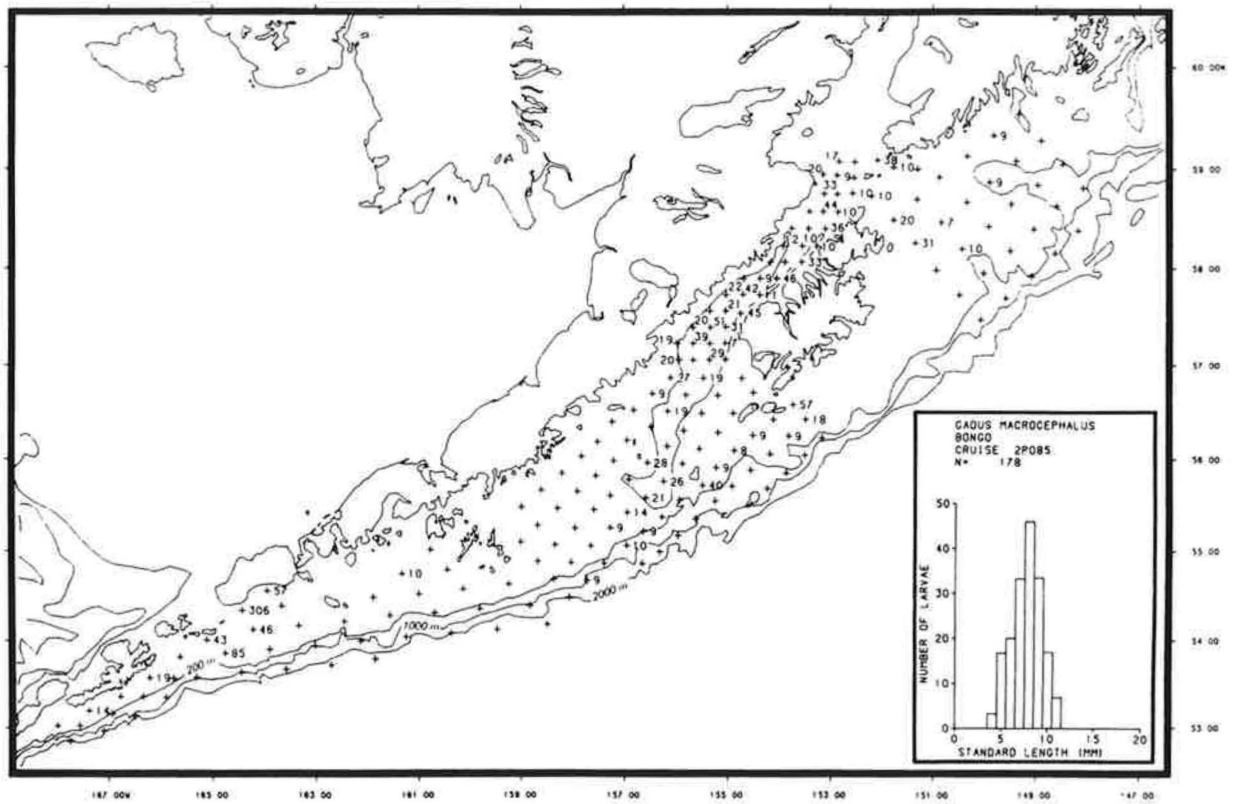
Appendix Figure 6. Station locations and catch/10m^2, cruise 2KE72.



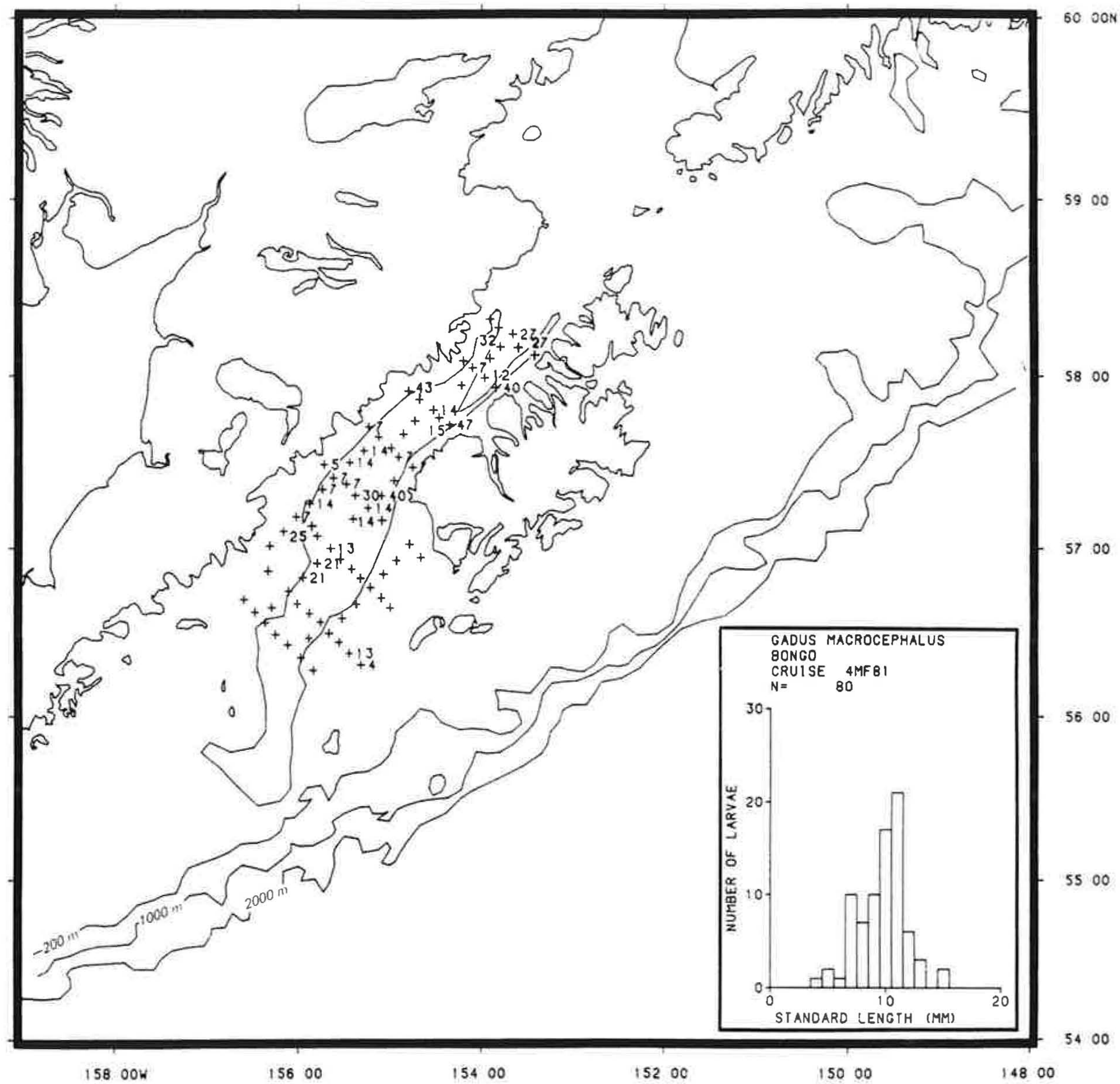
Appendix Figure 7. Station locations and catch/10m^2, cruise 3MF81.



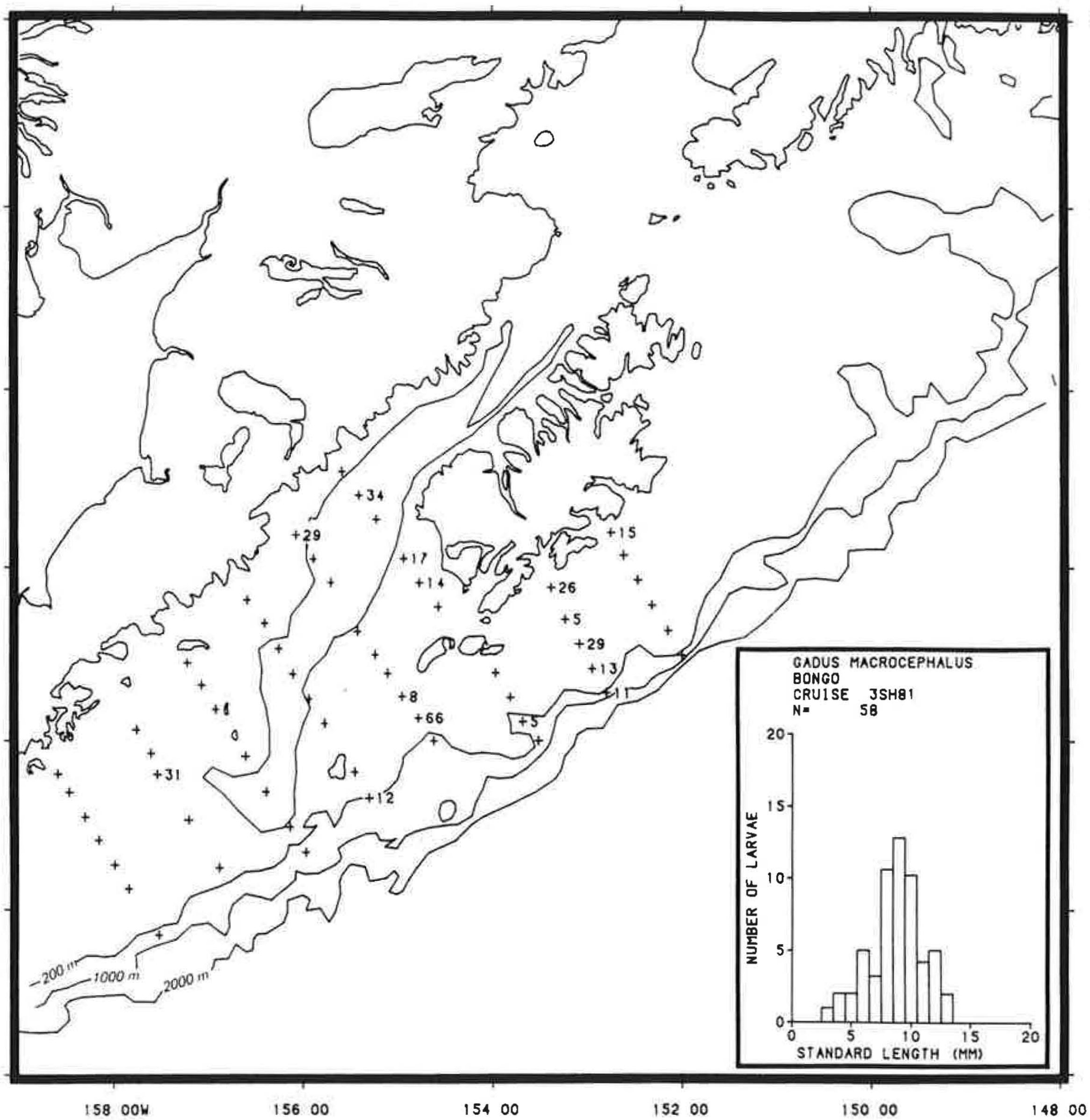
Appendix Figure 8. Station locations and catch/10m^2, cruise 5TI79.



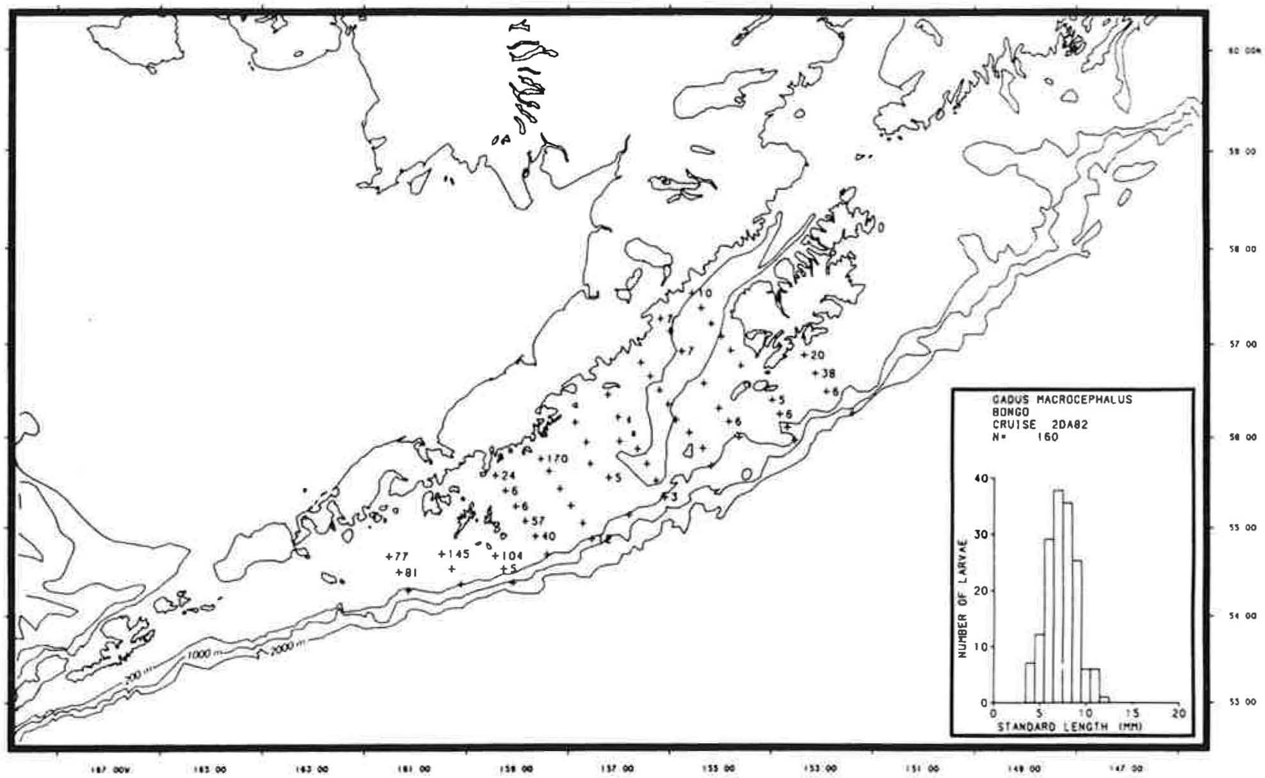
Appendix Figure 9. Station locations and catch/$10m^2$, cruise 2PO85.



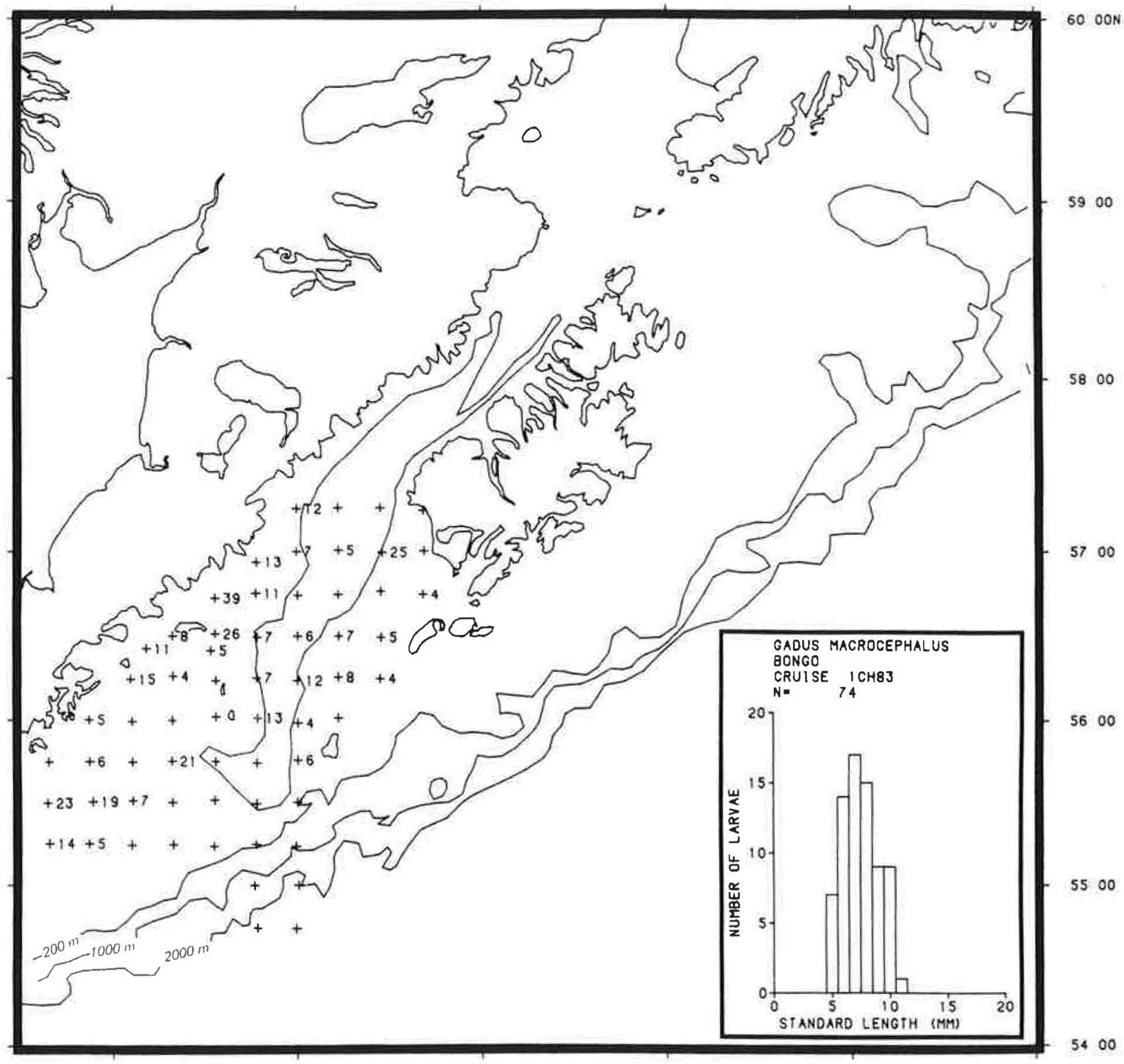
Appendix Figure 10. Station locations and catch/10m^2, cruise 4MF81.



Appendix Figure 11. Station locations and catch/10m^2, cruise 3SH81.



Appendix Figure 12. Station locations and catch/10m^2, cruise 2DA82.



Appendix Figure 13. Station locations and catch/10m^2, cruise 1CH83.