Seasonal Changes of Inshore Fish Populations on Sturgeon and Roberts Bank, Fraser River Estuary British Columbia

D. K. Gordon and C. D. Levings

Department of Fisheries and Oceans
Fisheries Research Branch
West Vancouver Laboratory
4160 Marine Drive
West Vancouver, British Columbia V7V 1N6

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SEASONAL CHANGES OF INSHORE FISH POPULATIONS ON STURGEON AND ROBERTS BANK, FRASER RIVER ESTUARY BRITISH COLUMBIA

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D. K. Gordon and C. D. Levings

Department of Fisheries and Oceans

Fisheries Research Branch

West Vancouver Laboratory

4160 Marine Drive

West Vancouver, British Columbia V7V 1N6

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ABSTRACT

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Results of a beach seine sampling program at three low tide refuges on Sturgeon and Roberts Banks, Fraser River estuary, are presented. Twenty-seven fish species were taken at Iona Island, a sandflat site on northern Sturgeon Bank impacted by domestic sewage. Twenty-five species were caught at a reference location in a sandflat on southern Sturgeon Bank (Steveston pit). Catches were lower at Iona compared to Steveston, and there were some differences in community composition. Fifty-two fish species were observed in the eel grass habitats on Roberts Bank and catches were generally much higher compared to Iona and Steveston pit. Starry flounder (Platichthys stellatus), threespine stickleback (Gasterosteus aculeatus),herring (Clupea harengus pallasi), and shiner perch (Cymatogaster aggregata) were among the five most abundant species, as judged by CPUE, at both Iona and Steveston pit. Juvenile chinook salmon (Oncorhynchus tshawytscha) and Pacific staghorn sculpin (Leptocottus armatus) completed the ranking at Steveston and Iona, respectively. At Roberts Bank herring, sandlance (Ammodytes hexapterus), shiner perch, staghorn sculpin, and tubesnout (Aulorhynchus flavidus), were the most abundant species. Seasonal trends in catches on Sturgeon Bank appeared to be closely related to seasonal variation in temperature but at Roberts Bank there was greater variability implying that other factors were involved. Dissolved oxygen was consistently lower at Iona and may have affected the distribution of some species. Rapid changes in species composition and abundance during the summer at all three sites was related to influxes of juveniles of various species. The inter-tidal habitats, both vegetated and non-vegetated, have a substantial capacity for fish rearing and as such deserve further investigation and continuing protection from disruption.

Key Words: Fraser River estuary, sand flats, Zostera marina, juvenile demersal fish, juvenile salmonids, seasonal changes.

RÉSUMÉ

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Les auteurs présentent les résultats d'un programme d'échantillonnage à la senne de rivage dans trois refuges de basses eaux des bancs Sturgeon et Roberts, dans l'estuaire du Fraser. Vingt-sept espèces de poisson ont été capturées à la hauteur de l'île Iona, vey de la partie nord du banc Sturgeon qui reçoit des eaux usées domestiques. À un site étalon sur un vey au sud du banc Sturgeon (Steveston), 25 espèces ont été pêchées. Les prises étaient moins nombreuses à Iona qu'à Steveston et il existait une certaine différence dans la composition des communautés. Au banc Roberts, les auteurs ont observé 52 espèces dans les herbiers de zostères et les captures y étaient généralement plus élevées qu'à Iona et à Steveston. À ces deux endroits, la plie étoilée (Platichthys stellatus), l'épinoche à trois épines (Gasterosteus aculeatus), le hareng (Clupea harengus pallasi) et le perch-méné (Cymatogaster aggregata) figuraient parmi les espèces les plus abondantes selon les PUE. En cinquième place venaient le saumon quinnat juvénile (Oncorhynchus tshawytscha) à Iona et le chabot armé (Leptocottus armatus) à Steveston. Au banc Roberts, le hareng, le lançon gourdeau (Ammodytes hexapterus), le perche-méné le chabot armé et la trompe (Aulorhynchus flavidus) étaient les espèces les plus abondantes. Les tendances saisonnières des prises au banc Sturgeon semblaient être liées aux variations saisonnières de la température mais, au banc Roberts, les variations étaient plus prononcées, ce qui porte à croire à la présence d'autres facteurs. À Inoa, la concentration d'oxygène dissous était uniformément inférieure et peut avoir influé sur la répartition de certaines espèces. Des changements rapides de la composition des espèces et de leur abondance pendant l'été aux trois sites ont été reliés à l'apport de juvéniles de différentes espèces. Les habitats intertidaux, couverts ou non de végétation, possèdent une grande capacité comme aire de croissance du poisson et, à ce titre, méritent des études plus poussées et une protection permanente contre toute altération.

Mots-clés: estuaire du fleuve Fraser, veys, Zostera marina, poissons démersaux juvéniles, salmonidés juvéniles, variations saisonnières.

INTRODUCTION

A preliminary study (Greer et al. 1980) showed significant catches of juvenile salmonids and other species at low tide refuges on the Fraser river estuary at Sturgeon and Roberts Bank, British Columbia. As this estuary is adjacent to Vancouver, the largest city on the west coast of Canada, such information is highly relevant to fish habitat management in an urban setting. A detailed sampling program was established in 1980 to examine fish use and the comparative ecology of three contrasting environments in this area to provide further data. The foreshore banks of the Fraser River estuary (Fig. 1) are extremely difficult to work on because of their size (14,000 ha) and exposure to the Strait of Georgia. Therefore 3 representative areas were chosen for detailed studies at low tide when a restricted body of water could be sampled. These were as follows: Roberts Bank pit: a dredge borrow area in eelgrass beds between the Tsawwassen ferry terminal causeway and the Westshore terminal causeway: Steveston Pit, located in a relict river channel through a sandflat on southern Sturgeon Bank: Iona pit, the seaward end of a man-made channel receiving domestic sewage discharged onto northern Sturgeon Bank. Data pertaining to environmental parameters and fish catches in beach seines were collected on 27 trips between March 1980 and July 1981. The original data are tabulated in a data report (Conlin et al. 1982). The present report provides a summary of the fish catch for all species sampled. In addition the results of statistical analyses of catches of the major species and environmental data are discussed.

Previous intertidal fish surveys in the northeast Pacific (e.g. Miller et al. 1980) used stations at more open coast environments and a quarterly sampling pattern. Our data therefore provide the first detailed information on temporal change in inshore fish communities in sheltered brackish environments on the British Columbia coast, specifically the southern Strait of Georgia and the lower Fraser River estuary.

DESCRIPTION OF THE STUDY AREAS

Roberts and Sturgeon Bank are major foreshore areas of the lower Fraser estuary that are open to the Strait of Georgia (Fig. 1). Sea dykes constructed in the late 1800's on Lulu, Sea, and Westham Islands, and the adjacent mainland preclude the movement of water at high tide over the seaward portions of the islands. The effective intertidal area of the Banks is currently approximately 14000 ha. Because of this extremely large expanse, we decided to sample only at low tide (<1 m above chart datum) when much smaller areas contain water. These low tide refuges, or pits, are the focus of the habitat studies reported herein.

Sturgeon Bank, except for a fringe of marsh 1-2 km seaward of the dykes is characterized by sand of relatively uniform diameter (500 μm) (Luternauer 1980). Other than adjacent to the marsh and near the Iona Island sewage outfall mud is uncommon. Two general sites on Sturgeon Bank were sampled. On southern Sturgeon Bank a relict river channel, named Steveston pit, was sampled. A sandbar demarcating the southwest shore of the channel begins to dry when tide levels fall to approximately 1.0 m in relation to chart datum (O.D.) (Fig. 1). The northeast and south shores begin to dry at 0 m O.D. A system of shallow channels forms a sill separating the pit from the Strait of Georgia at low tide. The deepest part of the channel is adjacent to the southwest sandbar, where bottom is located at about - 4.0 m O.D. Detailed bathymetric data are presented elsewhere (Conlin et al. 1982). When tidal levels permitted up to 6 stations (Fig. 1) were sampled at this location. On the northern part of Sturgeon Bank, the seaward portion of a man-made trench connected with the Iona Island sewage treatment plant was sampled (Fig. 1).

The third location studied was on southern Roberts Bank, between the Westshore Terminal causeway and the Tsawwassen ferry terminal causeway. Stations at this area were all on man-made beaches or in natural substrates that had been affected by industrial activity. Two stations were on the Westshore Causeway and another was on the ferry terminal structure. The remaining 5 stations were around the edge of the borrow pit formed by dredging to construct the Westshore Terminal. The borrow pit stations could only be sampled when tide levels were <0.5 m O D. In contrast to those on Sturgeon Bank, all Roberts Bank stations were either in or in close proximity to vegetation, namely eel grass (*Zostera marina*). Mean plant density on a transect across Roberts Bank and between the causeways at approximately the 1.0 m elevation was 136 turions m^{-2} in July 1981 (Levings and Gordon, unpublished data). These data are representative of the beach seine stations around the borrow pit. Eel grass at the lower sectors of stations on the Westshore causeway and the ferry terminal was sparser.

Tidal currents reach considerable velocities at the study areas, especially on large amplitude tides. Available data show that surface currents at Steveston pit and on Roberts Bank can range from 200 to 600 cm s^{-1} (Levings, unpublished data and WCHL 1981). Bottom currents at both sites were considerably weaker at the time these measurements were made but vary dramatically with tidal regime. On large ebb and flood tides current velocities at Steveston pit were sufficient to put sand in suspension, as observed in drift samples (Levings 1982).

METHODS

A 14.7 m beach seine was used, with 4.9 m wings (1 cm stretched mesh), bunt 4.9 m (3 mm mesh), and depth 3.5 m. This net was estimated to sample approximately 350 m^2. Except at stations where the beach gradient was steep, where outboard motor boats were used, the net was deployed by personnel wearing chest waders. The distance the net was pulled off the beach and subsequently retrieved varied from about 5 to 10 m. Samples were obtained at most of the sites approximately every 2 weeks, except during the winter months (October to March) when weather and darkness prevented frequent trips. Because of changes in tidal levels it was not possible to sample all stations on every trip. The work was scheduled so that the work occurred at tidal levels ± 2 h from the lowest tide of the day. However, at least 3 replicate seines were obtained at key locations on each sampling session. Complete information on stations sampled, dates, and times is presented elsewhere (Conlin et al. 1982.)

Whenever possible fish were identified in the field, counted, and released alive. Some specimens were fixed in 10% formalin for length/weight determination (Kotyk et al. 1983) as were fish that could not be identified without laboratory examination. Fork lengths of fish were measured to the nearest millimetre. Nomenclature for fish species follows Jean et al. (1981).

Salinity, temperature and dissolved oxygen (D.O.) measurements were made with the fish collections, usually from a depth of 25 cm. Replicates of 3 to 6 samples were usually obtained on each trip. Salinity estimates were determined from duplicate 75 mL samples using either an Autosal 8400 salinometer or an American Optical refractometer. Temperatures were obtained with a hand held thermometer. The Winkler method (Strickland & Parsons 1972) was used to determine the dissolved oxygen levels of duplicate 300 mL water samples. Data on temperature, salinity, and dissolved oxygen are tabulated in Conlin et al. (1982).

Multi-way analyses of variance (ANOVA) were carried out to compare fish abundance among areas and among sampling times using the University of British Columbia Computing Centre statistical package UBC Genlin (General Least Squares Analysis of Variance Program). Analyses were performed on the transformed [ln (x + 1)] catch data of major species and the temperature, salinity, and dissolved oxygen data.

RESULTS AND DISCUSSION

ENVIRONMENTAL PARAMETERS

Seasonal variation in temperature, salinity and D.O. are shown in Figures 2, 3 and 4. Winter and early spring temperatures were in the range 4 to 5°C. Late summer temperatures at Steveston and Iona pit were considerably higher than at Roberts Bank, exceeding 20°C compared to a maxima of about 19°C or lower at the latter location. ANOVA showed a significant difference ($p < 0.05$, $F = 122.9$) between locations.

The spring freshet of the Fraser River produces a dramataic seasonal effect on salinity at Steveston and Iona, decreasing values to the 2-4‰ range from winter maxima of approximately 23‰ (Fig. 3). In addition the proximity of these two sites to the Middle Arm and South Arm of the Fraser maintains the year-round salinities of these two sites at significantly ($p < 0.05$; $F = 1413.6$) lower levels than those found at Roberts Bank pit. On Roberts Bank freshening due to river runoff was less marked, and the seasonal range in surface salinities was from about 18 to 27‰ (Fig. 3). Based on salinity regimes Steveston and Iona were estuarine environments while Roberts Bank was a partial marine site.

Dissolved oxygen values at Iona pit ranged from minima of approximately 4 mg L^{-1} in October 1981 to about 10 mg L^{-1} in April 1982 (Fig. 4). Values at Steveston pit were higher, usually between 10 and 12 mg L^{-1}. On Roberts Bank, D.O. values were consistently >10 mg L^{-1}, reaching maximum values of close to 16 mg L^{-1} in spring. Dissolved oxygen (D.O.) values at Iona are significantly lower ($p < 0.05$, $F = 190.9$) all year round than those at Steveston and Roberts Bank, probably due to the continual discharge of sewage (Otte and Levings 1975, Birtwell et al. 1983). Mean values for percent saturation of D.O. in 1980 and 1981 at Iona pit were 61.0% and 75.8%, respectively, compared to 117.8% and 106.8% at Steveston and 166.3% and 165.1% at Roberts Bank. The latter super-saturated values are indicative of the high primary productivity of eel grass and algae.

SPATIAL VARIATION IN CATCHES AND SPECIES DISTRIBUTIONS

Roberts Bank showed by far the greatest population density and species diversity of the three sites (Table 1). Oceanographic features of Roberts Bank are more stable and in addition this area is characterized by a more complex habitat with the presence of eel grass beds, rock jetties, pilings, borrow pit and sand banks.

Catch per unit effort (CPUE) at Steveston was greater that at Iona (Table 1), but the species diversity of these two sites was essentially the same. Steveston and Iona are estuarine environments, located in relatively close proximity to one another and therefore they share the same species and show similar diversity levels. However, Iona is more stressful than Steveston due to the year-round influx of sewage and the lower levels of D.O.

A common result of several studies of northeast Pacific bay, estuarine and inshore fish populations, (e.g., Allen and Horn 1975: Horn 1980a) is that five or fewer species usually comprise 75% or more of the total fishes sampled even though there may be many other species collected. The results of the present study generally fit in with these findings. At Iona six species comprise 89.3% of the total catch over the program while at Steveston five species comprise 85.1% of the catch and at Roberts Bank four species represented 77.5% of the catch (Table 2a, b, c). Other species at all three sites each comprised less than 5% of the total catch.

Of a total of 57 species sampled, 18 were found to be common to all three locations (Table 2a, b, c). Roberts Bank had 25 endemic species of which at least 13 were considered rare (captured on few trips (n <2) and in small numbers (n <3)). Two species, the arrow goby and peamouth chub, were exclusive at Steveston and Iona. The peamouth chub, primarily a freshwater species may be excluded from Roberts Bank by higher salinities. Based on Clark and McInerney's experimental work (1974) this species is tolerant of brackish water and probably could occasionally use these habitats. Arrow gobies have been found at Roberts Bank above the eel grass beds at much higher tidal elevations than those sampled in the present study (A. MacDonald, pers. comm.).

The eulachon and brassy minnow were caught only at Steveston, on one occasion each. The brassy minnow and the large scale sucker are freshwater species (Carl et al. 1959) and the occurrence of them in the Steveston and Iona catches indicates a small number of individuals periodically get swept down the river and out into the estuary. These two species have low tolerance to salt water (Clark and McInerney 1974). As eulachon spawn in the Fraser River between March and May (Samis 1977), their presence probably indicates the capture of an individual as it was moving through the river to spawn or a spent fish carried out to the estuary. Six species, the saddleback gunnel, kelp greenling, buffalo sculpin, smoothhead sculpin, spinynose sculpin and sand dab were not caught at Steveston but were present at the other two sites. All of these species were captured infrequently (<2 trips) or in small numbers (<4) so at Iona that they would have to be considered rare and thus not making up an important component of the community. These species are probably not tolerant of the low salinities found on Sturgeon Bank. The kelp greenling and smoothhead sculpin are also rare at Roberts Bank whereas the other four species are considerably more numerous. Three species, the penpoint gunnel, butter sole and sand sole were found at both Steveston and Roberts Bank but not at Iona. The penpoint gunnel was only captured on two occasions at Steveston whereas at Roberts Bank it was taken on numerous trips and in large numbers. This suggests that the penpoint gunnel is essentially a marine species that has been caught incidentally at Steveston but should not be considered an integral member of the Steveston faunal assemblage. The butter sole and sand sole occur in moderate numbers at Steveston and Roberts Bank Iona and their absence at Iona could be due to sewage effects.

TEMPORAL VARIATION IN CATCHES

The seasonal trend in catch at Iona and Steveston (Fig. 5) appears to be very closely tied to the seasonal variation in temperature (Figs. 2, 3, 4). At Iona both catches and temperature increase through the spring to a maximum in early August, followed by a gradual decline through fall and winter then increasing again in March 1981. At Steveston the same general trend is also evident except that two peaks in both catch and temperature occur during June and August of 1980 and the increase for both catch and temperature in 1981 occurs somewhat earlier, in late February. At Roberts Bank the relationship between temporal variation in catch (Fig. 5) and temperature is weaker and the extreme variation in the Roberts Bank catches imply that some other factor(s) in addition to temperature at this site are involved. Time of day may affect the catchability and movements of some of the dominant fish on Roberts Bank. For example Wiebe (1968) and Gordon (1965, cited in Wiebe 1968), who also worked in the Vancouver area, found that adult surf perch (Cymatogaster aggregata) moved inshore for spawning at night over the period July to December.

Seasonal trends in the variation of the mean number of species per haul (Fig. 6) also appears to closely correspond to temperature. At Iona and Steveston there is a slight decrease over the winter months, however, the difference between summer and winter values is slight. The range of mean number of species per haul for these two sites over the length of the program is similar. Roberts Bank exhibits a much greater seasonal range. There is a tendency towards lower values during the winter however peaks in November and February are as high as summer values.

Several other studies of inshore fish population in temperate regions (reviewed in Allen and Horn 1975; see also Miller et al. 1980) have found similar seasonal relationships of temperature to the number of species and the number of individuals. Seasonal variation of salinity and D.O. do not appear to be correlated to seasonal fluctuations in number of species and number of individuals. On the Fraser River foreshore salinity and D.O. are more important in determining the spatial distribution of species, except that the occurrence of freshwater species is more likely during freshet when salinities are reduced. D.O. does not appear to be a limiting factor at Roberts Bank or Steveston, but at Iona there are transient periods of extremely low D.O. during the summer months which have been observed to lead to fish kills (Birtwell et al. 1983).

The seasonal changes in populations of the dominants leads to a shift in dominance (based on numbers) over the year and this was investigated graphically. To simplify the presentations that species data were summarized by families or family groups using Hart (1973) as a systematic guide. The twelve most abundant species on Roberts Bank and the three salmonids were used as a reference to compare the sites on Sturgeon Bank. Arrow goby were included at Iona because of their dominance at this location. Iona and Steveston are characterized by rapid large-scale shifts in composition and abundance during the summer months followed by slow, more stable changes during the fall and winter where one or two taxa tend to overshadow the others (Fig. 7, 8). Roberts Bank, however, has even more rapid fluctuations during the summer followed by a series of changes throughout the winter with dominance at any one point in time not being as restricted as at the other site (Fig. 9). The rapid changes in composition and abundance during the spring and summer at all three sites is due in a large degree to the sudden influx of juveniles of the various fish, as shown by length frequency data given below for the major species.

DIFFERENCES IN DISTRIBUTION, CATCH SIZE, AND LENGTHS

Catch patterns and length frequency changes, when sufficient data were available, were examined for the abundant commercial species, namely chum, chinook, and pink salmon, herring, English sole and starry flounder as well as five other species which were among the 10 top ranking species at both the Roberts Bank pit and the two locations on Sturgeon Bank (Iona, Steveston). These were as follows: threespine stickleback, shiner perch, Pacific staghorn sculpin, surf smelt, and Pacific sandlance. Spatial and temporal differences in catches among the 3 sample sites were the main statistical contrasts, and comments on reproduction and migrations are given when possible.

Salmonids

Chinook, chum, pink and coho were captured during the sampling program collectively composing 4.99% of the total catch for the three sites. Catches of these species accounted for 6.3% of the total at Iona, 13.8% at Steveston, and 2.3% at Roberts Bank. No sockeye and only a very few coho were captured in this study, probably because of the migratory behaviour of these species on their way to the sea. Coho and sockeye smolts are thought to move directly out to sea when they leave the Fraser estuary. Certain populations of sockeye fry which have been recorded from sloughs in the lower Fraser (Levy and Northcote 1982). Coho smolts were taken on Roberts Banks in an intensive sampling program and mark-recapture study (Levings et al. 1983).

Pink salmon, in accordance with their known cycle of even year outmigrations on the Fraser, were only captured during 1980. The pinks first appear at Steveston (Fig. 10) in early April and decreased in number, and thereafter increased at Iona and then Roberts Bank. This suggests pinks first leave the South Arm of the Fraser River at Steveston and then quickly move outwards from here, pausing at the other two sites during the movement away from the river mouth. Catches of pinks at the three sites were significantly ($p < 0.05$; $F = 4.2$) different from one another with Roberts Bank having the largest mean catch followed by Iona and Steveston. Modal length of pink fry at Iona and Steveston was approximately 35 mm in April. A month later pink from Roberts Bank showed modes at 40 and 57 mm, while June samples were unimodal over the range 54 to 47 mm (Fig. 11).

Chum salmon first appeared in early April 1980 at all three sites and in early March 1981. Catches at Iona were significantly larger ($p < 0.05$ $F = 5.7$) than at the other two sites during 1980 and significantly larger at Roberts Bank in 1981. Chum disappeared from the Steveston pit before Roberts Bank or Iona during both 1980 and 1981 (Fig. 12), suggesting a dispersion pattern similar to that for pinks. Intensive beach seining was conducted near our Roberts Bank Station 1 at a variety of tide levels to collect fish for mark/recapture experiments (Levings et al. 1983). Results from this latter study showed that chum were more abundant at higher tide levels, supporting Bax et al.'s (1980) conclusions from Puget Sound data. Our low tide sampling therefore underestimated the species abundance. Chum fry at Iona from April 1980 showed a wide size range, with modes evident at 39, 43, and 51 mm. In March 1980 only smaller chums were present at this site, with a mode at 40 mm. Chums taken on Roberts Bank in May 1980 and 1981 were larger than those from Sturgeon Bank, with the majority between 40 and 65 mm (Fig 13).

Chinook were the most numerous of the four salmonid species caught at all three sites. During 1980 chinook first appeared in large numbers at Steveston in early April whereas in 1981 they appeared first at Roberts Bank (Fig. 14) in early March. However this probably reflects sampling problems as the Steveston site was not seined between early March and late April 1981. Steveston showed the largest catches both years ($p < 0.05$; $F = 30.9$). Levings (1983a) provides further details on juvenile chinook ecology in the Fraser River estuary. Chinook fry dominated catches on Sturgeon Bank while both fry and smolts were taken on Roberts Bank.

The origin of salmon using the Banks cannot be established without further mark-recapture work, but some inference can be made from existing data. Based on 8 recoveries of hatchery chinook smolts (4 in 1981, 4 in 1982) (DFO, unpublished data) it is known that stocks from the lower Fraser (Chilliwack, Chehalis hatcheries) use Roberts Bank. Other wild smolts may be from upper Fraser stocks, some proportion of which are thought to over winter in the tributaries above the Fraser Canyon (Tutty and Yole 1976). Chinook fry using Sturgeon and Roberts Bank are likely Harrison River fish (Levings 1983a) which are used as broodstock for the Chehalis hatchery. Chum and pink are also likely to be from Fraser stocks, although the possibility of contributions from other south coast stocks cannot be ruled out. Chum taken on Roberts Bank in late June were larger than earlier fry and might well have been fish from other river systems that had been rearing in the Strait of Georgia for a month or so (Healey, 1980). The few coho smolts taken were probably of mixed stock origin as well.

Shiner perch

Shiner perch were primarily caught during the summer months, and were rare during the winter and spring at all three locations (Fig. 15). Roberts Bank pit was found to have larger catches than Iona and Steveston pit during 1980 but in 1981 more were taken at the latter location ($p < 0.05$; $F = 8.2$). The seasonal nature of the shiner perch reflects their life cycle. Young are born between May and August (Hart 1973) and mature over the subsequent months. Newly-born young of shiner perch were obtained at Iona, Steveston, and Roberts Bank pits in June 1980 and 1981, as shown by the distinct length modes at 30 to 40 mm (Fig. 16). Few fish over 50 mm were observed in samples from Iona.

Herring

Juvenile herring catches at all three sites show a distinct seasonality (Fig. 17) which also relates to their life cycle. As larval herring mature into the juvenile schooling stage there is a shift in diet and their habitat (Hart 1973; Levings 1983b). The catch data show that this change coincides with a movement into the nearshore during the summer months. Juvenile herring at Iona were observed in June and July 1980 and 1981, with major modes in July occurring at about 32, 46, and 55 mm. There was also evidence of very small herring (25 to 30 mm) in August 1980 (Fig. 18a). In June 1980 and 1981 herring juveniles from Steveston pit also showed 3 modes similar to those from Iona. July and August samples from this location were unimodal at about 33 mm Fig. 18b). Herring from Roberts Bank in June 1980 showed a small peak in abundance at about 40 mm, with a major peak at approximately 70 mm. In June 1981 only the mode at 40 to 45 mm was evident (Fig 18c). Differences in herring catches between sites were not found to be statistically different ($p > 0.05$, $F = 12.7$), however Roberts Bank had the largest catches followed by Steveston and Iona (Table 2).

Some of the juvenile herring using the Banks may be the progeny of fish that spawn in the eel grass on Robert Bank. Unfortunately spawning records are scanty for this site, which has not been regularly monitored. It is generally acknowledged that spawning is usually very light at this location (DFO, unpublished data). There are data from Point Roberts, about 5 km south of Roberts Bank and across the U.S. border. A moderate herring roe fishery is conducted at Point Roberts, and estimates of spawning escapements there have ranged from 2075 tons (1973) to 119 tons (1982) over the period 1973 to 1982. Escapement estimates for 1979 and 1980, which would match our sampling years for juvenile herring, were 754 and 307 tons, respectively, slightly below the 10 y average of about 806 tons (K. Buchanan, Washington Department of Fisheries (WDF), personal communication). Larvae produced from herring spawning at Point Roberts probably drift into Sturgeon and Roberts Bank. It is also likely that the 'jack' herring (3 to 10 cm) taken on Roberts Bank are the progeny of stocks spawning on the B.C. Gulf Islands (e.g. Mayne, Galiano), directly across the Strait of Georgia.

Surf smelt

Surf smelt did not show seasonal variations in abundance (Fig. 19) and ANOVA did not demonstrate a significant difference between locations over both years ($p > 0.05$, $F = 1.28$). Surf smelt are known (Hart 1973) to spawn on beaches during most months of the year.

Pacific sandlance

Sandlance were captured at all three sites, however so few were taken at Iona ($n = 3$) that they were not considered an important component of the Iona fish fauna. In both 1980 and 1981, there was a significant difference ($p < 0.05$, $F = 11.1$) in catches when Steveston and Roberts Bank were compared. During 1980 Roberts Bank had the larger catches while in 1981 Steveston had the greater values (Fig. 20). Large schools of this species were observed to avoid the beach seine, and in addition sand lance burrow into sand. For these reasons sand lance abundance data should be considered m.nimum estimates.

Pacific staghorn sculpin

The staghorn sculpin was present at all three sites and was found during most months of the year (Fig. 21). There was a decrease in numbers during the winter months. As spawning occurs in February (Hart 1973) the initial summer increase in numbers reflected an influx of young staghorn sculpins. ANOVA showed the difference in catch between locations to be significant ($p < 0.05$, $F = 18.1$) for both years. Staghorn sculpin catches were largest on Roberts Bank (Table 2). Immature staghorn sculpins at Iona and Roberts Bank pit appeared in May 1980 and 1981 as shown by distinctive modes at approximately 2 to 3 cm (Fig. 22). Adults up to 16 cm were also observed in samples at this time and larger fish were more common in winter months. A similar pattern was evident at Steveston pit, except that larger staghorns were infrequent during winter.

Threespine stickleback

The threespine stickleback was another species found at all three sites throughout the year but in reduced numbers during the winter months (Fig. 23). Differences in catch between locations were found to be significant ($p < 0.05$, $F = 7.7$) for both years with Roberts Bank having the lowest values. Threespine sticklebacks at Iona pit from 1980 showed evidence of recruitment of young in July through November when distinctive modes at 20 to 30 mm were evident (Fig. 24). The species was reported to breed from April to September in the Cowichan River on Vancouver Island (Scott and Crossman 1973) and appearance of young over a prolonged period would be expected. Larger fish (modal length 60 mm) were also present in July 1980 and June 1981. Except for August 1980, juvenile stickleback were uncommon at Steveston pit.

English sole

English sole were captured at all three sites, but only in very small numbers at Iona (<10). An ANOVA showed a significant difference in catches between Steveston and Roberts Bank, the latter having larger catches during both years ($p < 0.05$, $F = 43.3$) (Fig. 25). English sole spawn between January and March in British Columbia waters (Ketchen 1956; Hart 1973) and the larvae are pelagic for 6-8 weeks before moving onshore for the summer (Toole 1980). In early fall they enter deeper water, and the summer peaks and winter minima in the catch data reflect this. Relatively few samples of English sole lengths are available from Steveston pit but there was evidence of recruitment at 30 to 50 mm in June 1981. The data were much clearer from Roberts Bank, where major modes shifted from 30 to 80 mm over the period May to August 1980 (Fig. 26), showing shifts in size with time almost identical to that observed by Ketchen (1947) at Departure Bay near Nanaimo.

English sole are harvested in U.S. waters off Point Roberts and further south (K. Buchanan, WDF, pers. comm.). Since English sole move offshore to deeper water as they grow (Ketchen 1956) it is likely that juveniles rearing on Roberts Bank contribute to these stocks.

Starry flounder

The catch of starry flounder at Roberts Bank was found to be significantly ($p < 0.05$, $F = 15.5$) less than at Iona or Steveston for both years (Fig. 27). Catches at Iona and Steveston do not appear to display a strong seasonal component, as fish were abundant throughout the year (except March 1980). Roberts Bank data showed a fall and winter decrease in numbers with summer maxima. Very small starry flounder juveniles (20 to 50 mm) appeared in sizeable numbers in June 1980 and 1981 at Iona pit (Fig. 28a). Larger fish, sometimes composing modes at 20 and >30 cm (e.g. April 1980, March 1981) coexisted with the juveniles. A somewhat similar pattern was evident in data from Steveston pit but recruitment of the very small juveniles occurred earlier in 1981 (Fig. 28b). The recruitment pattern was consistent with a spawning period of February to April, as reported by Smith (1936, cited in Hart 1974) for Puget Sound.

CONCLUSIONS

Our data indicate that the lower intertidal zone of Roberts and Sturgeon Bank, both vegetated and non-vegetated has a substantial capacity for fish rearing and is used almost all months of the year. The areas therefore should be protected as important fish habitat. Results show that Roberts Bank eelgrass beds are characterized by high fish diversity (number of species) and the community appears to be similar to that found by Miller et al. (1980) at a station at the east end of the Juan de Fuca Strait, about 150 km southwest of the Fraser estuary. They recorded a total of 65 fish species from only 24 beach seine hauls at Discovery Bay. As we speculate from Roberts Bank, Miller et al. (1980) suggest the species richness at certain locations may have been influenced by habitat heterogeneity, in the case of Beckett Point (Discovery Bay), a steep sand slope and an eelgrass covered mudflat. The high abundance of food and use of Discovery Bay as a nursery area were also mentioned. The sandflats on Sturgeon Bank support fish communities like those found by Northcote et al. (1978) at seaward stations in the North Arm of the Fraser and by Levy and Levings (1978) at the Squamish estuary, also in the southern Strait of Georgia. A preponderance of brackish and/or freshwater species characterized the latter two study sites.

To determine if the eelgrass habitat is more productive of fish than the sandflats will require further study. Most of the fish found used the habitats in their juvenile stages, when they are growing rapidly and require most food. A comparison of invertebrate productivity would be needed to assess if there were differences in food production. A preliminary examination of diet data available (Levings, unpublished) shows that chinook appear to be a major piscivore in the fish community, and chinook smolts use forage fish such as herring, sandlance, and tubesnouts. These were widely distributed on the Banks. Like gobies in California bays and estuaries (Horne 1980b) the forage species probably channel substantial energy from invertebrates to piscivorous fish.

In addition to expanded productivity studies, future work should continue to evaluate loss of habitat due to man-made disruption on the Banks. Past studies have examined the lethal and sublethal impact of sewage (Birtwell et al. 1983) and causeways (Levings, 1980) on Sturgeon Bank. In 1982 and 1983 approximately 70 ha of sand and mudflats, and 30 ha of eelgrass were obliterated for recent construction of the Roberts Bank coal port (Fig. 1). The non-vegetated habitats are permanently alienated. This loss of habitat may have implications for commercially important fish stocks whose juveniles rear on Robert Banks.

ACKNOWLEDGMENTS

This study, conducted at an expansive and difficult estuary, was possible due to the collaboration of many colleagues, coauthors of the report where the original data are presented (Conlin et al. 1982). Thanks are also due to Dr. Alex Peden, B.C. Provincial Museum, D. Burt, and G. Sandercock for their help in verifying identification of the fish from the study. The manuscript was constructively reviewed by S. Macdonald, J. Westrheim and G. Hughes.

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Table 1. Summary statistics for fish catches on Sturgeon and Roberts Bank over the period March 1980 to July 1981.

	Iona	Steveston	Roberts Bank	Total
Number of hauls	111	80	135	326
Total catch	9426	11223	41940	62589
CPUE	84.9	140.3	310.7	191.9
Number of species	27	25	52	57

Table 2A. Ranked abundance of species taken by beach seine at Iona pit, March 1980 to July 1981 (111 hauls) (* indicates species also found at Steveston and Roberts pits)

Species	Number of individuals	CPUE
Starry flounder *	2070	18.65
Threespine stickleback*	1416	12.76
Pacific herring*	1381	12.44
Shiner perch*	1320	11.89
Pacific staghorn sculpin*	1145	10.32
Arrow goby	1084	9.77
Chinook salmon*	406	3.66
Surf smelt*	199	1.79
Chum salmon*	103	0.93
Pacific snake prickleback*	80	0.72
Pink salmon*	74	0.67
Tube-snout*	38	0.34
Coho salmon*	10	0.09
English sole*	9	0.08
Capelin*	8	0.07
Crescent gunnel*	8	0.07
Peamouth chub	6	0.05
Spinynose sculpin	4	0.04
Smoothhead sculpin	4	0.04
Pacific sanddab	3	0.03
Pacific sandlance*	3	0.03
Bay pipefish*	2	0.02
Saddleback gunnel	2	0.02
Buffalo sculpin	1	0.01
Kelp greenling	1	0.01
Tidepool sculpin*	1	0.01
Largescale sucker	1	0.01
Unidentified specimens	47	0.42
Total	9,426	

Table 2B. Ranked abundance of species taken by beach seine at Steveston pit March 1980 to July 1981 (80 hauls) (*indicates species found at Iona and Roberts pit as well)

Species	Number of individuals	CPUE
Threespine stickleback*	3270	40.88
Shiner perch*	2784	34.80
Chinook salmon*	1510	18.88
Starry flounder*	1060	13.25
Pacific herring*	923	11.53
Surf smelt*	353	4.41
Pacific sandlance*	290	3.63
Pacific Staghorn sculpin*	269	3.36
Pacific Snake prickleback*	307	2.74
Capelin*	145	1.81
English sole*	95	1.19
Arrow goby	65	0.81
Sand sole	49	0.61
Pink salmon*	27	0.34
Chum salmon*	16	0.20
Peamouth chub	12	0.15
Butter sole	14	0.12
Bay pipefish*	7	0.09
Crescent gunnel*	3	0.04
Penpoint gunnel	2	0.02
Tidepool sculpin*	1	0.01
Eulachon	1	0.01
Coho salmon*	1	0.01
Brassy minnow	1	0.01
Tube-snout*	1	0.01
Unidentified specimens	17	0.21
Total	11,223	

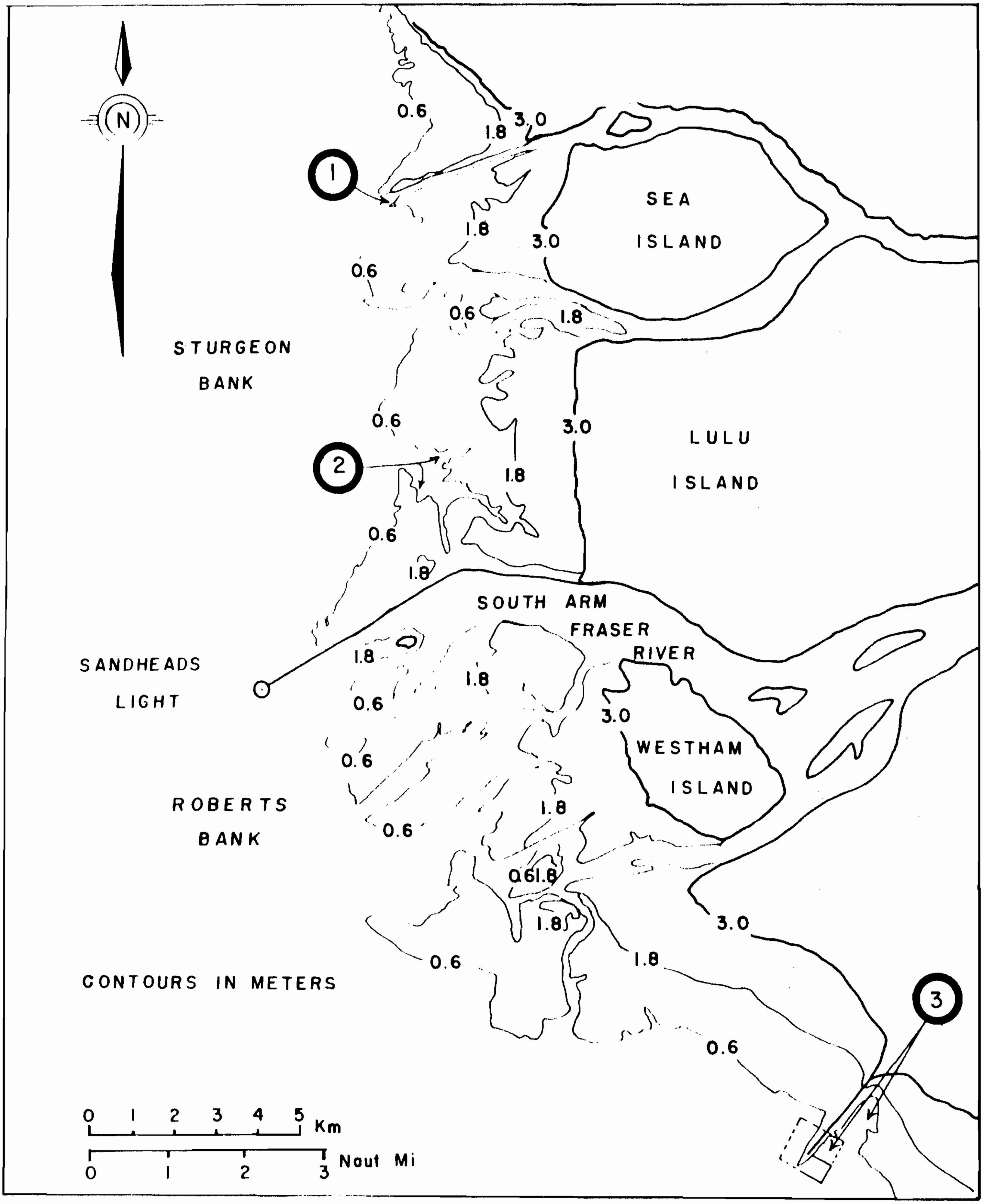
Table 2C. Ranked abundance of species taken by beach seines at Roberts Bank March 1980 to July 1981 (135 hauls) (*indicates species found at Iona and Steveston pits as well)

Species	Number of individuals	CPUE
Pacific herring*	13934	103.21
Pacific sandlance*	10653	79.91
Shiner perch*	5405	40.04
Pacific Staghorn sculpin*	2139	15.84
Tube-snout*	2017	14.94
English sole*	1289	9.55
Threespine stickleback*	921	6.82
Starry flounder*	666	4.93
Tidepool sculpin*	491	3.64
Pink salmon*	480	3.55
Chinook salmon*	463	3.43
Crescent gunnel*	415	3.07
Surf smelt*	373	2.76
Bay pipefish*	372	2.75
Pile perch	328	2.43
Penpoint gunnel	321	2.38
Chum salmon*	198	1.46
Pacific snake prickleback*	124	0.92
Tadpole sculpin	119	0.88
Padded sculpin	95	0.70
Buffalo sculpin	83	0.61
Capelin*	76	0.56
Sharpnose sculpin	68	0.50
Rock sole	40	0.29
Pacific Tomcod	34	0.25
Whitespotted greenling	31	0.23
Saddleback gunnel	28	0.21
Pacific sanddab	28	0.21
Butter sole	28	0.21
Mosshead sculpin	16	0.12
Spinynose sculpin	14	0.10
C-O sole	13	0.09
Sand sole	12	0.09
Sturgeon poacher	11	0.08
High cockscomb	9	0.07
Coho salmon*	9	0.07
Rosylip sculpin	8	0.06
Great sculpin	8	0.06
Kelp greenling	5	0.04
Flathead sole	4	0.03
Tidepool snailfish	3	0.02
Saddleback sculpin	3	0.02
Speckled sanddab	2	0.01

Table 2C. cont'd

Species	Number of individuals	CUPE
Silverspotted sculpin	2	0.01
Slender cockscomb	2	0.01
Prickly sculpin	2	0.01
Pacific Dogfish	1	0.01
Striped seaperch	1	0.01
Masked greenling	1	0.01
Smoothhead sculpin	1	0.01
Lobefin snailfish	1	0.01
Plainfin midshipman	1	0.01
Unidentified specimens	297	2.22
	41,371	

Fig. 1. Chart of Sturgeon and Roberts Bank, showing general location of Iona Pit (1), Steveston Pit (2), and Roberts Bank Pit (3). Topography (elevation above chart datum, m) is from Leroux and Luternauer (1979). The solid and dotted lines on Southern Roberts Bank show the 1981 and 1983 extent of the coal port, and dimensions are very approximate.


N
1
2
3
0.6
1.8
3.0
SEA
ISLAND
STURGEON
BANK
LULU
ISLAND
SOUTH ARM
FRASER
RIVER
SANDHEADS
LIGHT
WESTHAM
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ROBERTS
BANK
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0 1 2 3 4 5 Km
0 1 2 3 Naut Mi

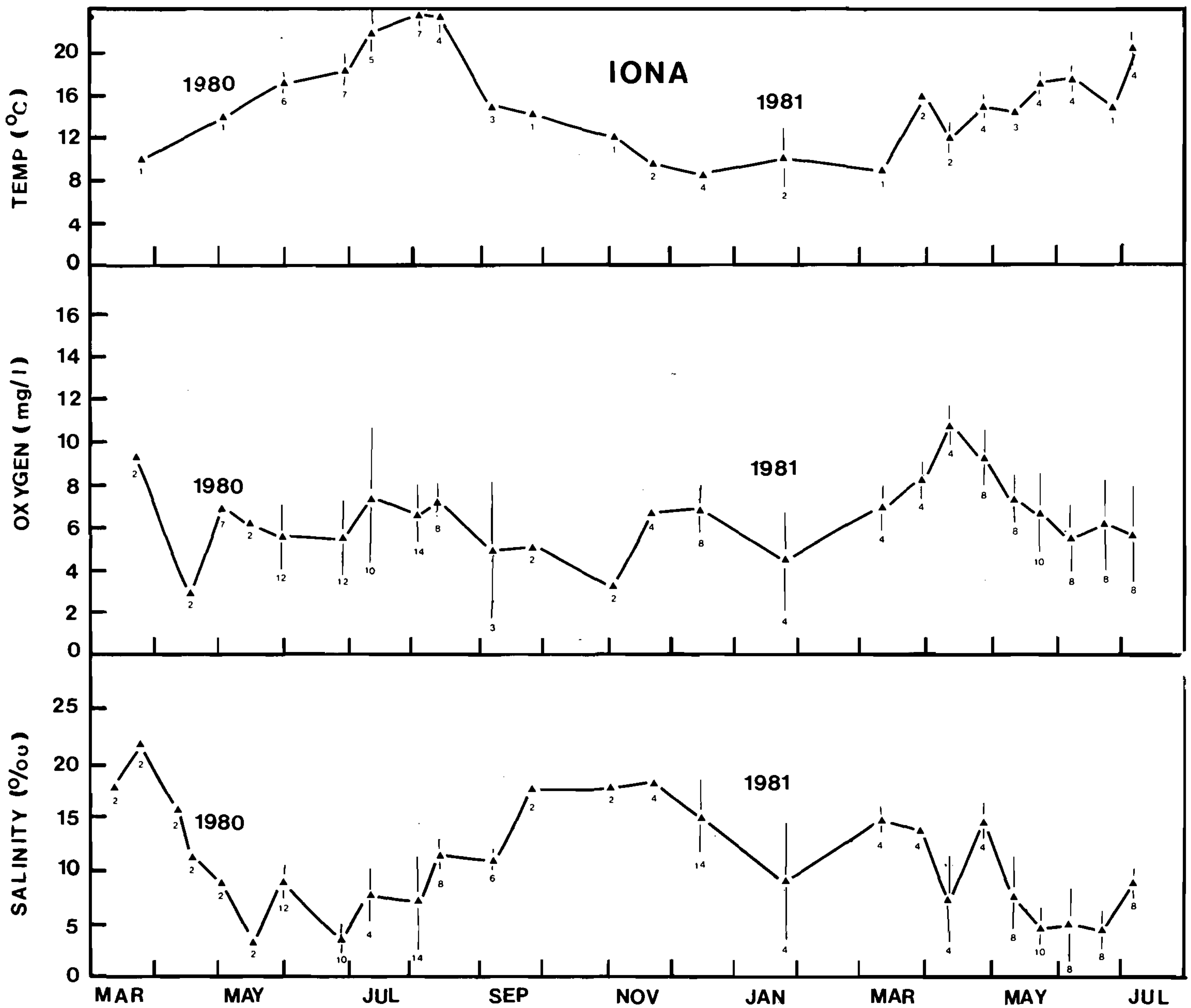


Fig. 2. Seasonal variation of temperature, salinity, and oxygen at Iona. Where > 3 samples were obtained on a particular trip, mean and standard deviation are shown.

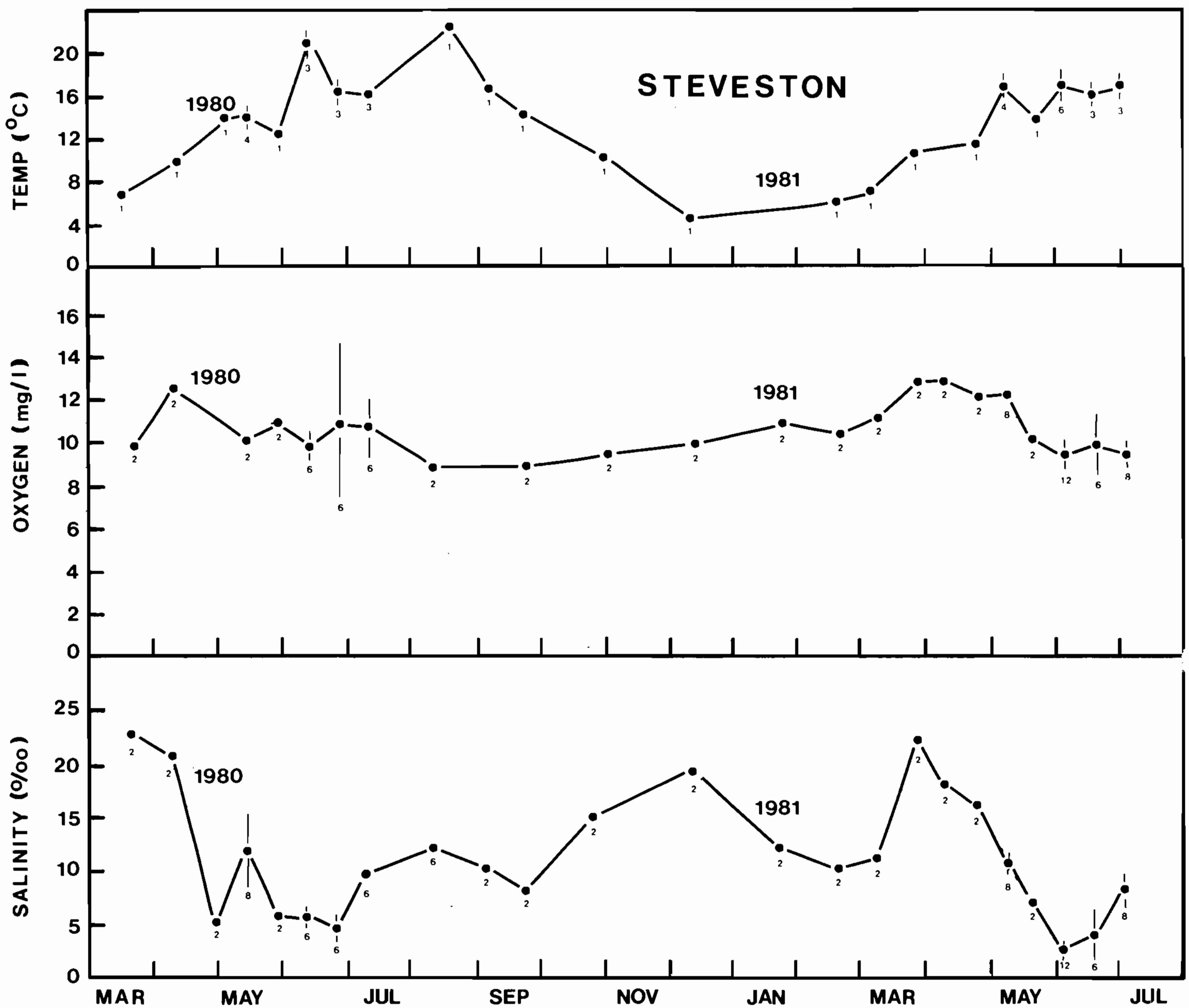


Fig. 3. Seasonal variation of temperature, salinity, and oxygen at Steveston. Where > 3 samples were obtained on a particular trip, mean and standard deviation are shown.

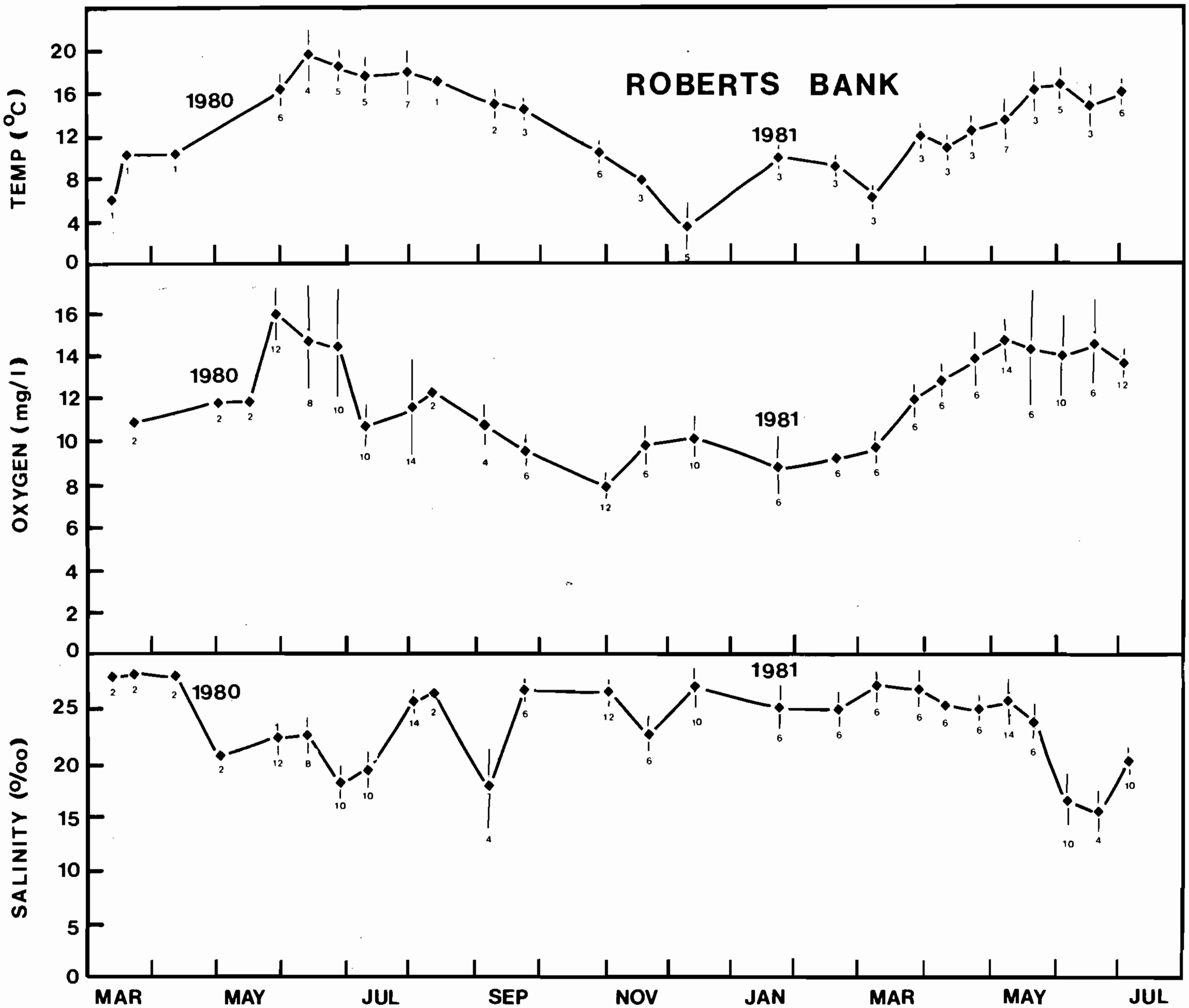


Fig. 4. Seasonal variation of temperature, salinity, and oxygen at Roberts Bank. Where > 3 samples were obtained on a particular trip, mean and standard deviation are shown.

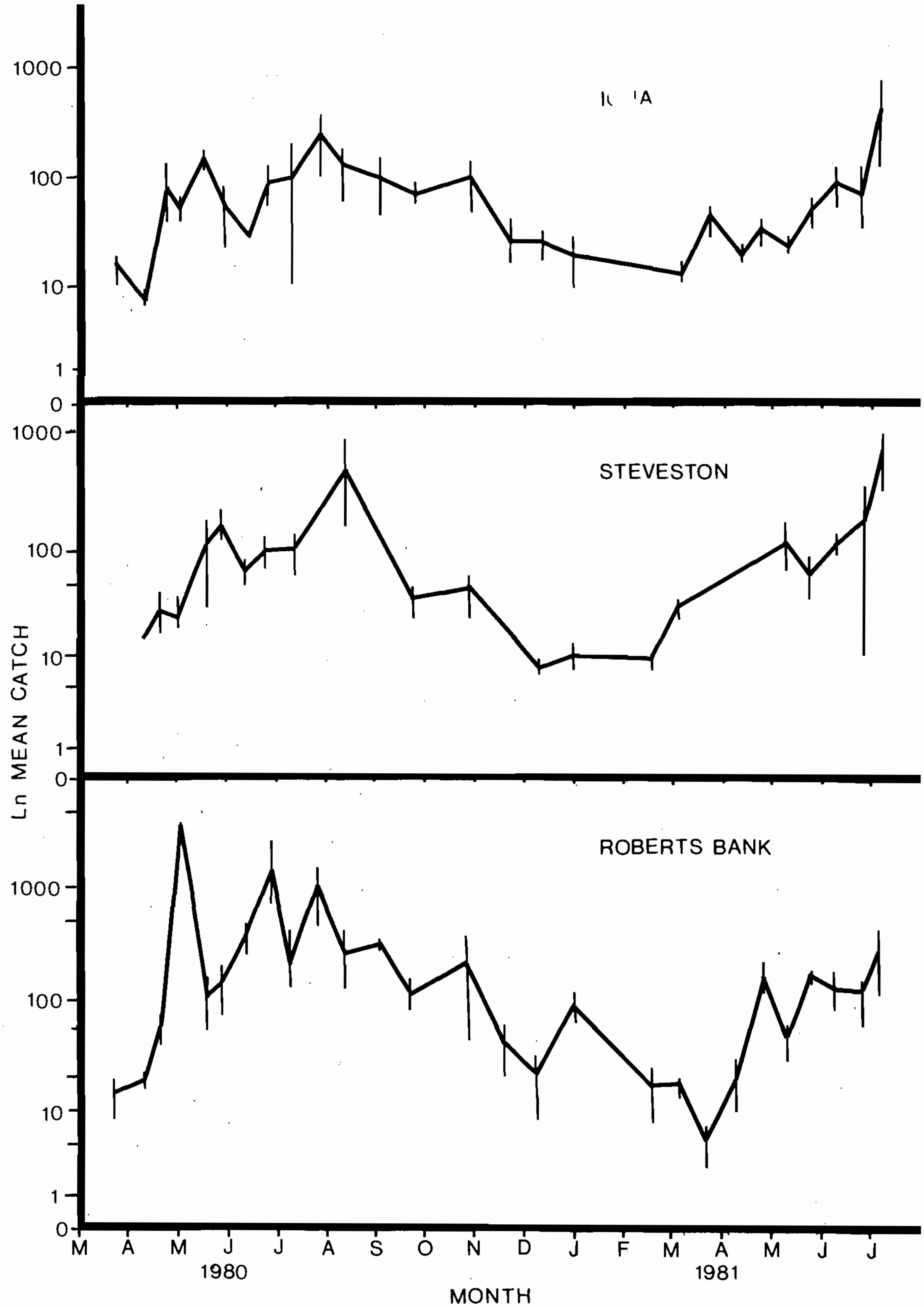


Fig. 5. Seasonal variation of the mean total catch per haul for Iona, Steveston, and Roberts Bank. Mean values and standard deviation are shown for each date.

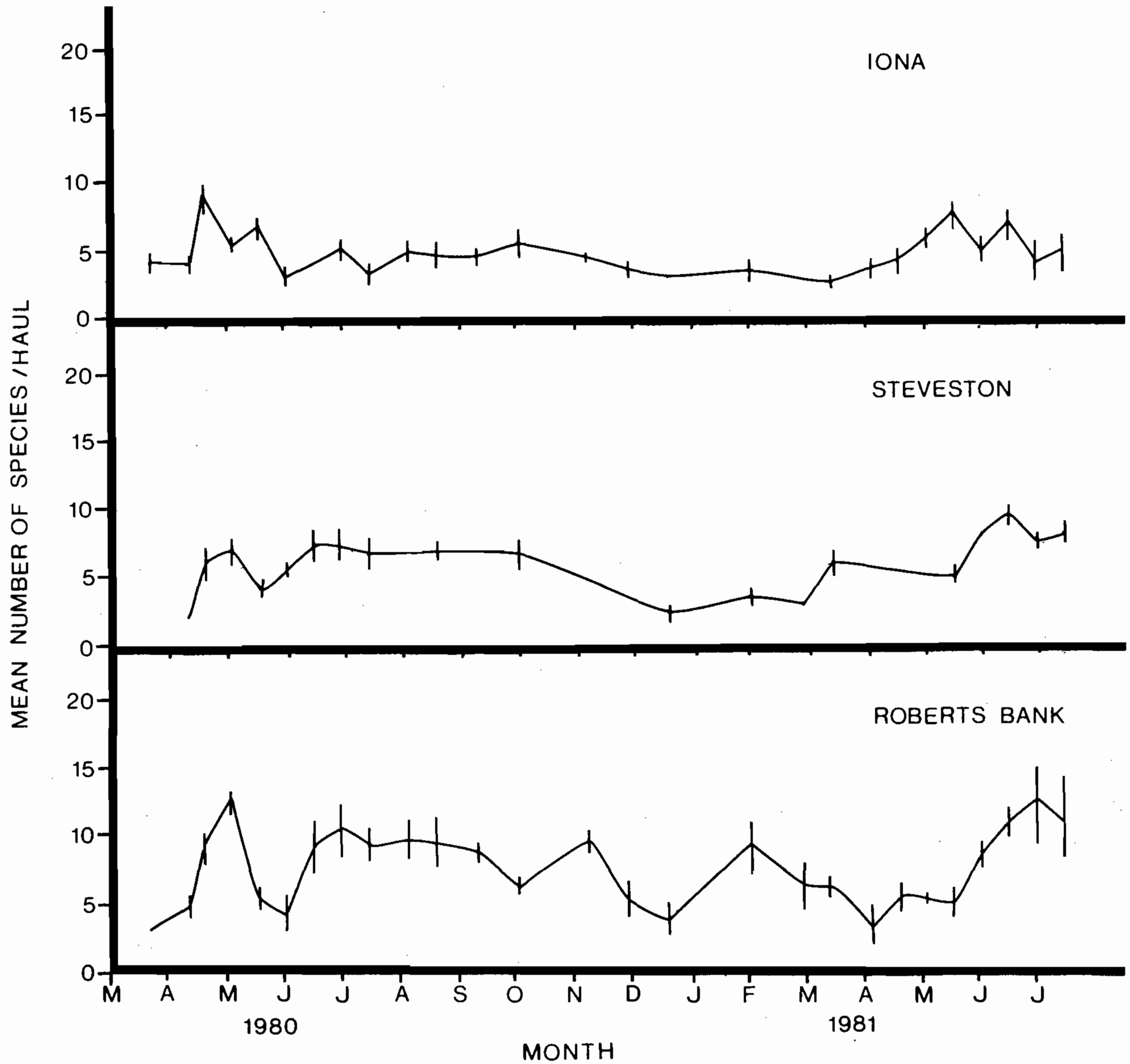


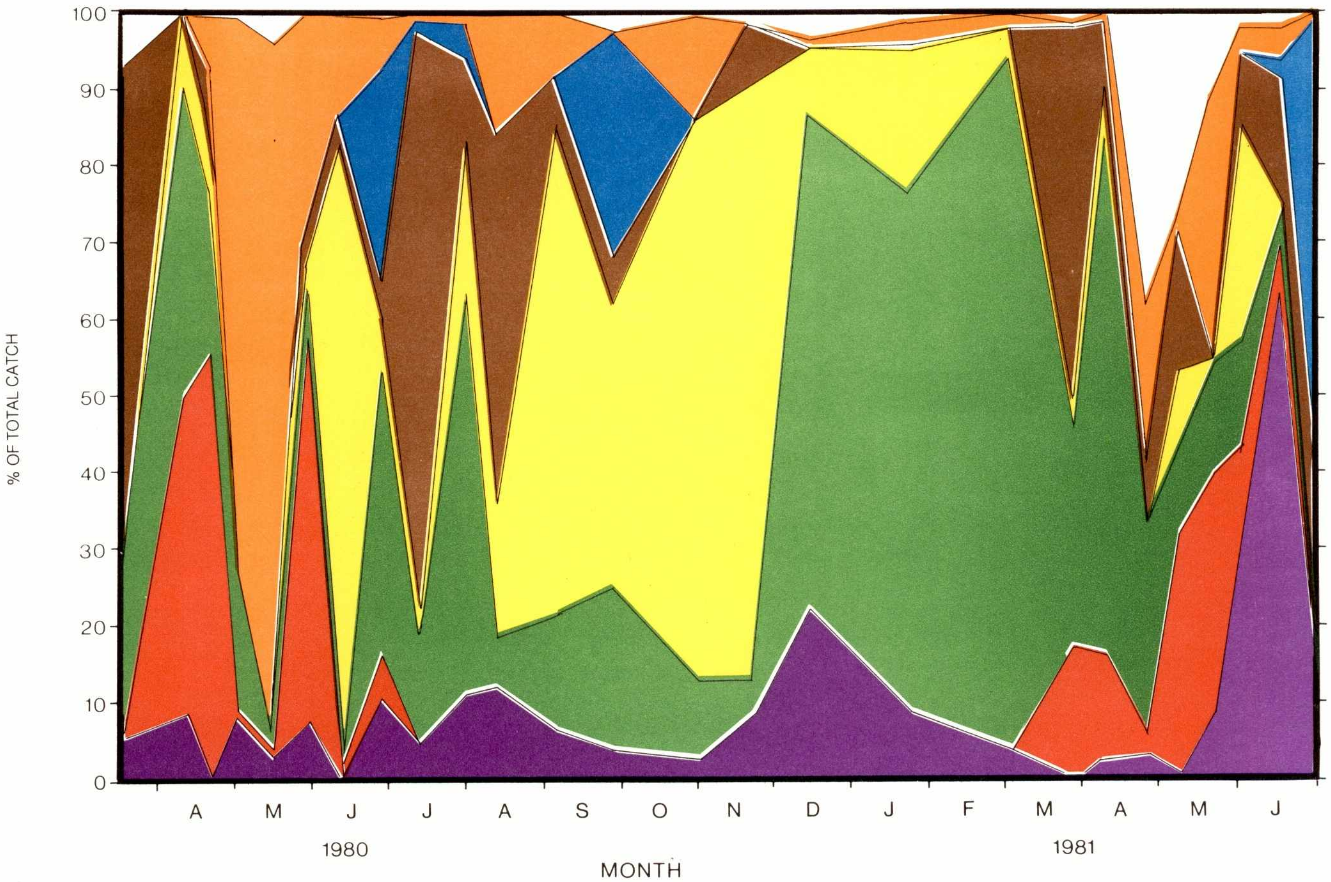
Fig. 6. Seasonal variation of the mean number of species per haul at Iona, Steveston, and Roberts Bank. Mean values and standard deviation are shown for each date.

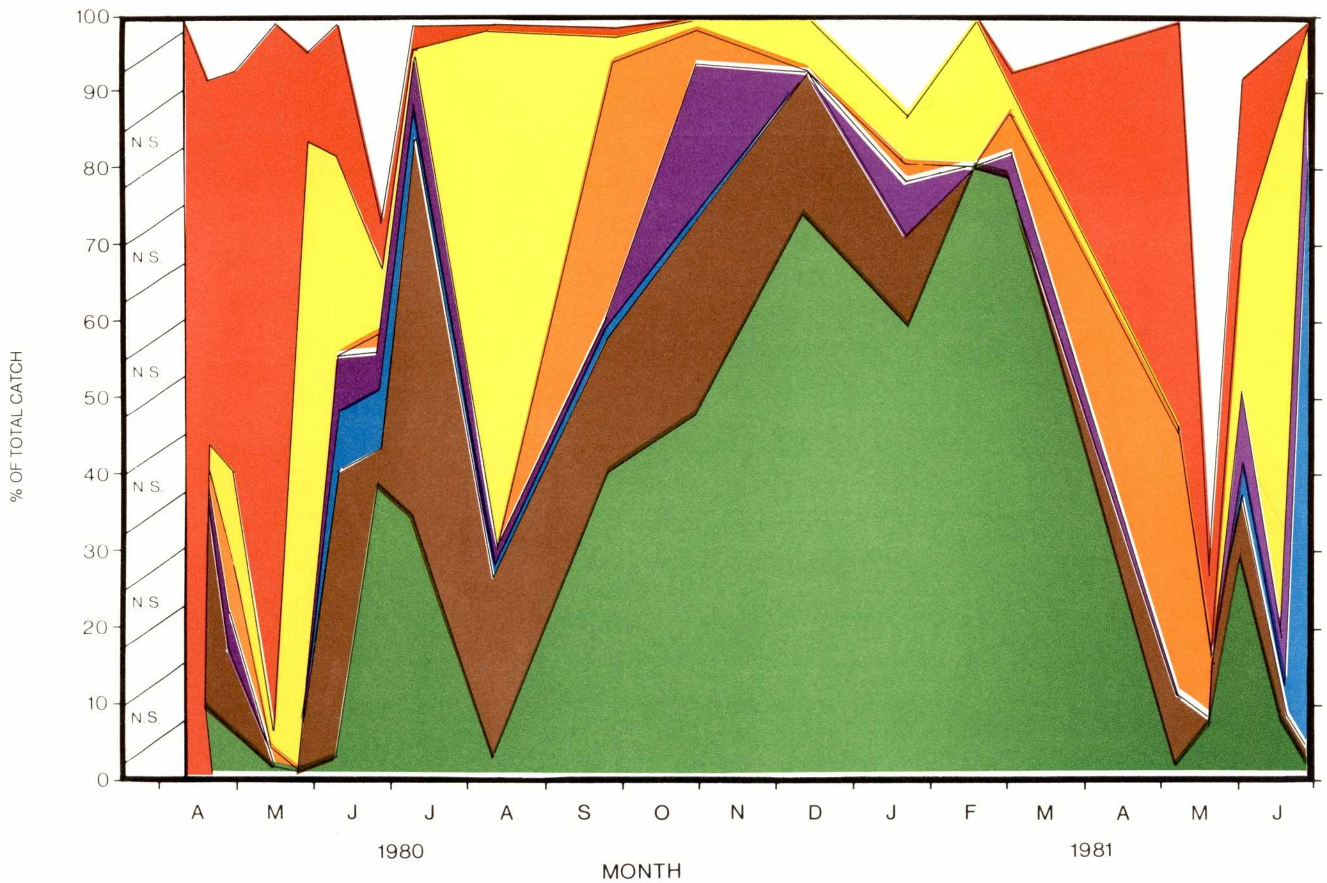
Fig. 7. Seasonal variation of the percent composition of total catch at Iona.

violet	- Pacific staghorn sculpin
red	- pink, chum and chinook salmon
green	- starry flounder
yellow	- threespine stickleback and tubesnout
brown	- Pacific herring and surf smelt
blue	- shiner perch
orange	- arrow goby
white	- other species

Fig. 8. Seasonal variation of the percent composition of total catch at Steveston.

green	- English sole and starry flounder
brown	- Pacific herring and surf smelt
blue	- shiner perch
violet	- Pacific staghorn sculpin
orange	- sand lance and arrow goby
yellow	- threespine stickleback
red	- pink, chum and chinook salmon
white	- other species


100
90
80
70
60
50
40
30
20
10
0
% OF TOTAL CATCH
A M J J A S O N D J F M A M J
1980
1981
MONTH


100
90
80
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40
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0
N.S.
N.S.
N.S.
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% OF TOTAL CATCH
A M J J A S O N D J F M A M J
1980
1981
MONTH

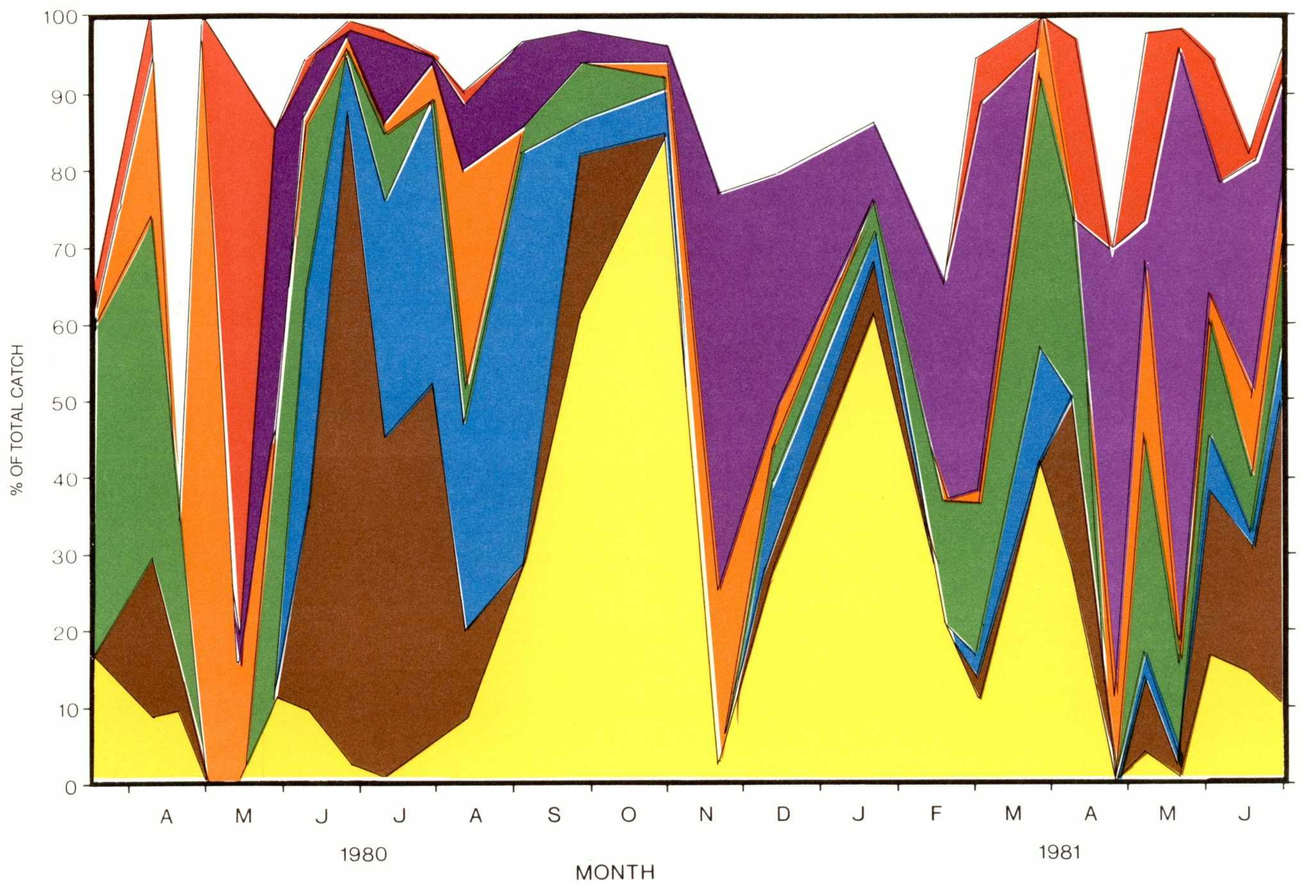


Fig. 9. Seasonal variation of the percent composition of total catch at Roberts Bank.

yellow	- threespine stickleback, bay pipefish and tube-snout
brown	- Pacific herring and surf smelt
blue	- shiner perch
green	- English sole and starry flounder
orange	- crescent gunnel and sand lance
violet	- Pacific staghorn and tidepool sculpins
red	- pink, chum and chinook salmon
white	- other species

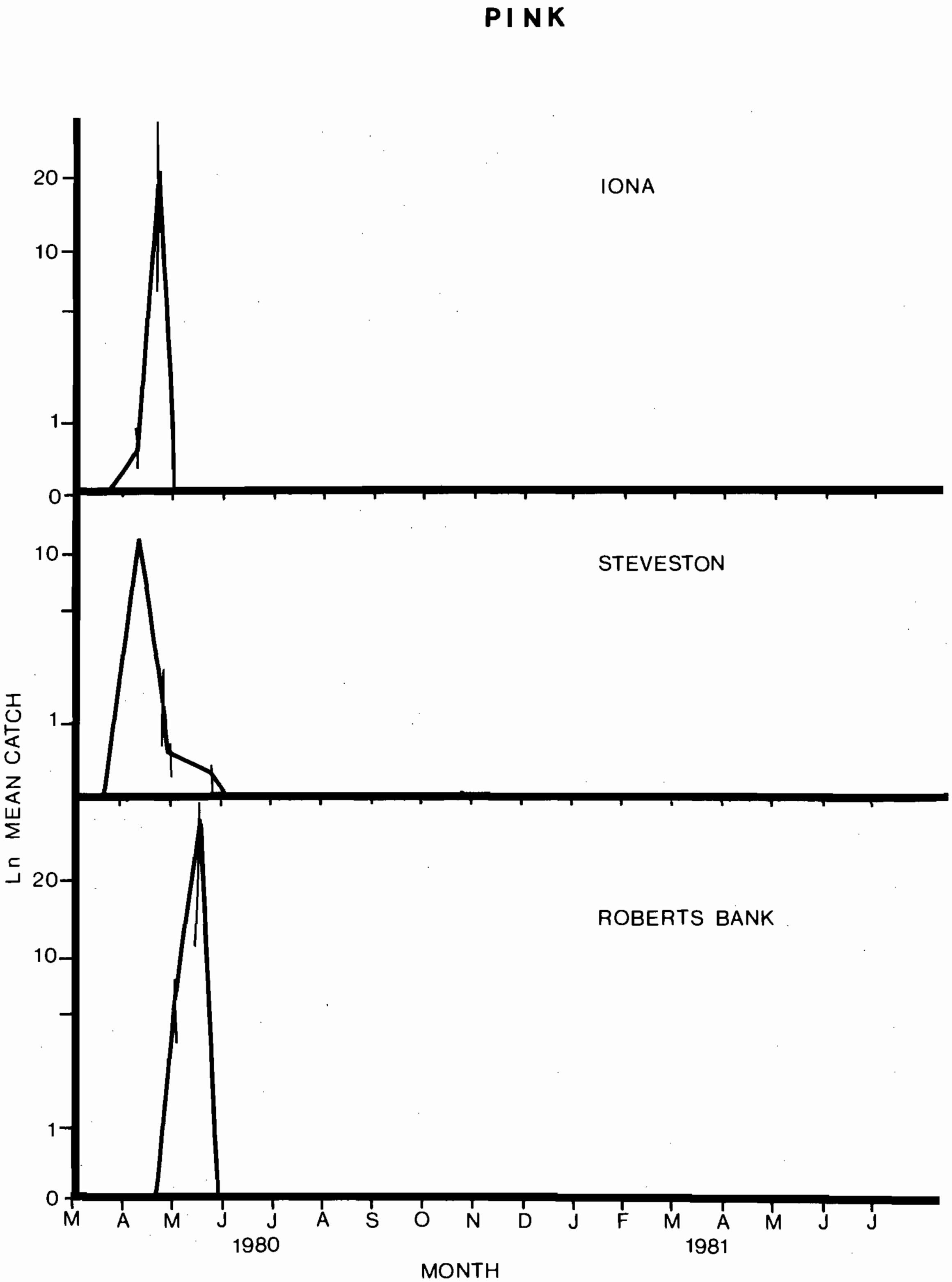


Fig. 10. Seasonal variation of pink salmon catches at Iona, Steveston and Roberts Bank. Mean values and standard deviation are shown for each date.

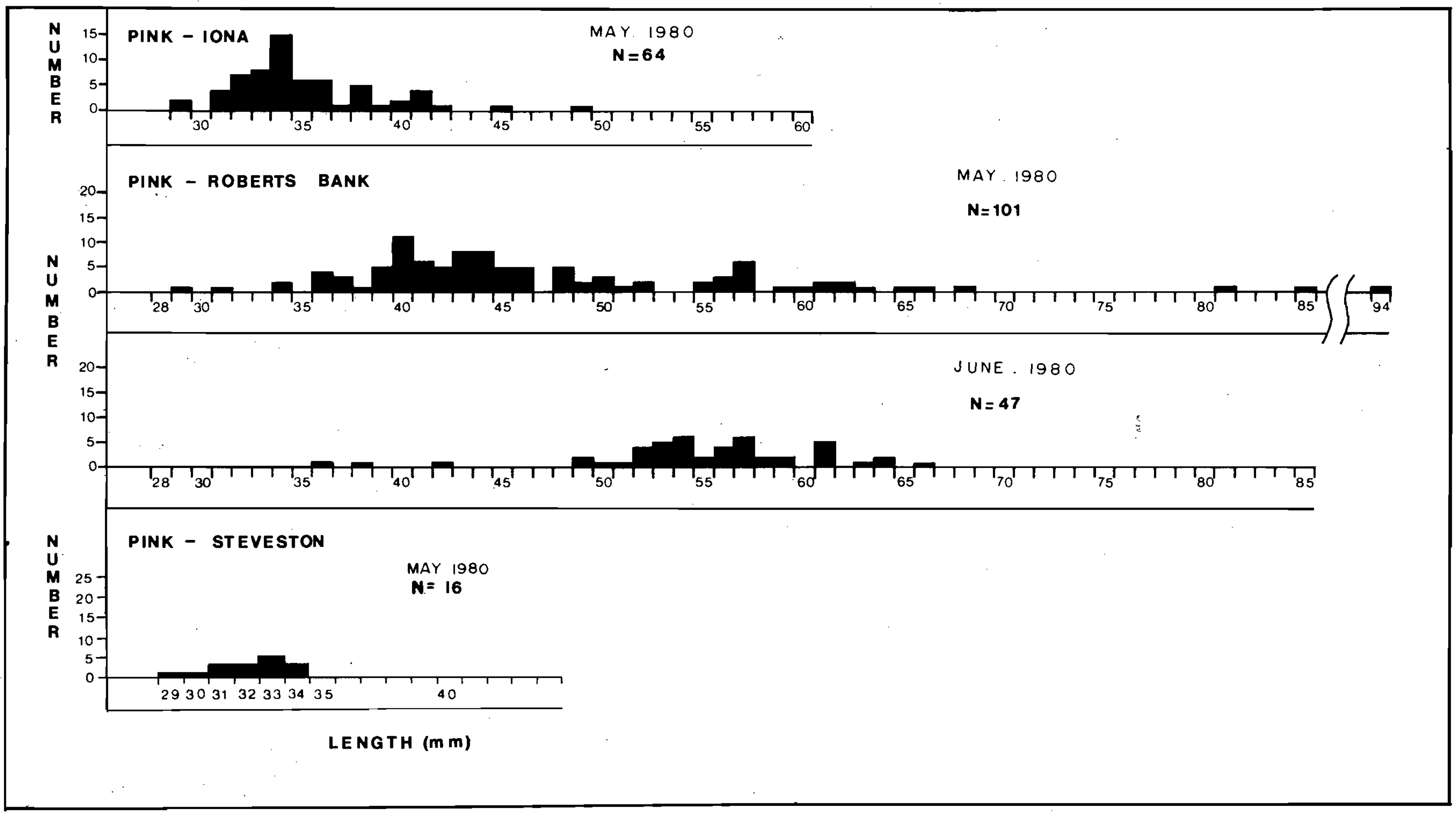


Fig. 11. Length frequency data for pink salmon at Iona, Steveston, and Roberts Bank pits in 1980.

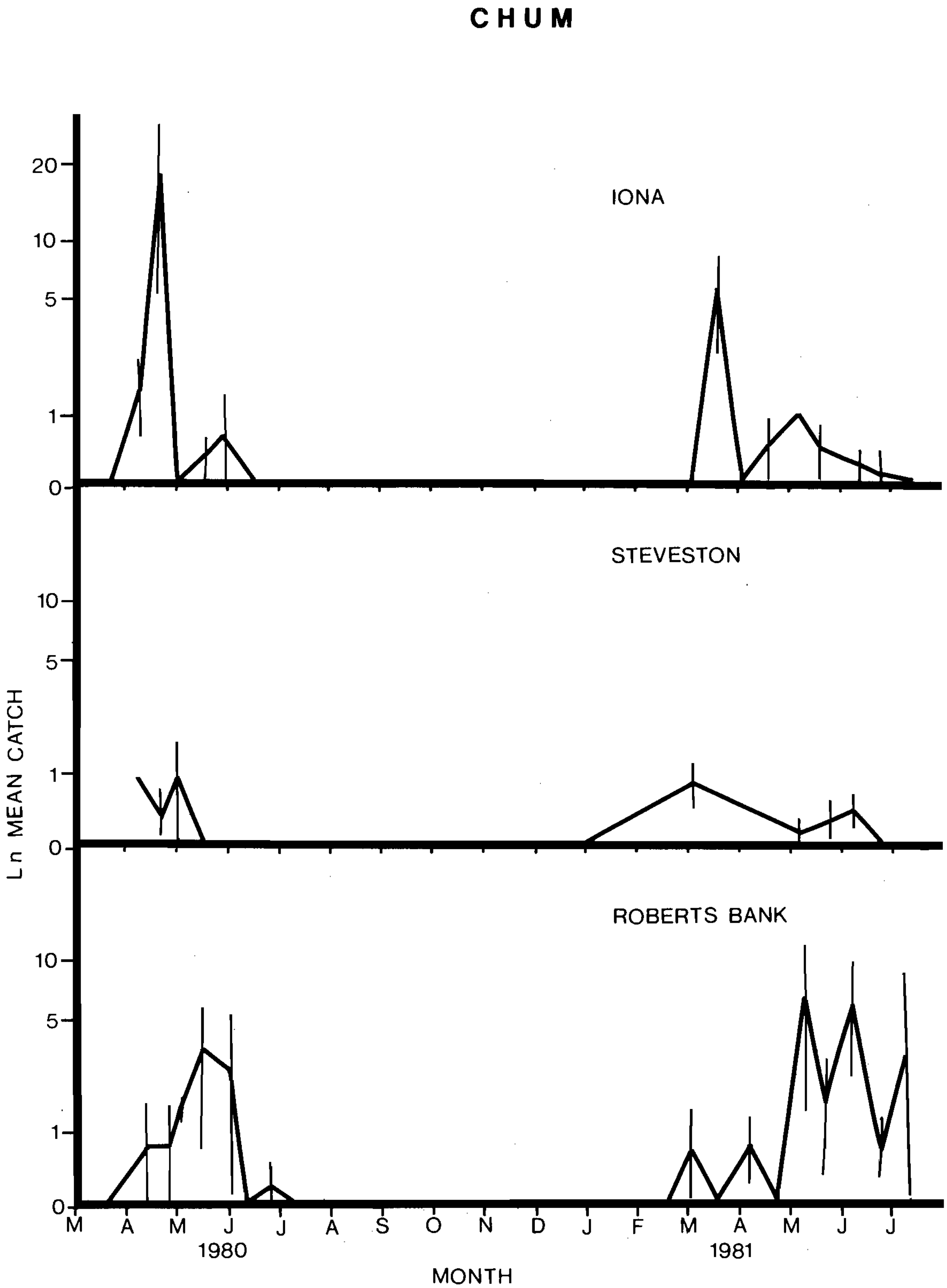


Fig. 12. Seasonal variation of chum salmon catches at Iona, Steveston and Roberts Bank. Mean values and standard deviation are shown for each date.

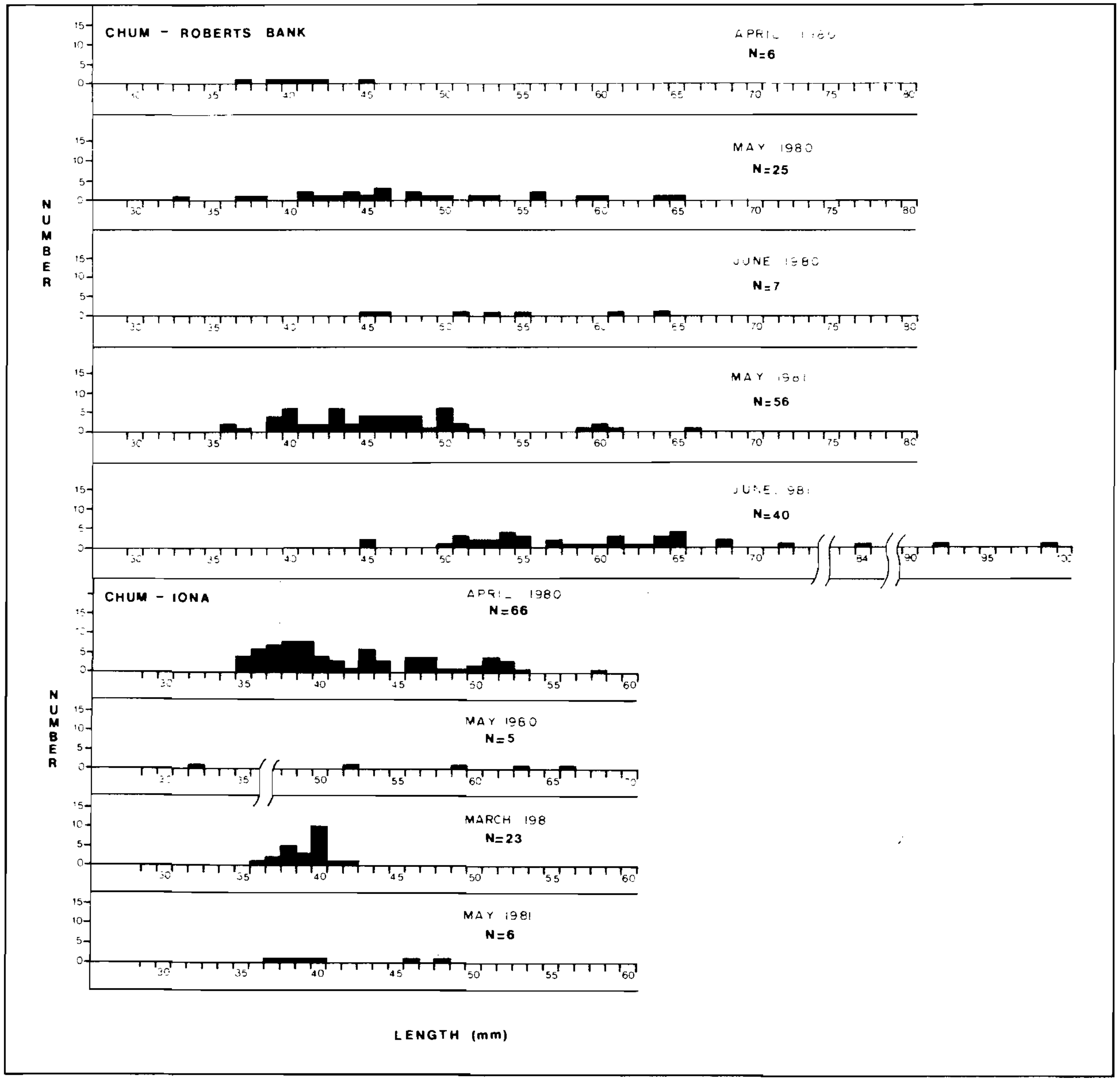


Fig. 13. Length frequency data for chum salmon at Iona and Roberts Bank pits in 1980 and 1981.

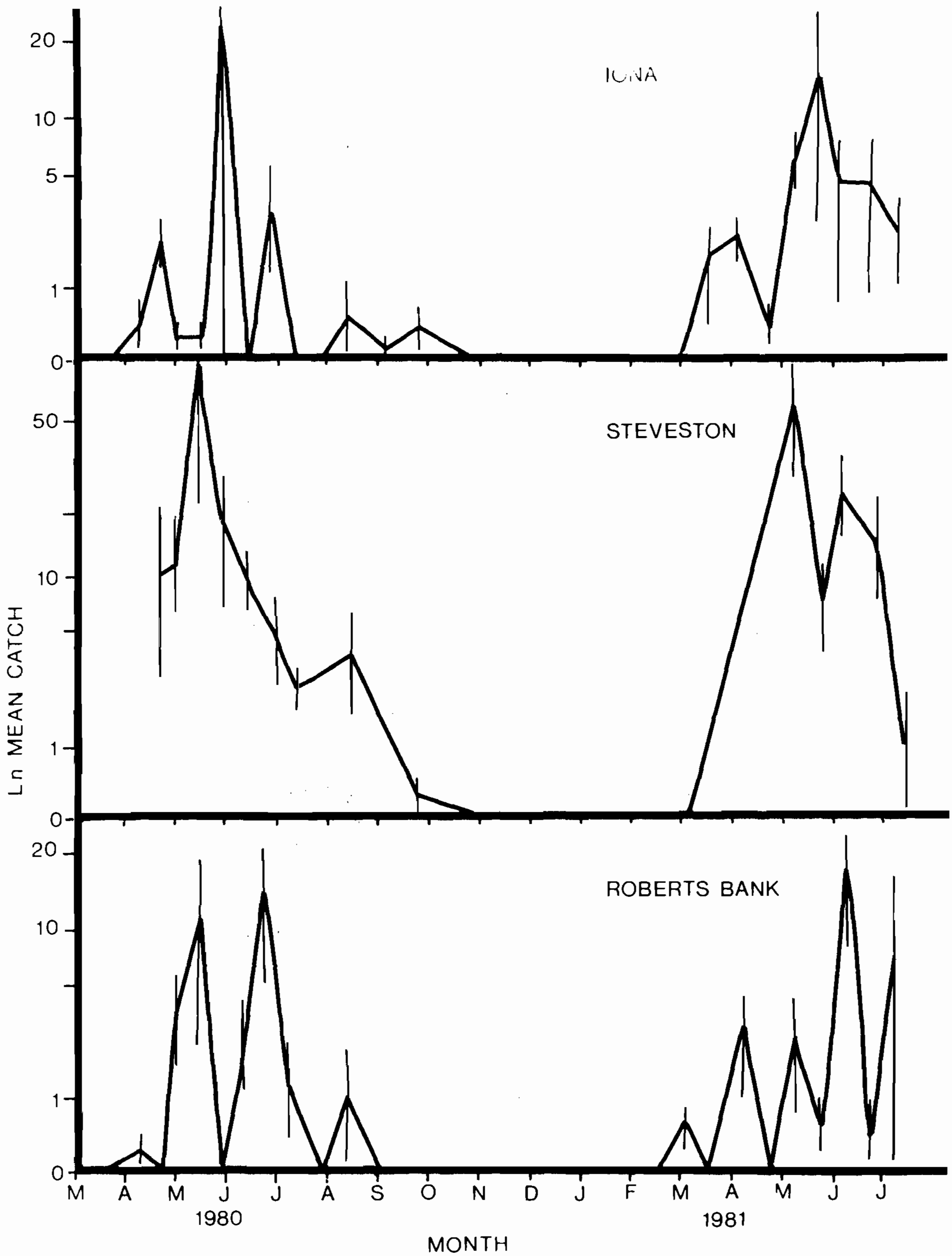


Fig. 14. Seasonal variation of chinook salmon catches at Iona, Steveston and Roberts Bank. Mean values and standard deviation are shown for each date.

SHINER PERCH

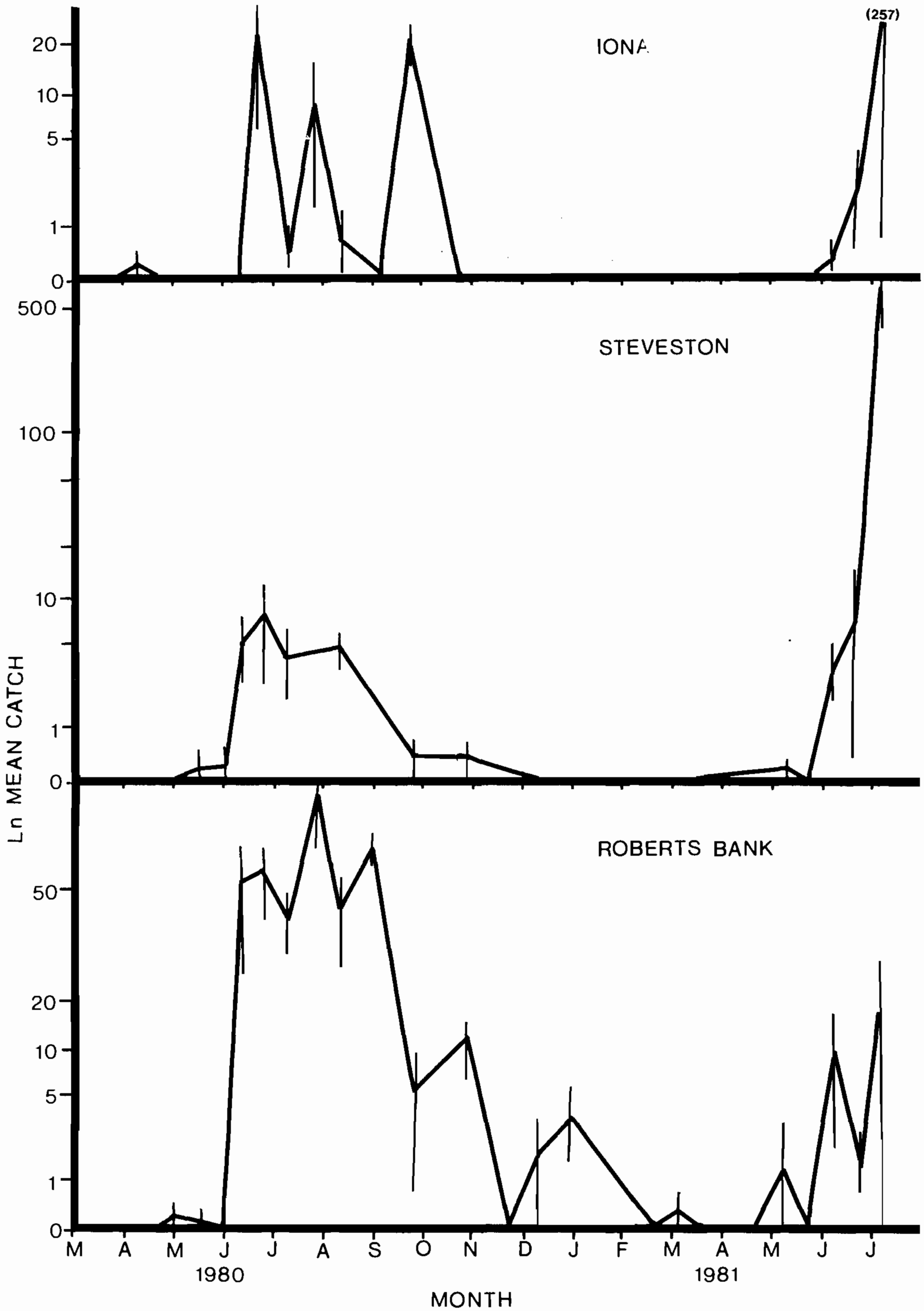


Fig. 15. Seasonal variation of shiner perch catches at Iona, Steveston and Roberts Bank. Mean values and standard deviation are shown for each date.

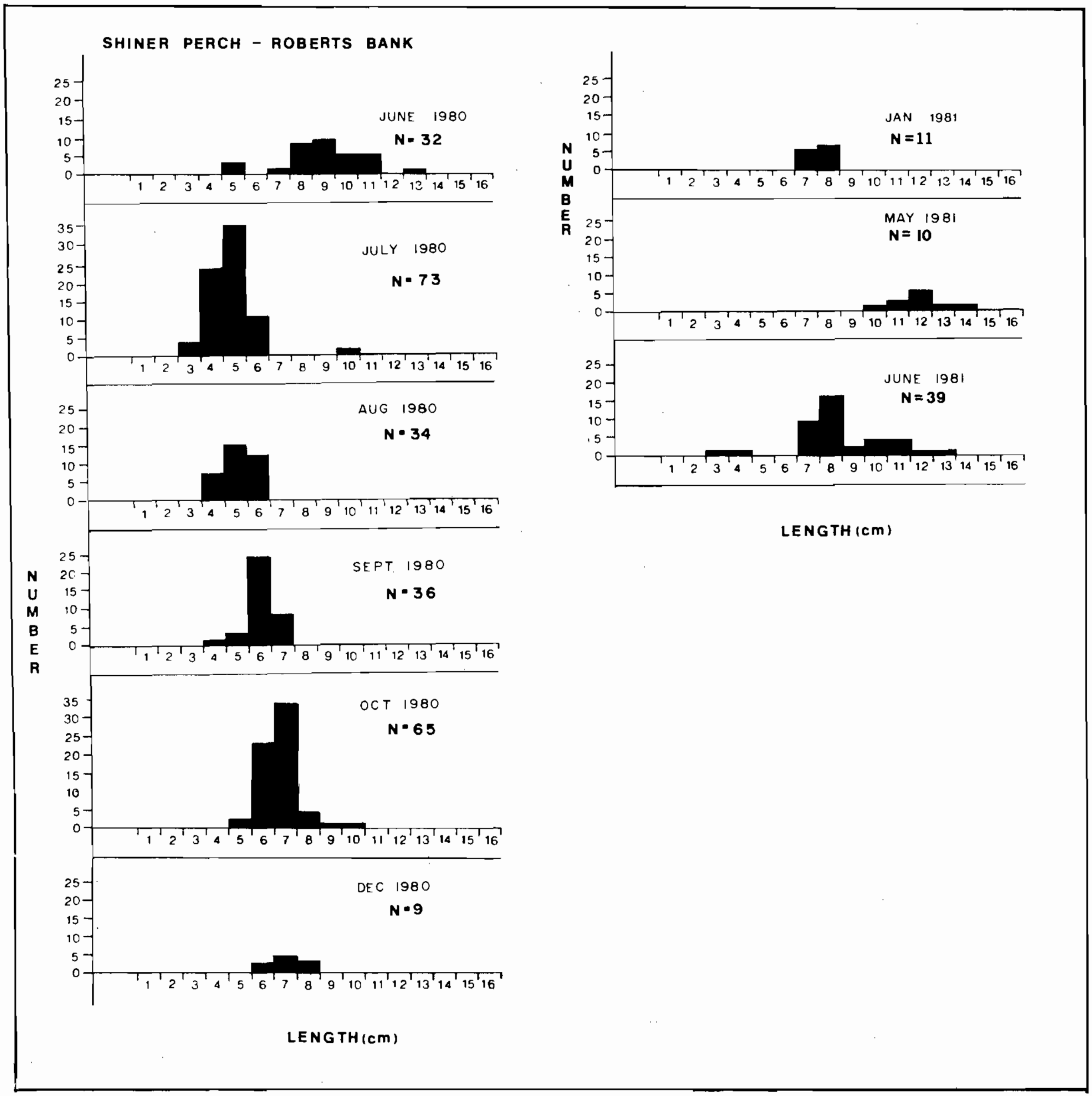


Fig. 16. Length and frequency data for shiner perch from Roberts Bank in 1980 and 1981.

HERRING

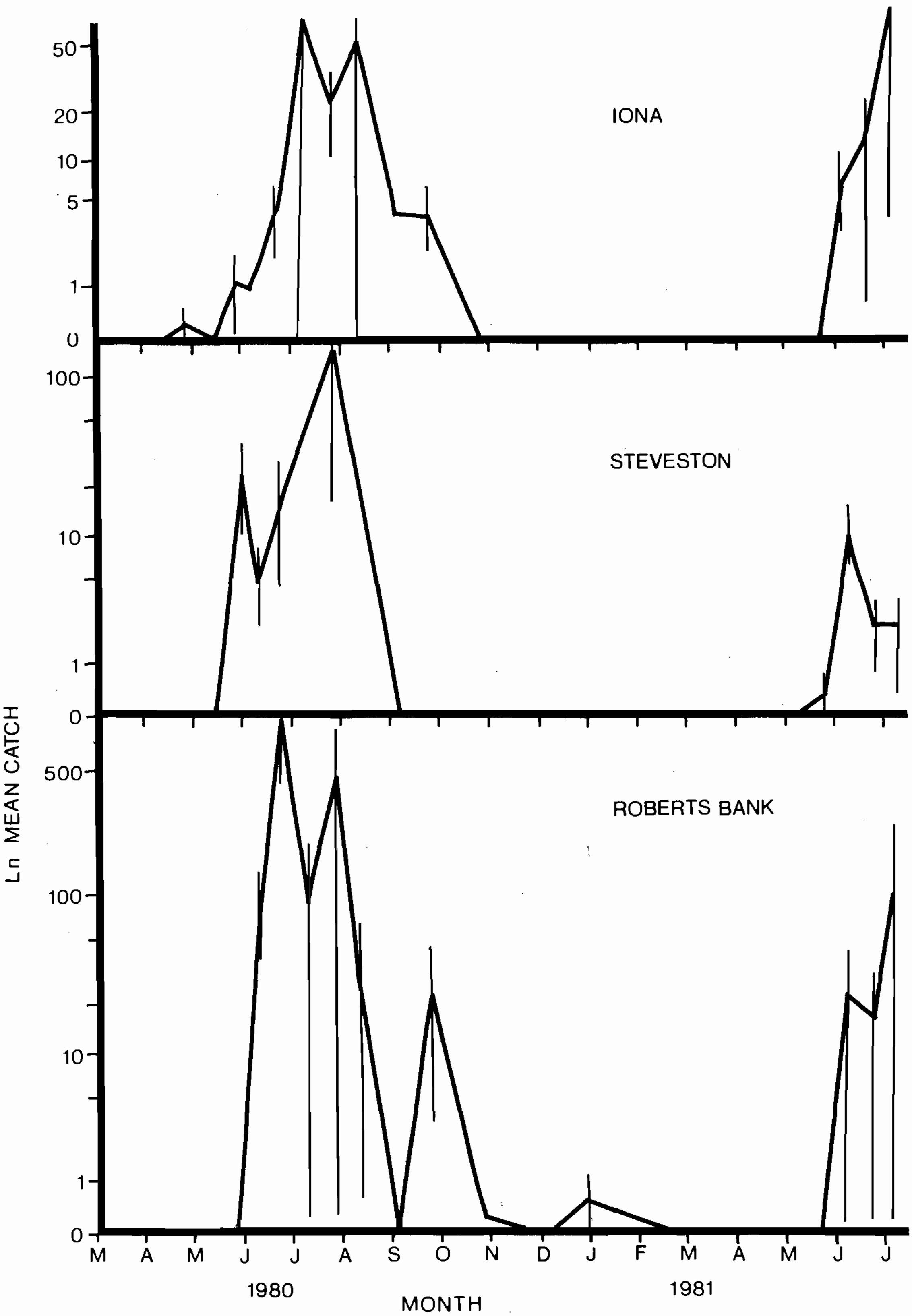


Fig. 17. Seasonal variation of herring catches at Iona, Steveston and Roberts Bank. Mean values and standard deviation are shown for each date.

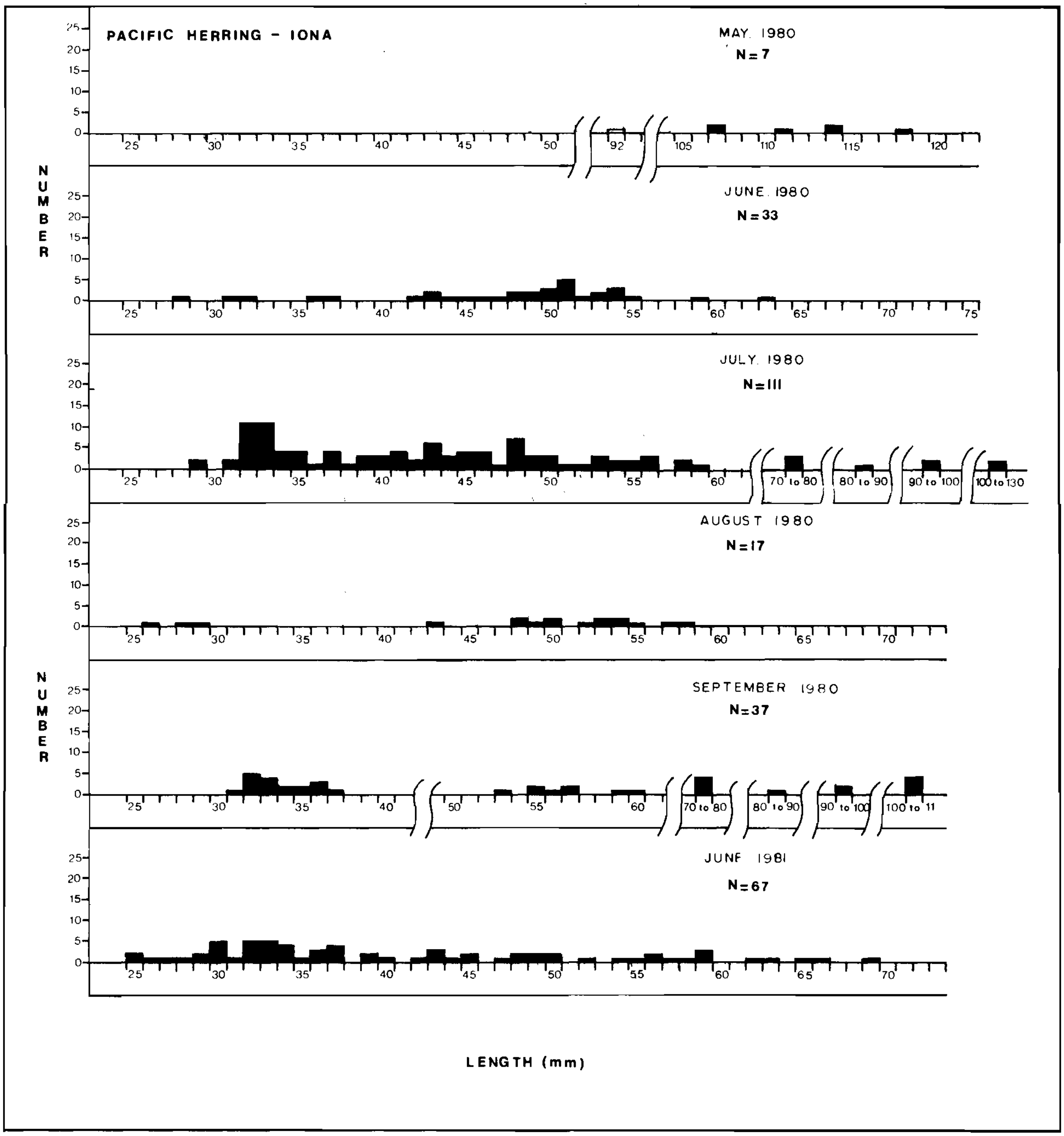


Fig. 18a. Length frequency data for herring at Iona pits in 1980 and 1981.

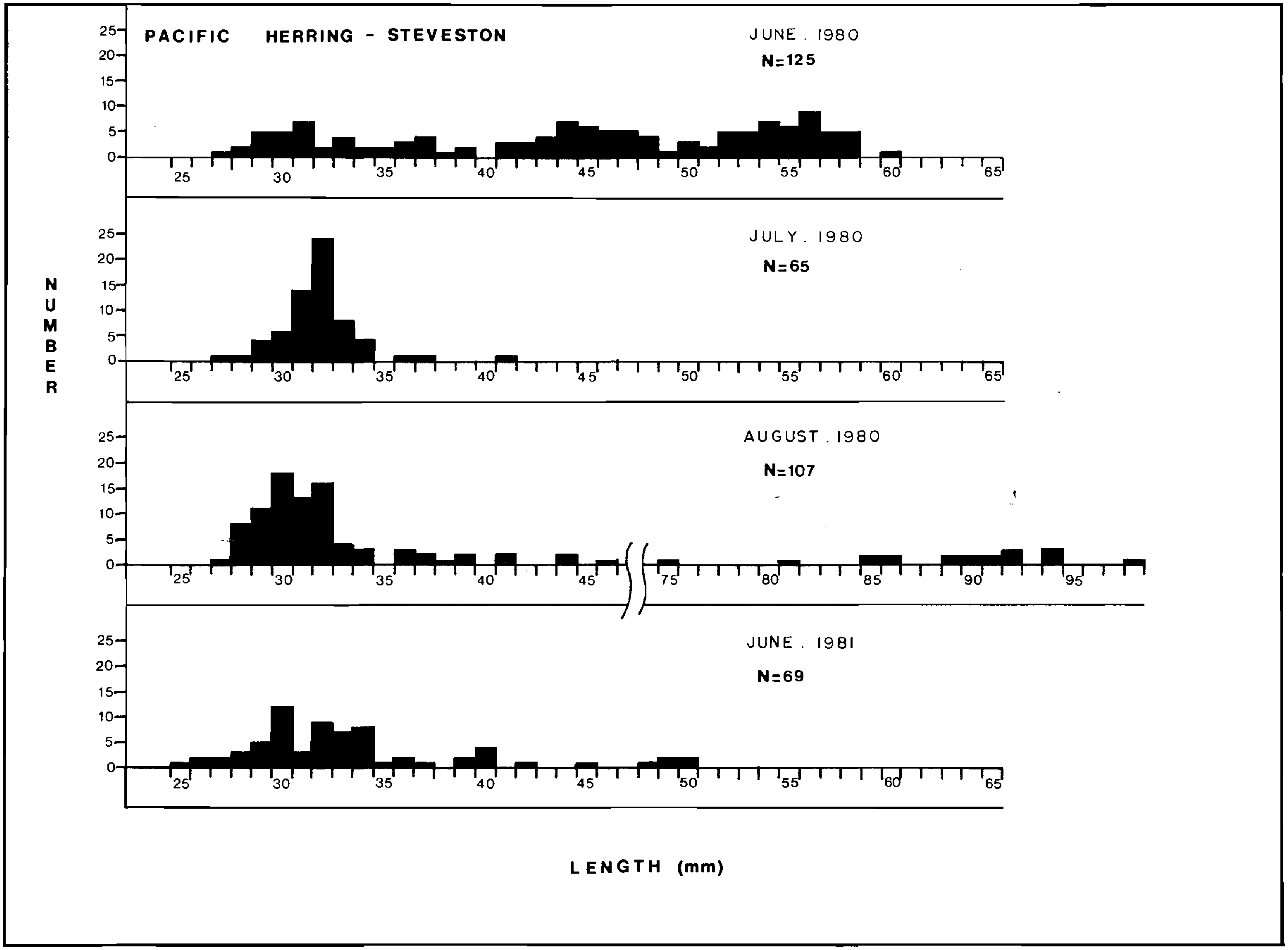


Fig. 18b. Length frequency data for herring at Steveston pits in 1980 and 1981.

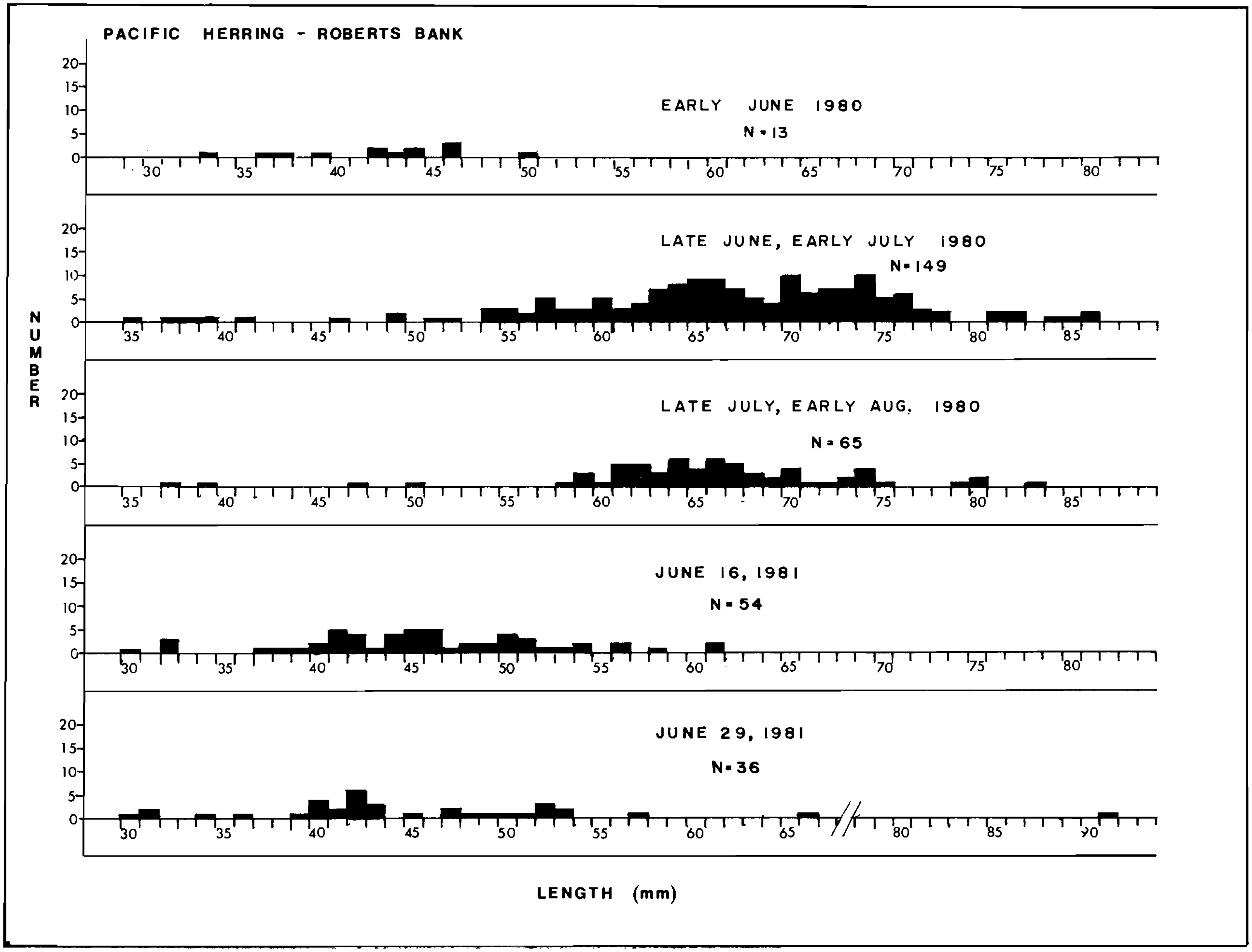


Fig 18c. Length frequency data for herring at Roberts Bank pits in 1980 and 1981.

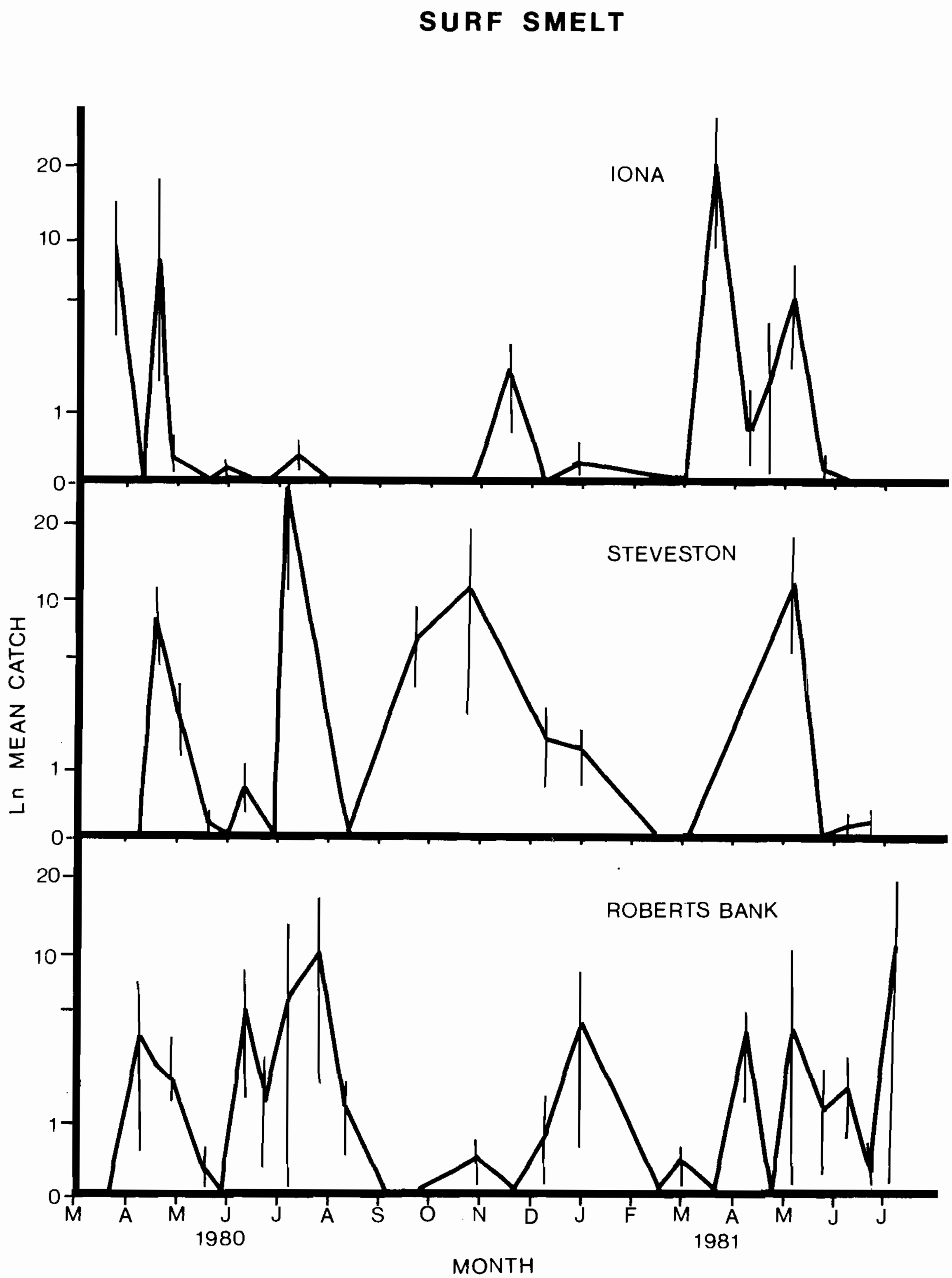


Fig. 19. Seasonal variation of surf smelt catches at Iona, Steveston and Roberts Bank. Mean values and standard deviation are shown for each date.

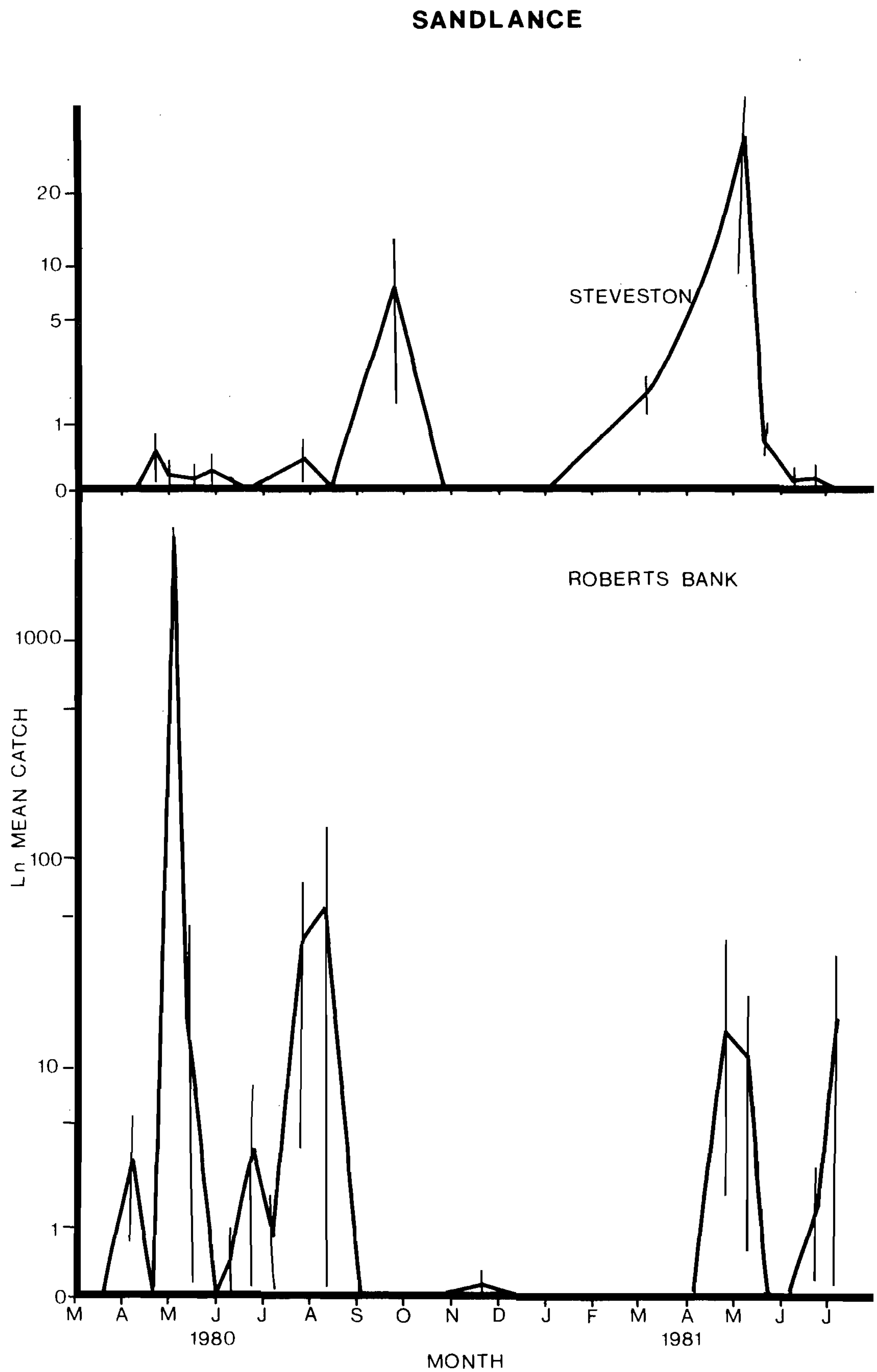


Fig. 20. Seasonal variation of sandlance catches at Steveston and Roberts Bank. Mean values and standard deviation are shown for each date.

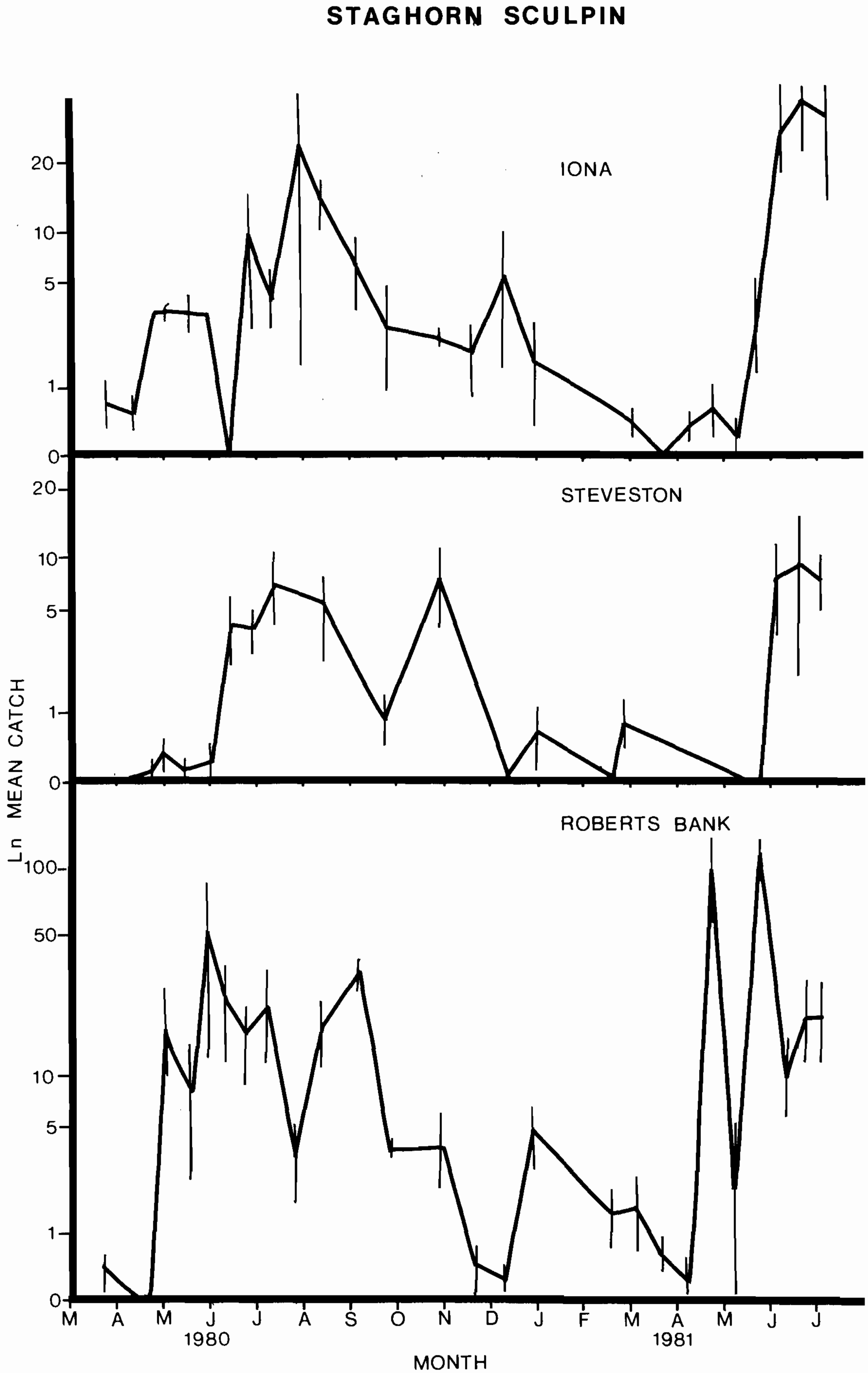


Fig. 21. Seasonal variation of Pacific staghorn sculpin catches at Iona, Steveston, and Roberts Bank. Mean values and standard deviation are shown for each date.

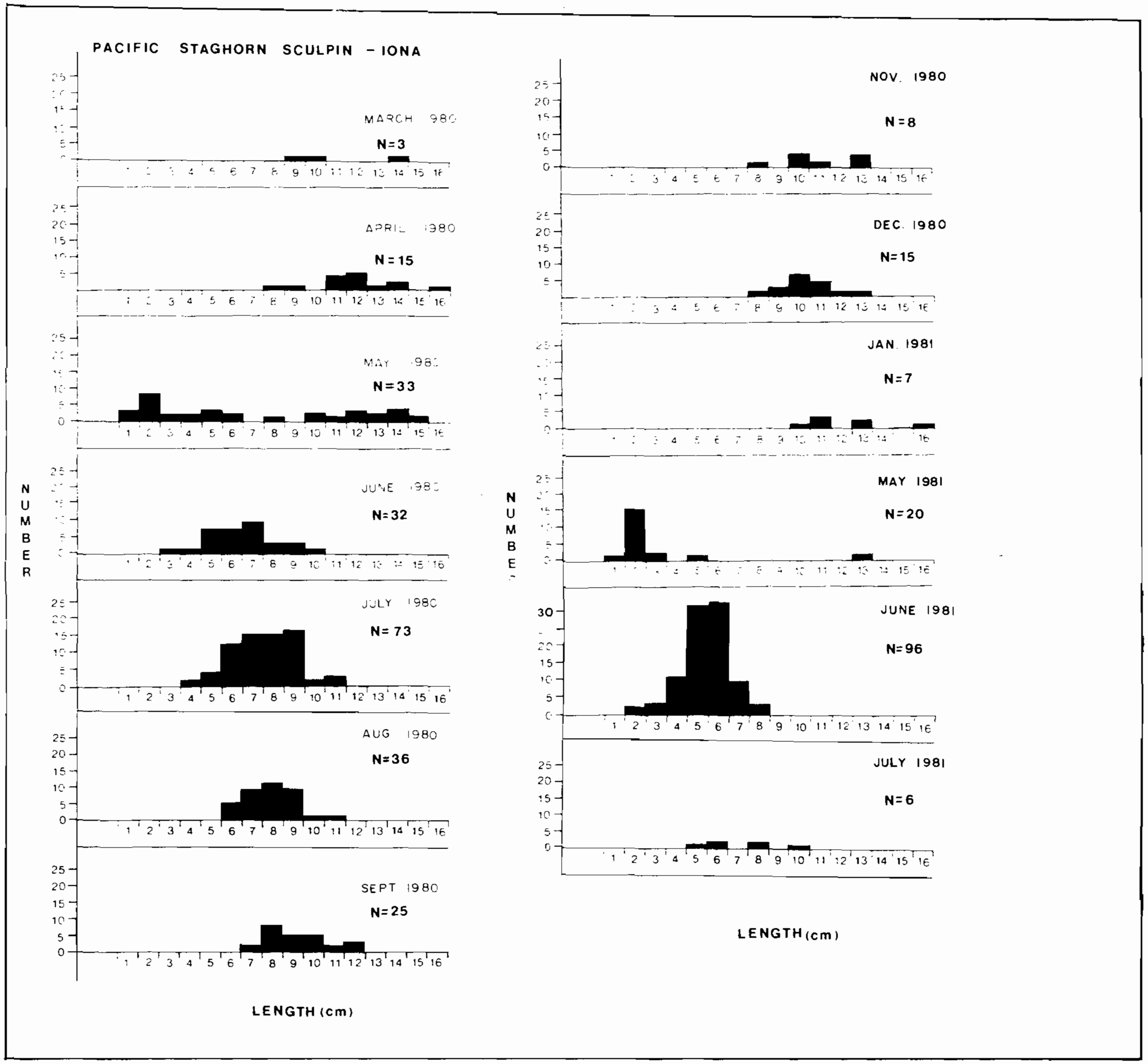
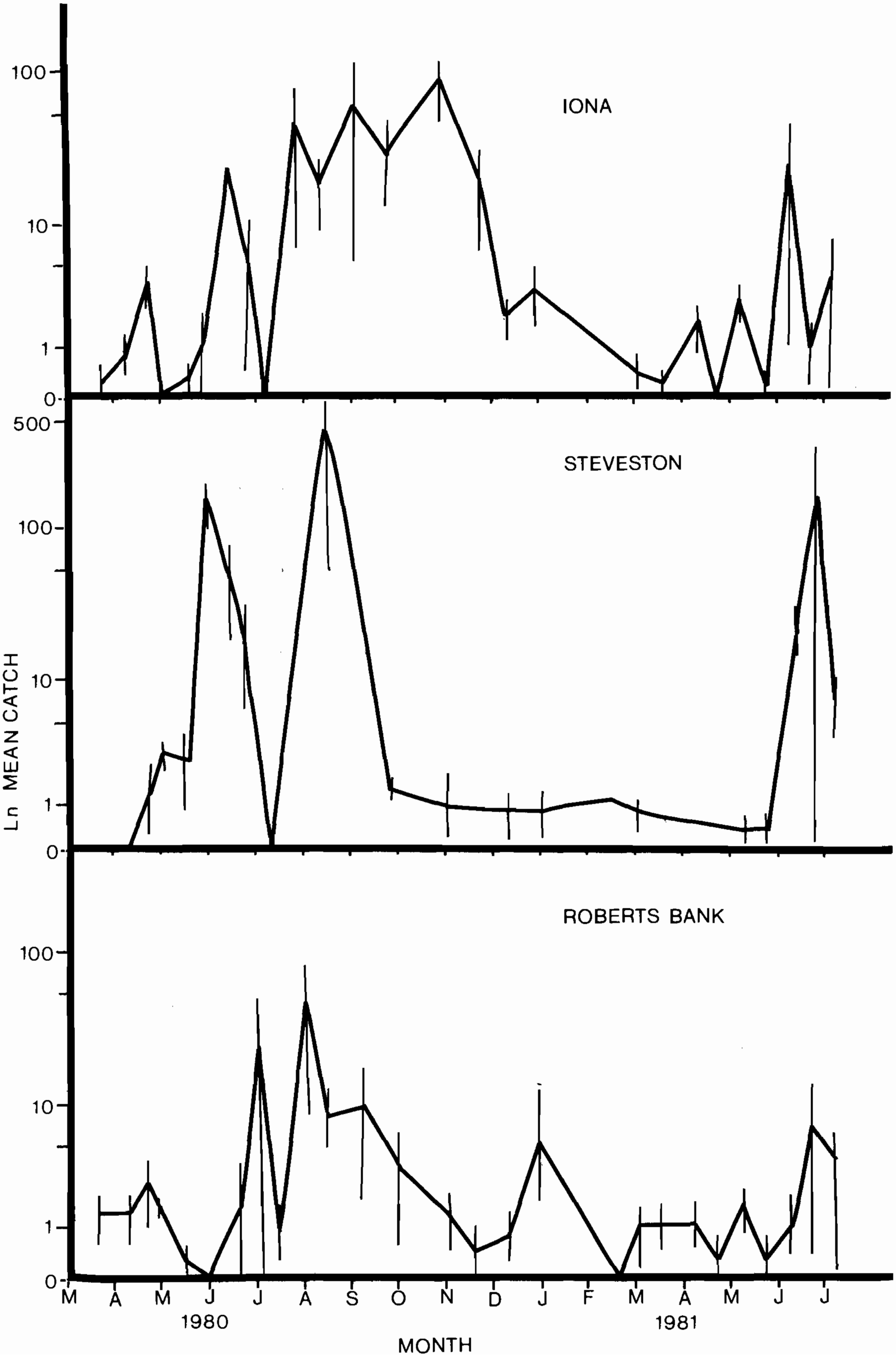


Fig. 22. Length frequency data for staghorn sculpin at Iona pit in 1980 and 1981.

Fig. 23. Seasonal variation of threespine stickleback catches at Iona, Steveston, and Roberts Bank. Mean Values and standard deviation are shown for each date.

THREESPINE STICKLEBACK



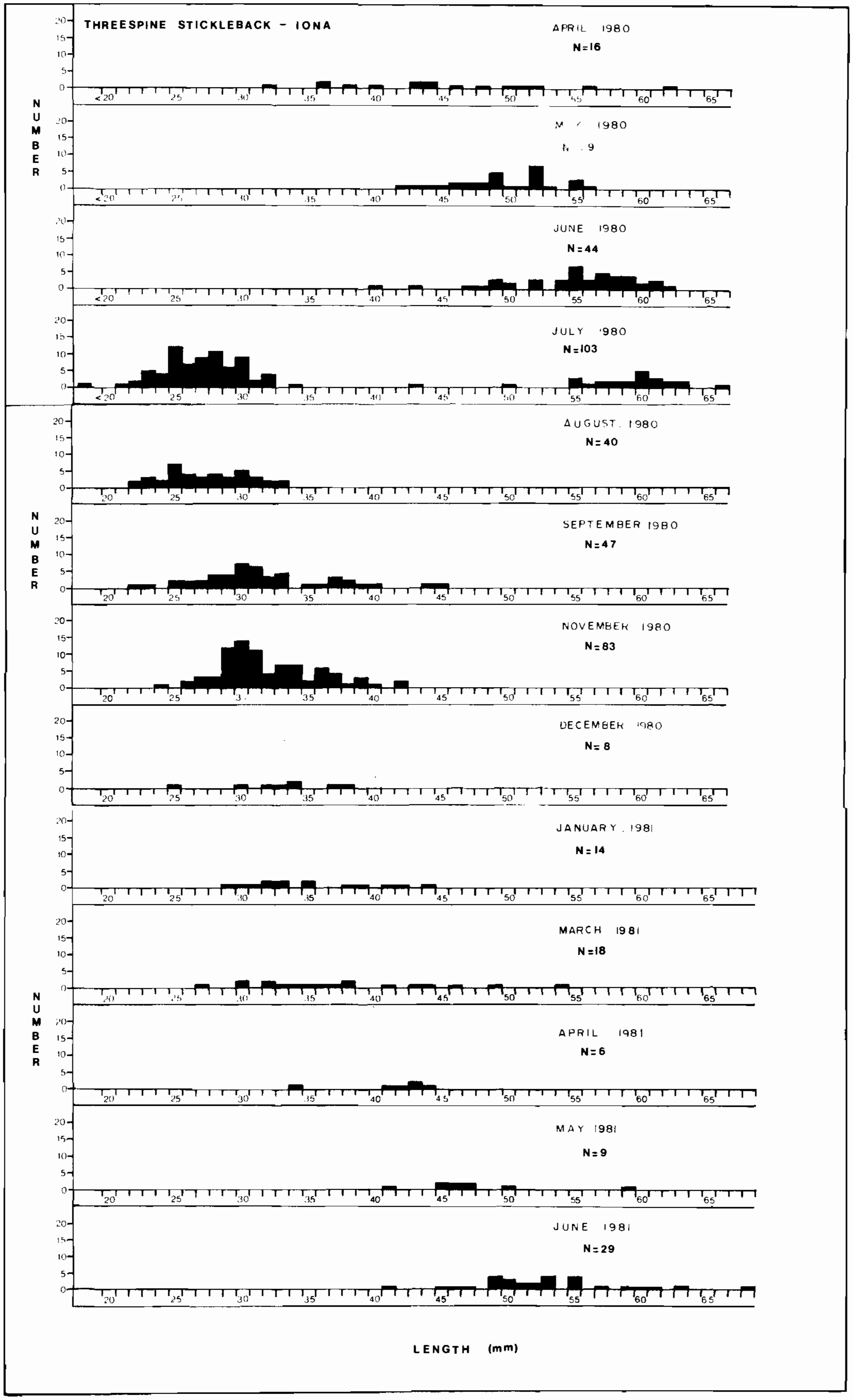


Fig. 24. Length frequency data for threespine stickleback at Iona pit in 1980 and 1981.

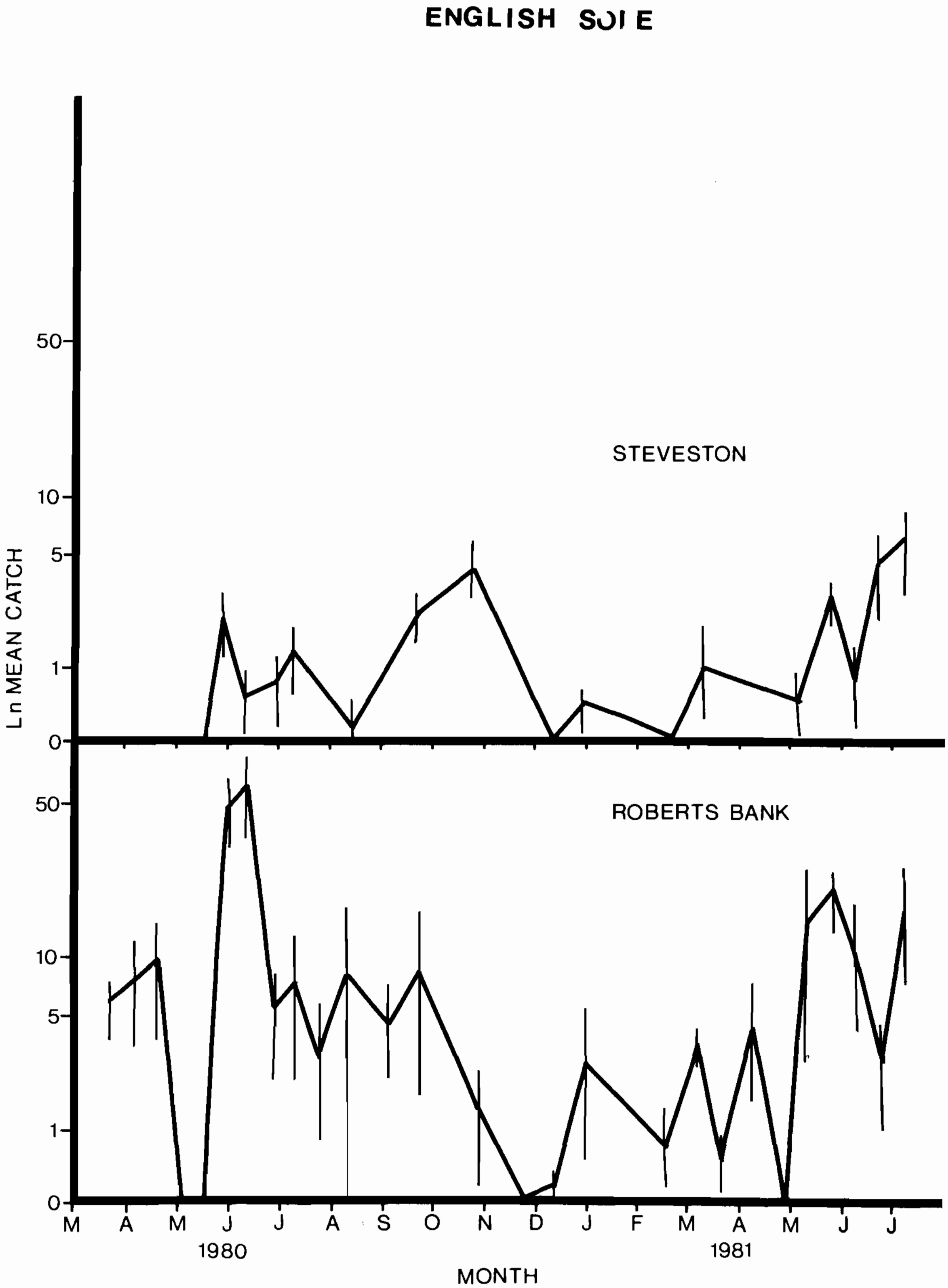


Fig. 25. Seasonal variation of English sole catches at Iona, Steveston and Roberts Bank. Mean values and standard deviation are shown for each date.

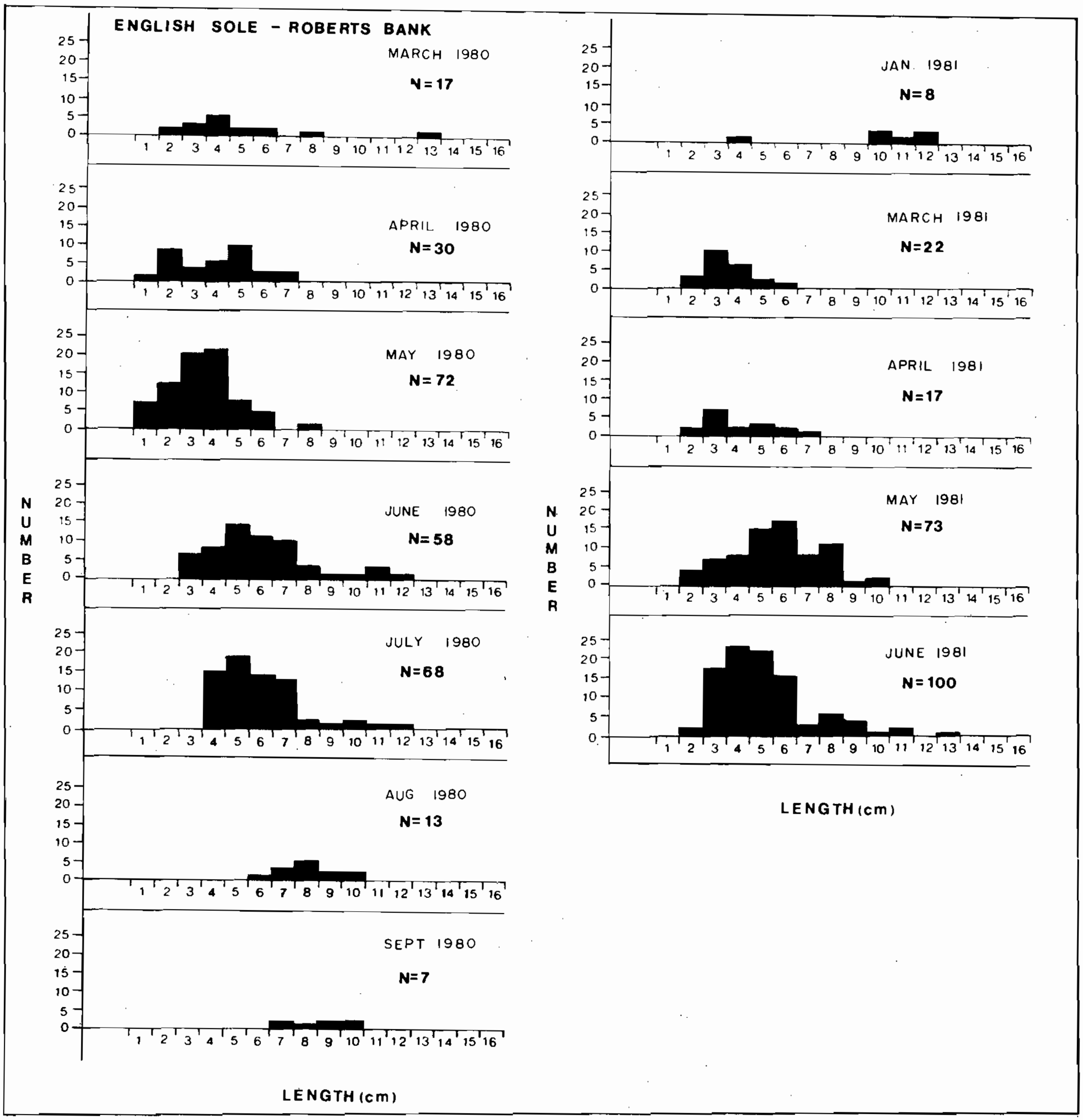


Fig. 26. Length frequency data for English sole Roberts Bank pit in 1980 and 1981.

STARRY FLOUNDER

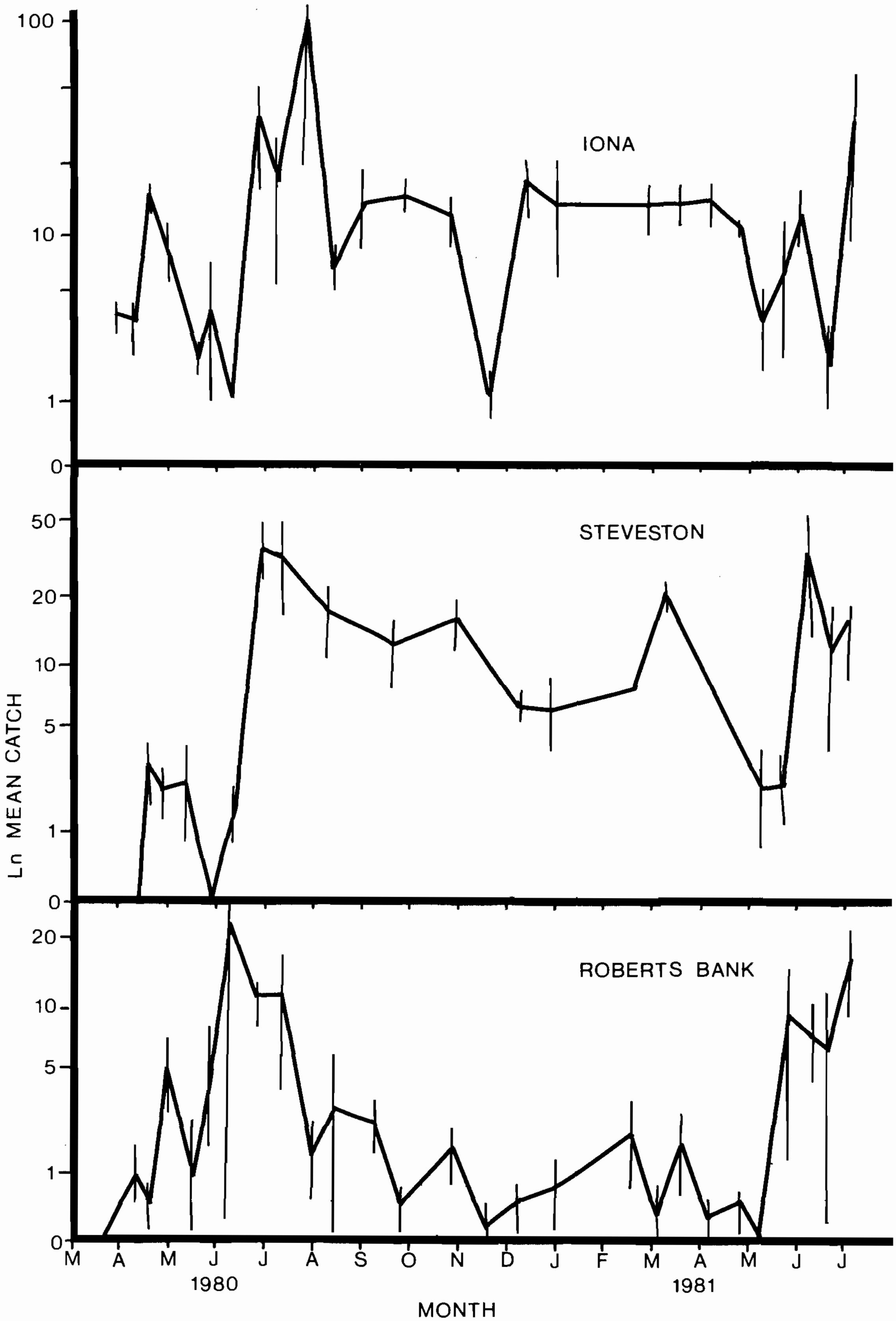


Fig. 27. Seasonal variation of starry flounder catches at Iona, Steveston, and Roberts Bank. Mean values and standard deviation are shown for each date.

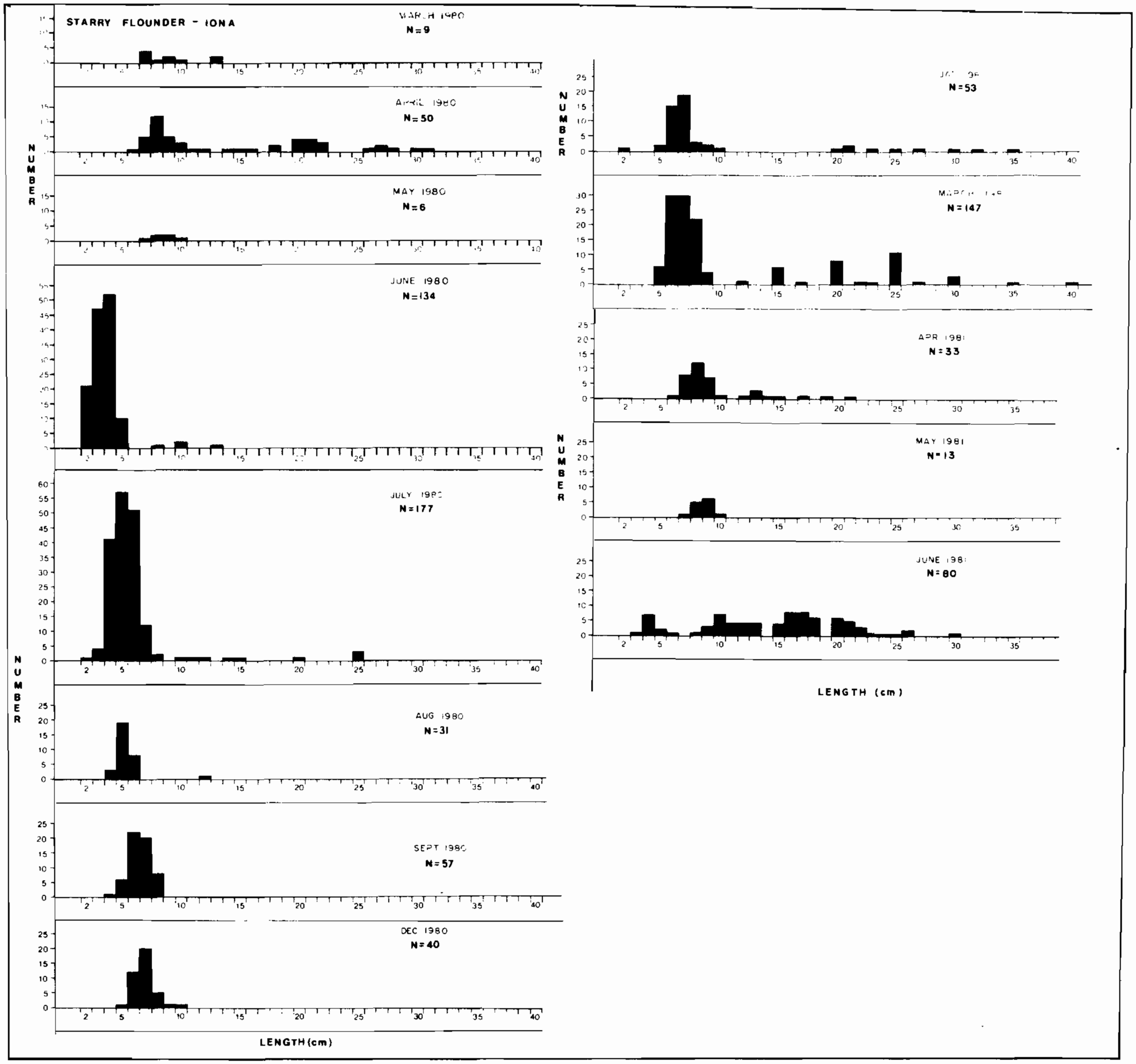


Fig. 28a. Length frequency data for starry flounder from Iona pit in 1980 and 1981.

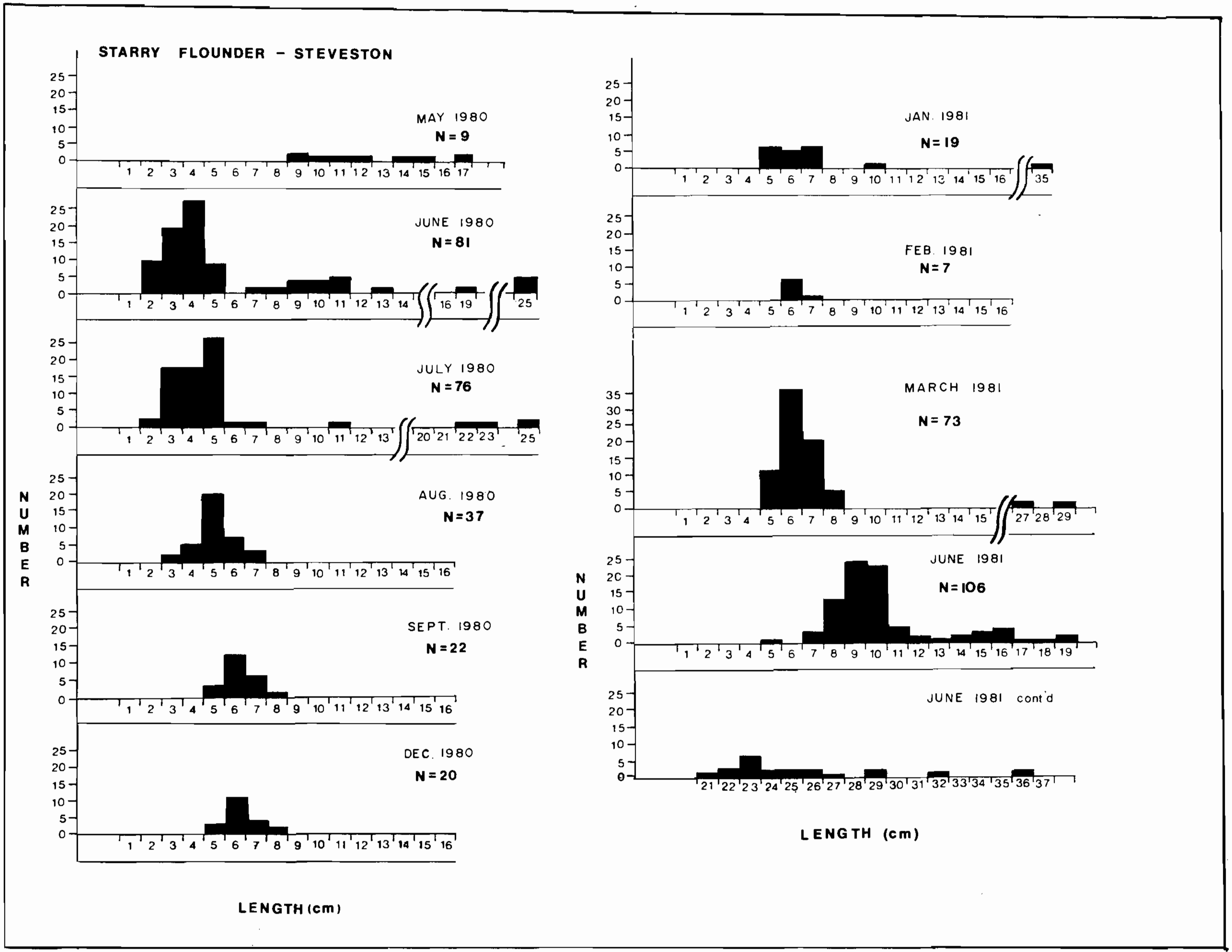


Fig. 28b. Length frequency data for starry flounder from Steveston pit in 1980 and 1981.