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A Research and Training Project on the Population Biology and Fishery of the California Spiny Lobster

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(Dexter; SDSC-4(b) GH-36)

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Graduate Student Training

In summarizing the training aspects of the Sea Grant Project, a number of students have gained experience in planning specific research programs, and in obtaining, analyzing, and interpreting data of the sort useful in studying the biology of a marine fishery. Most important, four students are using major aspects of the study for Master's thesis research in biology at San Diego State College. They are:

Joan Mitchell -	Food Preferences and Feeding Behavior of *Panulirus interruptus* Phyllosoma Larvae.
Anthony Roth -	Social Behavior of *Panulirus interruptus*.
John Rutherford -	Distribution of *Panulirus interruptus* Phyllosoma Larvae.
Stephen Serfling -	Recruitment, Habitat Preference, Growth, and Laboratory Rearing Studies of the Puerulus through Mid-Juvenile Stages of *Panulirus interruptus*.

In addition, a number of undergraduate and graduate students have been employed in collecting or analyzing data, supported in part by the Work-Study Program, they are:

Deanne Bigsby
James Blecha
Frederick Fineberg
Karen Huhne
Raymond Keyes
Michael Needham
Stephen Nelson

All of these students have had extensive opportunities: (1) to use a number of standard ecological, fisheries, and oceanographic techniques; (2) to integrate laboratory and field work; and (3) to examine aspects of the biology of benthic and pelagic habitats. Their contributions have added significantly both to the success of the project and to our knowledge of the California spiny lobster.

Distribution, Population Dynamics, and Habitat Preference Studies of Juvenile and Adult *Panulirus interruptus*

Richard F. Ford and Stephen A. Serfling

Introduction

The population ecology and related behavior of post-larval, juvenile, and adult *Panulirus interruptus*, and the relationships of these to the fishery, have been approached by several complementary lines of investigation. D.A. Farris has used conventional fisheries methods to analyze catch data for southern California, as well as data obtained from mark-recapture and catch sampling of the San Diego stocks. The thesis research of two graduate students has involved studies of recruitment, habitat preference, and related behavior of the puerulus, post-larval, and early juvenile stages (S.A. Serfling), and the social behavior of juveniles and adults (A. Roth). The purpose of the study described here has been to examine in detail some major aspects of distribution, population dynamics, habitat preferences, and related behavior of the demersal population through a direct, underwater sampling program in the San Diego area.

Materials and Methods

Quantitative field sampling of *P. interruptus* and associated organisms by observers equipped with SCUBA has been accomplished with modified techniques of the type described by Taylor (1963), Fager, et al. (1966), and Neushull (1967). The standard band transect sampling device developed for this study consists of a horizontally oriented PVC pipe, 1 m in length, which has a lucite board attached at its center. Acetate sheets and pencils for data recording, a compass, a metric scale, and an odometer tracking device are mounted on this board. The odometer consists of a string supply reel, a small revolution counter, and an attached lucite wheel, the latter driven by a taut string passed around the grooved wheel, and held in place by two tensioning devices.

In use, the free end of the string is anchored to an algal stipe or rock projection and then payed out around the counter wheel as the transect device is pushed along the bottom by the observer. This generates a band transect pattern 1 m wide, the length of which can be determined to approximately the nearest 0.1 m by reference to the calibrated odometer counter. The exact position of animals and habitat features along the transect can also be determined from counter readings. Comparison of a large number of replicate counter readings determined along an accurately measured path underwater indicated that odometer tracking error is negligible; lateral movement by surge, string breakage in turbulent water, and inability of the observer to sight accurately along the transect path width appear to be the major sources of measurement error, but these generally are not serious effects, considering the scale of the data estimates obtained.

The standard sampling pattern consists of two sets of paired transect paths run close together in parallel by two observers, each single transect covering a bottom area of 50 square meters, and resulting in a total sampling area of 200 square meters. A single transect pair (total area 100 square meters) has been employed in deeper water because of bottom time limitations. On each transect, the number, estimated carapace length to the nearest 1 cm, and position of all P. interruptus within the path have been recorded, together with systematic observations on their behavior and distribution in relation to microhabitat features and other species. Pertinent environmental measurements and representative density estimates of larger, conspicuous invertebrates and fishes also have been obtained. These visual observations have been supplemented by photography.

Two major station lines were established, one off Sunset Cliffs approximately 8 km north of the Point Loma lighthouse, San Diego, California, and the other off La Casa reef, approximately 0.75 km south of Point La Jolla. Standard transect sampling has been conducted approximately monthly or bimonthly since 1969 at permanent stations within the depth range 3 to 30 m. These station locations were selected as representative of P. interruptus habitats in southern California. Additional comparative sampling has been conducted in other areas off San Diego using the same standard techniques.

Relocation of stations is facilitated by the use of ranges on known shore points and by placement of transect markers on the bottom. The exact path and extent of the transect pattern has been marked on the bottom to facilitate precise repeat sampling of the same area with time. A combination of concrete block markers, with and without styrofoam floats, and brightly colored plastic forestry tape has been used for this purpose. The latter material, which is tied to algal stipes and rock projections, has proved to be the most durable and easily applied underwater marker.

Bathymetric Distribution and Abundance

Larger juvenile and adult lobsters are known to occur on almost all rocky or rock-sand areas in southern California and, to some extent, even on open sand or mud bottom. Such rocky areas are limited primarily to the depth range 0 to 35 m on the continental shelf off San Diego. Regular sampling within this depth range on the two representative station lines established off Point Loma and Point La Jolla, and at other San Diego localities, has provided a relatively detailed picture of size-specific bathymetric distribution and abundance on a short-term and seasonal basis. Typical seasonal plots of this kind for the Point Loma station line are shown in Fig. 1. These and similar data from the La Jolla stations indicate that P. interruptus was most abundant throughout the year at depths of 3 to 8 m (see mean densities shown in Fig. 1), and that the majority of the individuals found within this depth range were sub-legal or just legal in size (40 to 90 mm carapace length). A similar size-frequency distribution pattern was evident at the deeper stations. In general, both larger legal size (90 to 120 mm C.L.) and small juveniles (20 to 40 mm C.L.) also were more abundant throughout the year at depths of 3 to 4 m than in deeper water, and individuals 30 to 40 mm C.L. or smaller were almost never encountered deeper than 8 to 10 m. Qualitative sampling has shown that most small juveniles (20 to 30 mm C.L.) occur intertidally, or just subtidally, under conditions where they are extremely difficult to sample quantitatively.

The major size and sex-specific changes in bathymetric distribution observed seasonally by Mitchell et al. (1969) off San Clemente Island, California, were not evident on the two San Diego coastal station lines we have sampled, although there was a trend toward slightly increased densities at the 24 and 30 m stations during the late fall and winter months (Fig. 1). These results suggest that the major bathymetric movements reported by Mitchell et al., particularly the apparent movement of most individuals into deep water (> 15 m) during the winter months, may be restricted to steeply sloping rocky shelf areas characteristic of the offshore islands. In contrast, the San Diego coastal population appeared to exhibit a relatively stable pattern of bathymetric distribution and abundance throughout the year. It should be noted, however, that it has not been possible to determine the sex or molt condition of lobsters by the visual censusing technique employed in our study. Attempts are now being made to evaluate possible relationships of the observed subtle changes in size-specific bathymetric distribution and abundance to temperature and other environmental conditions. Similar evaluations will be made of possible separate seasonal shifts in the distribution of males and females and their relationship to environmental conditions, using catch and mark-recapture data obtained by D.A. Farris.

It is obvious from examination of size frequency data and density estimates of legal size P. interruptus (≥ 83 mm C.L.) that the San Diego stocks are heavily overfished. Compared with areas of low fishing pressure in Baja California and some offshore islands, individuals larger than 83 mm C.L. are present in very low abundance off San Diego, and those larger than 110 mm C.L. are extremely rare. The fishery removes small, legal-size animals as well as larger individuals from the population rapidly during the first few months of the season, a cropping effect which is evident from examination of the size-frequency data summarized in Fig. 1, and similar data obtained from catch sampling.

Our results suggest that catch per unit effort might be increased somewhat if it were possible to maintain trap lines regularly in very shallow water (< 5 m). This is attempted by some fishermen near the end of their participation in the fishing season, when their traps are expendable. These men report that such shallow trap lines are highly productive, but that there is considerable trap loss due to wave action (A.B. Cadman, personal communication). These shallow habitats thus appear to serve as a natural refuge for legal size individuals. The low densities of P. interruptus observed in most of the suitable areas sampled further suggests that "habitat improvement," such as the formation of artificial reefs, would have little effect in increasing population size.

Population Stability at Specific Localities with Time

It is the general concensus of lobster fishermen that P. interruptus move from one local area to another frequently, and that areas supporting a large number of individuals may be completely vacated within the space of a few hours or days. An understanding of this process is of obvious importance in evaluating trap placement techniques.

While the numbers of legal size individuals encountered in a standard transect pattern were low, density and size-frequency data obtained from repeat sampling of exactly the same transect positions with time provides some insight into this problem of local stability. Typical results for two localities on the Point Loma station line are shown in Fig. 2. At the 4 m station, the total densities and size composition of individuals remained surprisingly stable over periods of several months, for example, during the period of late July through November, 1969. In contrast, densities and size composition varied markedly during this same period at the 8 m station, located just offshore. These results suggest that local stability of individuals may vary depending on the nature of the habitat and possibly other factors. This is supported by the fact that, in terms of the depth and configuration of the rock ledges and their orientation to prevailing surge conditions, the 4 m station appeared to be a more suitable lobster habitat than the 8 m station.

An attempt is now being made to consider these and shorter term variations in stability as they relate to habitat suitability, changes in water temperature, and other hydrographic conditions. An attempt also will be made to mark resident individuals and determine by subsequent visual "recapture" the extent to which they remain in the same area. Preliminary observations by Lindberg

(1955) and in the present study suggest that individual P. interruptus may tend to remain in a localized area and exhibit homing behavior, but that gradual random mixing occurs within the demersal population. In general, this seems to be supported by data concerning local movements of tagged individuals, discussed by D.A. Farris in another section of this interim report.

Habitat Preferences

Although P. interruptus occupies a wide variety of specific habitat types, it appears to be most abundant in areas having low, deep ledges and/or flat, undercut table rocks, which in shallow water are generally covered with Phyllospadix or heavy algal growths. Individuals inhabiting very shallow water (< 5 m) usually occupy such deep ledges, which appear to provide very effective protection from surge and turbulence during periods of strong wave action. This seems to be the most logical explanation for the observed persistence of large numbers of individuals in shallow water throughout the year.

Rubble rock areas (Winget, 1968), consisting of undercut table rocks, boulders, and short ledges, constitute another habitat type which apparently is less suitable than that described above. Such areas, which are common at depths of 10 to 15 m off San Diego, generally are sparsely covered with algal growths and the microhabitat refuges for P. interruptus are more exposed and shallow. P. interruptus occupying the rubble rock habitat appear to be considerably more transitory than do individuals inhabiting suitable ledge areas.

Much of the rocky bottom off Point Loma and La Jolla consists of flat pavement rock, interspersed with boulders and covered by a variety of algal species. Because they lack suitable refuges, such areas represent a very marginal lobster habitat, and P. interruptus densities there are very low. However, the high productivity of lobster traps placed on open pavement rock bottom suggests that individuals may move into such areas at night to feed. More detailed aspects of habitat selection are now under study.

Relationships with Other Speces
Occupying the Same Micro-habitat

The ledges, holes, and undercut rock areas normally occupied by P. interruptus also are inhabited by a variety of other invertebrates and fishes. In the case of higher, more open ledges, particularly in deep water, the presence of predatory fishes such as the California sheephead (Pimelometopon pulchrum) may affect the abundance and size composition of lobsters found there. In some areas high densities of abalones (Haliotis spp.) and a large sea urchin (Strongylocentrotus franciscanus) appear to cause physical exclusion of P. interruptus. In both rubble rock and ledge hatitats, P. interruptus and S. francicanus replace one another periodically and the lobsters appear to avoid areas occupied by aggregations of sea urchins. The dynamics and specific nature of these "interactions" are now being examined in greater detail.

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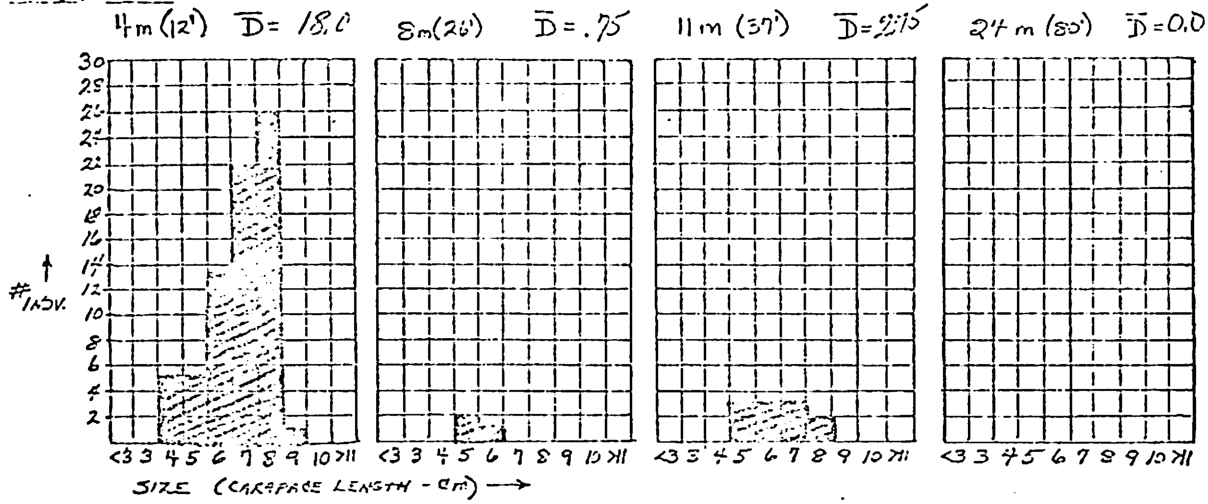
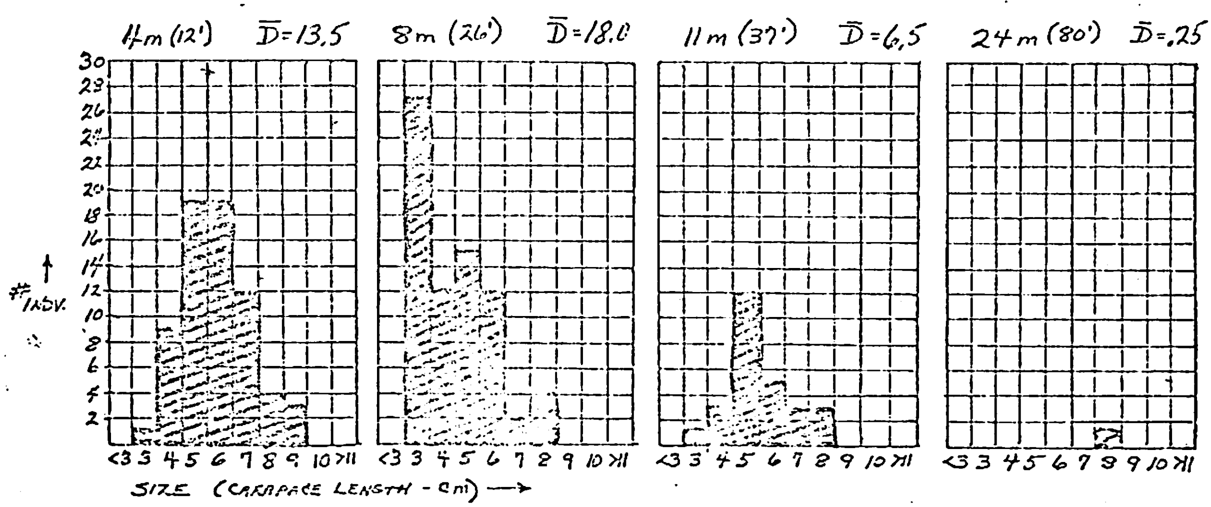
Figure 1. Size frequency and bathymetric distributions of *Panulirus interruptus* at 4, 8, 11, and 24 m stations on Point Loma station line for the period July, 1969-April, 1970. D̄ is the mean density for all size groups combined, expressed as number of individuals per 50 square meters.

July, 1969



September, 1969



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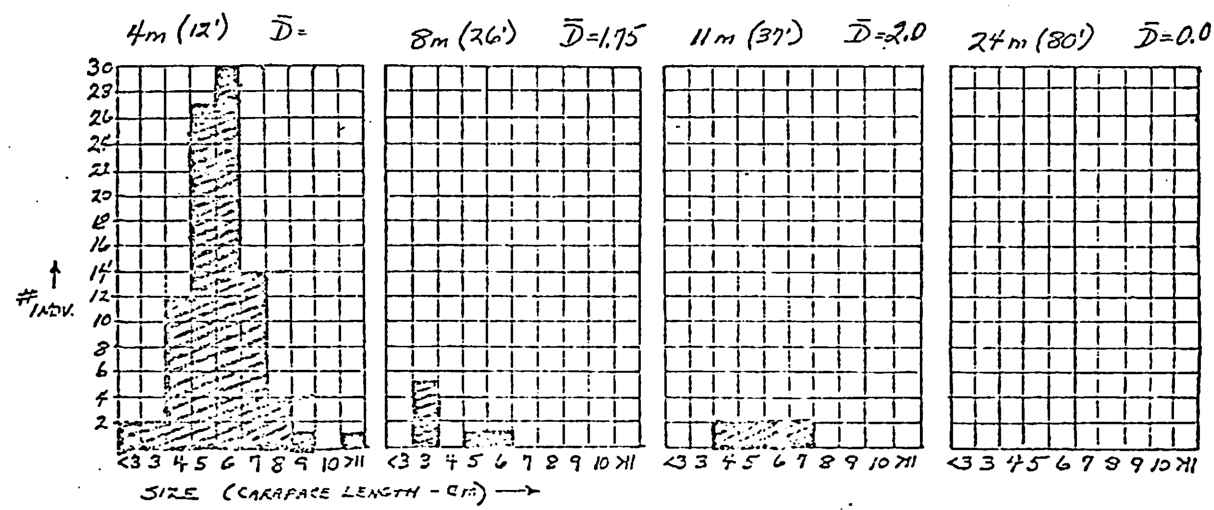
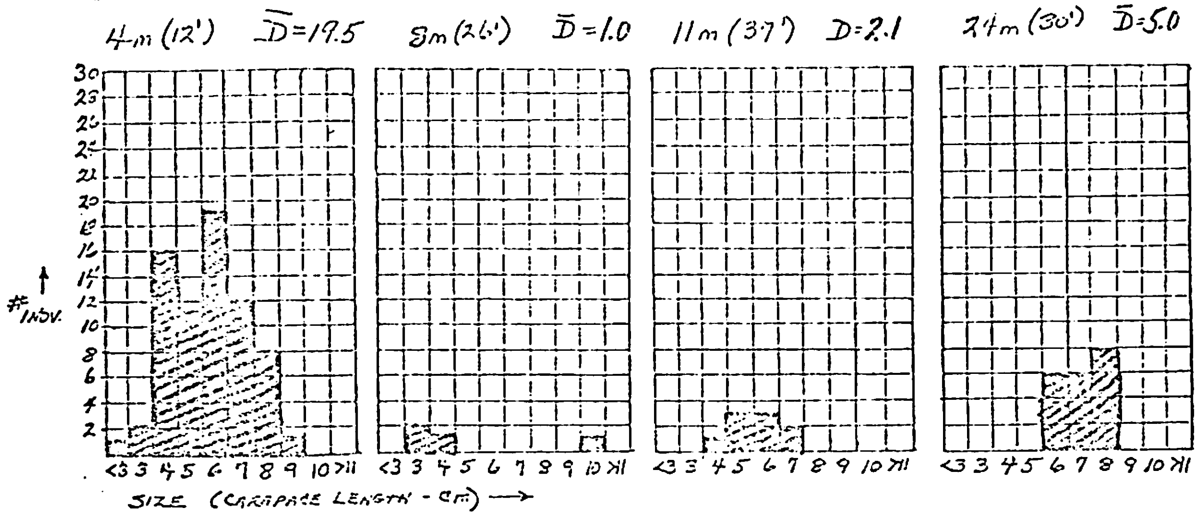


Figure 1, continued

November, 1969



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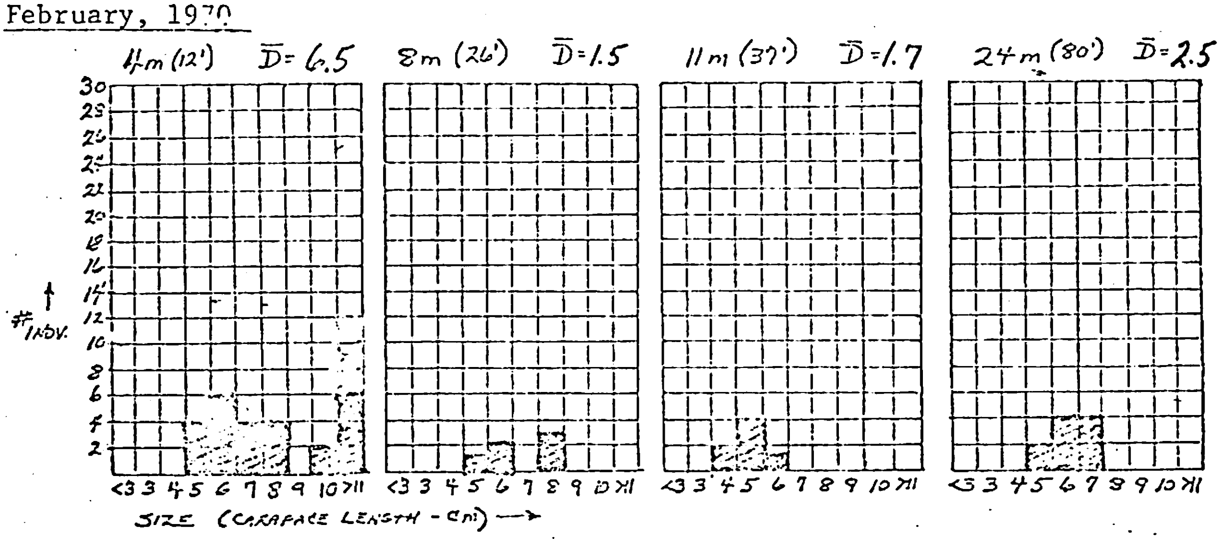


April, 1970

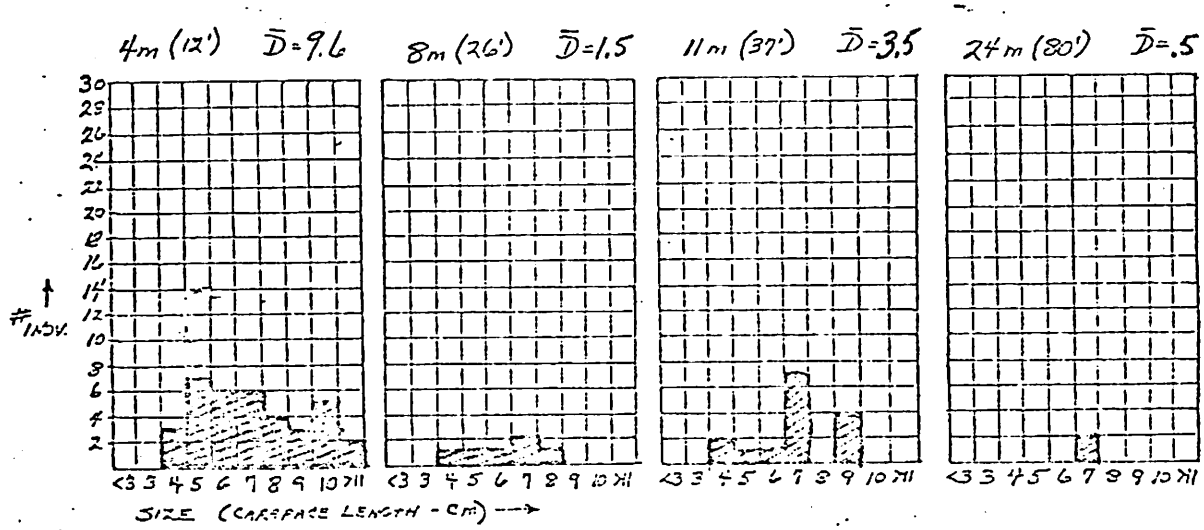
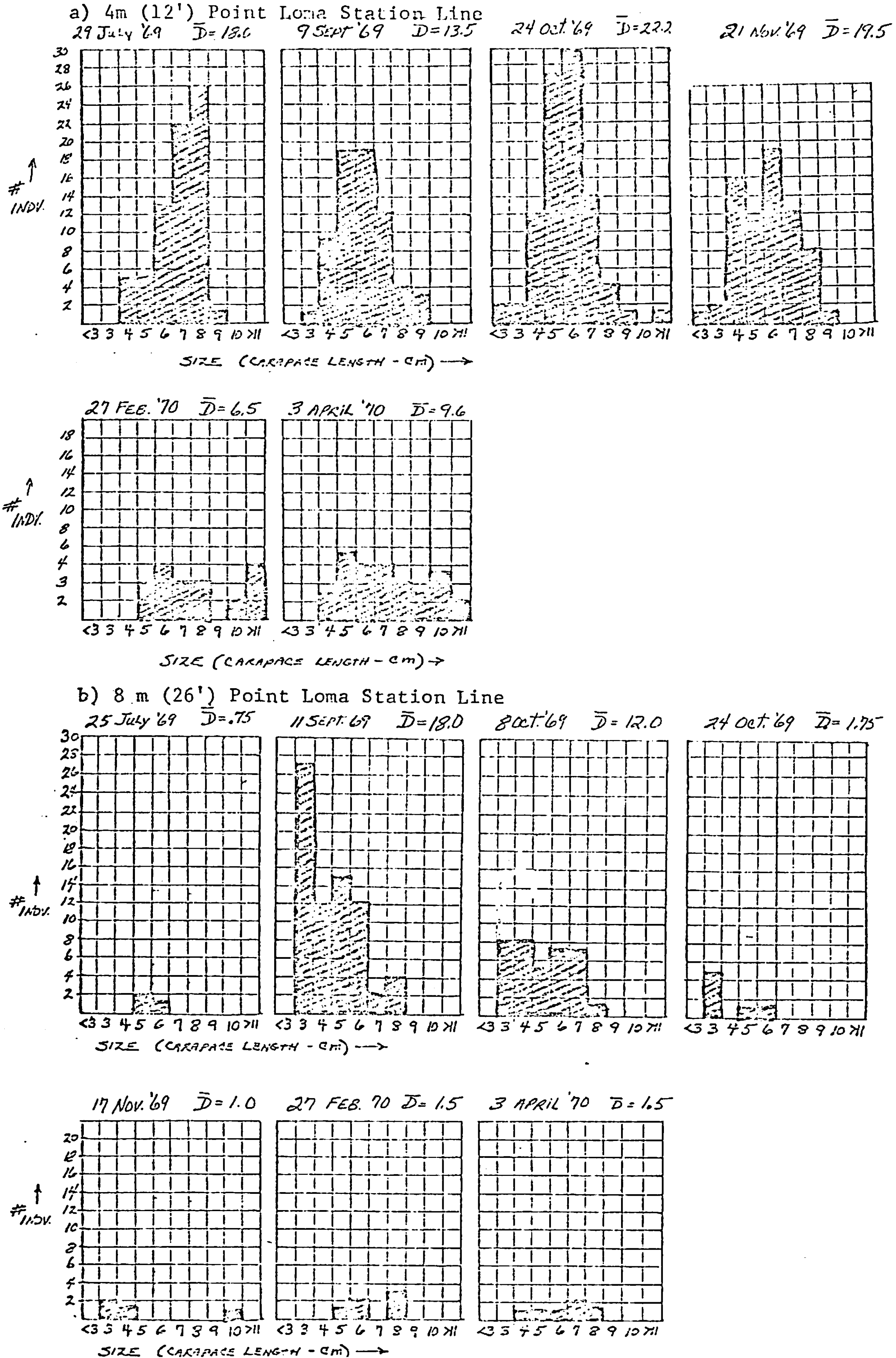


Figure 2. Short term and seasonal variations in size frequency distributions of Panulirus interruptus at two permanent stations on the Point Loma station line. D is the mean density for all size groups combined, expressed as number of individuals per 50 square meters.



Impoundment Studies of Tagging Techniques, Growth, and Molting Frequency in Juvenile and Adult *Panulirus interruptus*

Richard F. Ford, Anthony C. Roth, and David A. Farris

Introduction

With the exception of Lindberg (1955), no previous attempts have been made to conduct marking studies of *Panulirus interruptus*. The intensive mark-recapture program described by D.A. Farris in a separate section of this interim report required that recently developed tagging methods and the effects of tagging on *P. interruptus* be evaluated. Although some preliminary growth data for *P. interruptus* were obtained by Barnhart (1919), Lindberg (1955), and Bacus (1960), little information has been available concerning size-specific growth rates, molting frequencies, and the effects on these of water temperature and other seasonal influences. Such information is of obvious importance in understanding fishery production, age-size relationships, and related fishery regulation.

Thus, the purposes of the impoundment studies described here have been: 1) to evaluate tagging methods and tag effects as a basis for the fishery mark-recapture program, and 2) to obtain short and long-term data on growth and molting processes under simulated natural conditions. These two investigations have been conducted simultaneously during the period June, 1969 to the present, using the same groups of individuals in an adequately replicated experimental design.

Material and Methods

Impoundment System

Most of the experimental work is being conducted in a large, enclosed concrete pool, measuring 5 x 11 x 2.5 m deep, located at the base of the Scripps Institution of Oceanography pier. Filtered seawater is supplied continuously at a high flow rate (50 gpm) through a PVC pipe diffuser system on the floor of the tank, designed to suspend and remove particulate matter from the system, and to simulate natural bottom water circulation. A normal day-night cycle of illumination with dawn and dusk simulation is provided by banks of lights controlled by an outside photocell, and directly through small windows. Except on very warm summer days, the temperature regime of the tank has remained essentially the same as that of the water at a depth of 4 - 5 m off Scripps Institution, the seawater system source. Maximum and minimum temperatures over 1 - 3 day intervals in the tank have been determined continuously during the experiment using a recording thermometer. Ledges and holes of the approximate size selected by P. interruptus in nature have been simulated by using concrete blocks and sheets of corrugated fiberglass. Although the density of individuals in the tank has exceeded that normally observed in nature, the amount of useable refuge space provided appears to have been sufficient to avoid unnatural crowding.

Experimental Design and Maintenance

Four size groups of P. interruptus, representative of mid-juvenile to large adult stages, have been used in the study. The initial size ranges of individuals in these groups were:

1) 50 - 55 mm in carapace length
2) 66 - 72 mm C.L.
3) 78 - 83 mm C.L. (just sublegal - legal)
4) 92 - 142 mm C.L. (most 92 - 110 mm).

Of the 30 individuals in each size group, 1) ten were used as controls and marked for recognition by a coded sequence of holes punched in the telson; 2) ten were marked with sphyrion sub carapace anchor tags (Scarrett, 1970), as modified by Richard Cooper for use on Homarus americanus; and 3) ten were marked in the same manner with all nylon molded anchor tags (No. FD-67) and tagging gun produced by the Floy Tag Company (Dell, 1968). These anchor tags were inserted into muscle tissue under the dorso-posterior edge of the carapace just to the side of the body midline. Tag types were assigned to individuals at random, with equal numbers of males and females in each tag category.

In addition, all animals have been marked with a color coded antennal tag, consisting of glass beads strung on fine stainless steel wire, which is firmly attached to the base of the antenna. By using this double marking system, individuals which have either molted or lost their subcarapace body tag can be identified for growth and molting frequency or tag loss determinations. Because the antennal tag remains with the molted exoskeleton, the molts also can be recognized. Following each molt, a new antennal tag is attached. During the first few months, individuals which lost the subcarapace body tag either were retagged or removed from the experiment and replaced by another marked animal.

The 90 experimental animals, together with some six intermediate sizes, have been maintained on food in slight excess, established on the basis of ingestion rate estimates reported by Winget (1968), and empirical observations. The diet has consisted primarily of live Mytilus edulis and associated small organisms, supplemented by live sea urchins, frozen abalone, and fish. Initially, varying proportions of these foods were used to determine lobster preferences and to assess maintenance problems. Food has been added and the system checked for evidence of molting and tag loss every 2 - 3 days, supplemented by a more thorough search during weekly cleaning operations.

Initially, and at the time of each molt or tag loss, the carapace length, molt and reproductive condition, the condition of the tag and tag scar, and evidence of pathological and other effects have been determined. In addition, general observations have been made of social interactions and the effects of other individuals on the tags themselves. Data are routinely transferred to computer punch card form for ease in record maintenance and analysis.

Tag Evaluation

The criteria used in selecting the tag and tagging method for the fishery mark-recapture studies included ease of application, ease of visual recognition by the fishermen, low tag loss during and between molts, minimal injury or unnatural mortality, and mimimal effects on growth, molting, and behavior. The design employed has allowed direct, quantitative comparisons to be made, as well as the opportunity to observe short and long term qualitative effects under reasonably natural conditions.

Typical tag retention-loss data for a 30 week period are summarized in Table 1. Such results suggested that, in general, the two tag types, were similar in terms of their retention qualities. However, retention of the Floy tag was notably inferior when used on animals 78-83 mm C.L., and, over the long term, appeared to be somewhat inferior for the smallest (50-55 mm C.L.) size group. Tag retention in general was best on the largest animals (18%-21% loss) and poorest on those 50-55 mm C.L. (60-66%). The most logical explanations for this are the greater molting frequency of small *P. interruptus* and the smaller size of these animals in relation to tag size. There were few mortalities that could be attributed directly to tag effects. Of the total 10 deaths which occurred, half were among the 50-55 mm C.L. juvenile group (3 Floy, 1 sphyrion and 1 control animal). Assuming that the tagged animal deaths were due to tag effects, the Floy tag may have been somewhat less desirable for small individuals.

On the basis of the considerations discussed above, the relative ease of applying the tags, and the relative diameter of the anchor filament, the sphyrion tag was selected for use in the

Table 1. Tag retention-loss data for P. interruptus of three representative size groups (mm C.L.) over a 30 week period during 1969-70.

		Cumulative Percent Tag Loss by Size Group		
Week	Tag Type	66-72 mm C.L.	78-83 mm C.L.	95-142 mm C.L.
1	Floy	13.3	5.5	0.0
	Sphyrion	26.6	7.8	6.8
3	F	20.0	22.2	0.0
	S	28.8	10.5	6.8
5	F	26.6	27.7	0.0
	S	28.8	10.5	10.3
7	F	26.6	27.7	0.0
	S	28.8	10.5	10.3
9	F	26.6	27.7	0.0
	S	29.5	10.8	10.3
11	F	26.6	27.7	18.1
	S	29.5	10.8	17.2
13	F	26.6	27.7	18.1
	S	29.5	10.8	20.6
15	F	26.6	27.7	18.1
	S	29.5	10.8	20.6
17	F	33.3	33.3	18.1
	S	36.3	18.9	20.6
19	F	40.0	33.3	18.1
	S	37.2	18.9	20.6
25	F	42.8	33.3	18.1
	S	37.2	18.9	21.4
30	F	42.8	33.3	18.1
	S	37.2	18.9	21.4

field mark-recapture studies. The amount of sphyrion tag loss observed for *P. interruptus* is considerably higher than for similar tags used on *Homarus americanus* (Scarratt, 1970; Richard Cooper, personal communication). One possible explanation may be that the tag anchor is retained less well by the soft muscle tissue of *P. interruptus* and/or that this tissue is more susceptible to the formation of an open tag wound. Many animals in the impoundment experiment and in the field recapture samples had such wounds, and in some cases the tag was retained primarily by the membrane attached to the posterior margin of the carapace.

Other obvious causes of actual or effective loss for both tag types included breakage or abrasion of the anchoring filament and partial or complete abrasion of the vinyl tubing containing the tag number, through wear or chewing by other lobsters. The latter appeared to be a fairly significant problem in the impoundment system, where lobster densities were unnaturally high. These effects are now being evaluated in greater detail.

The possible importance of tag loss or increased susceptibility to injury or mortality as the result of picking at the tag by fishes was evaluated by placing individuals with both tag types in public display and holding tanks of the Scripps Institution public aquarium. Fishes in the tanks used included most species which occur commonly with *P. interruptus* in nature. Regular observations of interactions and records of tag loss are now being evaluated. Preliminary results indicate that the fishes considered had no obvious effects on tagged lobsters that can be attributed to the tag.

Growth, Molting Frequency, and Age-Size Relationships

Because the anchor tags used appear to have had little effect on the growth and molting processes, data for all individuals are being used to develop estimates of size-specific growth rate and molting frequency, and the effects on these of temperature and other factors. Comparable data on growth in nature were obtained from multiple recapture measurements on a large number of tagged individuals in the mark-recapture study.

On the basis of preliminary analysis, the field and impoundment system estimates appear to be similar. This suggests that the more extensive growth and molting data obtained under impoundment conditions probably are valid as estimates of these processes under natural conditions. The mean increase in carapace length for each of the size groups during the period July, 1969 to April, 1970 are given in Table 2.

Table 2. Mean increase in carapace length per day (mm) for *P. interruptus* of the four size categories.

Size (mm C.L.)	Mean increase per day (mm)
50-55	0.038
66-72	0.525
78-83	0.052
95-142	0.051

Annual molting frequency estimate will be made in July, 1970 at the end of the first year of the impoundment study. During the period July, 1969 to April, 1970, some individuals of all size groups molted as many as two times. Little molting was observed during the period December through April, when water temperatures were low.

Field and impoundment data on growth also are being used in conjunction with size-frequency data in an attempt to determine accurately the age-size relationships of P. interruptus. The most promising method of analysis appears to be an iterative computer technique developed by T.A. Ebert of San Diego State College, involving a model of hypothetical size-frequency distributions. If successful, the application of this technique will provide valuable information, now unavailable, on the age-size relationships of P. interruptus, and may be useful for the study of other decapod species.

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Recruitment, Habitat Preference, Growth, and Laboratory Rearing Studies of the Puerulus through Mid-Juvenile Stages of *Panulirus interruptus*

Steven A. Serfling

Little is known about the transitional and early benthic life history stages of *Panulirus interruptus*. The purpose of this study has been to obtain basic ecological information about these important stages in order that their recruitment, survival, and growth might be improved through habitat conservation and modification, and aquacultural methods. The problem has been approached by three major lines of investigation conducted simultaneously.

Field Sampling and Observation of the Puerulus Larval Stage

This has involved the development and testing of artificial and natural seaweed habitat traps, special 'butterfly' macroplankton nets, and high intensity underwater lights for determining the puerulus stage's location in the plankton, diurnal-nocturnal behavior, seasonal and lunar periodicity, general abundance, and habitat preference upon settlement.

Artificial and Natural Seaweed Habitat Traps.

Pueruli were readily collected using floating seaweed habitat traps. All such seaweed traps tested were remarkably superior in collecting pueruli to the Witham habitat (used with success for *P. argus* pueruli in Florida). Habitats maintained under the lighted end of Scripps pier yielded much greater catches than did unlighted habitats at this and other piers, and in the open ocean.

Night Lighting

Pueruli were also collected at night by dipnetting from the surface water individuals which were strongly attracted to a bright underwater light. Information gathered in this way supplemented and supported the information obtained from the seaweed habitat traps concerning seasonal and lunar periodicity. In addition, direct observation suggested that the puerulus stage swims directly on the surface, at a relatively rapid rate (approx. 8 cm/sec.), and that it exhibits both directed swimming activity and a strongly positive phototactic response.

Plankton Net Sampling

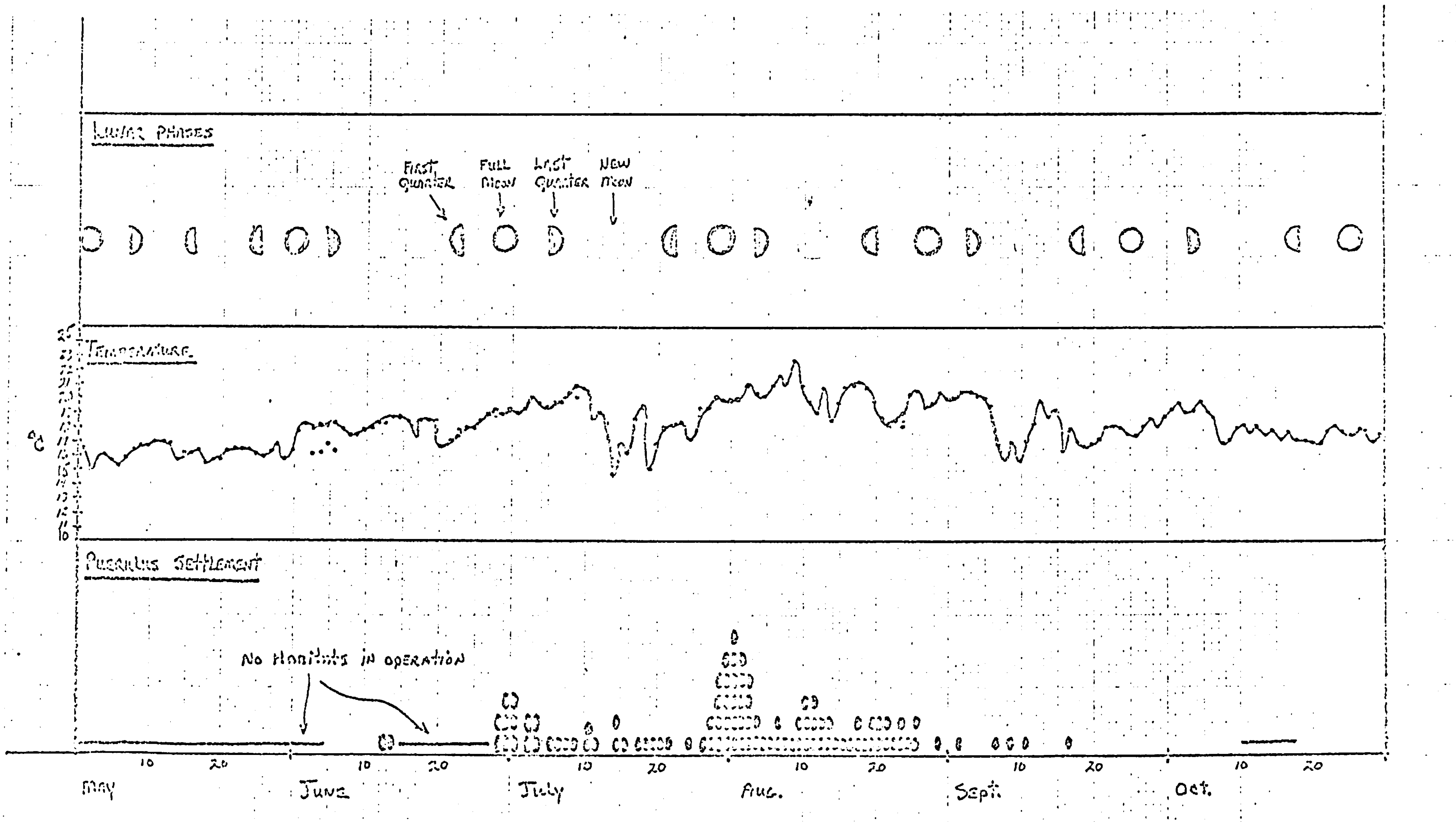
Special large mesh, paired plankton nets were developed to determine if the puerulus stage is a surface swimming organism, possible diurnal-nocturnal variations in this behavior, and the general abundance of this stage expressed as number per square meter of surface water. Results are inconclusive as yet, but sampling will be continued during the summer of 1970.

Conclusions

For the first time, *P. interruptus* pueruli have been readily collected and observed in their natural environment. Data shown in Fig. 1 indicate that pueruli appear regularly, but with no apparent lunar or temperature correlation, from late May (determined by night-lighting information) to September. The sharp peak during the first part of August is unexplained. Evidence obtained thus far indicates that the puerulus is a surface swimming pelagic stage that actively seeks out intertidal areas for settlement. Thus, it probably serves an important function in the recruitment of the benthic stages by migration to an area suitable for demersal life. Pueruli are very rare organisms in the plankton. Rough estimates obtained thus far indicate typical inshore

Figure 1.

The periodicity of puerulus settlement in seaweed habitat traps during summer, 1969, as related to lunar phases, and surface water temperatures.



densities of one individual per 1000 square meter surface water during the peak of settling period. It seems likely that by taking advantage of their strong attraction to intertidal flora, such as surf grass (Phyllospadix) and red algae, and their phototactic response, they might be concentrated in man-made, floating, illuminated seaweed traps. However, based on trapping and night light results obtained in this study, it appears that it may be impractical to attempt collecting large numbers of pueruli for aquacultural or other purposes. If areas with greater concentrations of pueruli are found, and improvements can be made in collecting methods, this may become feasible.

Rearing of Puerulus Stage Specimens Through the Mid-Juvenile Stage

Puerulus specimens collected from the habitat traps and night-lighting observations were reared at high temperatures in order to evaluate the feasibility of accelerated mass culture of the juvenile stages. This involved rearing pueruli through the mid-juvenile stage (40 mm carapace length) in closed circuit, high temperature (23° and 28°C) aquarium systems. Individuals were also reared in cages suspended in the ocean, as well as in running sea water aquaria at ambient ocean temperatures, to estimate natural growth rates. Physiological measurements of osmoregulation and metabolic rate at various temperatures and salinities, individual molting and growth rates, and growth efficiency measurements were obtained. Attempts have been also made to develop a suitable artificial food, but the primary food supply used was live and frozen Mytilus and abalone.

Natural growth rates

Based on the size-frequency distributions of juvenile lobsters collected throughout the year, it appears that juveniles reach an average size of 23 mm carapace length after one year of growth, and about 42 mm C.L. after two years of growth in nature. Growth curves of juveniles reared under ambient seawater temperatures, held in flowing sea water at Scripps Institution, and in live cages suspended in Mission Bay also support this conclusion.

The Effect of Increased, Constant Temperatures on Growth

The growth rates of lobsters reared at temperatures of 22.5° and 28°C, but otherwise under similar conditions, are shown in Fig. 2. In both cases, higher temperatures resulted in proportionally greater lobster activity and feeding rates, and in the reduction of the intermolt period. A comparison of the average growth rates at high temperatures with those attained at natural ambient temperature indicates an approximate 260% increase at 28°C, and 140% increase at 22°C. A projection of the growth rates at 28°C suggests lobsters could reach legal size (83 mm C.L.) within two years, allowing for a decrease in growth rate after reaching 50 mm C.L. Therefore, it seems apparent that any attempt at culturing lobsters for commercial reasons should include a serious attempt to utilize elevated temperatures, most logically by taking advantage of excess heat from power plant cooling water discharge.

Mortality

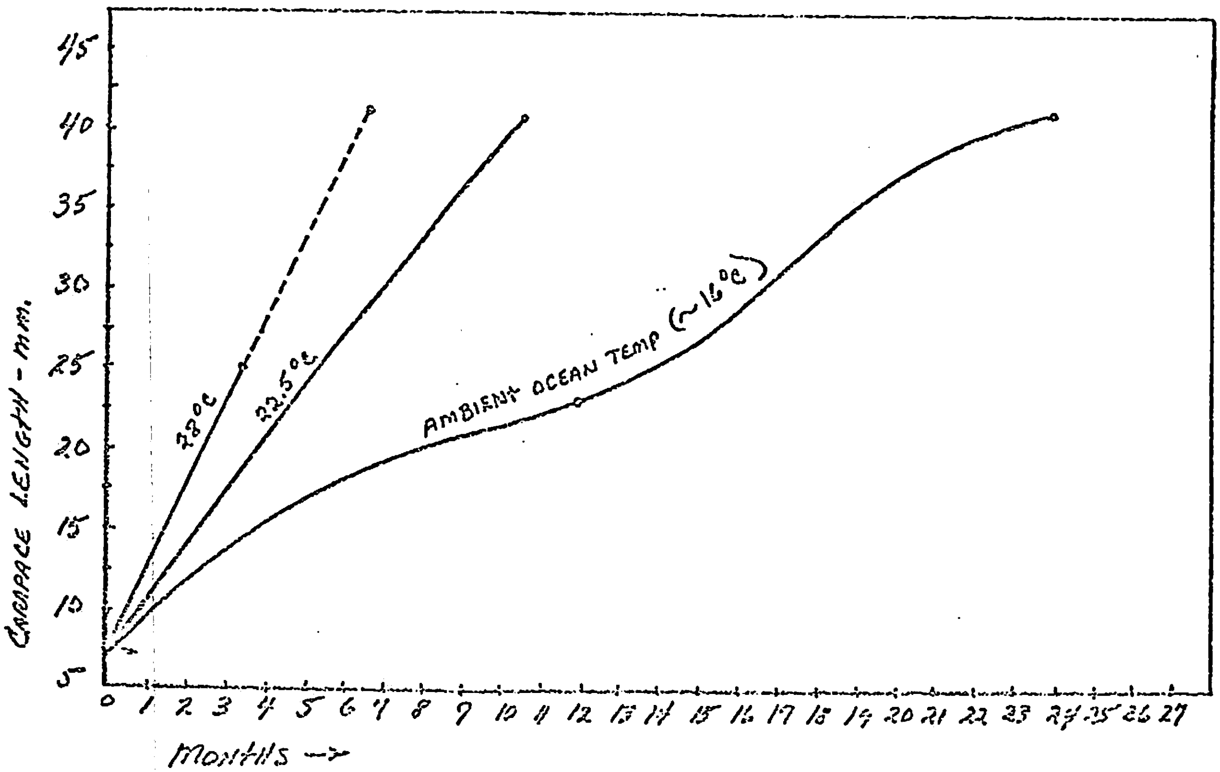
Approximately 90% of the mortalities which have occurred in the process of rearing experiments were attributable to inferior water conditions, or mechanical failure of the equipment. Normal mortality rates could be expected to be much lower than experienced in these pilot experiments. Most deaths occurred during the sensitive molting process. In addition, it was found that the early post-puerulus stages were much more sensitive to fouled water than later stages.

Field Sampling and Observations on the Habitat Preference of the Post-Puerulus and Early Juvenile Stages

This aspect of the study has involved intertidal and subtidal searching and special trapping techniques in an attempt to locate and characterize the habitat of the early benthic stages, so that laboratory rearing methods might be improved and recommendations made for proper management of the natural nursery grounds. As yet, these attempts have been relatively inconclusive. In general, first and second year class juveniles occur intertidally and at depths of 5 m or less, and in situations where quantitative sampling is nearly impossible. They appear to be extremely rare, but may be concentrated in areas as yet unexplored.

Figure 2.

A comparison of mean growth rates of juvenile lobsters reared at 28°C, 22.5°C, and ambient ocean temperatures (~17°C. mean).



Social Behavior of Panulirus interruptus

Anthony C. Roth

Introduction

Patterns of aggressive behavior and possible social relationships with reference to size, sex, and reproductive condition in *Panulirus interruptus* have yet to appear in the literature. This investigation in progress is concerned with the general social behavior of *P. interruptus*, with an emphasis on aggressive behavior, and especially the factors related to the establishment and maintenance of dominance hierarchies.

Preliminary Description of Behavioral Patterns

The patterns of aggressive behavior in *P. interruptus* have been studied for an extended period in the laboratory under simulated natural light conditions. Artificial shelters which consisted of two sizes of cinder block were provided. Aggressive contacts generally occurred in association with the shelters. A distinct reduction in aggressive behavior occurred during the light cycle, when most lobsters in the 400 l experimental aquarium was either occupying the shelters or walking about the bottom without aggressive contact. Preliminary results suggest that further differences in behavior exist, dependent on the presence or absence of food, with aggression reduced in the latter condition.

Observations to date have not effectively delineated motivation for noted behavioral patterns, due to inconsistencies in the data which may prove to be based on laboratory artifact. However, at this point, some general statements may be made.

Aggression associated with shelters may be termed "defense" in that the occupant uses the shelter as a base from which activity is directed to an "intruder" or approaching individual. The approach of an intruder elicits an antennae-forward, raised-body response on the part of the defender, and as the intruder approaches more closely, the defender's antennae orient toward the newcomer. If the approach of the challenger is insufficient stimulus to cause the defender to lose ground and leave the shelter, the new arrival may attempt to back into the shelter, but is usually blocked by the body of the occupant. Having failed to dislodge the occupant, the challenger may then try a frontal approach.

Aggression by a defender is initiated when the defender stands high on its legs and waves its first walking legs in a typical "threat" posture. If this stance is insufficient to dissuade an approaching individual, the determined occupant will grasp the intruder with its first walking legs, causing the newcomer to retreat by quick flapping of the tail.

Dominance Hierarchies

In spite of the noted aggressive patterns in P. interruptus, results of trials investigating the presence of dominance hierarchies have, thus far, yielded only inconsistencies. Fielder (1965) suggests that dominance hierarchies exhibited by Jasus lalandei are based primarily on relative size of individuals. My data suggest that there may be levels of aggressiveness, possessed in differing amounts among individuals, and that these levels may be as important as size in determining social relationships. During four separate observation periods, smaller lobsters were noted to displace larger individuals.

Territoriality

From extensive observation in both the 400 l aquarium and a large pool (5 x 11 x 2.5 m), it appears that under simulated natural conditions, static territoriality does not occur, in that specific and constant refuges are not defended. Rather, the habitat occupied at any one time may be defended, the defense of that area being temporary. As soon as an individual occupies another area, defense, if it occurs, takes place only while that individual is in the new area.

Conclusions

The overriding difficulty in observing Panulirus interruptus in both of the laboratory situations is that the above patterns of behavior may or may not occur during any one observational period. Long segments of time pass, apparently unrelated to time of day or presence or absence of food, when normally aggressive individuals tolerate close contact with former antagonists. The tolerance noted in the laboratory may be functioning in nature as well, leading to observable aggregations.

It may be possible that the apparent social behavior and noted lack of it is in some way related to population density. Testing this hypothesis and the establishment of a more workable test regime will occupy the next phase of the study.

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Catch Analysis and Mark-Recapture Studies of *Panulirus interruptus*

David A. Farris

Introduction

The California spiny lobster fishery is pursued by independent fishermen who operate lines of box-like wire traps, using small power skiffs. The season starts on October 1, and continues through March 31. The lobsters are sold to wholesale buyers who distribute them primarily to fresh fish markets or restaurants. For the period under analysis, an annual $15 license permitted fishing for all commercial species.

Commercial Landings

The total commercial landings for California are given in Fig. 1. Annual landings for this period are somewhat above those predicted by Lindberg (1955) and Wilson (1949). The high yield during the early 1950's may reflect increased abundance of lobsters owing to the relaxed fishing effort during the war years. This explanation is especially appealing if Lindberg's supposition that it takes a lobster seven years to reach legal size is true. In addition, a greater market for spiny lobsters has developed, resulting in an increased fishing effort during the early 1950's. Toward the end of the 1960's, total landings were declining, and preliminary data indicate that the 1969-70 season may have produced the lowest yield in over twenty years.

For the purpose of regional evaluations, the waters of California are divided into statistical regional blocks: Santa Barbara, Los Angeles, and San Diego (Fig. 2). The annual landings for the

Santa Barbara statistical block indicate a peak catch of 355,000 pounds in 1950, which then diminished to an average landing of about 100,000 pounds in the late 1950's (Fig. 3). Los Angeles landings (Fig. 4) gave a higher average yield in comparison with Santa Barbara, and the good years persisted for a longer period. The suggested equilibrium level for the present seems to be around 200,000 pounds per year. The San Diego landings (Fig. 5) are by far the most stable. The high yields of the early 1950's noted for Santa Barbara and Los Angeles were not evident for San Diego. The fishery appears to fluctuate around an annual landing value of about 150,000 pounds.

Catch per Effort

The unit of effort used in these studies is the trip ticket day. The fishermen are required by law to file a record of their catch with the California Department of Fish and Game at the time of sale (Staff, Bureau of Marine Fisheries, 1952). It is apparent that a weakness of the unit of effort is that it does not distinguish between catches resulting from small and large numbers of traps. The weakness, however, was not considered too critical a source of error, since catch and effort data were pooled over large regions and time spans.

When the California catch is adjusted for effort, a different picture emerges (Fig. 6). Whereas the greatest catch was in 1950, the catch per effort increased until 1952. A decline to 1960 then occurred, except for the year 1956. Catches per effort subsequent to 1960 did not fall below that level until 1968.

Catch per effort for the Santa Barbara region is given in Fig. 7. High catch per effort appeared sooner and persisted longer as compared with the state's totals. The catches per effort for this region are much higher than those of other regions. This is partly because much of the catch is taken in areas not directly accessible to the market and the daily catches are therefore retained in live receivers for a few days. Thus, they appear on a single trip ticket.

The catch per effort for the Los Angeles region (Fig. 8) appeared to lag behind those of Santa Barbara. The between-year fluctuations are less when compared with Santa Barbara also. San Diego regions catch per effort (Fig. 9) exhibit the greatest stability of all.

The foregoing data lend themselves to the following interpretations: the California stock of P. interruptus obviously was not fully exploited prior to 1950. The decreased fishing pressures dictated by the war years of the early 1940's permitted larger stocks of legal size P. interruptus to accumulate. An enlarged post-war lobster market brought about an increase in effort with subsequent higher yields. Regions farthest from the center of distribution (Central Baja California) were the first to exhibit the dimunition and wide oscillations of catch. The same sort of situation apparently occurred in the Los Angeles region, but the oscillations were somewhat smaller. Under present regulations and current market, new equilibria are being established. The San Diego region has had the appearance of an equilibrium fishery throughout the period of years considered in this analysis.

If regional equilibria are, indeed, being established, there are still large variations in landings from year to year. Although they have yet to be quantified, their importance should be mentioned. The fishery is pursued during the fall and winter months when the coast is often blanketed with dense fog. In such weather, the trap markers cannot be located, and the traps are left unattended, thus reducing the catch. Secondly, this is the period of sea storms. Traps placed in relatively shallow water are dislodged by surge and lost. Severe storms can destroy virtually all the traps out. If such a disaster strikes early in the season, and the fishing has been good, the fisherman will make new traps and continue. However, if the storms come later, the fisherman may withdraw from fishing until the following year. Some appreciation of the effect of the fisherman's experience during the first part of the season is given in Fig. 10. Catch per effort for October is the measure of fishing success. If it has been high, one hypothesizes that the fisherman will persevere longer, and that the total effort expended for the year will be high. This is what we have observed. Secondly, it is hypothesized that the October catch is a relatively good indicator of the total season's catch. This also proves to be reasonably correct, as shown in Fig. 11.

Additional factors affecting the California spiny lobster fishing are the price and availability of imported spiny lobsters. Imports of P. interruptus from Mexico represent from two to three times the amount of the California catch. On a national basis, between 80% and 90% of the spiny lobsters marketed are produced by Australia, Brazil, New Zealand, and South Africa.

The steady increase in price per pound is being examined (Fig. 12). Preliminary evaluation suggests that during the period 1947-1968, the increase was in the neighborhood of six to seven cents per pound. Adjustments for increased costs and inflation would not indicate any real increase in fishermen's income.

In Figure 13, the average income in dollars per day is given for the three statistical regions for the period 1947-68. Once again, there are tremendous variations in the two northern regions in comparison with the San Diego region.

Marking Experiment

During the month of September, 1969, 4152 lobsters were marked with serially numbered sphyrion tags. At the time of tagging, the carapace length, the sex, the reproductive and moult condition, the tag number, the release site, and date of release were noted. The same information was gathered at the time of recapture, allowing estimates of population size, natural growth rates, and other characteristics on a size-specific basis. These data are now being analyzed. All releases were made in an area between Point Loma and La Jolla, San Diego, California. About two weeks before the opening of the season, a large number of informational posters were distributed along the waterfront, indicating that a dollar reward would be paid for each tagged animal returned. In addition, commercial fishermen agreed to keep log books for us. In this fashion, we were able to evaluate catches of both legal and sub-legal *P. interruptus*. The bulk of our returns and most of our interpretations are based on these log book records. For reasons not understood by me, the dollar reward for a tag return was not sufficient incentive for some fishermen. Shortly after the season opened, we made additional arrangements for tag reports from the buyers. The most important datum lost in the case of this source of returns was the site of recovery. Very few tagged animals were reported seen by SCUBA divers, leading me to believe that sportsmen take very few lobsters when compared to commercial catches. R.F. Ford and others involved in underwater sampling of *P. interruptus* also have reported relatively few sightings in areas of active commercial fishing.

Population Size

For the intensive study area, the Petersen estimate is about 15,000 legal lobsters (Ricker, 1958) at the start of the season. Our records show about 11,000 removed during that season.

Lobster Movements

The 32 km (20 mile) coastal strip from Point Loma to La Jolla was divided into 1.25 square km (0.5 square mile) squares for purposes of site identification and references. The square where the lobster was released was noted as well as the square where it was recovered. Fishermen identified the recovery site using aerial photographs of the area. We believe that our records are accurate to within a half mile. A summary of these recovery data is given in the following table.

	Direction of recovery site from release site									
	Zero	unknown	S	N	SW	NW	NE	SE	E	W
Number of recaptures	262	37.0	323	299	67	88	1	5	0	41
% of total recaptures	23.3	3.3	28.8	26.6	6.0	7.8	.1	.4	0	3.7

About one quarter of the lobsters are recovered in the area where they are released. This suggests that the lobsters do move locally, but in some random fashion. By examining a direction and 180° counterpart, north and south (longshore) movements seem equally likely; relatively few moved offshore. No east recoveries were possible, because all lobsters were released close to shore.

Size Distribution

The size distribution of trapped lobsters taken in September cannot be distinguished from the size distribution of those taken in January, although the January catches are quite low, and many fishermen have left the fishery. Of the 4152 lobsters tagged, about 11% were of legal size. Of the tag recoveries reported by the log book fishermen, 12% were of a legal size.

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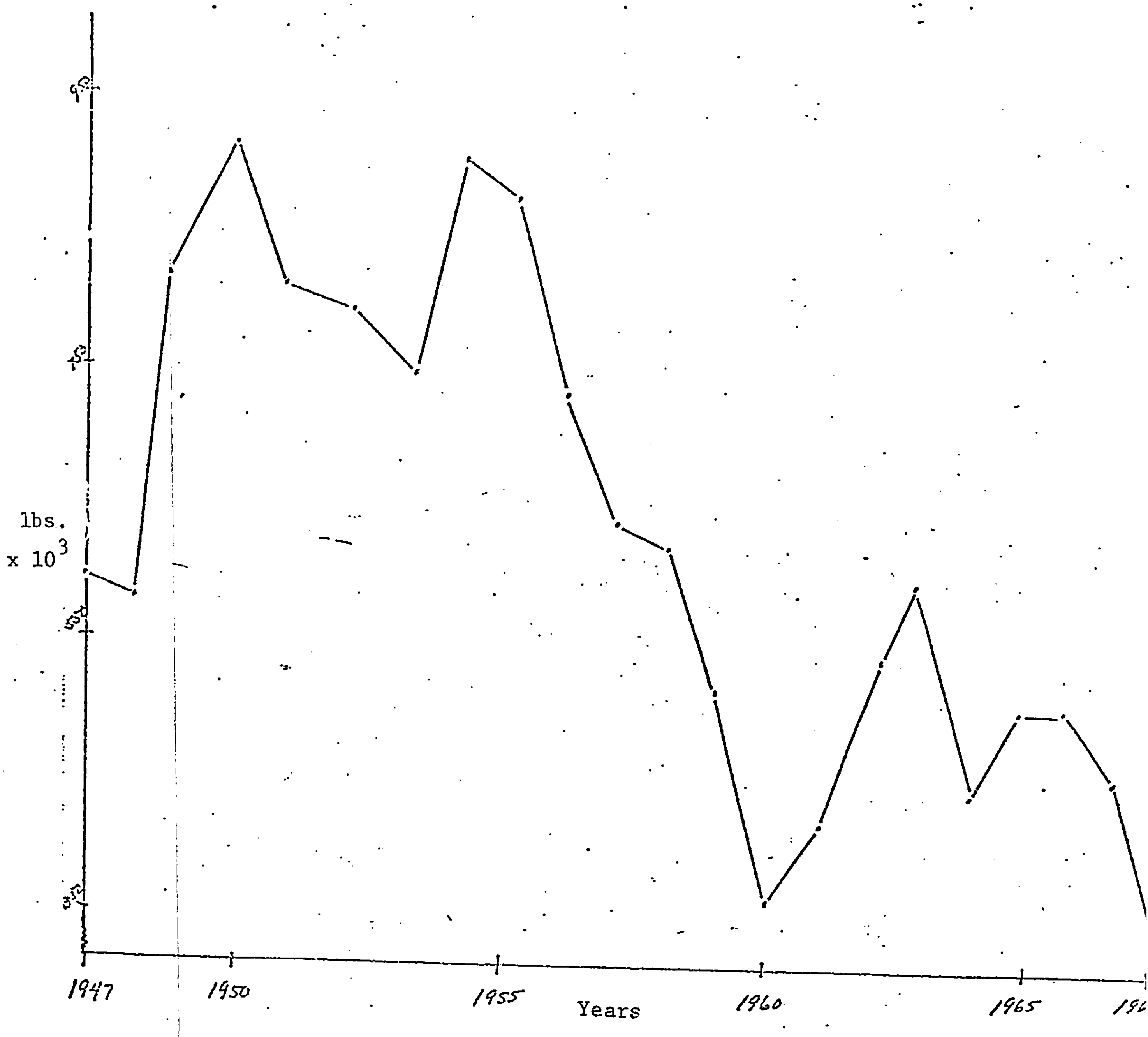
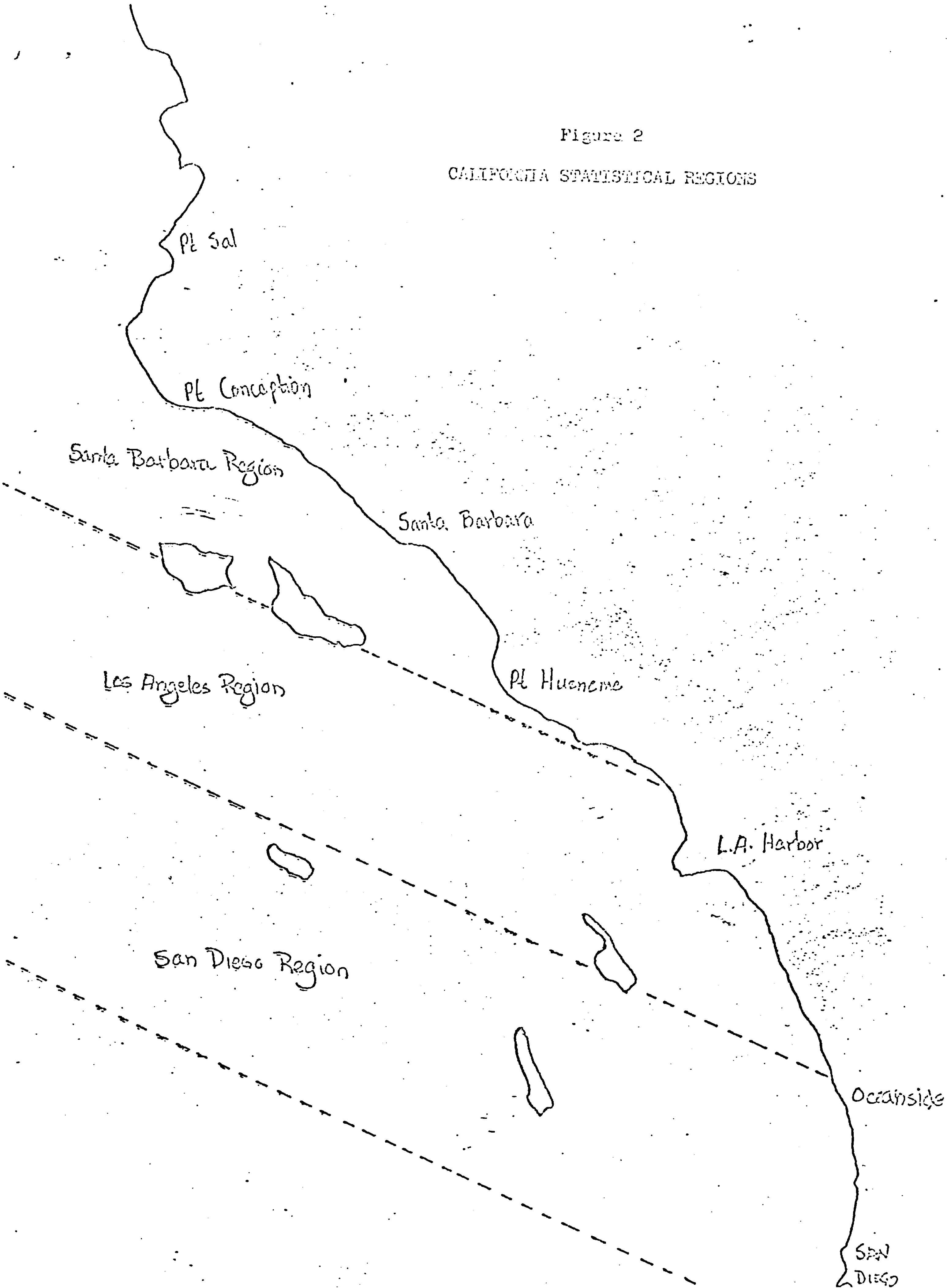


Figure 1

TOTAL CALIFORNIA LANDINGS
1947 - 1968

Figure 2

CALIFORNIA STATISTICAL REGIONS



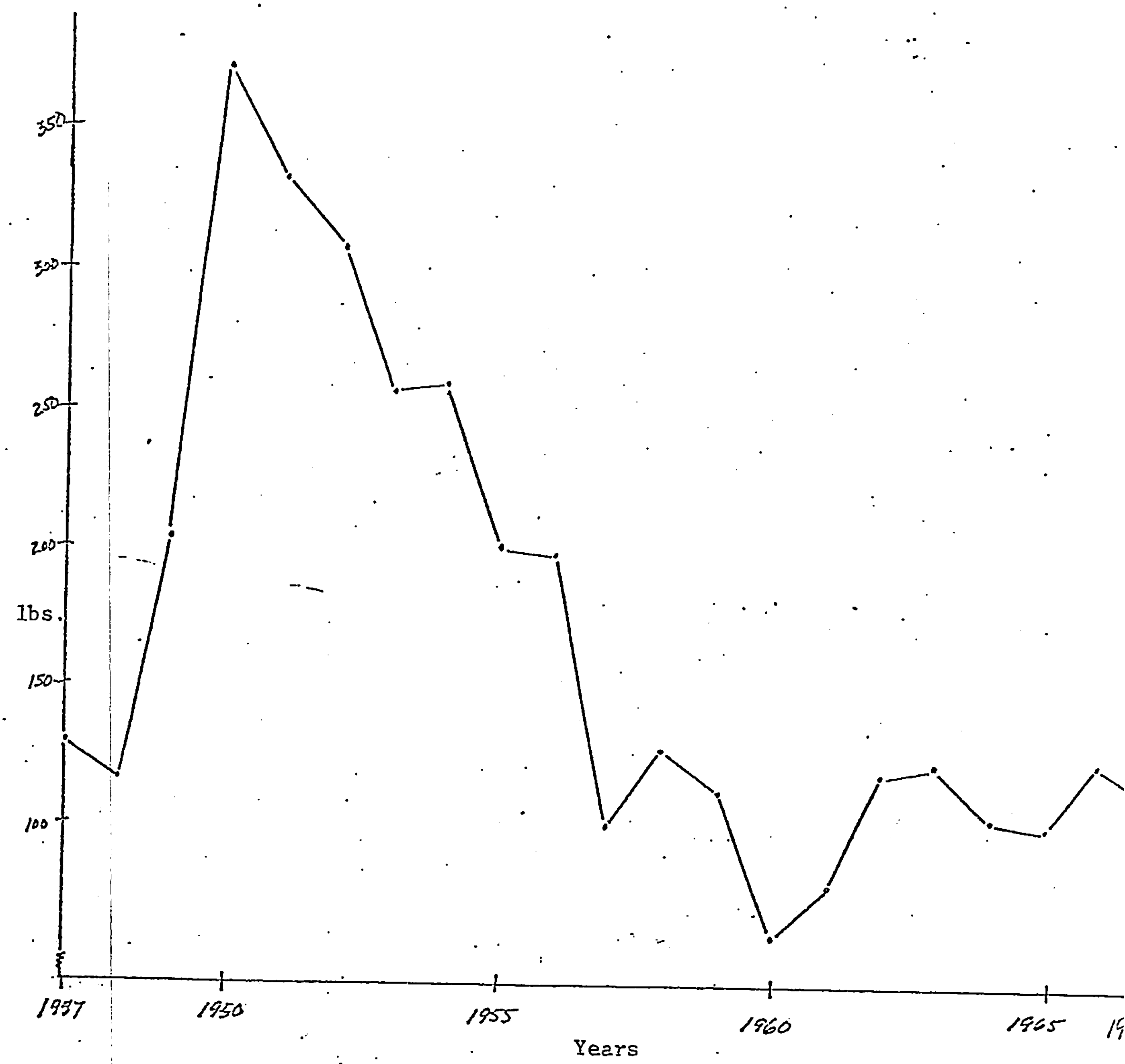


Figure 3

ANNUAL LANDING - SANTA BARBARA REGION
1947 - 1968

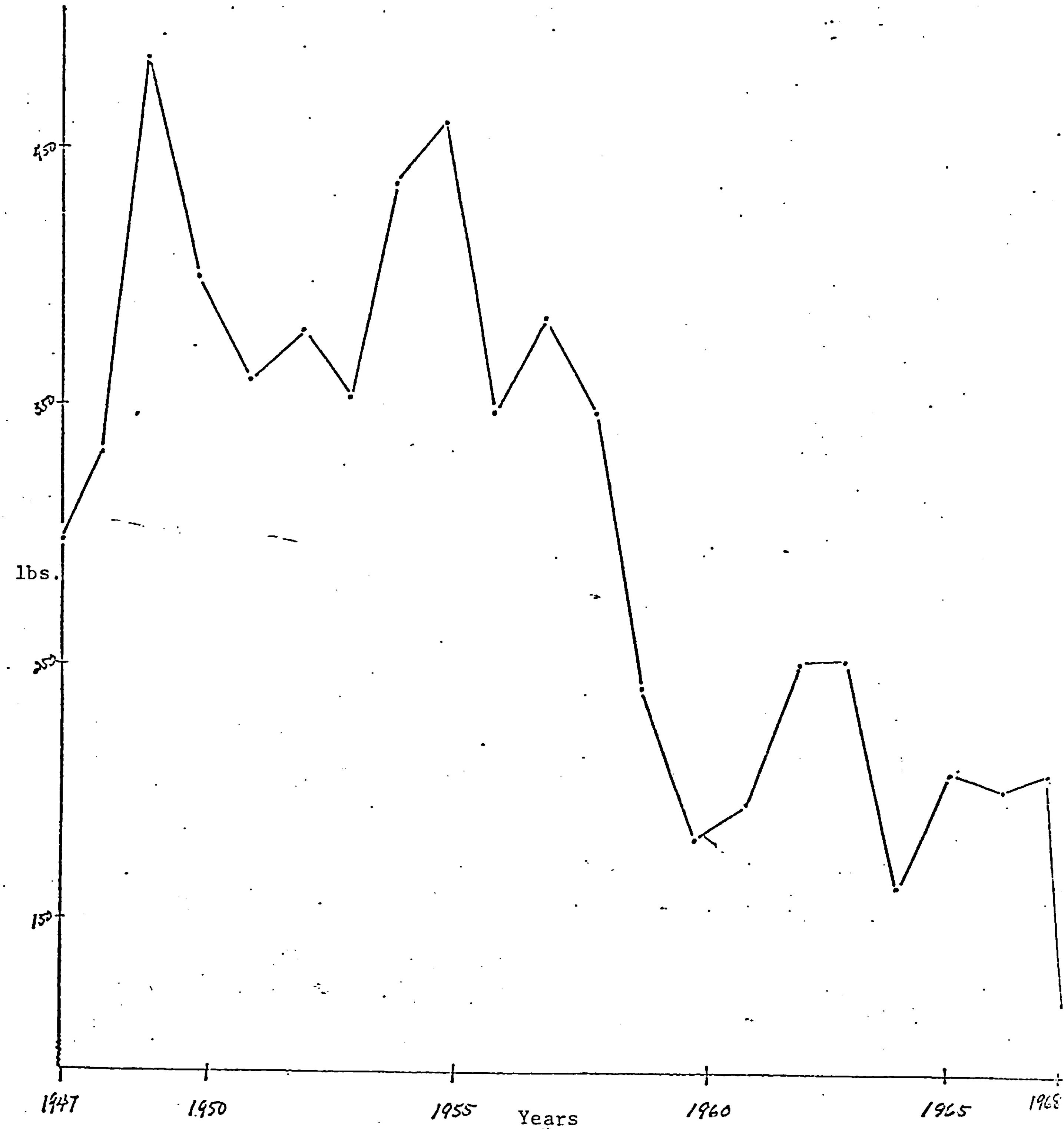


Figure 4

ANNUAL LANDING - LOS ANGELES REGION
1947 - 1968

Figure 5

ANNUAL LANDING - SAN DIEGO REGION
1947 - 1968

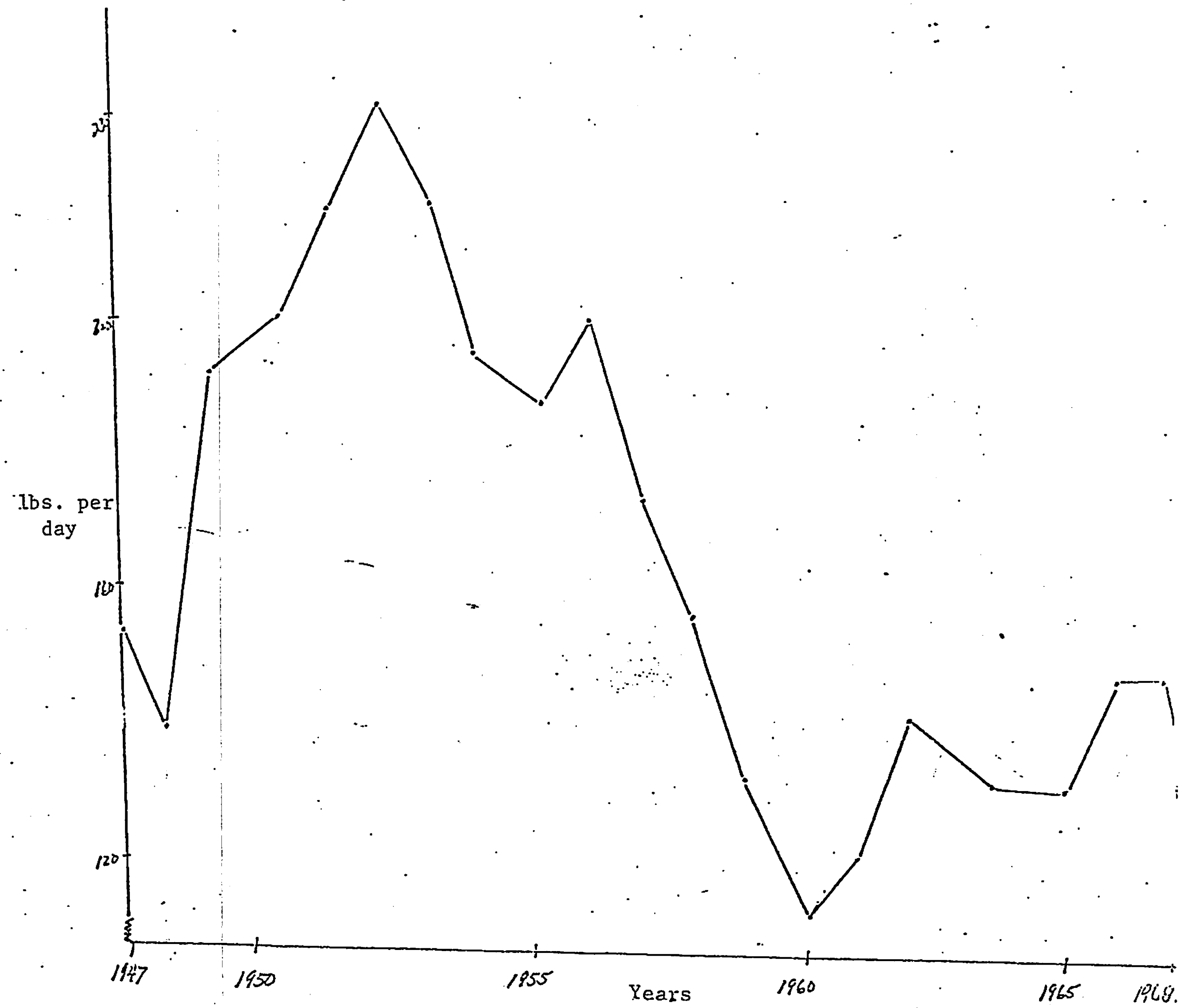


Figure 6.

TOTAL CATCH PER EFFORT -- CALIFORNIA LANDINGS

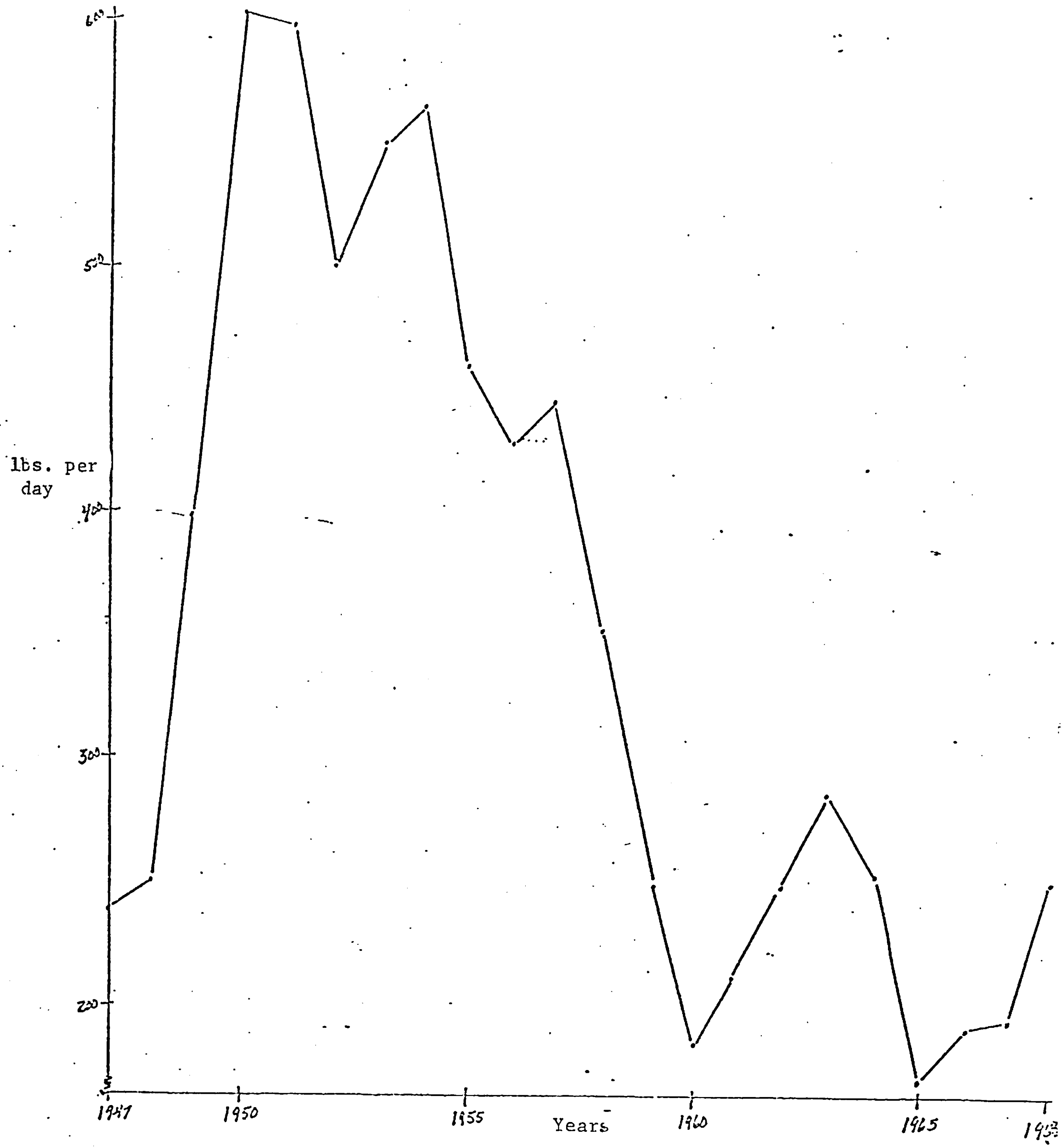


Figure 7

CATCH PER EFFORT SANTA BARBARA REGION
1947 - 1968

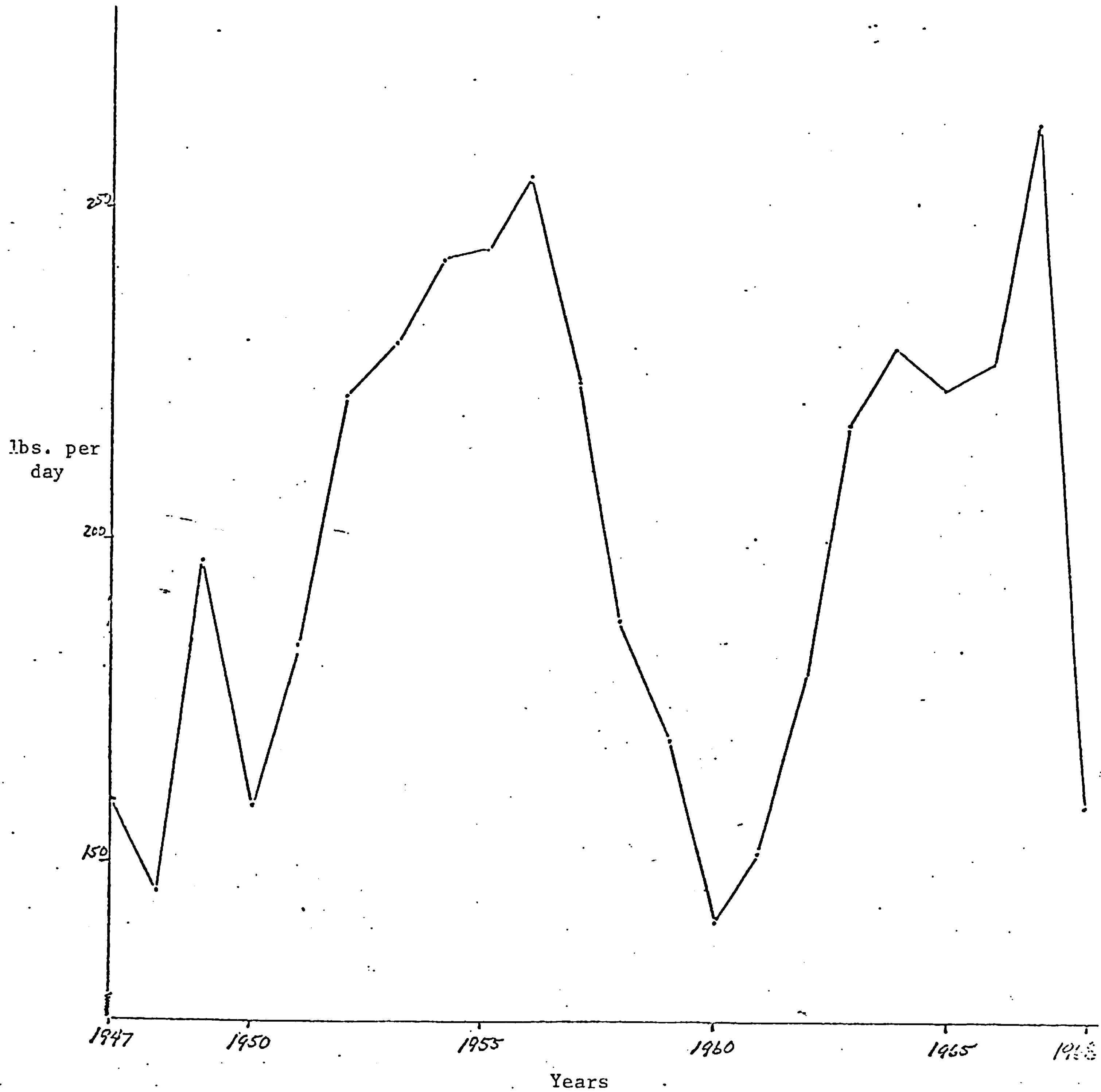


FIGURE 8

CATCH PER EFFORT-LOS ANGELES REGION
1947 - 1968

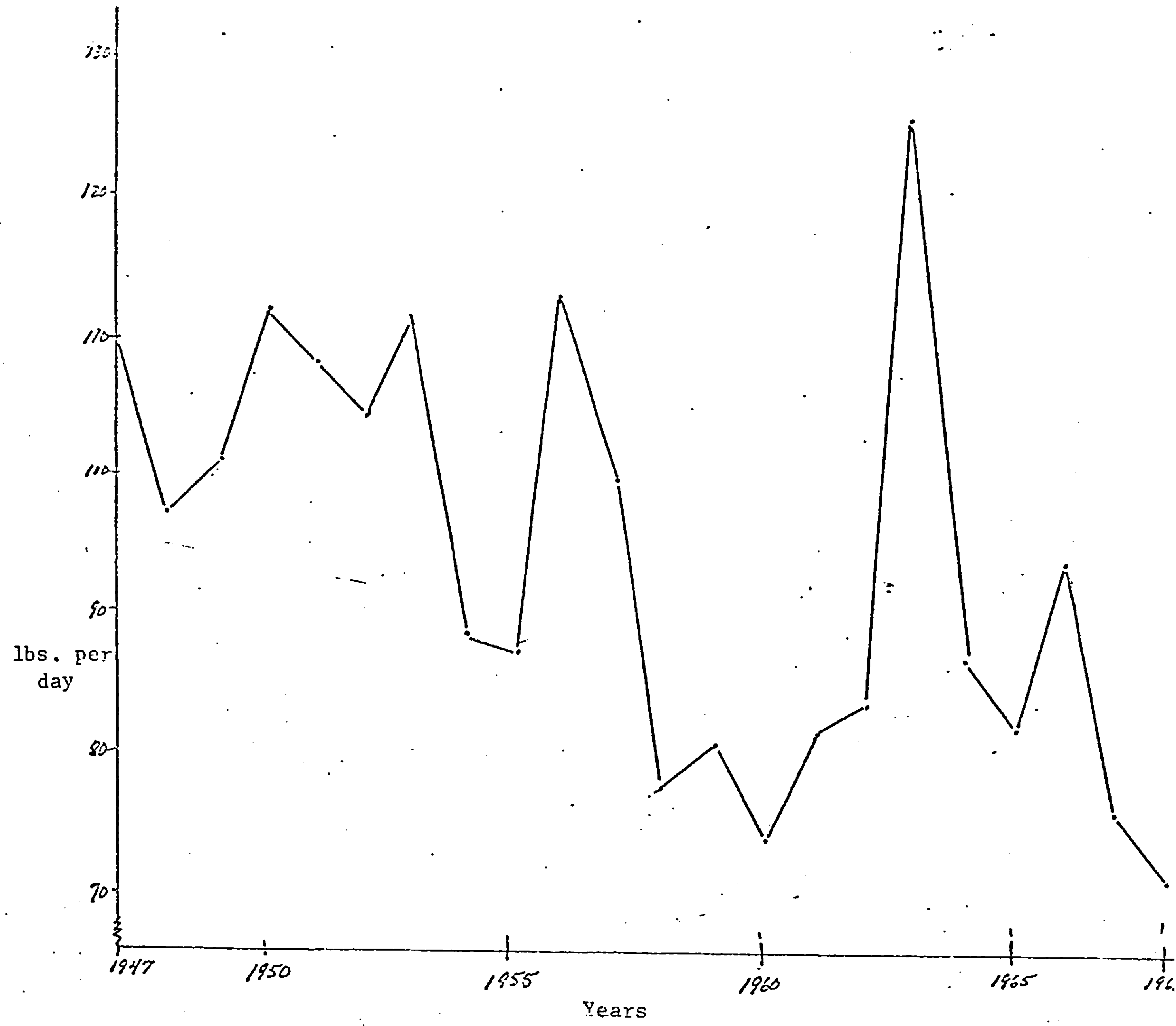


FIGURE 9

CATCH PER EFFORT-SAN DIEGO REGION
1947 - 1968

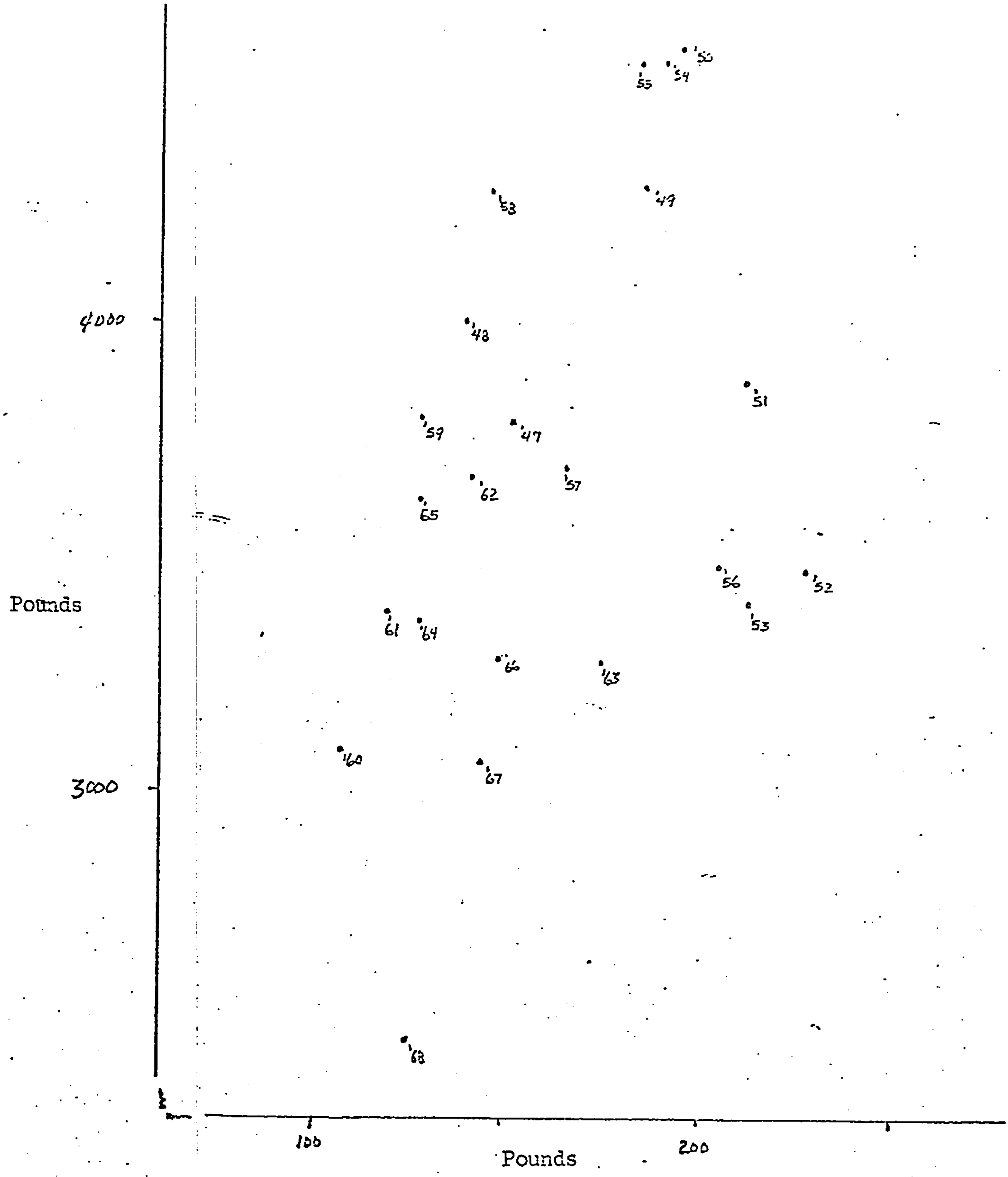


FIGURE 10

OCTOBER CATCH PER EFFORT VS TOTAL EFFORT
1947-1968

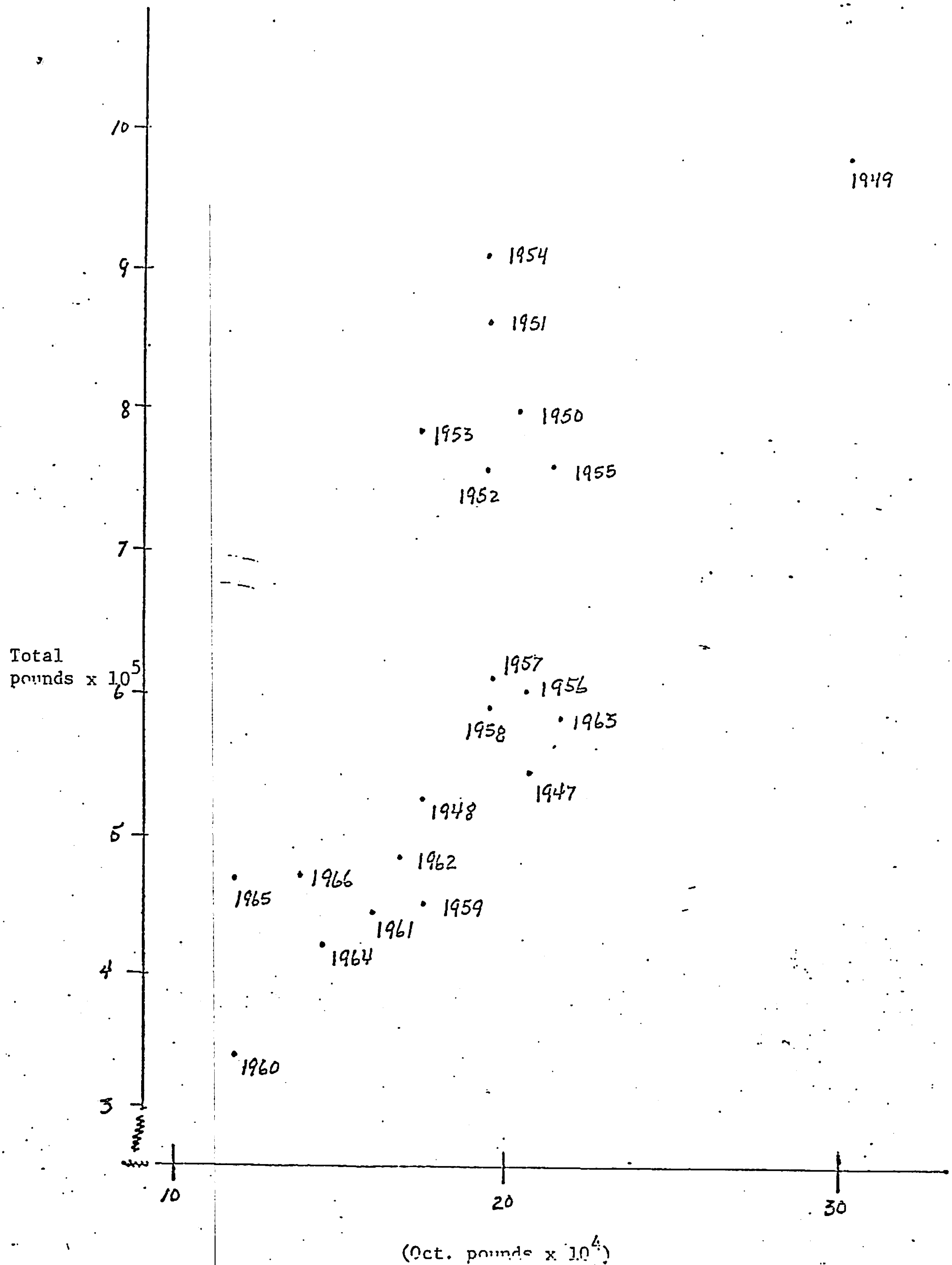


Figure II
OCTOBER CATCH VS THE CATCH FOR THE SEASON

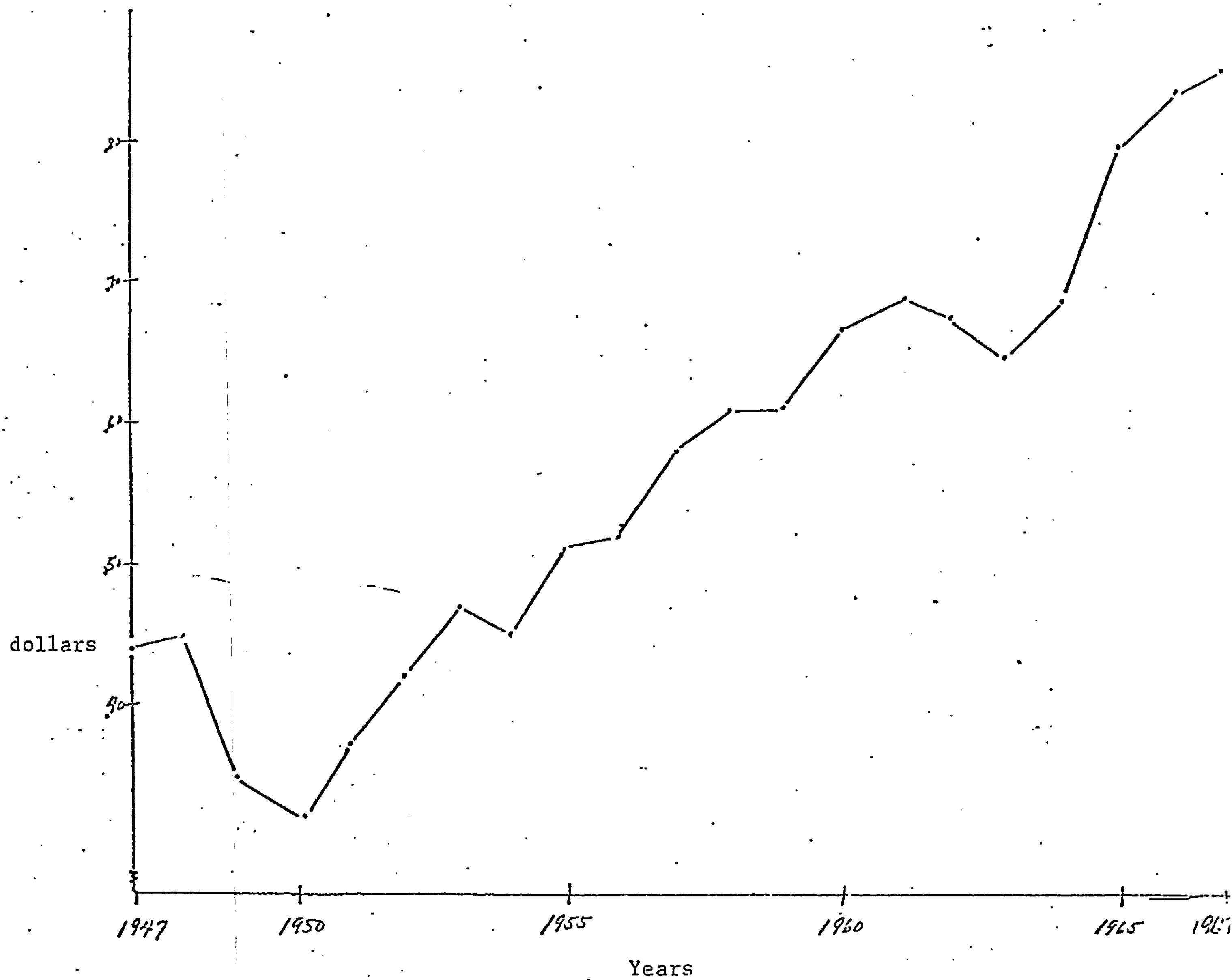
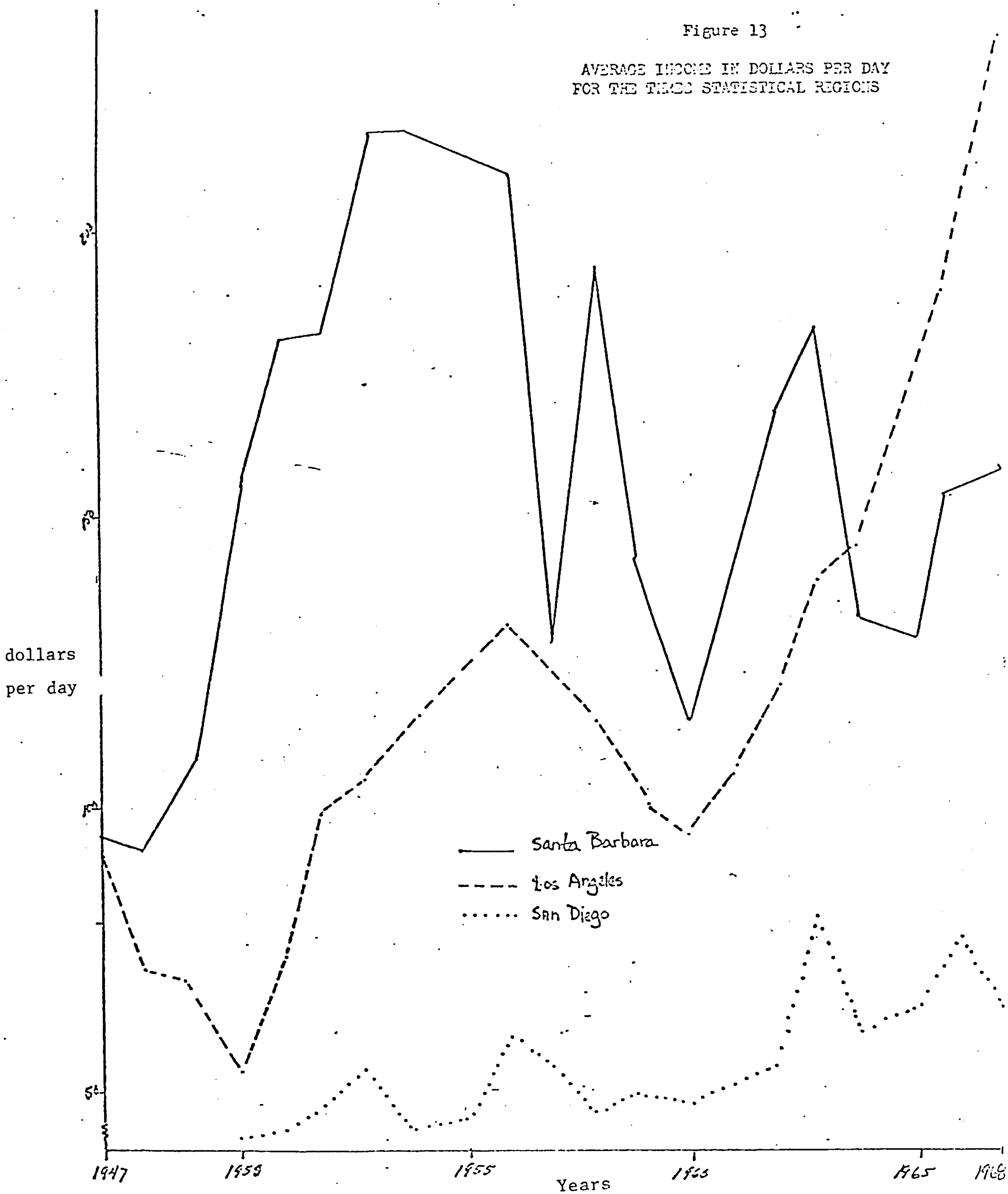


Figure 12

PRICE PER POUND-CALIFORNIA SPINY LOBSTER
1947 - 1967

Figure 13

AVERAGE INCOME IN DOLLARS PER DAY FOR THE THREE STATISTICAL REGIONS



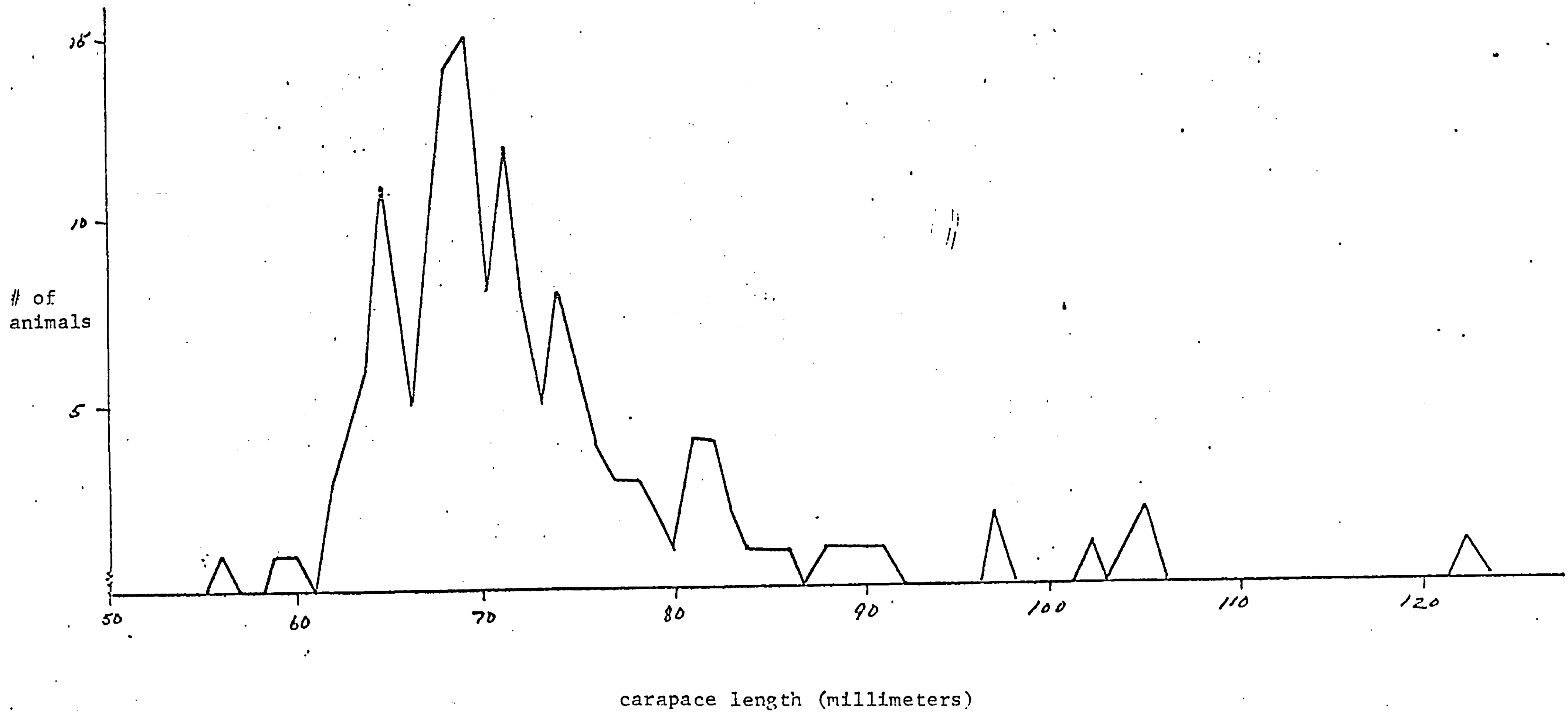


Figure 14

SIZE DISTRIBUTION OF THE SEPTEMBER CATCH

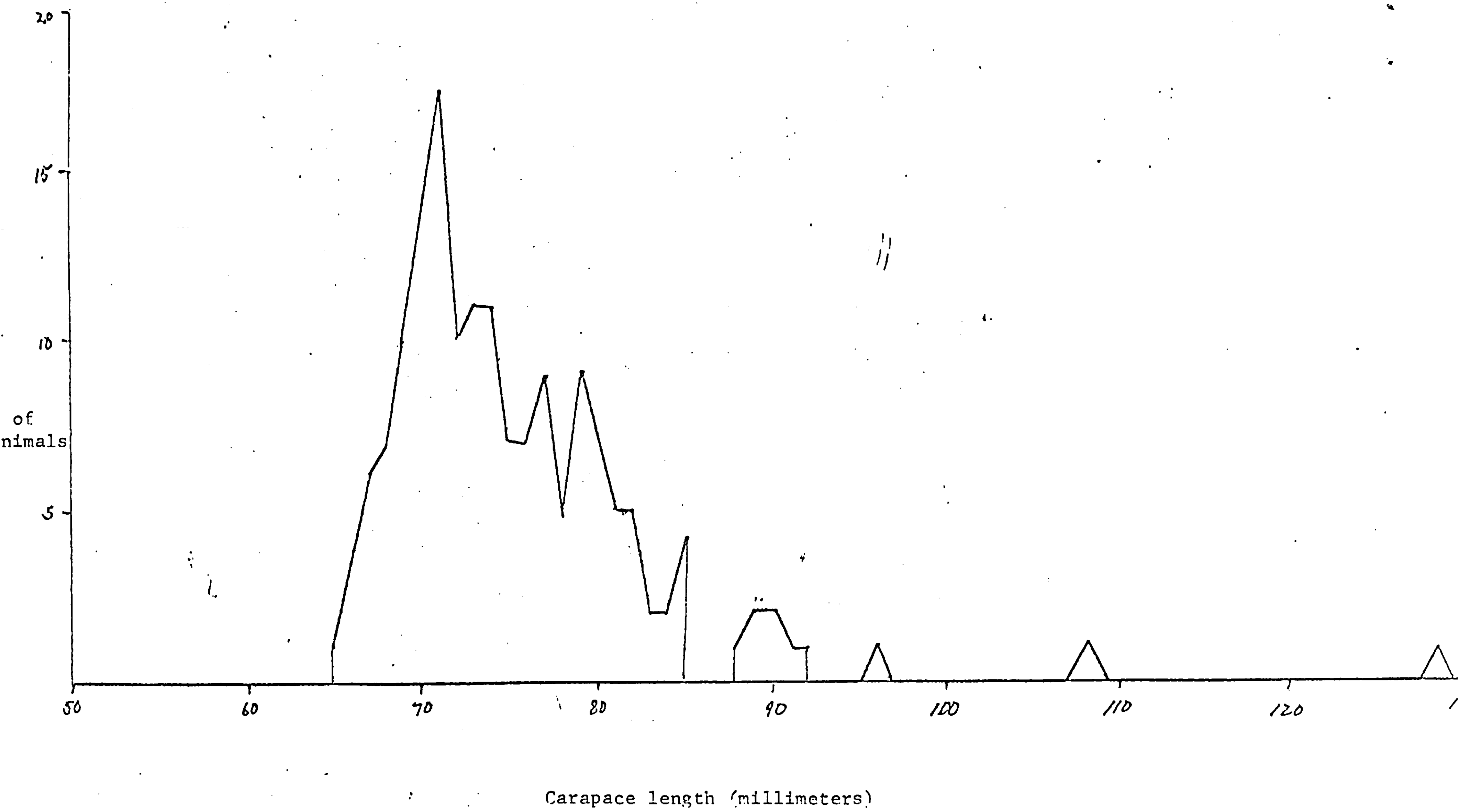


Figure 15

THE SIZE DISTRIBUTION OF THE JANUARY CATCH

Investigation of Larval Populations

William E. Hazen and John Rutherford

In the portion of the study devoted to the populations of phyllosomes, the principal results so far are taken from a series of 30-minute horizontal plankton tows, carried out approximately 0.8 km (0.5 mile) offshore in the stretch of coast approximately 3-4 km (two miles) north of the Mission Bay channel entrance, where the water is between 25 and 35 m deep. In addition, some data are available from recent California Cooperative Oceanic Fisheries Investigation (CalCOFI) cruises, and a number of plankton tows have been made by project personnel during the two survey cruises of the California Fish and Game Research Vessel Alaska.

During the sampling period of June 27, 1969 through December 23, 1969, a total of 780 phyllosomes were taken in eight horizontal plankton tows. These, taken from surface tows, were all Stage I phyllosome larvae, indicating a marked shift in behavior at the time of the molt leading to the Stage II larva. Most probably, the later stages are found in the portions of the water column close to the bottom, which are to be more comprehensively sampled during the 1970 season. The data are summarized in Fig. 1.

The data show an highly aggregated distribution of the phyllosomes caught, with 16 of the 49 tows taken during the season when stage I's were present having no specimens, and, at the other extreme, one sample with 304 specimens. This type of pattern is typical of zooplankton distribution, and is shown in such studies as that of Johnson (1960) and Chittleborough and Thomas (1970).

Although the samples are evenly distributed between night and day, the total number of phyllosomes taken at night is much greater than during the day -- 544 as contrasted to 120. The discrepancy in number of phyllosomes counted is because some samples taken during twilight were omitted. Even when the most frequent sample -- 304 phyllosomes -- is omitted, the likelihood that Stage I larvae are found in equal numbers at different times of day is less than 0.005, using an X^2 test of goodness of fit.

The night data were also examined for the possible effect of the phases of the moon, the lunar period being divided into two parts, one that half closest to full, the other that half closest to new moon. It is, of course, not possible to separate the possible effect of spring as opposed to neap tides from the state of illumination. When the largest sample is included, the likelihood that phase of moon has no effect is less than 0.005; omitting this datum reduces the likelihood to approximately 0.9. Examining the data in another way, using then only those night collections made during the seven-day period closest to full or new moon, no difference can be shown. An answer to the problem of to what extent the appearance to Stage I larvae at the surface depends on light intensity must await an analysis of the series of horizontal plankton tows at the bottom, and at intermediate depths.

In addition to the local plankton samples, two other sets of data are available and have been in part analyzed. These are the routine California Cooperative Fisheries Investigation plankton tows, similar to those used for analysis by Johnson (1960), and a series of tows made during cruises of the R.V. Alaska, of the California Department of Fish and Game.

The data from the Alaska, taken in two series, one in August, one in January, are similar to the local data. The tows were taken in a similar fashion, but were offshore as far as ten miles. Phyllosomes were taken only in August, when a total of 73 were taken, restricted to Stage I. The largest number was taken by night, as suggested for the local sampling.

The CalCOFI samples, examined for the period January 1, 1969 to June 10, 1969, yielded a total of 21 phyllosomes, ranging in stage from VI to XI, Stages VIII and IX being the most frequent. The positions where these were found, and the stages are summarized in Fig. 2. A reasonable expectation is that the later samples would contain phyllosomes of later stages. Applying a two-sample rank test to the data, no difference in phyllosome stage can be shown, either between January and February, or between January and June. Possibly the time interval is sufficiently short, the mean elapsed time being a month, that an insignificant amount of growth has occurred in the interval, and that an examination of a larger series would reveal growth, since growth must occur during this time. Another possibility is that a behavioral difference between the earlier and later stages makes it more likely that phyllosomes of a given stage will be caught. Because the numbers are so small, it is clear that the population is sampled inadequately, and no conclusion can be drawn.

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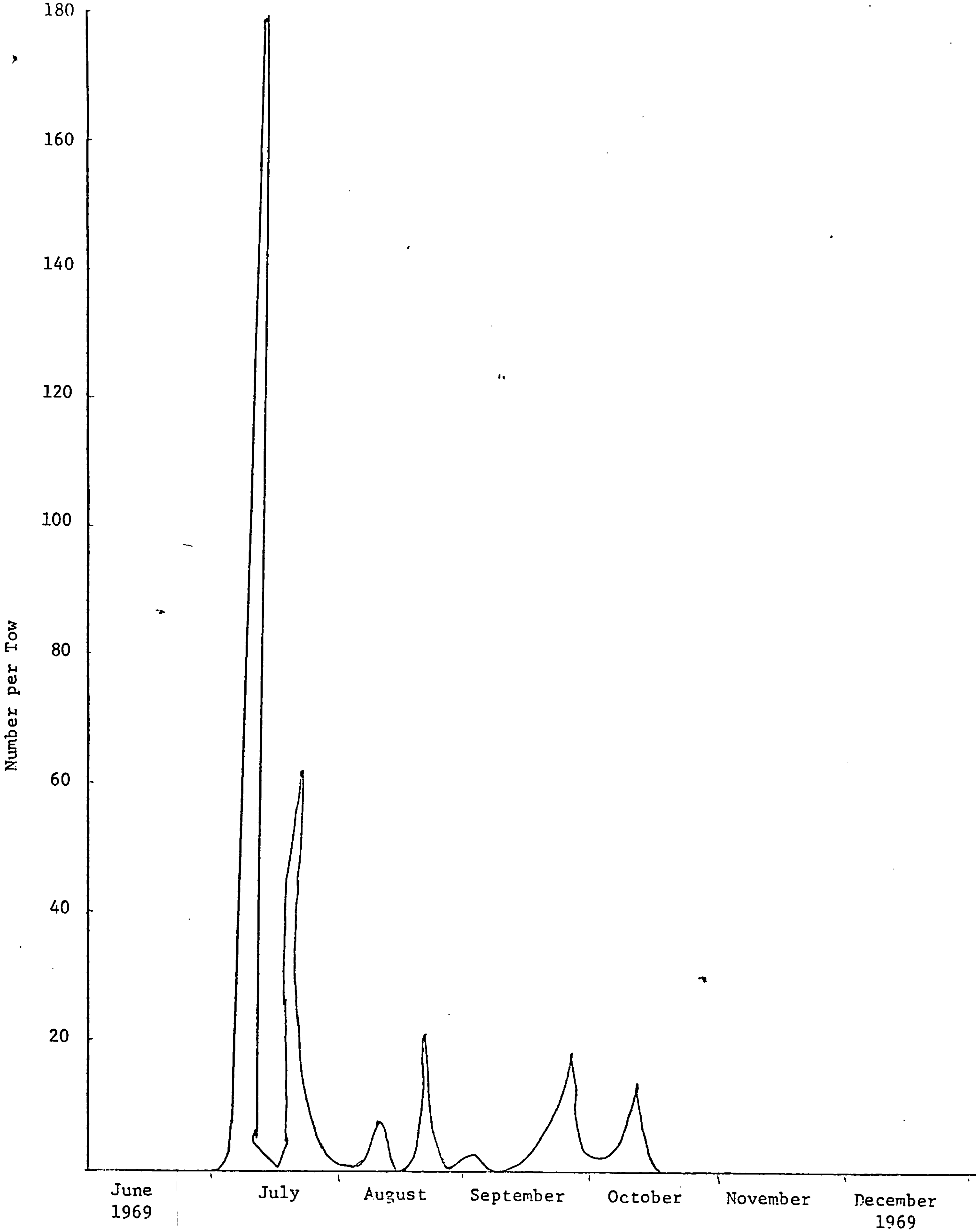

Figure 1

Phyllosomes Collected off La Jolla, California

June-December, 1969

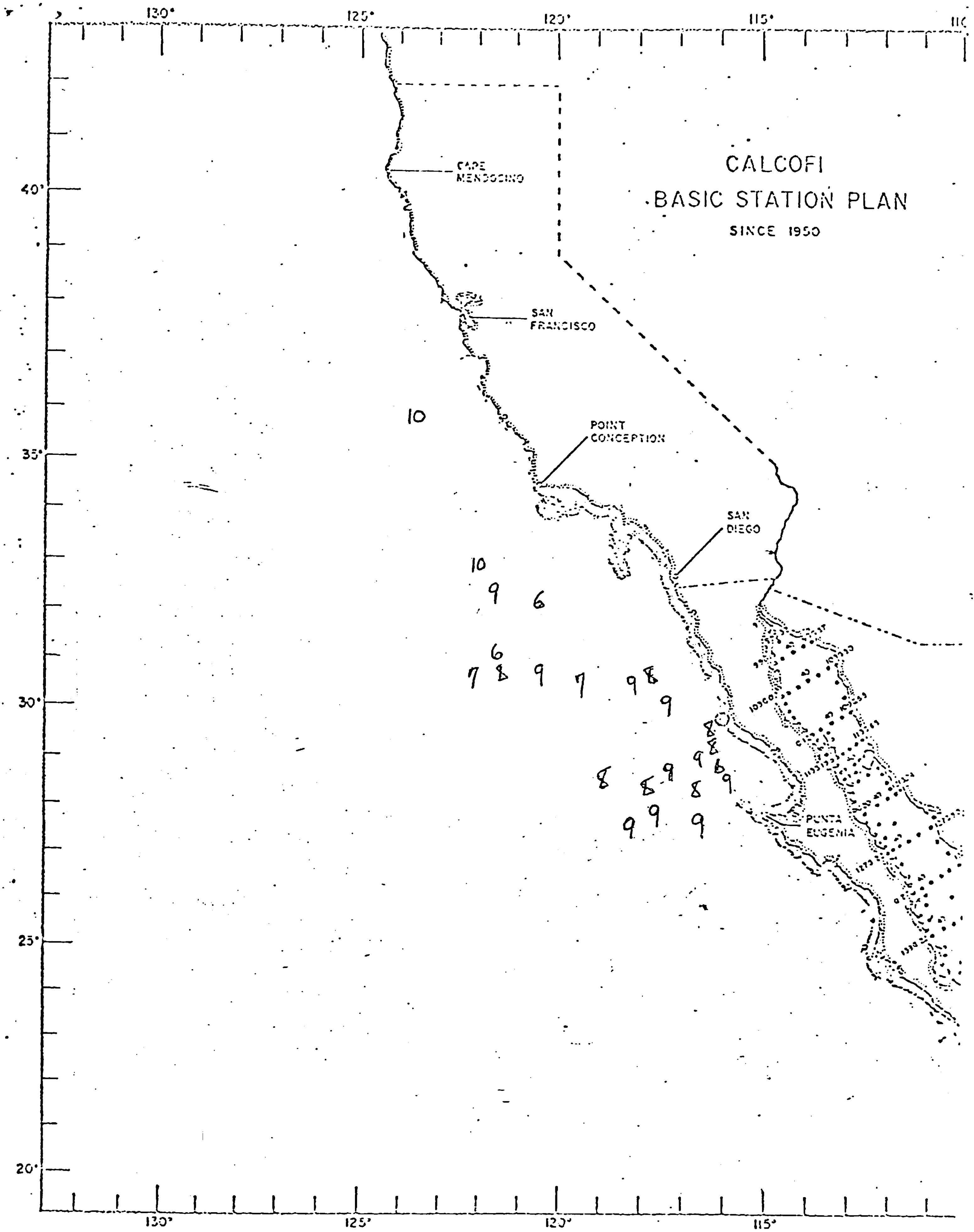

Figure 2.

Positions and stages of phyllosomes from CalCOFI cruises

Laboratory Studies of *Panulirus interruptus* Phyllosome Larvae

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Introduction

The purpose of this study is to rear phyllosome larvae of *Panulirus interruptus* through their developmental stages in the laboratory to determine the length of larval life, sequence of larval stages, duration of stages, and number of molts within each stage. In addition, stage-specific food habits and feeding behavior are being investigated. Particular attention is being given to the effects of temperature and food on larval growth and development.

Materials and Methods

Equipment

Closed circuit sea water systems were used in this study. Four plywood tanks, coated with black fiberglass resin, measuring 1.5 m x 0.6 m x 0.2 m, were used as culture tanks for individual and multiple cultures of phyllosome larvae. Two corner filters containing glass wool and charcoal were placed in each of these 132 l (35 gal.) tanks. An ultraviolet sterilizing unit was attached to a dynaflow filter containing calcium carbonate chips, charcoal, and glass wool, so that water was both filtered and sterilized before returning to the tank. Large sclae aeration of the tank was obtained by using a 2 cm diameter PVC tube, 1.2 m long, into which a series of small holes had been drilled. A lead rod, sealed in rubber surgical tubing, was placed inside the air tube to keep it on the bottom of the tank. Small 25 and 50 watt heaters were used to maintain two tanks at 25°C, while two tanks were kept at ambient room temperature (20 - 22°C). Black plexiglass sheeting was placed over each tank to reduce water evaporation and to prevent foreign material from falling into the tank. Offshore coastal water was collected, filtered through a Buchner funnel, and added to the tanks.

Two 23l (5 gal) planktonkreisels, similar to those designed by Greve (1968) were used for mass cultures of phyllosomes. These were provided with subsurface sand filters and aeration designed to maintain the phyllosomes in a slow, circular motion.

Containers used in individual and multiple cultures were similar to the compartmentalized plastic trays of Modin and Cox (1967), with the added advantage that each container could be removed and examined separately. Plexiglass tubing, 2 cm, 2.5 cm, 3 cm, 4 cm, and 5.5 cm in diameter, was cut into 3.2 cm lengths. Small windows were made in the sides of the four larger tubes. Nylon netting, mesh size of 253 microns, was glued with silicone cement to the bottom and windows of these containers. Smaller containers were used for Stage I and II phyllosomes; larger containers were used for older larvae and for multiple cultures. The containers were leached in fresh water for at least 48 hours before being used. The containers were placed into styrofoam sheets 30 cm x 10 cm x 1 cm which were floated on the surface of the water.

Maintenance

Berried females were kept in running sea water tanks in the Scripps Institution of Oceanography experimental aquarium, and fed on Mytilus. Released phyllosomes were brought from Scripps to the San Diego State laboratory where they were introduced into individual, multiple, or mass culture. Artemia nauplii provided the main food source during this study, but fresh plankton, Tubifex, and *Mytilus* were also used on a pilot basis. All phyllosomes were fed daily. Records were kept of temperature and salinity of the seawater culturing systems.

Approximately 700 phyllosomes were followed individually in the small plexiglass containers. These were checked daily to determine their condition, stage, and molting frequency. About 3,000 larvae were placed in multiple culture dishes of 5 to 10 animals per dish. As larvae died in the individual dishes, they were replaced with larvae from the multiple cultures. Mass culture was attempted on about 10,000 phyllosome larvae.

Preserved larvae were measured with an ocular micrometer under a dissecting microscope to determine growth in size with time. Size measurements were made on length of the cephalic shield, thorax, and abdomen combined, and width of the cephalic shield. Attempts to measure preserved molts were unsuccessful.

Results

Description of Stages and Molts

Johnson (1956) described 11 phyllosoma stages of *Panulirus interruptus*. These descriptions were based on preserved planktonic material and could not take into account the dynamics of growth, either with respect to duration of stages or number of molts within stages. Johnson's stages will be used as references at present, and our stages will be subscripted to identify molts within that stage. The laboratory-reared phyllosomes progressed through three stages in a series of five molts (Table 1). They did not reach Stage IV.

Survival in Laboratory Cultures

Phyllosomes raised in mass culture in the planktonkreisels survived for a maximum of 10 days. Those in multiple cultures (five to ten individuals per container) remained healthy for up to 30 days before being transferred to individual containers. Maximum length of life in the laboratory, 71 days, was obtained for the phyllosomes living in individual containers.

Approximately 30% (Table 2) of the phyllosomes at 25°C died between molts, and about 50% of the phyllosomes at 20°C died between molts. Unfortunately, leakage around the ultraviolet unit in the 25°C tank resulted in complete mortality of the phyllosomes during Stage IIIa.

Growth Rates

There is considerable variation in size among the phyllosomes at the same stage (Table 3). The largest increase in size occurred with the first molt, but the animals continued to grow with each additional molt.

Effects of Food and Temperature on Survival and Molting

The results of a preliminary study (Table 4) indicate that food may play a critical role in determining molting frequency and survival. The duration between molts was significantly less in phyllosome larvae reared at 25°C than at 20°C, as shown in Table 5.

Food Habits and Feeding Behavior

Little is known concerning the feeding habits of *P. interruptus* or other palinurid lobster larvae, either under natural or laboratory conditions, primarily because of difficulties in culturing them during the relatively long developmental period. Because *Artemia* nauplii are not natural food for the phyllosomes, some of the information on growth, molting, and feeding processes determined with *Artemia* as the culture food may not be indicative of what occurs in nature. Batham (1967) observed several early stages of *Jasus edwardsii* phyllosomes feeding on pieces of adult polychaetes.

Thomas (1963) and Shojima (1963) found later stages of *Ibacus* (a scyllarid) associated with medusae in nature. It has been suggested that the phyllosomes may use the medusae for transportation and protection, as well as food. Sims (1968) examined the gut contents of phyllosomes and found that those containing food also contained nematocysts, indicating that medusae do serve as food.

Although most of these published observations were made using species collected in the plankton, there has been very little laboratory work done to determine the natural foods of the larvae. Therefore, further observations and experiments on food preferences are essential to ascertain more precisely the feeding habits of *P. interruptus* phyllosomes in nature.

Preliminary observations on the food habits and feeding behavior of the early stage phyllosomes indicated that they feed on organisms which vary considerably in size and morphology. Different methods of capture and feeding are used, depending on the prey involved. Larvae of all stages reared in the laboratory were observed feeding on *Artemia* nauplii. The larvae caught the nauplii with the dactyls on the ends of their abdominal legs; the prey was then brought to the mouth and grasped there with the second maxillipeds. It was possible to observe the complete ingestion of *Artemia*, which generally took about 10 minutes. A different type of behavior was exhibited by phyllosomes feeding on both *Tubifex* worms and small *Sarsia* medusae. In capturing both of these prey, the larvae would repeatedly puncture them with the dactyls of the first and second legs. In the case of the medusae, they would transfer the prey to their third legs soon after it was caught. Replicate observations of this kind are now being made, using other natural prey species obtained from fresh plankton samples.

During the summer of 1970, an attempt will be made to define which food or foods produce the greatest growth and survival rates by maintaining a series of replicate tray cultures in a 132 l tank. *Artemia* nauplii will be used as a control, because phyllosome growth and molting rates using *Artemia* have already been established. Several other potential prey species will be tested alone and in combination with *Artemia*, using organisms which similarly can be obtained or cultured in sufficient numbers to be used as a continuous food source. Medusae, larvaceans, veligers, fish eggs and larvae, polychaetes, cladocerans, and possibly centric diatoms, appear to be the most promising.

Inoue (1965) found that as phyllosomes of *P. japonicus* molted, they would accept increasingly larger *Artemia*. Thus, later stages of *Artemia* and other prey of various sizes are being introduced to phyllosomes at different stages in order to assess their value as food, and the relationship of prey and predator size.

In addition to the laboratory studies on the feeding habits of the phyllosomes, an attempt will be made to dissect and examine the mouthparts of the different stages. Those of each stage will be examined to determine possible specific changes in functional morphology during development.

Discussion

These preliminary studies confirm reports from the literature of the difficulty in culturing phyllosome larvae. The remainder of our laboratory rearing studies will be conducted at 25°C because mortality between stages is reduced and molting rate is increased. Detailed observations of food preferences and feeding behavior, combined with examination of mouth parts and other feeding appendages, should provide insight into the degree of development of feeding morphology and the type of prey which can be utilized at each stage. It is possible that phyllosomes at all stages require large, soft-bodied, slow-moving prey. The major culturing problem is to find an adequate food source for larger phyllosomes which is easily reared or maintained in the laboratory. It seems feasible that laboratory life span can be increased significantly under these conditions.

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Table 1 Description of Stages and Molts

Stage	Comments	Identifying Characteristics	
		Peraeopod 3	Peraeopod 4
I	initial condition upon release from berried female Johnson	coxal spine present	--
II	occurs after molt 1	1 segment exopod	--
IIIa	occurs after molt 2	exopod sátose	bud barely visible
IIIb	occurs after molt 3	"	bud $\frac{1}{2}$ length of abdomen
IIIc	occurs after molt 4	"	bud and abdomen equal in length
IIId	occurs after molt 5	"	bud longer than abdomen
IV	Johnson	"	bud about twice length of abdomen, exopod bud present

Table 2 Survival in Laboratory Cultures

Stage	Survivorship Number entering into stage 20°	25°	Total	Mortality Number dying during stage 20°	25°	Total
I	538	153	691 100%	287/533 53.3%	42/153 27.5%	329/691 47.6%
II	251	111	362 52.4%	128/251 51.0%	48/111 27.5%	176/362 48.6%
IIIa	123	63	186 26.9%	39/123 31.7%	63/63 100%	102/186 54.8%
IIIb	84		84 12.2%	50/84 59.5%		50/84 59.5%
IIIc	34		34 4.9%	31/34 91.2%		31/34 91.2%
IIId	3		3 .4%	3/3 100%		3/3 100%

Table 3 Growth rates

Stage	Length			Width			N
	Mean± std. dev.	Minimum	Maximum	Mean± std.dev.	Minimum	Maximum	
I	1.442± 0.125 mm	1.2	1.72	0.711± 0.058 mm	.6	.89	91
II	1.806± 0.140	1.6	2.2	0.8334± 0.070	.8	1.02	72
IIIa	2.135± 0.113	1.82	2.31	0.943± 0.071	.8	1.06	34
IIIb	2.375± 0.197	2.10	2.64	1.062± 0.055	.99	1.12	11
IIIc	2.638± 0.116	2.38	2.90	1.159± 0.095	.99	1.32	16

Table 4 Effect of food on survival and molting

Number of phyllosomes entering into stage

	Food		
Stage	*Artemia* nauplii	*Tubifex*	*Mytilus* gonad
I	80	80	80
II	28	2	0
IIIa	3	0	0
Maximum days lived	35	25	18

Table 5 Effect of temperature on molting frequency

	20°C Mean days ± std. dev.	N	25°C Mean days ± st.dev.	N
Total days to molt 1	13.124 ± 2.885 range 9-29 days	538	11.342 ± 1.604 range 9-19 days	153
Total days to molt 2	22.644 ± 2.845 range 19-34 days	146	17.718 ± 1.436 range 16-24 days	71
Total days to molt 3	32.043 ± 4.339 range 25-46 days	93	27.750 ± 3.105 range 24-33 days	8
Total days to molt 4	45.212 ± 4.762 range 39-58 days	33		
Total days to molt 5	52.750 ± 4.113 range 49-58 days	4		