KINDS AND ABUNDANCE OF FISHES IN THE CALIFORNIA CURRENT REGION BASED ON EGG AND LARVAL SURVEYS[1]

ELBERT H. AHLSTROM
U.S. Bureau of Commercial Fisheries Biological Laboratory
La Jolla, California

Egg and larval studies have formed an integral part of the research of the La Jolla Laboratory for 25 years. The first extensive survey cruise to determine the areal extent of sardine spawning was made in 1939 in cooperation with the Scripps Institution of Oceanography. Subsequently we have made egg and larval surveys in 18 additional years, all in cooperation with Scripps.

Although our studies have centered on the Pacific sardine, it soon became evident that the collections we were making were equally useful in assessing the distribution and abundance of the egg and larval stages of other pelagic fishes in the California Current system. It is this latter aspect of egg and larval studies that I wish particularly to develop in this presentation.

It is a fortunate circumstance that sardine spawning was found to have an extensive and varying areal and temporal distribution. Because of this, our surveys could not be limited to a part of the year or to a part of the California Current system off California and Baja California. We had to cover an extensive area systematically. Throughout the 1950's, egg and larval surveys were conducted at approximately monthly intervals. Only since 1961 have they been restricted to quarterly cruises.

There are perhaps three principal reasons why fishery scientists conduct egg and larval surveys.

(1) For one thing, scientists are interested in the present abundance of an adult fish population and its distribution at time of spawning, and they hope to determine this from the distribution and abundance of its pelagic eggs.

(2) Secondly, they are interested in the dynamics of a fish population; in how good or poor the year class resulting from the season's spawning will be; and in the reasons for the marked variations in survival that occur. They hope to determine this by systematically sampling the larvae and their environment during the spawning season.

(3) They are interested in marine fish resources, latent as well as exploited, and in their distribution, abundance, and interrelations. Since the majority of fishes have pelagic larvae and many have pelagic eggs, the studies can be carried out on these stages.

There are other reasons for conducting surveys in addition to the above. Fish eggs and larvae constitute only one of a number of groups of animals that make up the zooplankton community. Some zooplankters are predators on fish eggs and larvae while others constitute the food of developing fish larvae. Hence, our studies must include the kind and amount of zooplanktonic organisms (including biomass estimates). Of primary importance is an understanding of the physical and chemical features of the dynamic ocean environment and their influence on productivity and on the distribution and abundance of fishes.

Let us consider for a moment a few of the problems involved in using planktonic fish eggs as a means of assessing the distribution and abundance of the adult population. The developing embryos in pelagic fish eggs cannot dodge a plankton net. They can be sampled quantitatively at any given place in the ocean merely be encompassing their vertical distribution with adequate gear hauled in a uniform manner. Utilizing the information on the distribution of eggs, the areal distribution of adult fish at time of spawning can be determined with considerable precision. The basic requirements are (1) extensive enough coverage in space to completely delimit the areal distribution of spawning and (2), surveys repeated at frequent enough intervals to delimit the spawning season in the several parts of a species' range. Delimiting the areal and seasonal distribution of spawning is a straightforward reconnaisance problem.

Estimating the amount of spawning within acceptable limits of precision is another matter, however. This is a far more difficult problem, as it involves the manner in which fish are distributed at time of spawning, the extent of spawning patches, the rate of diffusion of eggs away from such patches and many other variables that probably will differ for each species of fish being investigated. Our yearly estimates of sardine egg abundance are consistent enough to lend support to the determination that the fiducial limits for our annual egg estimates are roughly half or double.

Furthermore, if surveys were limited to this one aspect, it would be possible to devise sampling techniques that would increase reliability of sampling. We demonstrated that horizontal strip sampling along cruise tracks using a series of high speed samplers is an excellent way of integrating the patchy distribution of sardine eggs over area (Ahlstrom *et al.* 1958). We did not adopt this technique routinely because high speed samples were of limited value in collecting fish larvae. The volume of water strained was just too small to get an adequate size sampling of larvae. Even when employing only oblique plankton hauls made with our CalCOFI net, reliability of egg estimates can be enhanced by increasing the frequency of sampling within known spawning areas.

[1] Figures 1–15 appear at end of paper, pages 38 to 52.

We have found that estimates of larval abundance are more consistent than estimates of egg abundance. This is an interesting point, as it is often assumed that the reverse is true. In fact this latter opinion was expressed by Alan Saville in a review paper on egg and larval studies that he contributed to the ICES symposium at Madrid in 1963. I will present data to substantiate this point later in my talk.

Larval estimates are assumed to be less reliable than egg estimates when they are used for estimating the relative abundance of the various pelagic species spawning in an area. There is an element of truth in this. Considerable mortality has been experienced during both the embryonic and larval stages—and it must differ from species to species.

There are a number of advantages to using larvae in preference to eggs and none is more convincing than the following: larvae can be identified with more certainty. I need only mention the similarity in appearance of early stage gadid eggs that has plagued studies on the haddock or the difficulty that Tom English had in separating the early stage eggs of three species of flatfish so that he did his studies on reliability of estimates of egg abundance on composite samples of all three.

Then too there are more species represented as larvae than as eggs. Some fishes incubate their eggs and extrude them only when they hatch. There are some 50 species of *Sebastodes* in California waters that are ovoviviparous, and some other fishes including *Brosmophycis*. Larvae of various species with demersal eggs also occur in the plankton; the Pacific herring, osmerid smelts, and cultus cod are examples.

There is another advantage for using larvae for estimates of abundance that appears to me to be of prime importance. The eggs of many of our common species—sardine, jack mackerel, Pacific mackerel hatch in 2 to 4 days at the temperatures usually prevailing in our waters. Hence, only as many days spawning can be represented in our collections. Larvae, however, require a month or more to develop through the size range we take in our samples. Thus a larval sample represents, in a real sense, an integration over time. With cruises spaced at monthly intervals larval numbers should adequately reflect the sequence of spawning. Another consequence of this accumulation is that larvae tend to be more widely distributed than eggs and hence taken in more collections.

I do not intend to go into the subject of larval survival to any extent. John Isaacs discusses this subject with respect to the sardine and anchovy in this symposium. A few aspects of this problem will be presented in a latter part of this paper.

Now that I have presented the case for using larvae, I will get to the main thesis of my talk, which is simply this; there is no better technique available for fish resource evaluation than systematic larval surveys.

I will remark to begin with that I am impatient with the often used excuse that such surveys are impractical because of the difficulty of identifying larval fish. There also are difficulties in identifying copepods, medusae and most other groups in marine plankton. This has not prevented a number of scientists from becoming quite competent in the taxonomy of such planktonic groups. It is just one of the facts of life that a taxonomist has to expend rather considerable time and effort in learning his trade. Larval fish taxonomy is not a task to assign to a junior fishery biologist without experience in taxonomy.

It is very difficult to evaluate the kind and amount of our adult fishery resources. Bottom trawls could be used to collect a segment of the fish biomass, midwater trawls another fraction, long-lines another, etc. This is because fish are so various with respect to size, depth distributions, behavior patterns, food habits, etc. Juvenile and adult fishes possess one characteristic in common, agility. This characteristic has led us to class fish as nekton.

Fishes are passive, however, or only moderately agile during their early development stages as embryos and larvae. Pelagic fish eggs and larvae are temporary members of the plankton community and can be sampled by plankton gear. The sampling problem of fish eggs and larvae is orders of magnitude more simple than with juvenile and adult fishes. It is possible to use fish eggs and especially fish larvae for resource evaluation because most marine fishes have a pelagic larval stage. The majority of pelagic fishes spawn their eggs in the open sea in a manner that permits each egg to be a separate, free-floating entity. Egg masses are the exception in the pelagic realm and only a few fishes like the flying fishes and atherinids spawn their eggs with strings attached.

At the risk of being repetitious, I will restate several points made previously. Ovoviviparous fishes, such as rockfish, coddle their embryos, but extrude their newly hatched larvae to fend for themselves in the open sea. The larvae of many fishes with demersal eggs become members of the plankton community. Only sharks and their relatives and a few marine teleost groups such as embiotocids completely bypass the planktonic larval stage.

The eggs and larvae of the majority of pelagic fishes have a relatively shallow depth distribution, occurring principally in the upper mixed layer. On CalCOFI survey cruises, we haul our plankton nets obliquely from about 140 meters deep to the surface. This depth of haul is enough to completely encompass the vertical distribution of most of our common fish larvae including sardine, anchovy, Jack mackerel, Pacific mackerel and rockfish.

On Norpac, the wide-ranging survey of the north Pacific made in August 1955, we sampled two depth levels, the usual upper level between 0–140 meters and the adjacent level between 140 and 280 meters. Only about ⅑ as many larvae were taken in the deeper level as in the upper; fully half of these were hatchet fish larvae, a group seldom taken in the upper level.

I have reached the point in my talk at which I would like to present several kinds of information simultaneously. These data are concerned with three things: kinds of fish larvae taken in our surveys, their numerical abundance, and their distributions.

I can cover the first item, kinds of larvae, very succintly. There are many kinds of fish larvae in the California current area. Some are abundant, some are common, many more are rare. Over the years we have taken some hundreds of kinds of fish larvae.

When tabulating the numbers of larvae taken during a cruise or season, we soon noticed that most of the larvae belonged to relatively few kinds. By kind I am referring to species in most instances, but sometimes to genus.

Our data are most completely analyzed for the years 1955 through 1958. During these four years, 12 kinds of larvae made up between 90 and 93% of the larvae collected. These 12 kinds include two genera and 10 species. In three of the four years the same 12 kinds of larvae were the most abundant numerically, and in the remaining year, 1956, there were 2 displacements.

Of the 12 kinds of fishes that are consistently abundant as larvae, 6 are of present or potential commercial importance, 6 have no foreseeable commerical use. All 12 must be important in the food web.

The larvae making up the second group of 12 kinds, i.e., the larvae ranking between 13th and 24th in abundance, contributed 4.3 to 5.5% of the total during 1955 through 1958. Abundance of larvae of the more common species is summarized in Table 1.

The remainder, after both of the above categories are taken into account, constitutes as little as 2.7% of the total in 1955, 4.3% in 1958, 4.6% in 1956 and 5.5% in 1957.

It should be evident from the above groupings that a great deal could be learned about the fish resources of an area without identifying every larva. If only the larvae of the 25 most common kinds of fishes were known, for example, a name could be given to 19 out of every 20 larvae collected on our surveys. From the standpoint of biomass, these are the larvae of the fishes that will make up most of it.

I'm not suggesting that one's attention be limited to the common kinds of larvae. Far from it; many of the fishes of greatest interest to the larval taxonomist are in the 5% remainder, including some important apex predators.

TABLE 1

COMPARISON OF RELATIVE ABUNDANCE OF FISH LARVAE IN THE CALIFORNIA CURRENT REGION BASED ON YEARLY SUMMARIES OF NUMBER OF LARVAE OBTAINED IN PLANKTON COLLECTION FROM CalCOFI SURVEY CRUISES 1955–1958

	1955			1956			1957			1958		
	No. Taken	% of Total	Rank*	No. Taken	% of Total	Rank*	No. Taken	% of Total	Rank*	No. Taken	% of Total	Rank*
Engraulis mordax	140,183	39.03	1	134,931	33.05	1	146,631	29.70	1	205,457	45.21	1
Merluccius productus	60,090	16.73	2	94,277	23.10	2	78,283	15.86	2	58,368	12.84	2
Sebastodes spp.	29,344	8.17	3	29,144	7.14	3	36,473	7.39	4	23,931	5.27	4
Citharichthys spp.	20,411	5.68	4	23,635	5.79	4	15,813	3.20	9	6,655	1.46	11
Leuroglossus stilbius	15,111	4.21	5	18,620	4.56	5	29,506	5.98	5	4,859	1.07	12
Sardinops caerulea	14,121	3.93	6	15,523	3.80	6	9,833	1.99	11	11,423	2.51	7
Trachurus symmetricus	13,246	3.69	7	8,027	1.97	10	20,006	4.05	6	6,409	1.41	10
Lampanyctus mexicanus	13,165	3.67	8	10,802	2.65	8	16,207	3.28	8	16,514	3.63	5
Vinciguerria lucetia	12,654	3.52	9	9,832	2.41	9	55,114	11.17	3	55,756	12.27	3
Lampanyctus leucopsarus	7,454	2.08	10	15,125	3.71	7	16,808	3.40	7	11,892	2.62	6
Diogenichthys laternatus	4,771	1.33	11	3,158	0.77	13	11,603	2.35	10	7,061	1.55	8
Bathylagus wesethi	3,245	0.90	12	2,146	0.52	17	6,347	1.29	12	7,021	1.54	9
Lampanyctus ritteri	1,988	0.55	13	1,924	0.47	18	2,789	0.56	14	3,091	0.68	13
Pneumatophorus diego	1,950	0.54	14	1,520	0.37	20	1,865	0.38	18	1,273	0.28	20
Electrona spp.	1,823	0.51	15	1,852	0.45	19	1,415	0.29	22	1,775	0.39	15
Bathylagus ochotensis	1,301	0.36	18	2,231	0.55	15	1,078	0.22	25	1,550	0.34	16
Melamphaes spp.	775	0.22	25	1,051	0.26	24	1,328	0.27	24	1,255	0.28	21
Cyclothone spp.	1,532	0.43	16	814	0.20		2,880	0.58	13	2,795	0.62	14
Tarletonbeania crenularis	999	0.28	21	3,352	0.82	12	1,570	0.32	21	526	0.12	
Argentina sialis	832	0.23	24	1,288	0.32	22	1,400	0.28	23	276	0.06	
Prionotus spp.				2,470	0.60	14	2,731	0.55	15	1,307	0.29	19
Synodus spp.	641	0.18		958	0.23	25	2,338	0.47	17	1,219	0.27	23
Pleuronichthys spp.	1,038	0.29	19	1,118	0.27	23	579	0.12		164	0.04	
Diaphus theta	1,022	0.28	20	3,562	0.87	11	713	0.14		588	0.13	
Cynoscion spp.	860	0.24	23	104	0.02		31	0.06		1,350	0.30	18
Symphurus atricauda	73	0.02		1,373	0.34	21	1,603	0.32	20	222	0.05	
Ceratoscopelus townsendi	446	0.12		222	0.05		2,598	0.53	16	1,409	0.31	17
Symbolophorus californiense	653	0.18		462	0.11		1,645	0.33	19	1,236	0.27	22
Icichthys lockingtoni	1,385	0.39	17	898	0.22		768	0.16		438	0.10	
Palometa simillima	933	0.26	22	611	0.15		797	0.16		114	0.02	
Tetragonurus spp.	490	0.14		2,154	0.53	16	708	0.14		60	0.01	
Stomias atriventer	411	0.11		81	0.02		271	0.05		1,188	0.26	24
Hygophum spp.	400	0.11		223	0.05		795	0.16		993	0.22	25
All others	5,808	1.62		14,652	3.60		21,023	4.26		16,280	3.58	
TOTAL	359,155	100.00		408,140	100.00		493,549	100.01		454,455	100.00	

* Rank includes only first 25.

I wish to discuss the top 12 for a few moments. Larvae of the northern anchovy consistently have been the most numerous in the CalCOFI survey area; hake larvae have been consistently ranked second in abundance. Neither of these species is fished to any extent. They represent potential fishery resources. Larvae of Pacific sardine, jack mackerel, rockfish (*Sebastodes spp.*) and sanddabs (*Citharichthys spp.*) are the other 4 kinds that represent present or potential commercial resources.

The six species with no forseeable commercial importance are the gonostomatid, *Vinciguerria lucetia,* two deep sea smelts, *Leuroglossus stilbius* and *Bathylagus wesethi,* and three myctophid lantern fish, *Lampanyctus leucopsarus, Lampanyctus mexicanus* and *Diogenichthys laternatus.* There can be little doubt about the ecological importance of these six.

Illustrations (Figs. 1–10) are included here of the larvae of fishes making up the top 12, and of the larvae of a half-dozen other species. Species having elongated, thread-like larvae are grouped in figures 1 and 2. These all are (larvae of) isospondylous fishes. The five species illustrated, listed in their descending order in the two plates are: 1) larvae of the Pacific sardine (*Sardinops caerulea*), 2) larvae of the northern anchovy (*Engraulis mordax*), 3) larvae of the gonostomatid lantern fish, *Vinciguerria lucetia,* 4) larvae of the deep sea smelt, *Leuroglossus stilbius* and 5) larvae of another deep sea smelt, *Bathylagus wesethi.* The two tones of background shading are indicative of the depth zone in which the larvae predominantly occur. The light shading indicates distribution in the upper mixed layer, the darker shading indicates that the species occurs mostly below the thermocline. All of these species rank among the top 12 in abundance. The larvae of the two deep sea smelts have not been illustrated previously.

Our plankton hauls routinely sample the complete depth distribution of larvae of the upper mixed layer, but do not necessarily sample the complete depth distributions of the larvae that occur most commonly in and below the thermocline (dark shading). The marked decrease in abundance of *Leuroglossus* in collections made during 1958 for example, may be due in part, to less complete depth sampling during this "warm-water" year.

The larvae of 3 of the 4 species illustrated in Figures 3 and 4 are of present or potential commercial importance. These larvae as a group are deeper bodied and have larger heads than the larvae in Figures 1 and 2. The top species is a pomacentrid, the blacksmith, *Chromis punctipinnis.* The larvae of this species are moderately common, but *Chromis* does not rank among the top two dozen kinds. The larvae of the next species illustrated, Pacific mackerel, ranked between 14th and 20th in abundance during the 4-year period, 1955 to 1958. The early development of this species was described in detail by Kramer (1960). The third species in these figures, the carangid, *Trachurus symmetricus,* known commercially as the jack mackerel, is one of the abundant kinds of larvae in the CalCOFI area. The bottom illustrations are of the deeper-dwelling larvae of hake, which occur mostly below the thermocline. The embryonic and larval development of jack mackerel was described by Ahlstrom and Ball (1954), and of hake by Ahlstrom and Counts (1955).

Larvae of seven species of myctophid lantern fishes are illustrated in Figures 5 to 7. Figures 5 and 6 illustrate larvae of the same group of species at different sizes. These are: *Lampanyctus leucopsarus, Lampanyctus mexicanus, Lampanyctus ritteri, Symbolophorus (Myctophum) californiense, Tarletonbeania crenularis.* The larvae of *Lampanyctus leucopsarus* and *L. mexicanus* are shaped rather similarly, but differ in ventral pigmentation and larger larvae of *L. mexicanus* possess a dorsal adipose spot lacking in *L. leucopsarus.* Both differ rather markedly from the larvae of *L. ritteri,* which have the deep stubby body shape that is more characteristic of the genus *Lampanyctus.* The interesting larvae of *Symbolophorus californiense* are moderately stalk-eyed, while the large larvae of *Tarletonbeania crenularis* develop an envelope-like fin fold.

Larvae of *Diogenichthys atlanticus* and *D. laternatus* are illustrated in Figure 7. Larvae of the latter species occur in abundance in the southern part of the CalCOFI area. *D. atlanticus* is only moderately common; it is distributed to the north of *D. laternatus,* with some overlap off central Baja California. These two species are very similarly pigmented but *D. atlanticus* has a barbel, making it unique in this character among myctophid larvae.

Five species of sanddabs *(Citharichthys spp.)* occur in the CalCOFI survey area. Three of the more common species are shown in Figures 8 and 9. The more northerly distributed sanddabs are *Citharichthys stigmaeus* (upper) and *C. sordidus* (middle). *C. xanthostigma* larvae occur in abundance off central Baja California, In bothid flatfish it is usual to have one or more anterior dorsal and pelvic rays elongated. Note that larger larvae of *C. sordidus* and *C. xanthostigma* have two elongated anterior dorsal rays (actually the 2nd and 3rd anterior rays) and two correspondingly elongated pelvic rays. The other 2 species of *Citharichthys* in the CalCOFI area, *C. fragilis* and *C. gilberti* also possess this larval character. Hence *C. stigmaeus* is the more unusual in lacking such elongated rays at all larval sizes. It also develops much less pigmentation than any of the other species of *Citharichthys.*

Larvae of rockfish *(Sebastodes spp.)* are illustrated in Figure 10. *Sebastodes* contains many more species than any other genus in the eastern Pacific, over 50 in California waters. Because of this complexity, very few larval series have been established as yet for individual species. An exception is *Sebastodes paucispinis,* whose larvae are figured in the lower half of this plate. This species develops elongated pectoral and pelvic fins, which are rather heavily pigmented near their tips. The paired occipital spines, on the back of the head, sometimes bifurcate, are characteristic of rockfish larvae.

Another aspect of egg and larval surveys that is of prime importance in resource evaluation is the information obtained on distribution. Before Cal-

COFI little was known about the distribution of jack mackerel, for example. The CalCOFI surveys soon showed that jack mackerel eggs and larvae occurred throughout the CalCOFI area. Larvae were taken as far seaward as the cruises extended. On Norpac, jack mackerel eggs and larvae were taken 1100 miles at sea off Washington. There seems little doubt that jack mackerel is an oceanwide resource in the temperate north Pacific.

The southward extent of the distribution of jack mackerel eggs and larvae is adequately delimited by our cruises but not the offshore or northward extents. The southern boundary shifts in response to changing oceanographic conditions, as is illustrated by the more southward extent of jack mackerel larvae in 1954 (Fig. 11B) as co-mapped to 1958 (Fig. 11A).

Hake furnishes another example. Hake larvae consistently have been the second most abundant kind in CalCOFI collections, exceeded only by anchovy larvae. Hake eggs and larvae are almost as widespread in the CalCOFI survey area as jack mackerel (Fig. 11C). Adult hake apparently move offshore to spawn, and return to the area of the continental slope after spawning.

Distribution of larvae of rockfish (Fig. 12B) and sanddabs (Fig. 12C) represent the composite distributions of a number of species; 5 in *Citharichthys*, up to 50 in *Sebastodes*. Both genera have a greater offshore extent than is anticipated for near bottom dwelling fishes. This offshore distribution is a consistent phenomenon, occurring in all years covered by our investigations.

Species with tropical-subtropical distribution extend varying distances to the north depending in part on the species, in part on hydrographic conditions. *Vinciguerria lucetia,* perhaps the most abundant fish larvae in the tropical eastern Pacific, is distributed as far north as Point Conception, California in most years (Ahlstrom and Counts 1958, Figs. 18 and 19) and off central California in favorable seasons (Fig. 12A). The distribution of this species in the CalCOFI area constitutes but a fraction of its distribution in the eastern Pacific (Ahlstrom and Counts 1958 Fig. 21).

Another abundant tropical-subtropical species with an equally extensive distribution is *Diogenichthys laternatus* (Fig. 13A). On Shellback Expedition, larvae of this species were by far the most abundant myctophid larvae in the eastern tropical Pacific. In most years this species extends as far north as off Pt. San Eugenio, central Baja California, but in favorable (warmer) years it can reach southern California. Hence the distribution of this species in the CalCOFI area constitutes only the northern portion of extensive range. The area of distribution of *D. atlanticus* is in offshore oceanic waters off central and southern Baja California and in the portion of the CalCOFI area lying between Pt. San Eugenio and San Francisco, California. It is a much less abundant species than its close relative (Fig. 13B).

Two myctophids having subarctic-temperate distributions are *Tarletonbenia crenularis* (Fig. 13C) and *Lampanyctus leucopsarus* (Fig. 14C). Larvae of such temperate water species occur in greatest abundance during the colder season of the year—winter and spring; larvae of the subtropical myctophid, *Lampanyctus mexicanus* (Fig. 14B) are rare in winter collections, and build to a peak during the summer cruises. The distribution of this species is more restricted than that of many other myctophids, hence the area shown probably constitutes a larger portion of the total distribution of this species in the eastern north Pacific exclusive of the Gulf of California than for such species as *Lampanyctus ritteri* (Fig. 14A) or *Lampanyctus regalis* (distribution not illustrated). Within its area of occurrence, however, it is probably the most abundant myctophid present.

The most abundant of the deep sea smelts is *Leuroglossus stilbius.* It is as widely distributed in the CalCOFI area as jack mackerel or hake (Fig. 15C). Furthermore it is widely distributed in the Gulf of California, and as a matter of interest was initially described from Gulf material. Incidentally in some groups of fishes the differences between larvae of the several species are more striking than differences between adult fishes. The deep sea smelts are one such group. Although larvae of *Bathylagus wesethi* are abundant enough to put it among the top 12, it has a somewhat circumscribed distribution (Fig. 15A) being replaced in the north by *Bathylagus ochotensis* and to the south by *Bathylagus nigrigenys.* The distribution of *B. ochotensis* is shown in Figure 15B. This species is very widely distributed in the north Pacific in subarctic to temperate waters. Some of this wider distribution is shown in Figure 16. This figure summarizes the distribution of bathylagid and argentinid fishes in the part of Norpac that was covered by CalCOFI vessels in August 1955. Note the offshore occurrences of *Bathylagus ochotensis* and the more circumscribed distribution of *B. wesethi. Leuroglossus* is principally a winter and spring spawner and this is undoubtedly why there are so few occurrences during Norpac which was made during August.

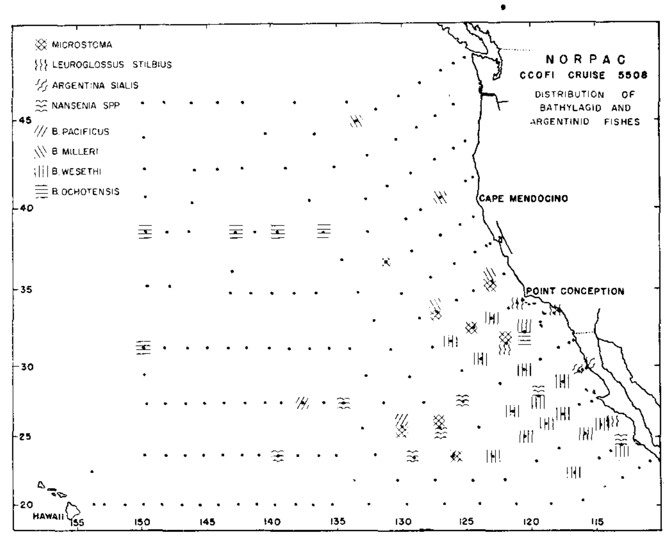

FIGURE 16. Distribution of larvae of Bathylagids and Argentinids on Norpac.

We obtained such excellent information on distributions of fish larvae on Norpac, that I consider this the most important survey made during the history of CalCOFI. Despite its value, it so far has been only a one-time thing. There is nothing I would like better than to see Norpac repeated at the other seasons of the year, especially in February–March when hake spawning is at its peak, and in May–June when jack mackerel spawning is at its peak.

As I mentioned at the beginning of my presentation, the sardine has been the pivotal species in our studies. We have circumscribed its spawning distribution and in doing this have largely circumscribed the spawning distributions of other important wetfishes, including the anchovy and the Pacific mackerel.

One of the important things that we have learned about the distribution of fish at spawning is that it varies from season to season. There is no such thing as fixed spawning areas for pelagic fish in the California Current system. The only way to outguess the fish is to sample so widely that you are bound to fence them in. The marked differences in spawning distribution that can occur in adjacent years is most strikingly shown by the spawning distribution of sardines in 1953 and 1954 (for distributional charts refer to Ahlstrom, 1959). In 1953, sardine spawning was mainly restricted to central Baja California, with only about 1% occurring off California. In 1954 the fish reinvaded California in numbers, having a very widespread spawning distribution. The 1954 spawning has an areal extent that is nearly 2½ times as great as spawning distribution in 1953.

In such years as 1954 and 1955, sardine spawning was more widely distributed off southern California than anchovy, especially in offshore water. There was a zone offshore in which sardine larvae occurred alone. The pattern was repeated in several years, and I began to consider it characteristic of sardines to move fairly far offshore to spawn. Anchovies didn't appear to be so venturesome.

In recent years, larval abundance of anchovies has continued to increase. Anchovy larvae, instead of being only 3.3 times as numerous as sardine larvae in 1951 became over 9 times by 1955 and nearly 24 times by 1958. Since then the disproportion has further increased until it was approximately 80 to 1 in 1962, as determined from the four quarterly cruises made in that year.

With the changes in abundance, the spawning distribution of the 2 species markedly altered. The moderate sardine spawning remaining is concentrated inshore. Anchovy larvae are now abundant in the offshore waters of southern California, as well as in inshore waters. In fact they seem to be everywhere. Anchovy larvae co-occur in nearly all hauls containing sardine larvae—94% of the hauls in 1958, 98% in 1962. There were 6 anchovy larvae for each sardine in co-occurrence hauls in 1962.

It is because of the information gained on egg and larval surveys that we have been able to document the increase in the anchovy population. The anchovy is but little fished commercially; only 1382 tons were landed in 1962 and another 6000 or 7000 tons were used for bait by sportfishermen. Hence the fishery yields little information on the state of the anchovy resource.

The numbers of anchovy larvae that were taken on CalCOFI surveys during 1952 through 1959 are given in Table 2.

TABLE 2

ABUNDANCE OF ANCHOVY LARVAE

	Census estimates $\times 10^8$
1951	15,100
1952	17,070
1953	23,680
1954	38,410
1955	37,660
1956	38,510
1957	40,440
1958	56,930
1959	54,170

I am using estimates that take unequal spacing of stations into account; and designate them as "census estimates".

The anchovy population more than doubled in size between 1951 and 1954 and trebled in size by 1958. The anchovy population is even larger in 1962 and 1963. We presently are conducting only quarterly surveys, but on these anchovy larvae are as numerous as all other fish larvae combined. We have been impressed by the consistency of our anchovy data.

	No. hauls taken	*Occurrences of anchovy*	*Ave. no. per haul*	*Ave. no. per positive haul*
1954	1474	758	109	213
1955	1375	616	102	218
1956	1397	536	97	252
1957	1493	580	98	253
1958	1853	778	111	264

For example, between 1954 and 1958 the average number of anchovy larvae per haul made in the CalCOFI area, was 109 in 1954, 102 in 1955, 97 in 1956, 98 in 1957 and 111 in 1958, a range fo from 97 to 111. The figures are based on all hauls taken, whether anchovy larvae were present or not. When only positive hauls are considered, the average number per haul increased somewhat between 1954 and 1958. In 1954 it was 213 larvae, then in succeeding years 218, 252, 253 and 264—15% more larvae were taken per positive haul in 1958 than in 1954.

One reason for the consistency in the above figures is that we sample about the same proportion of large concentrations of anchovy larvae, moderate concentrations, etc., during each season. During 1954–1958, the proportion of hauls containing few to many larvae were as follows:

Hauls containing 1 to 10 larvae: 24 to 29% of positive hauls

Hauls containing 11 to 100 larvae: 30 to 42% of positive hauls

Hauls containing 101 to 1000 larvae: 25 to 33% of positive hauls

Hauls containing over 1000 larvae: 5.5 to 7.5% of positive hauls

We report on the size composition of anchovy larval samples. For ready comparison the larvae are grouped by about 3 mm intervals:

	Percent of seasonal total in size categories				
	1954	*1955*	*1956*	*1957*	*1958*
2.50– 5.75	60.3	60.3	48.4	55.8	62.3
6.75– 8.75	28.1	27.2	32.7	29.8	25.6
9.75–11.75	8.8	9.7	15.4	11.5	9.1
12.75–14.75	2.14	2.01	2.77	2.28	2.26
15.75 & larger	0.57	0.68	0.64	0.62	0.66

There were about the same proportion of larvae of different sizes during the five years. This as a gratifying result, for if the proportion of larvae of different sizes is about constant, then estimates based on total number of larvae are quite meaningful.

But there is one aspect of the above that isn't as gratifying. We had hoped to be able to distinguish between good and poor year classes of fishes by differences in survival of larvae. The survival curves for anchovy larvae are surprisingly similar from year to year. This uniformity can be seen by looking at the proportion of larger lervae that were present in the 1954–1958 samples. Larvae 15.75 mm and larger constituted 0.57% of the total in 1954, 0.68% in 1955, 0.64% in 1956, 0.62% in 1957, 0.66% in 1958. A similar uniformity is found in our sardine larval summaries. I am just pointing this fact up, not trying to develop it here. It is a problem that will have to be dealt with separately.

REFERENCES

Ahlstrom, E. H., 1959. Distribution and abundance of eggs of the Pacific sardine, 1952–1956. *U.S. Fish and Wild. Serv., Fish. Bull.,* 60 (165) : 185–213.

Ahlstrom, E. H., and O. P. Ball, 1954. Description of eggs and larvae of jack mackerel *(Trachurus symmetricus)* and distribution and abundance of larvae in 1950 and 1951. *U.S. Fish and Wild. Serv., Fish. Bull.,* 56 (97) : 209–245.

Ahlstrom, E. H., and R. C. Counts, 1955. Eggs and larvae of the Pacific hake, *Merluccius productus. U.S. Fish and Wild. Serv., Fish. Bull.,* 56 (99) : 295–329.

Ahlstrom, E. H., and R. C. Counts, 1958. Development and distribution of *Vinciguerria lucetia* and related species in the Eastern Pacific. *U.S. Fish and Wild. Serv., Fish. Bull.,* 58 (139) : 363–416.

Ahlstrom, E. H. , J. D. Isaacs, J. R. Thraikill and L. W. Kidd, 1958. A high-speed plankton sampler. *U.S. Fish and Wild. Serv., Fish. Bull.,* 58 (132) : 187–214.

Kramer, D., 1960. Development of eggs and larvae of Pacific mackerel and distribution and abundance of larvae 1952–56. *U.S. Fish and Wild. Serv., Fish. Bull.,* 60 (174) : 393–438.

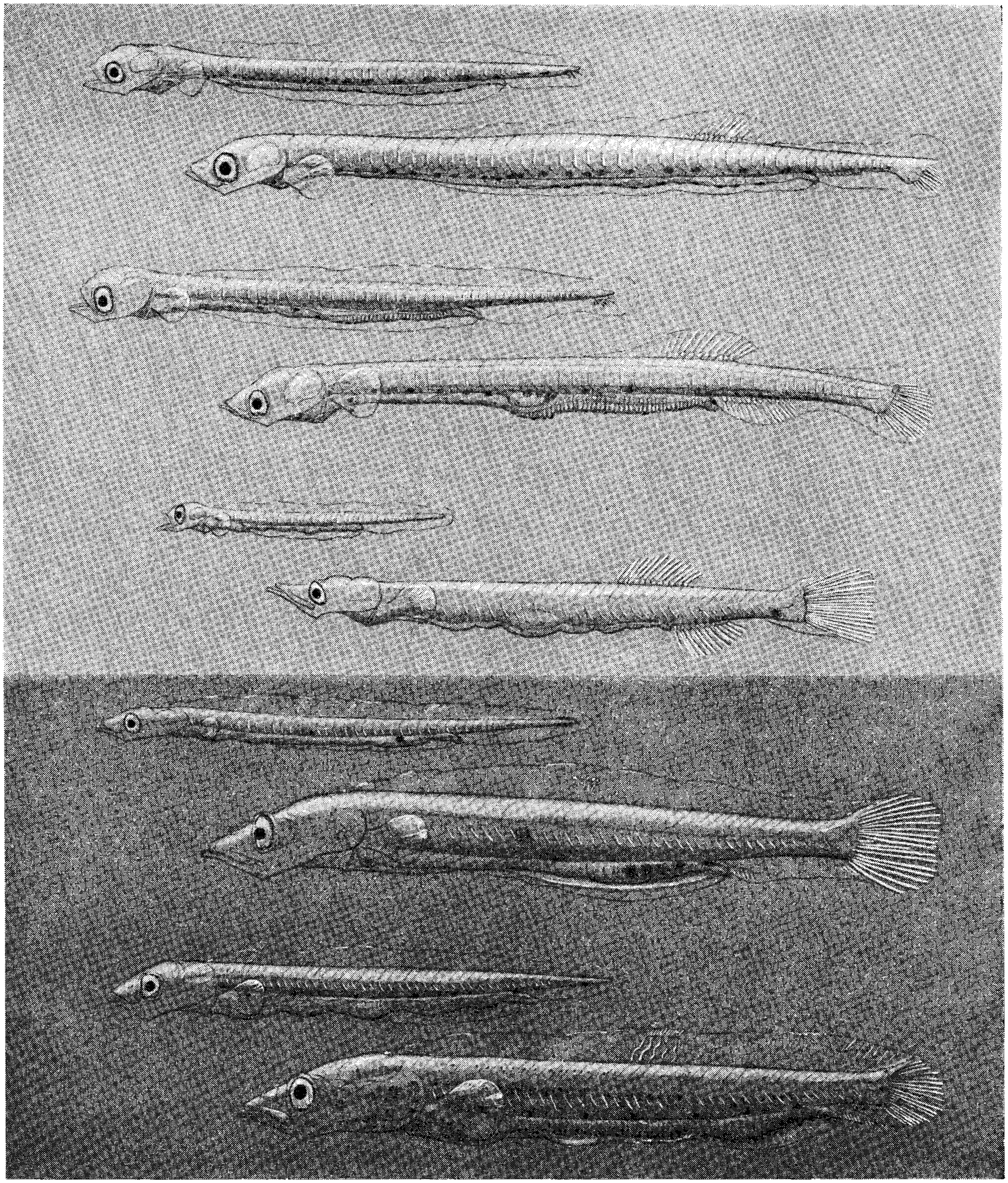

FIGURE 1. From top to bottom—*Sardinops caerulea* 5.6mm–12.5mm; *Engraulis mordax* 6.0mm–11.5mm; *Vinciguerria lucetia* 3.2mm–9.0mm; *Leuroglossus stilbius* 5.4mm–15.7mm and *Bathylagus wesethi* 5.7mm–11.3mm.

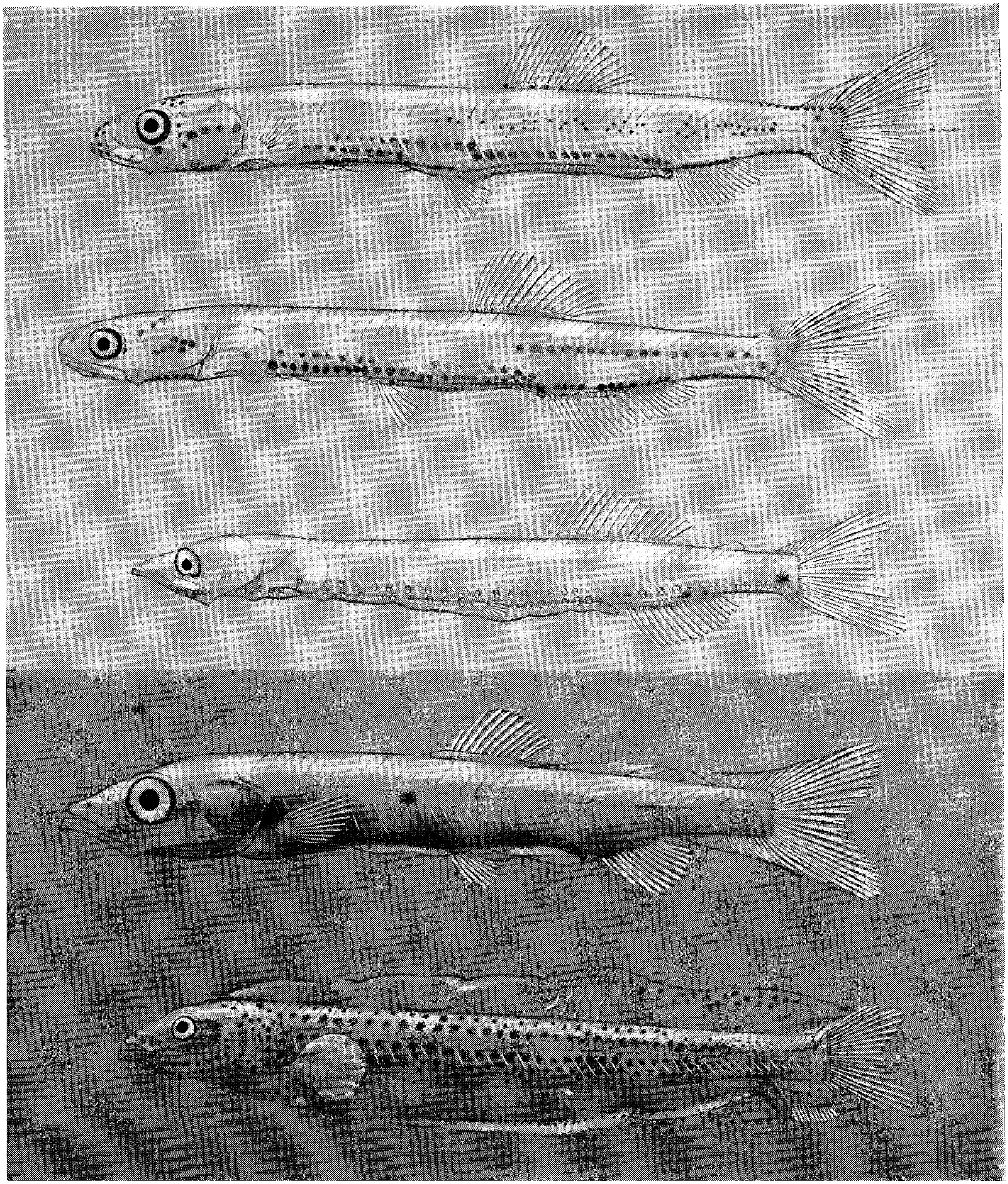

FIGURE 2. From top to bottom—*Sardinops caerulea* 31.3mm; *Engraulis mordax* 31.0mm; *Vinciguerria lucetia* 15.0mm; *Leuroglossus stilbius* 28.5mm and *Bathylagus wesethi* 24.5mm.

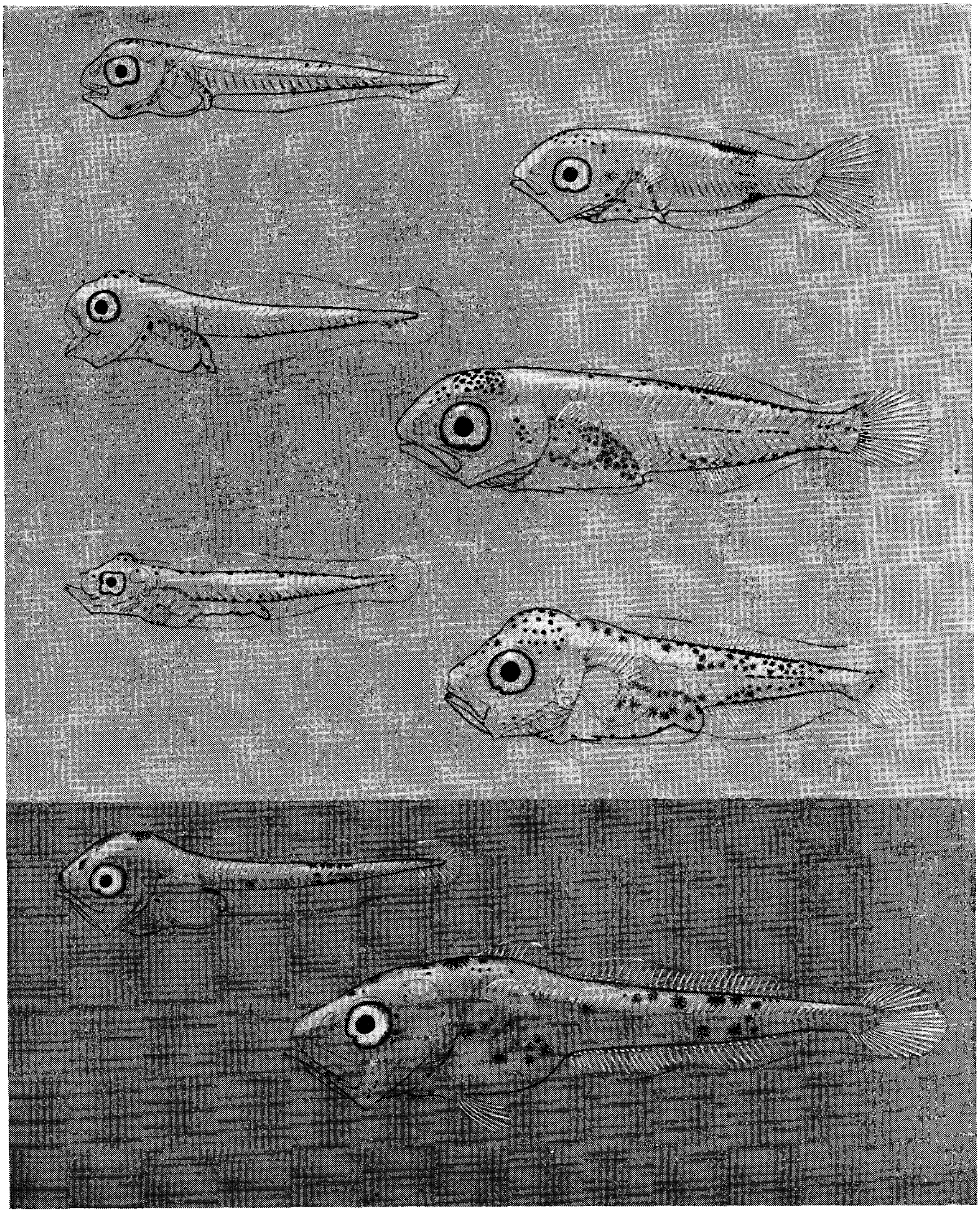

FIGURE 3. From top to bottom—*Chromis punctipinnis* 4.25mm–5.5mm; *Pneumatophorus diego* 4.0mm–7.8mm; *Trachurus symmetricus* 3.5mm–7.4mm and *Merluccius productus* 4.3mm–10.11mm.

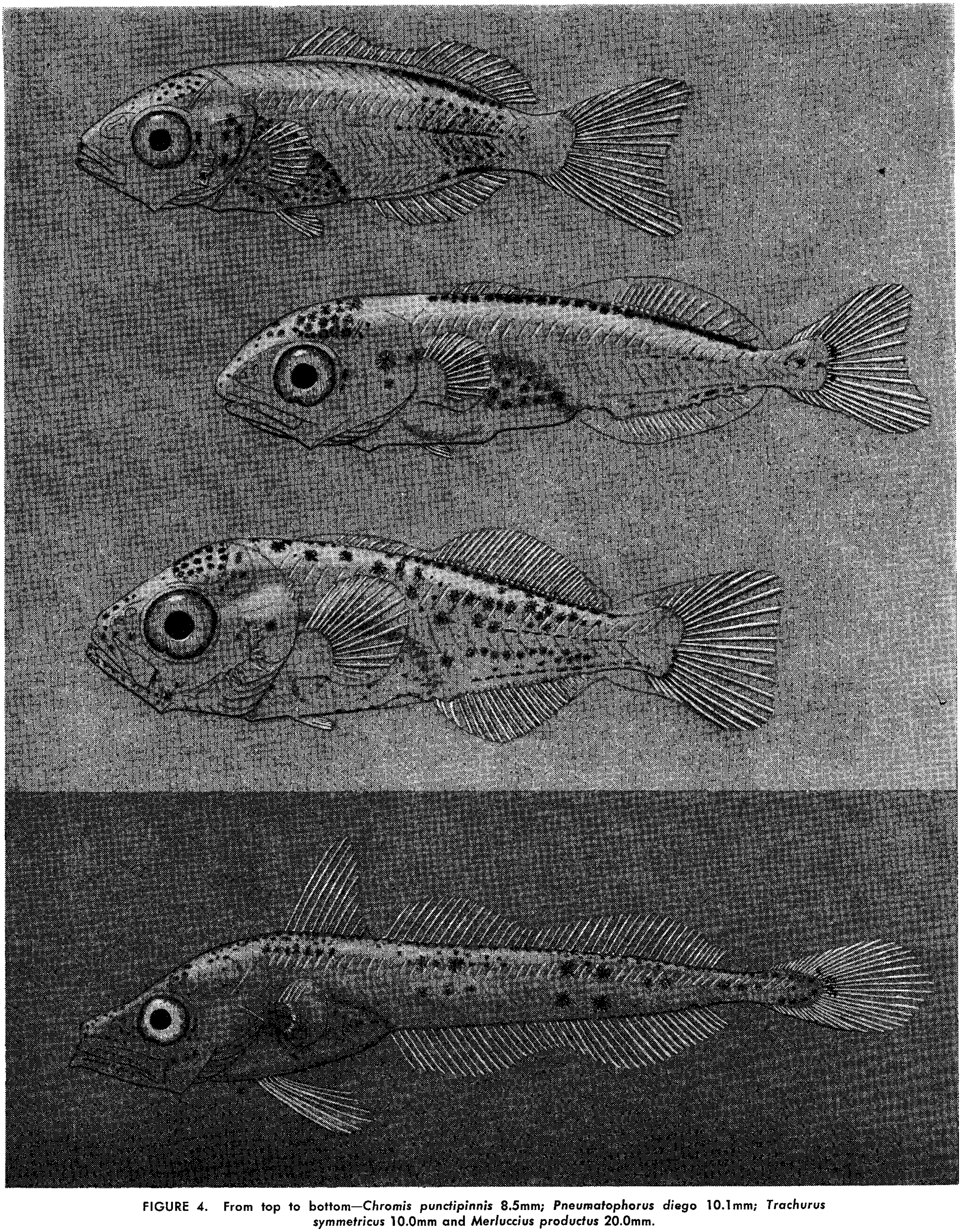

FIGURE 4. From top to bottom—*Chromis punctipinnis* 8.5mm; *Pneumatophorus diego* 10.1mm; *Trachurus symmetricus* 10.0mm and *Merluccius productus* 20.0mm.

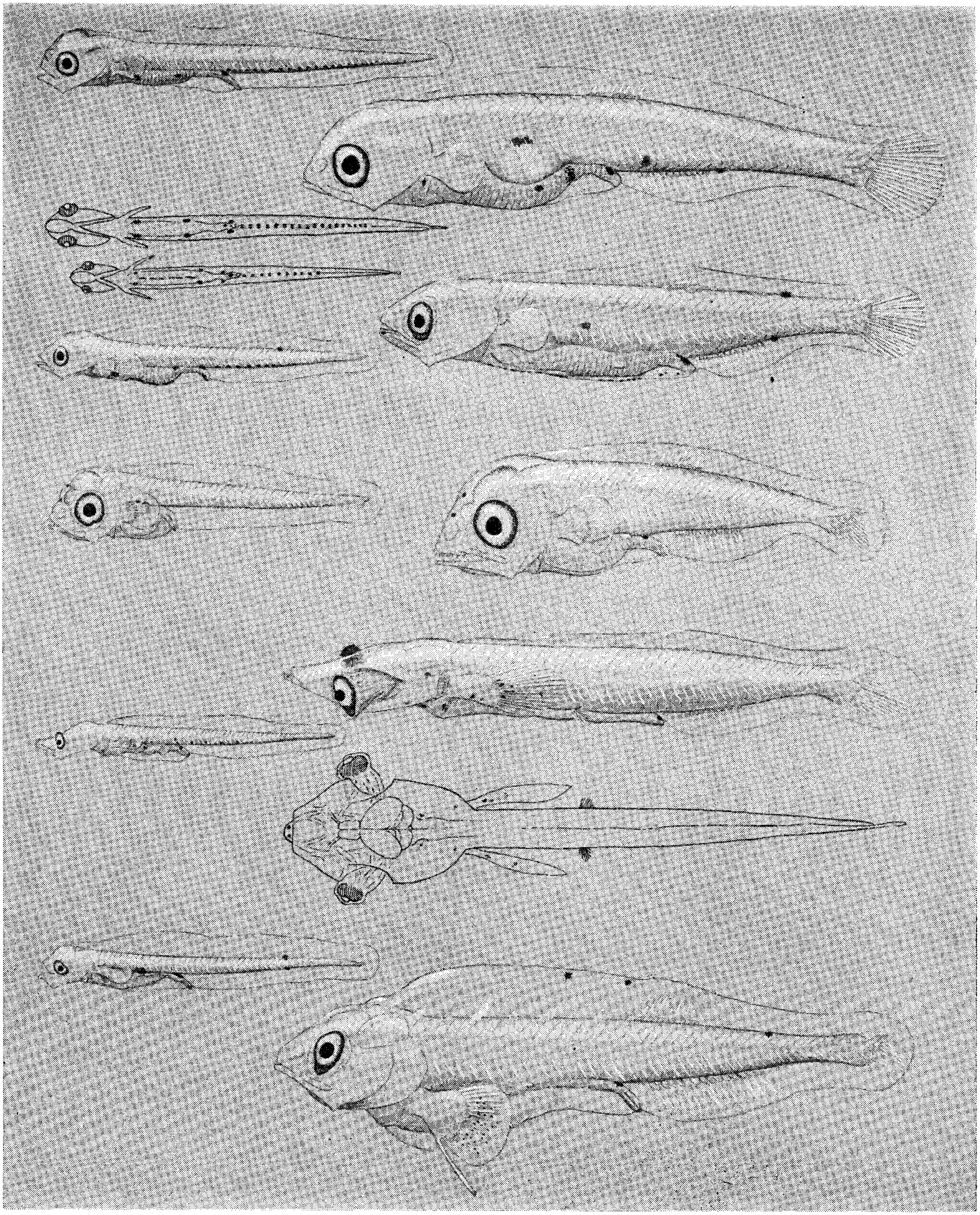

FIGURE 5. From top to bottom—*Lampanyctus leucopsarus* 5.3mm–7.8mm; *Lampanyctus mexicanus* 4.4mm–6.75mm; *Lampanyctus ritteri* 4.3mm–5.75mm; *Symbolophorus californiense* 4.0mm–8.0mm and *Tarletonbeania crenularis* 4.2mm–7.8mm.

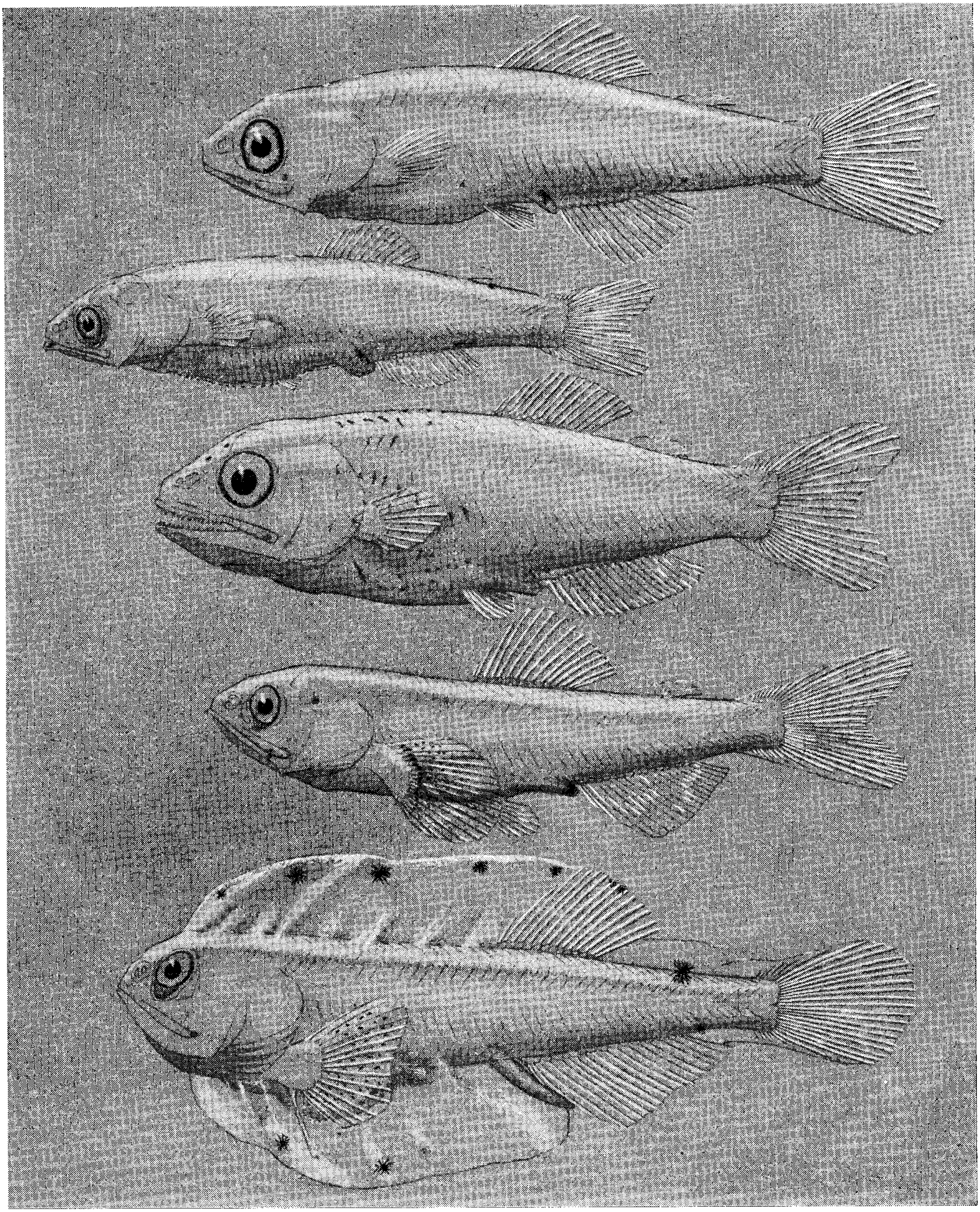

FIGURE 6. From top to bottom—*Lampanyctus leucopsarus* 12.5mm; *Lampanyctus mexicanus* 10.5mm; *Lampanyctus ritteri* 12.5mm; *Symbolophorus californiense* 23.0mm and *Tarletonbeania crenularis* 17.8mm.

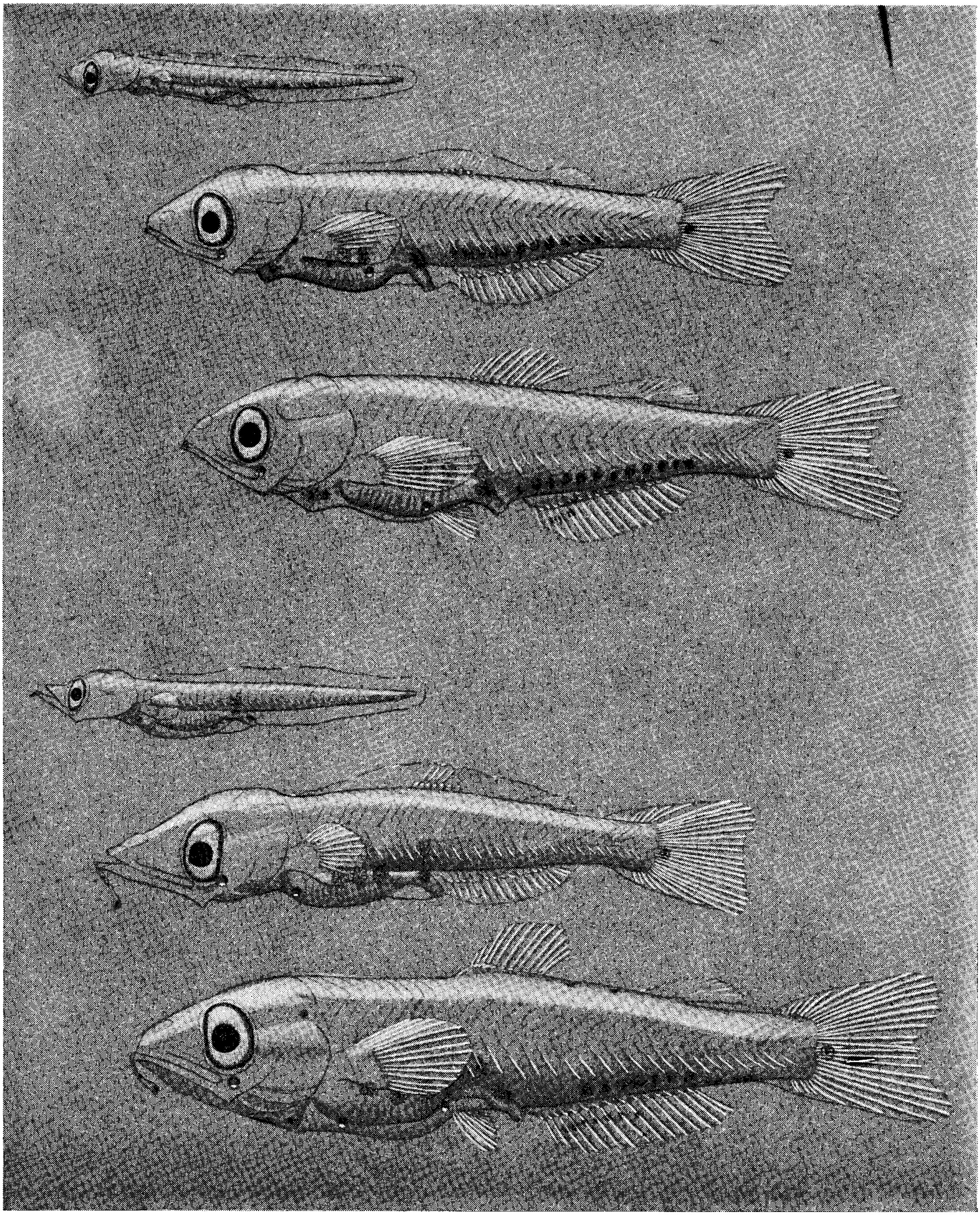

FIGURE 7. From top to bottom—*Diogenichthys laternatus* 3.7mm–7.0mm–9.75mm and *Diogenichthys atlanticus* 4.0mm–6.0mm–11.25mm.

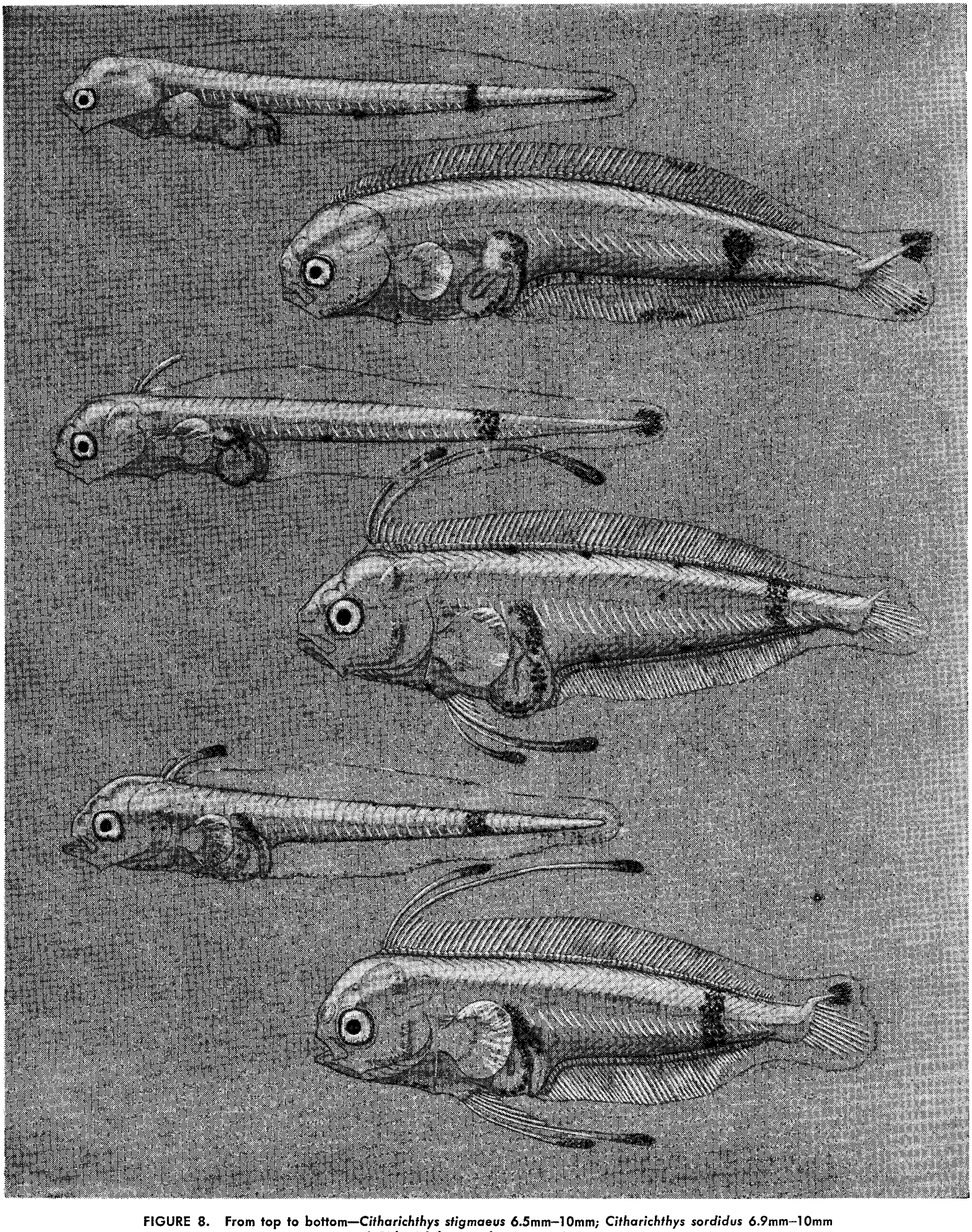

FIGURE 8. From top to bottom—*Citharichthys stigmaeus* 6.5mm–10mm; *Citharichthys sordidus* 6.9mm–10mm and *Citharichthys xanthostigma* 6.2mm–9mm.

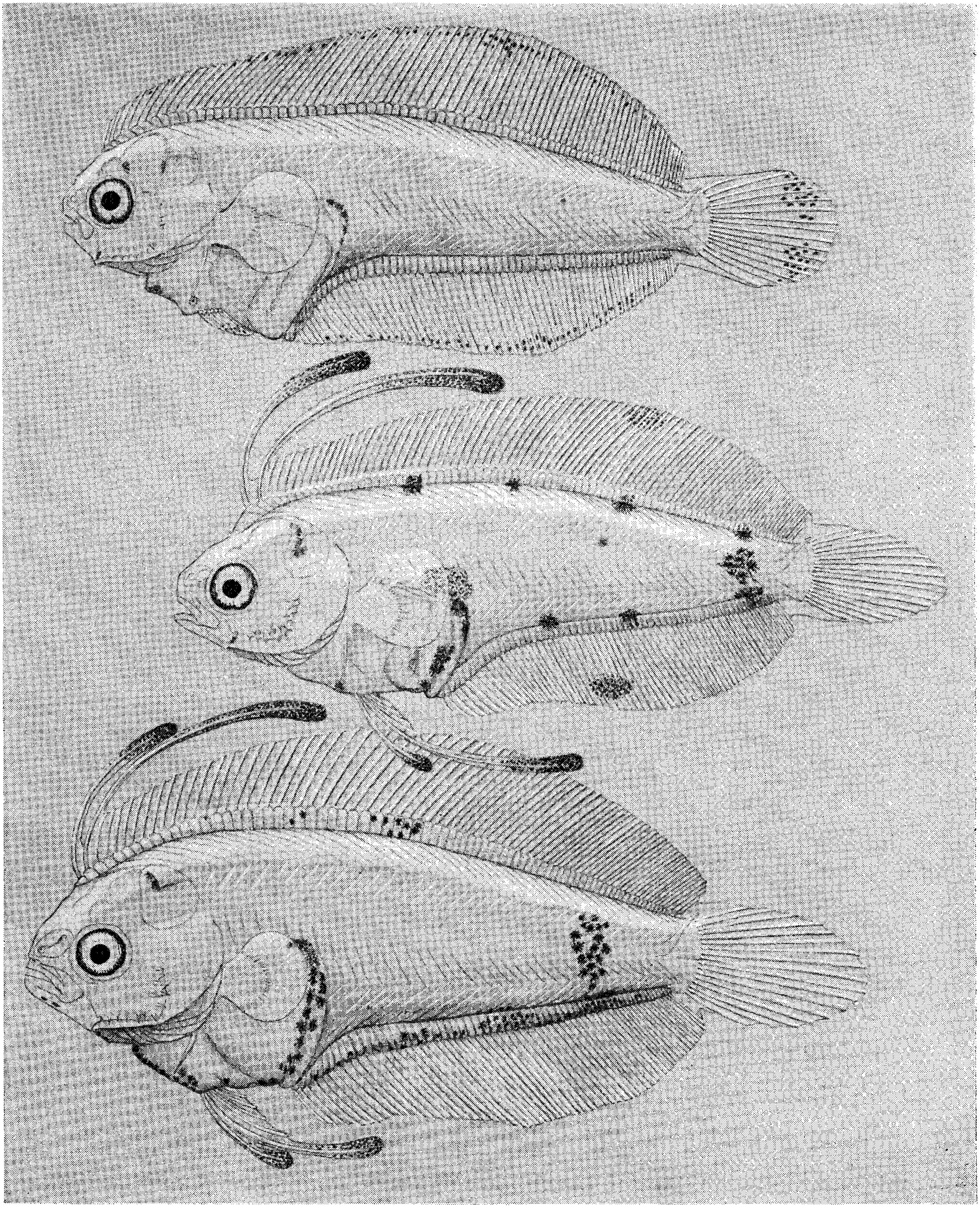

FIGURE 9. From top to bottom—*Citharichthys stigmaeus* 14.75mm; *Citharichthys sordidus* 14.5mm; and *Citharichthys xanthostigma* 15.3mm.

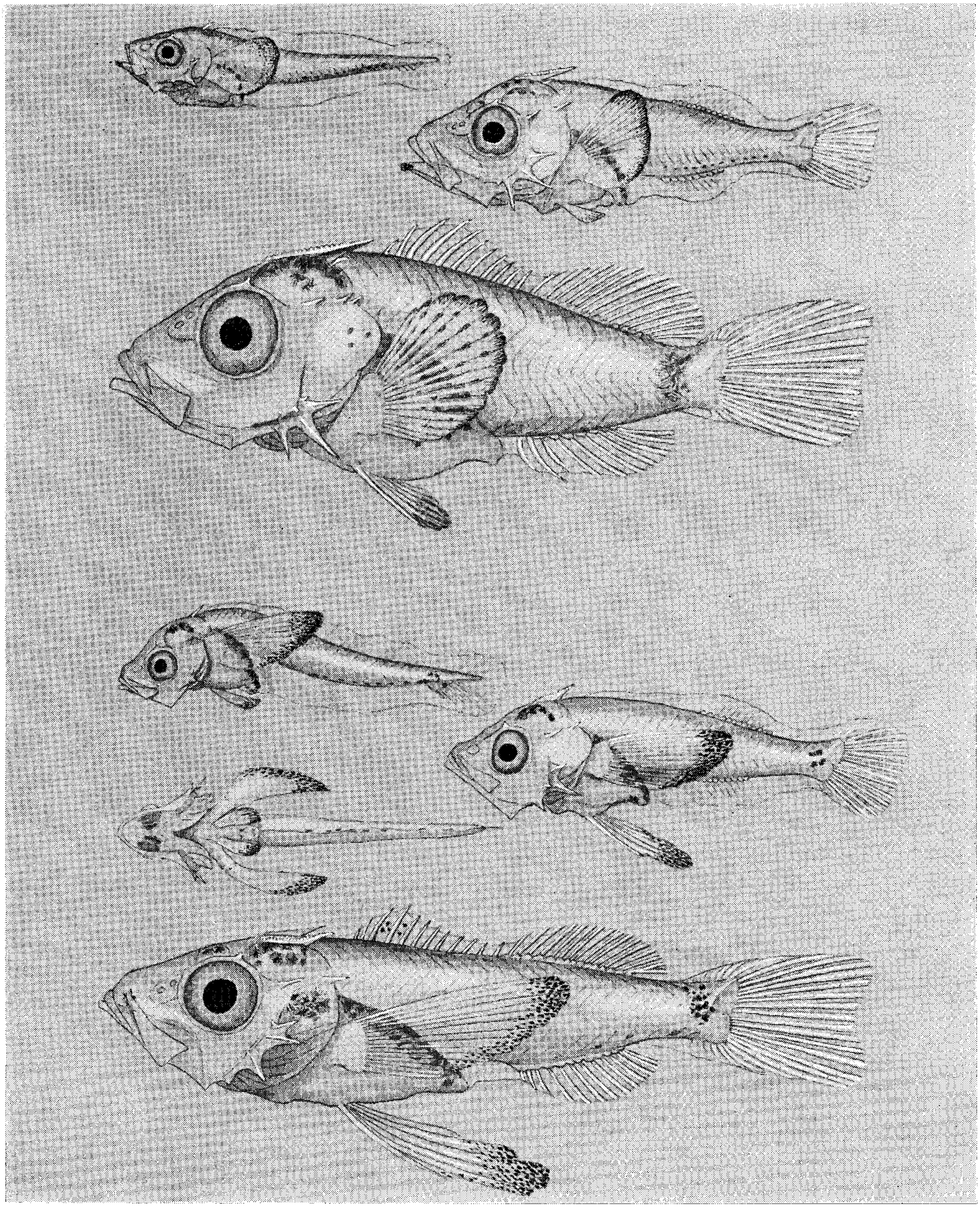

FIGURE 10. From top to bottom—Sebastodes species 6.0mm, 7.8mm, 12.7mm, 6.8, 8.0mm , 6.8mm, and 11.9mm.

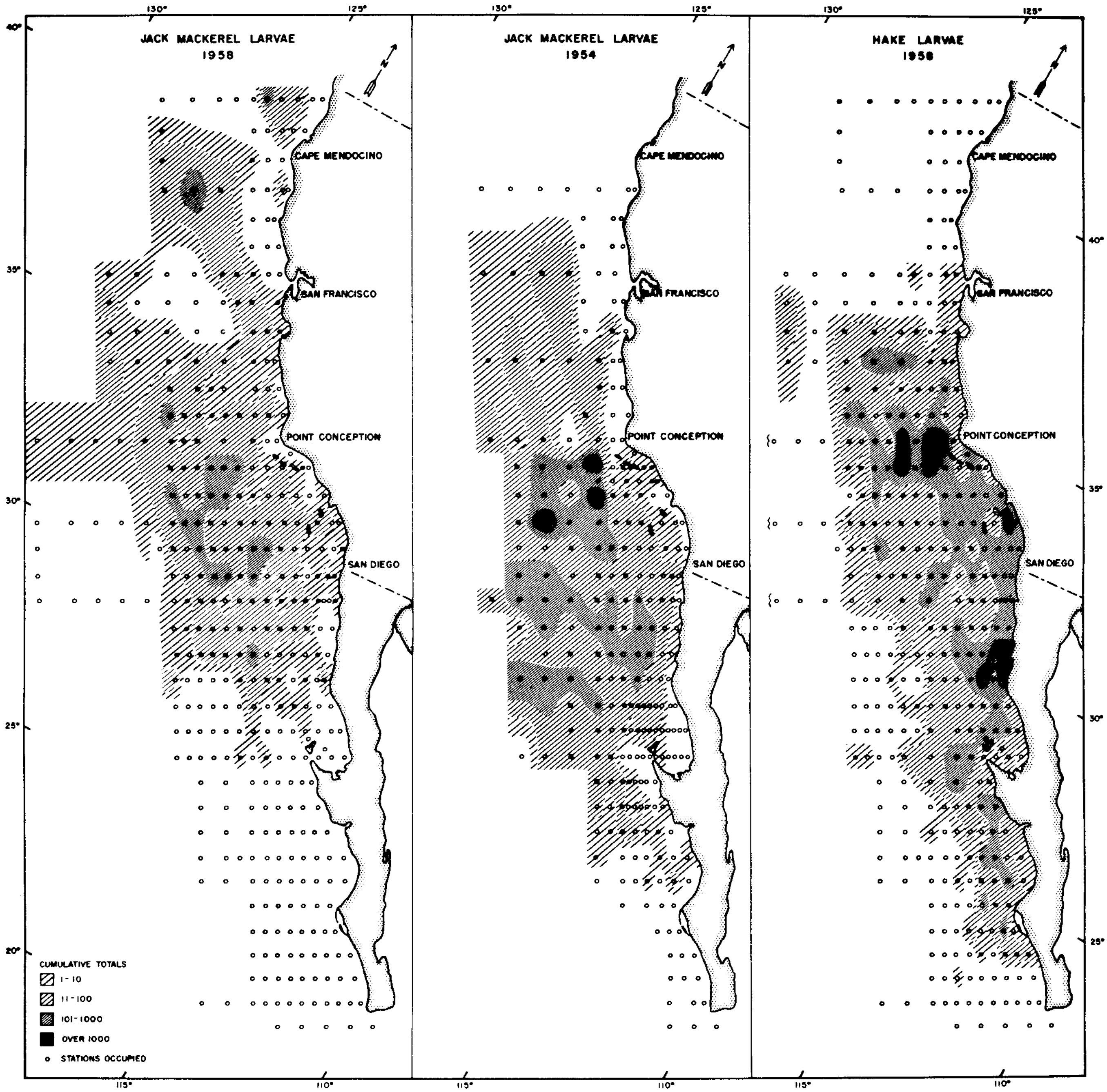

FIGURE 11. Distribution and relative abundance of Jack mackerel larvae, A: 1958; B: 1954; C: Hake larvae, 1958.

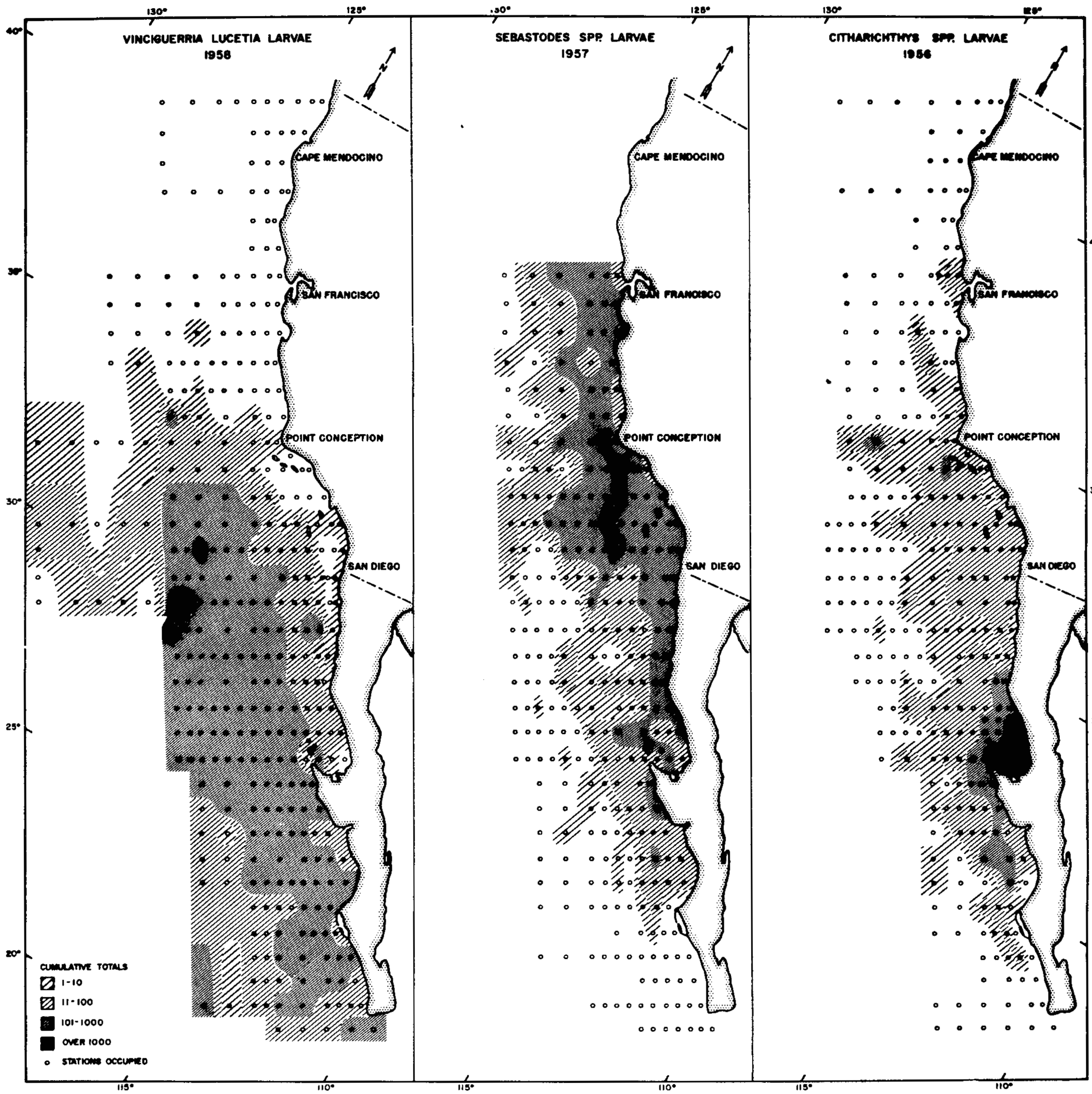

FIGURE 12. Distribution and relative abundance of *Vinciguerria lucetia* larvae, A: 1958; B: *Sebastodes* spp. larvae, 1957; C: *Citharichthys* spp. larvae, 1956.

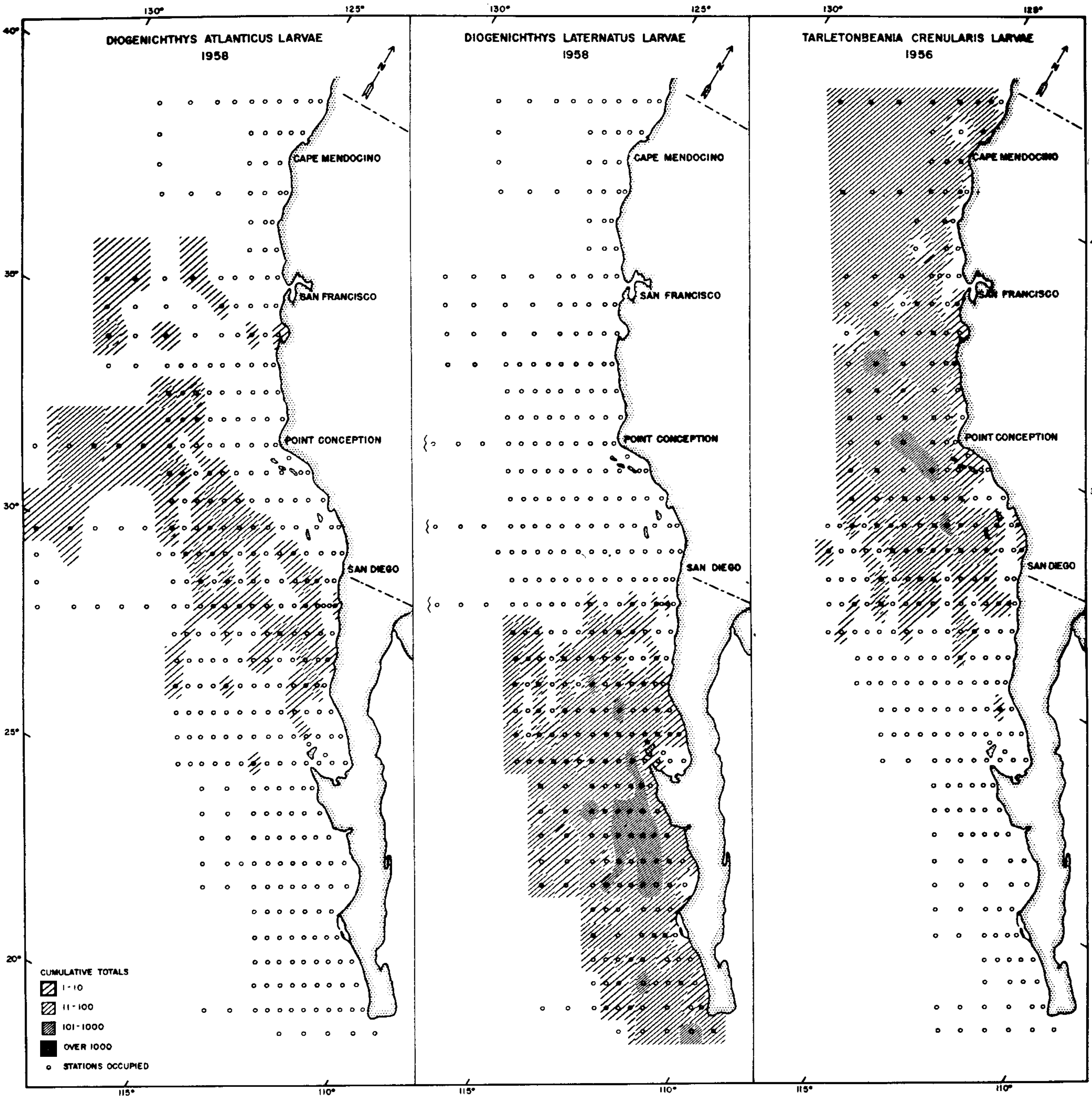

FIGURE 13. Distribution and relative abundance of *Diogenichthys atlanticus* larvae, A: 1958; *Diogenichthys laternatus larvae*, 1958; C: *Tarletonbeania crenularis* larvae, 1956.

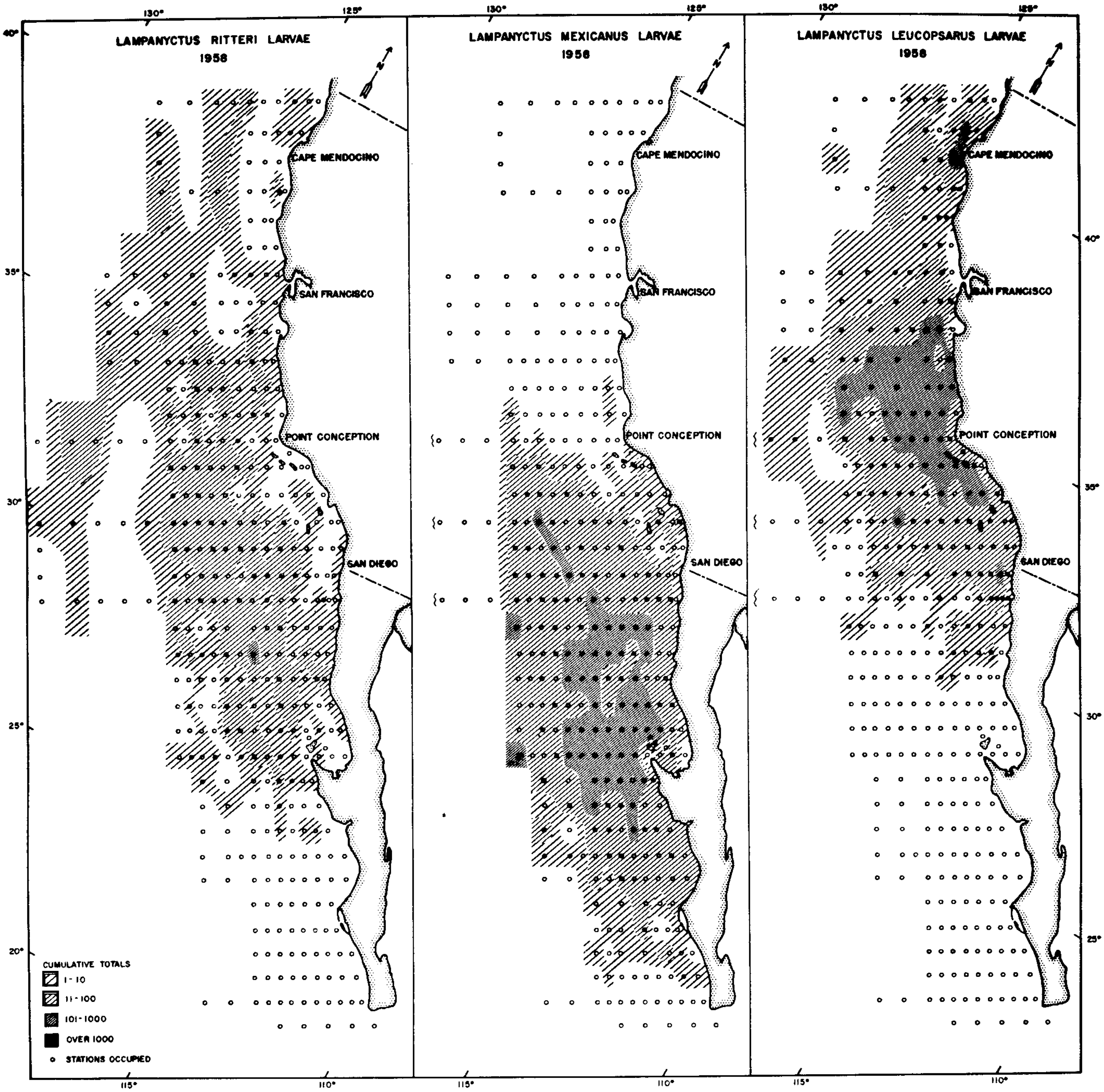

FIGURE 14. Distribution and relative abundance of *Lampanyctus ritteri* larvae, A: 1958; B: *Lampanyctus mexicanus* larvae, 1958; C: *Lampanyctus leucopsarus* larvae, 1958.

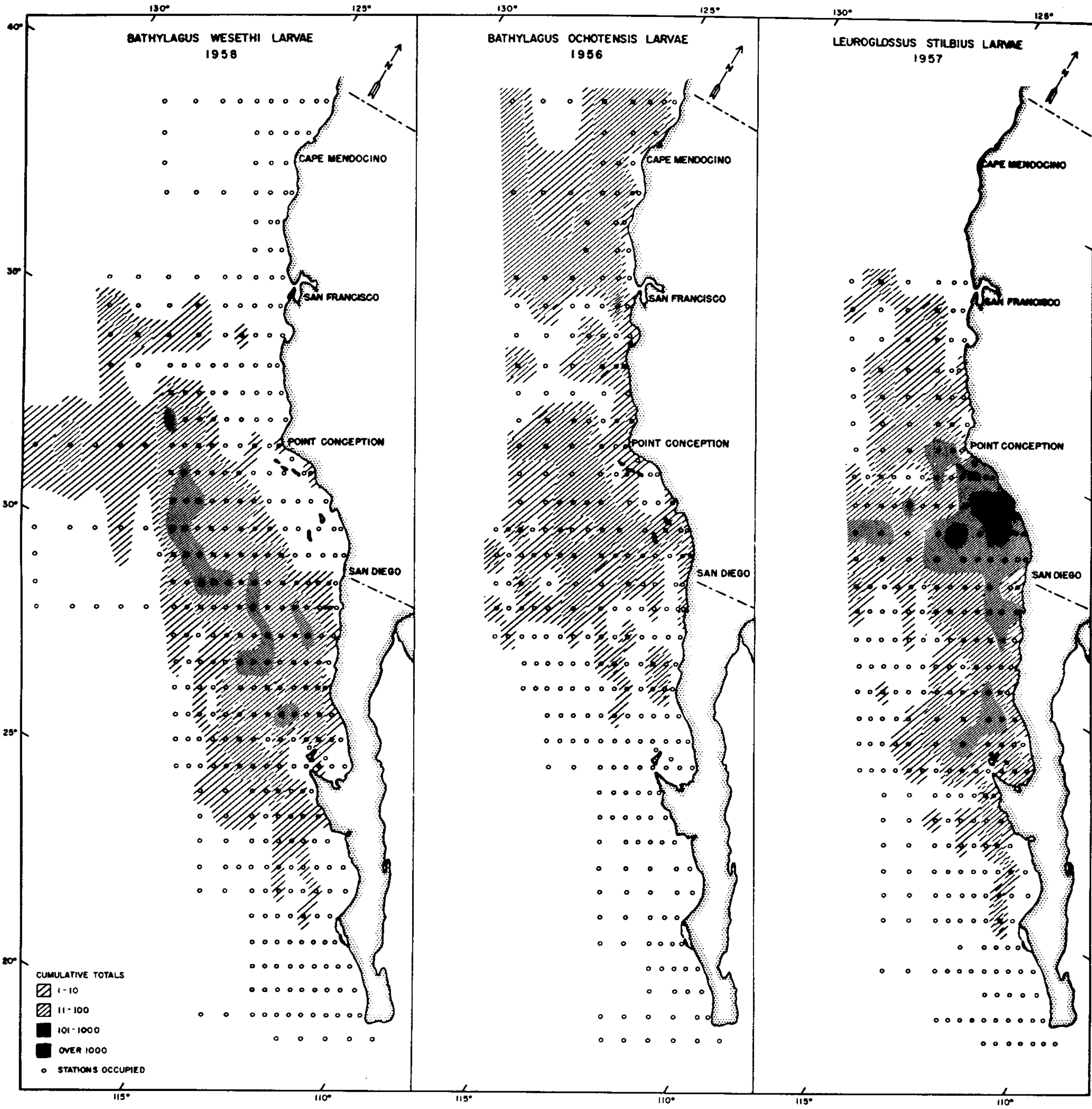

FIGURE 15. Distribution and relative abundance of *Bathylagus wesethi* larvae, A: 1958; B: *Bathylagus ochotensis* larvae, 1956; C: *Leuroglossus stilbius* larvae, 1957.