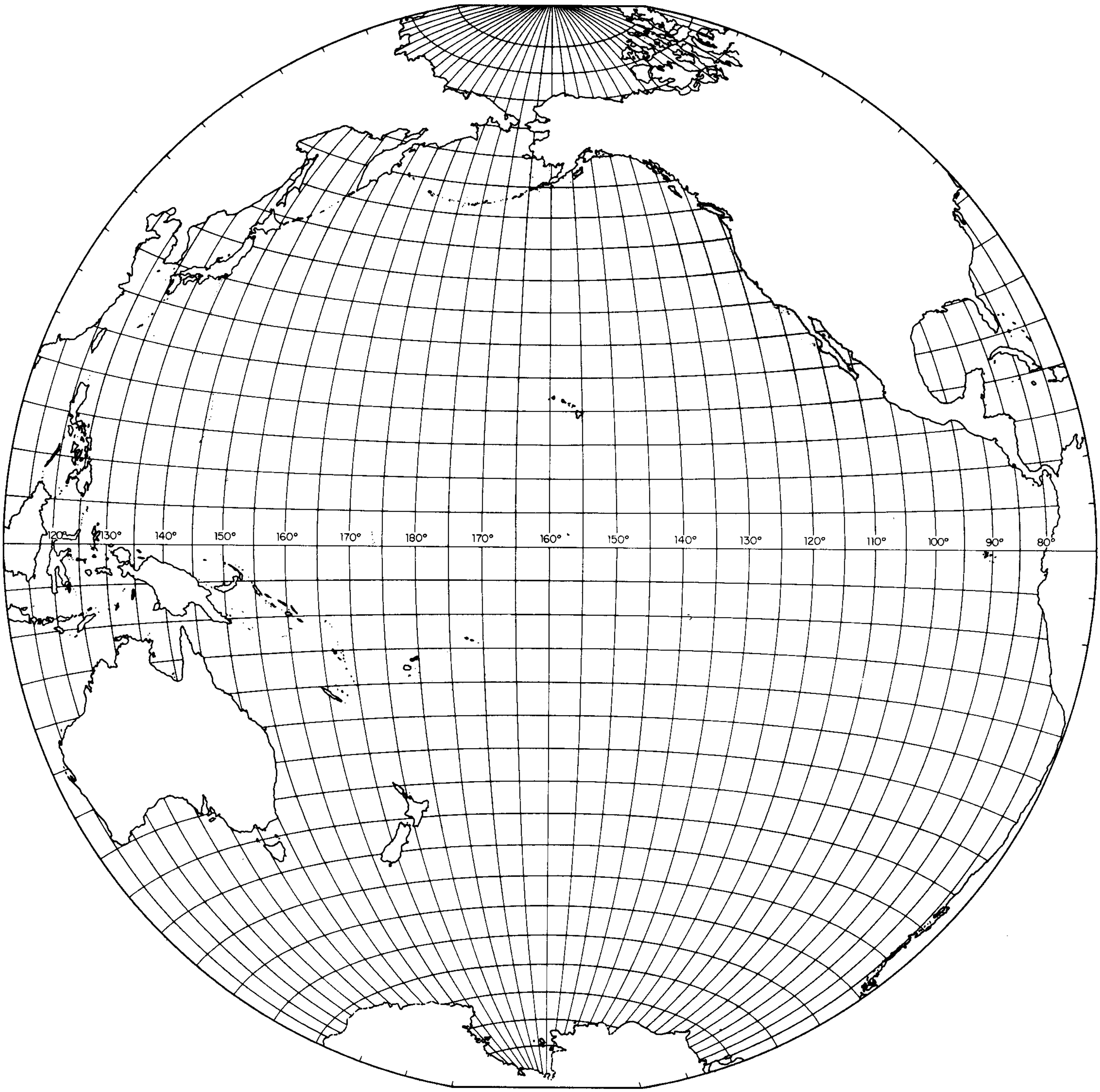
STATE OF CALIFORNIA
MARINE RESEARCH COMMITTEE



CALIFORNIA COOPERATIVE OCEANIC FISHERIES INVESTIGATIONS

REPORTS

VOLUME XIV
SEPTEMBER 1970

CODEN COFR-A

STATE OF CALIFORNIA
DEPARTMENT OF FISH AND GAME
MARINE RESEARCH COMMITTEE

CALIFORNIA COOPERATIVE OCEANIC FISHERIES INVESTIGATIONS

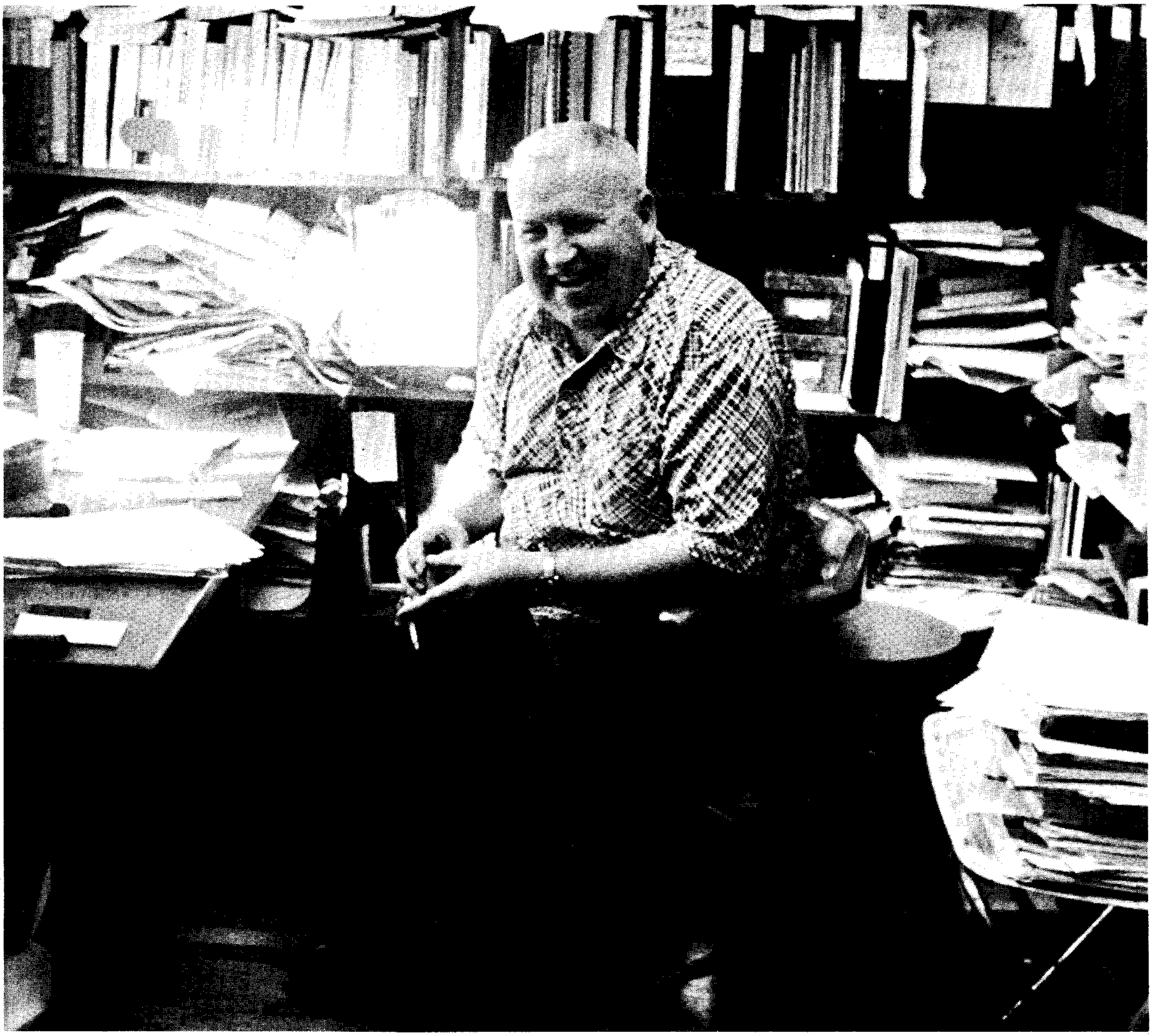
Reports

VOLUME XIV
1 July 1968 to 30 June 1969

Cooperating Agencies:

CALIFORNIA ACADEMY OF SCIENCES
CALIFORNIA DEPARTMENT OF FISH AND GAME
STANFORD UNIVERSITY, HOPKINS MARINE STATION
UNIVERSITY OF CALIFORNIA, SCRIPPS INSTITUTION OF OCEANOGRAPHY
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, NATIONAL MARINE FISHERIES SERVICE

1 September 1970



STATE OF CALIFORNIA
MARINE RESEARCH COMMITTEE

RESOLUTION

WHEREAS Dr. Wilbert McLeod Chapman died on 25 June 1970 after a lifetime of service to the fishing industry; and

WHEREAS he materially assisted in the establishment of the Marine Research Committee and served as a member from 1963 to 1970; and

WHEREAS he gave unselfishly of his time as a student, teacher, scientist, critic and friend to the work of the Committee; and

WHEREAS the Committee will never again be blessed with his wit, intelligence, zest, and expertise, the Committee does recognize that his contributions will strongly influence the world of fisheries for decades to come:

NOW THEREFORE BE IT RESOLVED, That the Marine Research Committee expresses its profound sympathy to Mrs. Chapman and her family for their great loss; and

BE IT FURTHER RESOLVED, That the Committee dedicate Progress Report, Volume XIV in memory of our great friend, Wib Chapman.

STATE OF CALIFORNIA—RESOURCES AGENCY

RONALD REAGAN, *Governor*

DEPARTMENT OF FISH AND GAME

MARINE RESEARCH COMMITTEE

1 September 1970

The Honorable Ronald Reagan
Governor of the State of California
Sacramento, California

Dear Governor Reagan:

We have the honor to submit the fourteenth report on the work of the California Cooperative Oceanic Fisheries Investigations.

The report consists of three sections. The first contains a review of the administrative and research activities during the period 1 July 1968 to 30 June 1969, a description of the fisheries, and a list of publications arising from the programs.

The second section consists of papers prepared for a most interesting and fruitful symposium, "World population and fisheries," held in December 1968. Participants in the symposium included key figures from industry and government as well as members of the scientific community.

The third is compiled of original scientific contributions which are either a direct result of CalCOFI research programs or represent research directly pertinent in research development of the pelagic realm of California.

Respectfully submitted,

Charles R. Carry

THE MARINE RESEARCH COMMITTEE
Charles R. Carry, *Chairman*

CONTENTS

Calif. Mar. Res. Comm., CalCOFI Rept., 14:5–15, 1970.

PART I

REVIEW OF ACTIVITIES

1 July 1968–30 June 1969

REPORT OF THE CALCOFI COMMITTEE

This report of the CalCOFI Committee consists of the individual reports of the several contributing agencies, the contributed papers and the proceedings of the Symposium on Population and Fisheries.

In introducing this report, it is not inappropriate for the Committee again briefly to reiterate the status of the principal pelagic marine resources of the California Current System. These resources have been the object of study of the CalCOFI program over two decades.

With the exception of the type of information derivable only through active fisheries, the scientific understanding of these pelagic resources, of their magnitude, their biology and their ecological and environmental relationships, is now the most thorough for any similar region in the world.

The understanding is certainly most adequate for the scientific management of appropriate multi-use domestic fisheries. Indeed, the research has generated many new approaches of worldwide applicability and importance. Yet California's resources are very little utilized.

The constraints on California's utilization of the living resources in her waters now are not scientific but, rather, they are institutional, involving misunderstanding and mistrust between mutual users of the resources, simplistic and anachronistic economic evaluation and a number of other factors.

These nonscientific and ofttimes irrational trammels to California's meaningful utilization of her resources are now the vital issues. The symposium reported in this volume attempts to develop the context and perspective in which the resolution of these issues must be discerned and developed. *John L. Baxter, John D. Isaacs, Alan R. Longhurst, and Charles H. Turner, July 1970.*

AGENCY REPORTS

CALIFORNIA ACADEMY OF SCIENCES

Collections made by Eric Knaggs of the California State Fisheries Laboratory, Terminal Island, from commercial catches in southern California during the period January–July, 1969, and collections made from the commercial catch in Monterey Bay on June 3 and July 15, through the courtesy of Joseph L. Olivieri, President of the Santa Cruz Canning Company, Moss Landing, California, supplemented by a few specimens taken incidentally during the study of food habits of the northern anchovy in 1965–66, provided a total of 516 stomachs of jack mackerel and 166 stomachs of Pacific mackerel. These have all been examined by Anatole S. Loukashkin, who noted the general character of the stomach contents and sorted them out for more detailed identification.

Most of the stomachs were found partially filled with food. Empty stomachs occurred infrequently. Some of the stomachs were filled to capacity with mackerel scales, presumably ingested after the fish were netted. This was true of both species.

Both species, as far as the material at hand indicates, are primarily carnivorous, feeding on animal plankton, smaller fishes, etc. They are both filter feeders and particulate feeders, depending on the size of the food in their immediate environment.

Among planktonic elements in the stomach contents examined, crustaceans in larval and adult stages occupy a dominant position. This category includes euphausiids, some other shrimp-like crustaceans, larger copepods, and larval crabs. Fish larvae and young fish of several different kinds were found, including juvenile flatfish and rockfish. Among other animals found in the stomachs of both species were small squids, small octopi, salps, and polychaetes. Thus far no phytoplanktonic organisms have been found.

The food of jack mackerel and Pacific mackerel appears to be closely similar, except in the size of the organisms ingested.—*R. C. Miller*

CALIFORNIA DEPARTMENT OF FISH AND GAME PELAGIC FISH INVESTIGATIONS

Sea Survey

Nine cruises, totaling 177 days at sea, were conducted during the year. Northern and central California waters were surveyed in August 1968. Southern California was covered by 7 cruises, 2 of which were of short duration, and Baja California was surveyed in January 1969. All areas except Baja California have now been adequately surveyed on a seasonal basis. Spring and summer surveys have yet to be accomplished in this region.

The cruises' objectives were modified from the broad general surveys of previous years and more emphasis was placed on locating commercial concentrations of fish and discovering areas of prime habitat. Schooling habits and behavior also were more intensively studied.

An intensive survey for commercial quantities of Pacific hake was made in northern California. Extensive echo sounding in areas considered prime hake habitat failed to locate concentrations such as occur off Oregon and Washington. Although surveys to date indicate this region contains the lowest pelagic fish populations, adequate seasonal coverage has not been achieved due to the extreme weather conditions which prevail during most of each year.

The results of the central California cruise (August 1968) corresponded with those of previous surveys which found a relatively small anchovy population consisting of large adult fish. This population was distributed close to shore and was usually confined to rather localized areas. Rockfishes were the second most abundant species. This central California region now has been broadly surveyed during nearly every month of the year. A change from broad general surveys to an intense detailed search for commercial concentrations of anchovies and rockfishes will commence through a series of cruises in the fall of 1969.

A broad anchovy survey of southern California, made during the spawning season in May and June of 1969, found the anchovy population widely distributed in various sized surface schools. School estimates, from echo sounding transects, totaled 543,121. This is 21 percent less than estimated from a similar survey the previous year. School sizes were highly variable, ranging from several hundred pounds to over 100 tons; the majority being small and located well offshore. All commercial size schools were found within 20 miles of shore. Purse seiners fishing on these concentrations during daylight hours made excellent catches.

A series of cruises in the fall of 1968 were designed to locate anchovy concentrations and make studies of schooling behavior and habitat preference. During these surveys we observed anchovies densely schooled in relatively small localized areas characterized by near-shore steep bottom gradients (drop-offs) and submarine canyons. During the day dense schools were located 60 to 120 fathoms below the surface over bottom depths of 70 to 175 fathoms. At night these fish came to the surface and dispersed until shortly before dawn when they re-schooled at the surface. These schools then descended to the daytime depth with the first light of dawn. This behavior limits commercial fishing to the short period of time just before dawn when the fish are schooled near the surface. We located a sizeable proportion of these fall concentrations within three miles of the coast, an area closed to commercial fishing of anchovies for reduction.

During our fall cruises we expended some effort on jack mackerel scouting. Some of the unfished offshore banks were searched by echo sounder and sonar but with negative results. However, additional experience was gained in visual observation and acoustic detection of known jack mackerel concentrations. Our results indicate that this species concentrates in a rather restricted habitat and is difficult to detect both visually and acoustically. For example, jack mackerel are much more difficult to survey than anchovies.

A one day cruise was conducted to assess the effect of an oil well leak on the pelagic species of Santa Barbara Channel. No ill effects could be determined. A second short cruise was conducted to study methods of assessing anchovy school sizes from echo sounder and sonar records. A commercial purse seiner was chartered to catch schools monitored and recorded by our acoustic equipment; the catches and corresponding echograms were then compared. This work substantiated the difficulty of determining school sizes solely from acoustic records, except on a gross relative scale. School density and compaction largely determine the amount of fish and the existing electronic equipment cannot accurately measure these factors.

Central and southern Baja California were surveyed by a cruise in January 1969. A most significant finding was our discovery of a large concentration of Panama lightfish (*Vinciguerria lucetia*). These fishes were in loose discontinuous midwater schools covering an estimated area of 32 square miles. They were found where bottom depths varied from 100 to 300 fathoms.

The anchovy population of this Baja region was highly dispersed with virtually no surface schools observed. During the day, loose, layer-type schools were found near the bottom at depths of 40 to 80 fathoms. At night these fish rose to the surface and dispersed. Midwater trawling on the surface produced good catches; however, not one school suitable for purse seining was observed or detected.

Further evidence that a subpopulation of anchovies exists in this region was collected. Nearly all fish were in a spawning condition, yet none exceeded 110 mm SL which is the minimum size of sexual maturity for California anchovies.

This region has been surveyed in all but the spring and summer months. We propose to expand more effort in these seasons to assess adequately this area's pelagic fish populations.

Our evaluation of sonar indicates it is extremely effective for detecting fishes schooled near the surface over deep water. Those fishes schooled close to the bottom or over rocky areas are detected much less effectively. Another factor limiting this gear's effectiveness is the variability of the thermal structure in the water column. This refracts the sound beam, resulting in reduced range and the confusion of boat wakes with fish schools. School sizes can be more accurately assessed; however, and the effect of fish flaring away from the vessel's path is eliminated. Further, the large horizontal range greatly increases our search area, producing more comprehensive transect surveys. This gear permits us to maintain contact with a given target for long periods of time, providing an excellent means of studying school behavior and movement.

The prospect of using sonar in purse seining operations appears fair, particularly under certain conditions. Our experience to date indicates this equipment would be most effective for anchovy fishing.

Sea Survey Data Analysis

During this report period (July 1, 1968–June 30, 1969) the first computer program using our newly instituted magnetic tape storage system was completed. The program output gives a summary of 16 years of sea surface temperature readings and the occurrence of seven species of fish and two invertebrates.

The data are summarized by year, in each of six geographical areas, and show the general distribution and occurrence in relation to surface temperature, of all Pacific sardine, northern anchovy, Pacific mackerel, jack mackerel, Pacific saury, round herring, thread herring, squid, and red crab taken by dynamite or blanket net from 1950 through 1965.

Preliminary examination of the summaries has shown some interesting north-south distributional patterns, but the raw output of temperature vs. species occurrence needs further analysis.—*Charles H. Turner.*

HOPKINS MARINE STATION

DDT residues have entered all compartments of the world ecosystem due to their mobility, environmental stability, and affinity for biological materials (Risebrough *et al.*, 1968; Risebrough, 1969). Due to estuarine and airborne transport of DDT residues into the ocean and their relatively irreversible fixation in marine organisms, one would expect an eventual net transport of these materials to the ocean and their accumulation in oceanic food chains (Wurster, 1969). Under certain conditions, organochlorine compounds such as the DDT type compounds tend to become increasingly concentrated in successive tropic levels in aquatic food chains (*e.g.*, Langford, 1949; Hoffman and Surber, 1949; Rudd, 1966; Hickey *et al.*, 1966; Woodwell *et al.*, 1967). If this "tropic magnification" effect quantitatively reflects tropic relationships, it has potential usefulness for the study of the energetic requirements of pelagic organisms. The approach is based on the following assumptions:

(1) DDT residues accumulate in phytoplankton and detritus in proportion to their energy content as food.

(2) Zooplankton which graze on this material retain the associated DDT residues.

(3) Plankton-feeding fish (or other pelagic animals) retain the DDT residues from assimilated food (or they retain a constant, measurable proportion of the residues in the food).

The amount of DDT residues in an anchovy therefore may be directly related to its cumulative caloric assimilation during the period of the year that it feeds on phytoplankton, and indirectly during the balance of the year. Two initial conditions must be

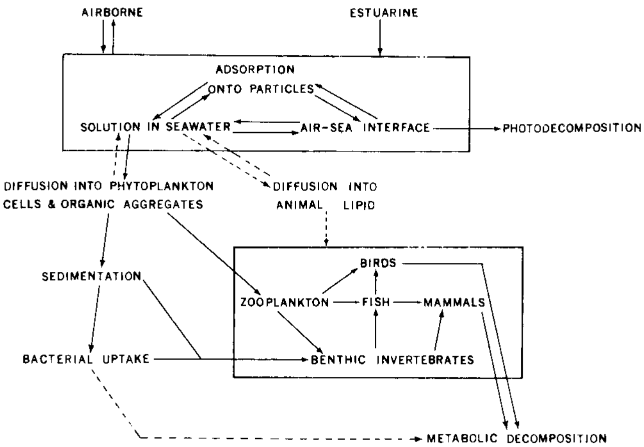


FIGURE 1. A schematic depiction of the various processes likely to control the fate and distribution of DDT residues entering the ocean. Residence time of the compounds in the upper box, the physical equilibrium system, is probably very short; eventually residues are taken up into organisms and cycle in the food chain, indicated by the lower box. See text for details.

met. First, DDT residues in the phytoplankton and other finely divided organic material must be quantified in order to interpret residue concentration data from the consumer organism. Second, it must be determined if the residue levels are constant enough to produce coherent increments of residues found in the consumer, such that they would be interpretable in terms of cumulative food assimilation. This report summarizes studies dealing with these two conditions.

Uptake of ^{14}C-DDT by Phytoplankton

The numerous processes involved in the transfer of DDT residues into the marine environment will affect the temporal and spatial distribution of DDT residues found in the phytoplankton and detritus which forms the food base for pelagic animals. Figure 1 shows some of these processes and the potential routes of residues once they reach the ocean. While environmental input of DDT residues into air and fluvial currents is probably seasonal and erratic, some damping of the pulses must occur. Once in surface waters, DDT will tend to accumulate at the air-sea interface, adsorb to particles, or be taken up by the particulate organic material—principally the phytoplankton, detritus, and microzooplankton. Direct uptake by larger organisms is relatively unimportant compared to assimilation via food (Macek and Korn, 1970). Phytoplankton accumulate residues by rapid absorption from the surrounding medium (Sodergren, 1967) but it is not clear what physical state the DDT is in when it is taken up. Some of it is probably in solution, but the term "solution" may be misleading. The study of aqueous mixtures of DDT suggests that it exists as a collection of aggregations of molecules in suspension; the maximum solubility of DDT in water is in fact operationally defined as that concentration in a supernatant after an arbitrary amount of ultracentrifugation (Biggar *et al.*, 1967). Concepts which assume normal solubility properties cannot be applied without modification to DDT in aqueous systems. Thus the idea of a partition coefficient, which has been suggested as a means for consideration of the biological concentration of DDT residues (Freed, 1970), cannot be used without qualification. Other conditions, such as the area of adsorptive interface in the system and the physical state of the DDT when it enters the system will affect the uptake of DDT by phytoplankton as well as the "dissolved" concentration in the water. However, it is difficult to account for such effects in experimental situations. Our experiments with ^{14}C-DDT uptake were designed to either minimize them or keep them constant. These experiments are described in detail elsewhere (Cox, 1970), but the results are presented here in Table I.

The concentration factors for the species of phytoplankton tested exceeds the estimate of Keil and Priester (1969) for *Cylindrotheca closterium* when correction is made to make our figures comparable to theirs. This discrepancy probably reflects the fact that they used high concentrations. Actual partition coefficients (ratios using the same concentration base) were calculated using known carbon to volume percentages for the algal clones used in these experiments; they are 3×10^4 for *S. carterae* and *T. fluviatilus*, and 8×10^4 for *A. carterae*. These values are equivalent to wet weight concentration factors.

Using a mean value of 2×10^5 for a carbon-based partition coefficient, and a local estimate of the

TABLE 1

^{14}C-DDT Uptake by Three Species of Marine Phytoplankton

Species	Total* pg^{14}C-DDT	Uptake* pg^{14}C-DDT	Cell C g	Equil. ppt	ppb/C in algae	Relative Part. Coefficient
Syracosphaera carterae	274 34(2)	143 31(2)	301	2.0	475	2.3×10^5
Syracosphaera carterae	274 34(2)	112 16(2)	151	2.6	741	2.9×10^5
Thalassiosira fluv.	362 20(2)	238 32(2)	730	2.4	326	1.4×10^5
Thalassiosira fluv.	362 20(2)	194 15(2)	365	3.3	532	1.6×10^5
Amphidinium carteri	323 22(2)	273 6(2)	1226	1.0	223	2.2×10^5
Amphidinium carteri	128(1)	68(1)	961	0.5	70	1.4×10^5
Amphidinium carteri	192(1)	92(1)	961	0.8	96	1.2×10^5

* Mean followed with standard deviation of the estimate; number of values shown in parentheses. The symbol pg denotes picograms, or 10^{-12} grams.
Column 1 shows the estimate of total activity in terms of ^{14}C-DDT added to the system. Column 2 shows the amount recovered from the cells after equilibration with the medium. The equilibrium concentration in parts per trillion is calculated from the difference between columns 1 and 2. Algal concentrations are expressed in terms of weight of ^{14}C-DDT per unit weight of wet combustion carbon in the algal cells. The relative partition coefficient is a ratio of columns 4 and 5.

concentration of DDT residues in whole seawater of 15 ppt (Odemar *et al*, 1967), we obtain an expected value of 30 ppm (concentration based on carbon content) of DDT residues in the phytoplankton. This value is encompassed by the confidence interval (95%) of values obtained by gas chromatographic analyses of phytoplankton samples from the same approximate time and location as the water concentration sample.

Analyses of Phytoplankton Samples

Samples for DDT analysis consisted of current net haul samples from CalCOFI station 3 in Monterey Bay (samples kept frozen until use) and formalin preserved samples taken at the same station from 1955 until the present. The samples were passed through fine mesh zooplankton netting (0.33 mm) to exclude the larger zooplankters prior to the analyses for carbon content and DDT residue content. Carbon was determined on replicates of each sample by the wet combustion method of Strickland and Parsons (1968). Some error is to be expected when carbon determinations are done on formalinized material, but the error involved is negligible in these studies when the range of variation of the DDT estimates is considered. Preliminary studies have indicated that there is no interference of formalin with the DDT determinations, but these results await further study and confirmation.

Two methods were used for the DDT determinations on the frozen and preserved samples. Originally, samples were filtered onto combusted GFC filter pads, ground in a glass and teflon homogenizer with successive rinses of high purity n-hexane, and passed through an acid-Celite column (Stanley and Le Favoure, 1965). The column eluate was collected in a Kuderna-Danish concentrator and concentrated for gas chromatographic injection. Subsequent experiments showed that the percent extraction efficiency of this method was poor (50%). Later analyses used different cleanup and concentration procedures resulting in better than 95% extraction and recovery efficiency. Hexane extracts in this procedure were chromatographed on silica gel microcolumns (Kadoum, 1968) and the eluates were concentrated at 37°C under a stream of nitrogen. All glassware for both procedures was combusted at 350°C overnight or run through an exhaustive rinsing procedure with redistilled and high purity solvents. Glassware was used when the cleaning procedures provided essentially a zero background of interfering peaks on the gas chromatograph.

The extracts, after cleanup and concentration were injected into a Beckman GC-4 gas chromatograph equipped with two columns and two electron capture detectors. Each sample was chromatographed on two columns of different composition; we used 5% DC-200, 5% QF-1, 5% mixed bed QF-1 and DC-200; and 6% SE-30 with 3% QF-1, all on DCMS Chromsorb W. Operating parameters were those suggested by the U.S. Food and Drug Administration.

Results of the determinations of DDT residues per unit of carbon are shown in Figure 2. Figure 2 shows

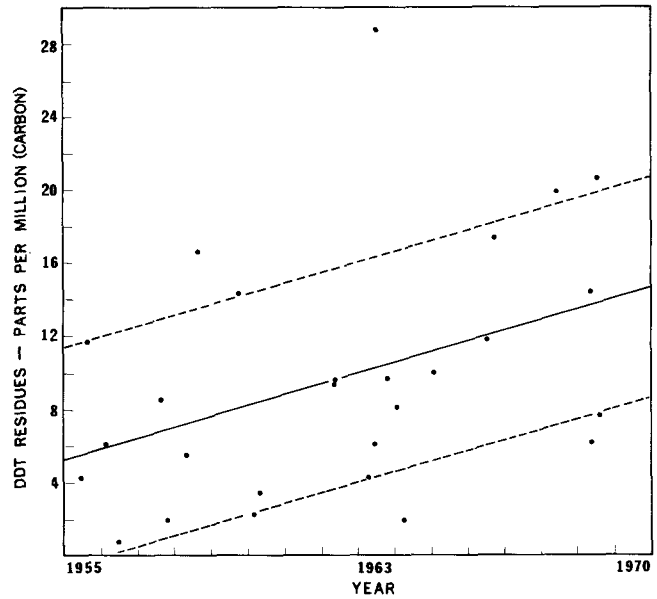


FIGURE 2. DDT residues (sum of p, p′-DDT, p, p′-DDE, and p, p′-DDD) concentrations in marine phytoplankton samples from CalCOFI station 3 in Monterey Bay. The solid line shows the least squares regression line; the dashed lines are a standard error of the estimate away from the regression line.

the results obtained by the original method. Results produced by the improved procedure show the same trend. This data will be reported in detail elsewhere when more analyses are completed. The trend toward higher residues in later samples could be produced either by loss of analyzable residues due to sample storage or by an actual increase in the residues to be found in phytoplankton from later years. Two lines of evidence indicate that the trend seen in Figure 2 is caused principally by the actual increase in environmental levels of DDT residues: first, the relative proportion of the three principal constituents of DDT found in all samples (p,p′-DDT, p,p′-DDD, p,p′-DDE) is quite constant and second, when ^{14}C-DDT is heated in sealed ampoules with the sample material, these compounds are produced as the principal breakdown components and their proportion changes with the degree of decomposition of the parent compound. The evidence is not conclusive on this basis, however, and the matter merits further study.

Sources of Variability

The variability of points in Figure 2, if they reflect actual levels of DDT residue concentrations in the phytoplankton, could have various sources. Short term variation in the amount of DDT entering the study area is undoubtedly a source. Another source is the change in size of the phytoplankton standing crop. Since our carbon measurments are based on a standard aliquot from a standard vertical net tow sample, they are an index of the standing crop size. When these carbon values are plotted against the DDT residue concentrations there appears to be an inverse relationship. This might be expected on the basis of a concentration-dependent or partition mechanism for uptake of residues. This was previously observed by Wurster (1968) who noted that the phtosynthetic depression he observed for phytoplankton (which is presumably dependent upon internal concentrations of DDT) diminished when larger amounts of cells were present in the test cultures, independently of the nominal concentration of DDT in the medium.

Conclusion

DDT residues found in marine phytoplankton samples from Monterey Bay vary considerably relative to the carbon content of the analyzed samples. Residue concentrations increase significantly in samples taken over the last 15 years. Two important sources of variation in the estimates of the DDT residue concentrations are standing crop size at the time of sample collection and short term variations in environmental levels of DDT residues in the collection area.

The prospects for using DDT as an energy tracer depend upon how the variability of phytoplankton DDT concentrations affects the DDT-based estimate of how much phytoplankton carbon has contributed to the growth of the consumer. If certain assumptions can be made concerning the relative contribution of grazing upon standing crops of phytoplantkon of diferent size, perhaps the study could be continued to analyses of consumer organisms. Preliminary estimates of carbon assimilation of anchovies based on available analyses of their DDT residue concentration cannot be made since age data are not available for the fish used in those analyses.

LITERATURE CITED

Biggar, J. W., G. R. Dutt, and R. L. Riggs. 1967. Predicting and measuring the solubility of p,p′-DDT in water. *Bull. Environ. Cont. Toxicol.* 2:90–100.

Cox, J. L. 1970. Low ambient level uptake of ^{14}C-DDT by three species of marine phytoplankton. *Bull. Environ. Cont. Toxicol.* 5 (3): 218–221.

Freed, V. H. 1970. Global distribution of pesticides. *In: Symposium on the Biological Impact of Pesticides in the Environment.* Oregon State University Press, Corvallis. P. 1–10.

Hickey, J. J., J. A. Keith, and F. B. Coon. 1966. An exploration of the pesticides in a Lake Michigan ecosystem. J. Appl. Ecol. *3* (suppl.): 141–154.

Hoffman, C. H., and E. W. Surber, 1949. Effects of feeding sprayed insects to freshwater fish. *U.S. Fish. Wildlife Serv. Spec. Sci. Rep. Fish.* No. 4, 9 pp.

Kadoum, A. M. 1968. Application of the rapid micromethod of sample cleanup for gas chromatographic analysis of common organic pesticides in ground water, soil, plant, and animal extracts. *Bull. Environ. Cont. Toxicol.* 3: 65–70.

Keil, J. E., and L. E. Priester, 1969. DDT uptake and metabolism by a marine diatom. *Bull. Environ. Cont. Toxicol.* 4: 169–173.

Langford, R. R. 1949. The effect of DDT on freshwater fishes. *Dept. Lands Forests Bull.* 2: 19–38.

Macek, K. J., and S. Korn. 1970. Significance of the food chain in DDT accumulation by fish. *J. Fish Res. Bd. Canada* (In Press).

Risebrough, R. W. 1969. Chlorinated hydrocarbons in marine ecosystems. Ch. I, p. 5–23. *In: Chemical Fallout: First Rochester Conference on Toxicity,* (M. W. Miller and G. G. Berg, eds.) Thomas, Springfield. 531 p.

Risebrough, R. W., P. Reiche, D. B. Peakall, S. G. Herman, and M. N. Kirven. 1968. Polychlorinated biphenyls in the global ecosystem. *Nature* 220:1098–1102.

Rudd, R. L. 1964. *Pesticides and the Living Landscape.* University of Wisconsin Press, Madison and London. 320 p.

Sodergren, A. 1967. Uptake and accumulation of C14-DDT by *Chlorella* sp. (Chlorophyceae). *Oikos 19:* 126–138.

Stanley, R. L., and H. T. LeFavoure. 1965. Rapid digestion and cleanup of animal tissues for pesticide analysis. *J. Assoc. Office. Agr. Chemists 48:* 666–667.

Strickland, J. D. H., and T. R. Parsons. 1968. A practical handbook of seawater analysis. *Fish. Res. Bd. Canada Bull. 167,* 311 p.

Woodwell, G. M., C. F. Wurster, Jr., and P. A. Isaacson. 1967. DDT residues in an east coast estuary: a case of biological concentration of a persistent insecticide. *Science* 156: 821–824.

Wurster, C. F., Jr. 1969. Comments section, p. 20. *In: Chemical Fallout: First Rochester Conference on Toxicity,* (M. W. Miller and G. G. Berg, eds.) Thomas, Springfield. 531 p.

——, 1968. DDT reduces photosynthesis by marine phytoplankton. *Science* 159: 1474–1475.

—*James L. Cox.*

SCRIPPS INSTITUTION OF OCEANOGRAPHY MARINE LIFE RESEARCH PROGRAM

The Marine Life Research Group at Scripps has advanced on many fronts during the last year toward increasing our understanding of the California Current. These advances have been toward both broadening the program and intensifying the attack on specific problems. Only a few of the advances can be briefly presented below. Added funding for the programs has been obtained from a variety of sources including the National Science Foundation, the Atomic Energy Commission, and the Office of Naval Research.

The Marine Life Research Program has approached the following problems:

A. The continued monitoring of the California Current System with 1969 being the year set for intensified coverage.

B. The behavior of the northern types of zooplankton as they encounter the less hospitable subtropical conditions of the southern portions of the current.

C. The nature and causes of the large-scale changes in the oceanography and biology of the eastern North Pacific.

D. The history of changes in the conditions, general biology, and fish stocks of the California Current as indicated in special sediments found in the California Basins.

E. The nature of the populations of larger organisms on the deepsea floor.

F. The characterization and quantification of the zooplankton component in California waters into "functional" groups and a study of the various changes in these groups that occur in the California Current.

G. The behavior of important zooplankton populations.

During 1969, on nearly a monthly basis, patterned cruises from San Francisco to southern Baja California were carried out with the National Marine Fisheries Service. Hydrographic, chemical, and biological material were collected. Twelve special 24-hour stations on lines 70, 90, and 120 were carried out, on four of these cruises, to explore the vertical distribution of zooplankton. These special stations used Brown-McGowan opening and closing nets to collect plankton at various depths to 500 m, twice a day, near midnight and near noon. Nutrient, productivity, chemical, and temperature measures were obtained.

At the same time as our near monthly sampling of the California Current, we maintained deep-moored instrument stations in the North Pacific at 41° N, 148° W; 43° N, 158° W; and 42° N, 164° W. These instrument stations were anchored in September, 1968, and are continuing to gather continuous water temperature and meteorological data. The data from the moored stations plus historical North Pacific water temperature and meteorological data are leading toward an improved understanding of the fluctuation of the California Current, and provide improved ocean weather, and fishery forecasting along the coast. Records of meteorological and oceanographic data continuing for months at a time are beginning to make it possible to understand some of the factors affecting the temperature structure of the surface layer of the ocean. It is hoped that in the near future one or more buoys will also be anchored in the California Current. Data gathered would be substantially help to augment our knowledge of the spectrum of variability in the CalCOFI regime and to enhance the value of the long series of records that have been collected from CalCOFI cruises.

The varved anaerobic sediments in the Santa Barbara Basin are continuing to be analyzed to establish the past changes and to understand the natural fluctuations of the California Current. It should be possible to establish the nature and magnitude of the effect that man is producing on the environment of the California Current since these detailed and virtually continuous varved sediments preserve many of the plant and animal remains on a year-to-year basis from prehistoric times into the present. A positive correlation between rainfall, tree growth, and sedimentation rate supports the sediment chronology and begins to open up an important climatic and marine biological record. The distribution of pelagic fish scales in the surface sediments closely parallels the recent history of these fish as found from the fishing records and CalCOFI data. This lends credence to the studies of fish population fluctuations over the last two thousand years, which have previously been reported.

Some experimental sable fishing (*Anoplopoma fimbria*) was carried out near San Diego, the Los Coronados Islands, and San Clemente Island. This is an important fish off the Pacific Northwest and Alaska, but has been fished rarely off Southern California, because of their much deeper occurrence. The free vehicle technique using traps and set lines with hooks were dropped to depths between 250 and 500 fathoms. Yields of fish per hook ranged between 0.1 and 0.75 on 30 hook lines, while the traps yields were between 1.7 and 8 fish per trap. The potential ultimate size and areal extent of this fishery off Southern California has not been established, but the population can be estimated from present data as exceeding hundreds of thousands of tons. Additional research is expected on this during the next year.

The Biomass Analysis Laboratory has just published its first Atlas of the biomass in the California Current. This covers biomass in the spring and fall for several important years. This Atlas shows large changes in the various functional groups of zooplankton between the colder years and warmer years in the CalCOFI area. The laboratory is presently working on the winter and summer periods for the same years.

The presence of salps in bloom conditions in the California Current may have a critical effect on other members of the plankton communities. Some feeding experiments have shown that the highest filtering rates were exhibited by actively-growing young solitary salps. Chains of *Salpa fusiformis* may increase by 1–2 cm/hr in unenriched sea water, suggesting that these organisms are well adapted for immediate use of suitable food conditions. Considering the high densities achieved by salps at various times in the California Current it appears that salps may remove half of the available microplankton food in bloom areas in less than 24 hours! Of the 24 known species of salps, 21 occur in the California Current.—*John D. Isaacs.*

NATIONAL MARINE FISHERIES SERVICE FISHERY-OCEANOGRAPHY CENTER

The commitment of the National Marine Fisheries Service to investigation of the abundant pelagic marine fish resources of the California Current area has continued, mainly within the framework of the California Cooperative Oceanic Fisheries Investigations, for more than 20 years. This work is conducted by the Fishery-Oceanography Center, La Jolla, which is the Federal laboratory responsible for fishery research in the Service's Pacific Southwest Region.

Research is oriented towards specific fisheries, but organized within the laboratory into four groups—Fishery-Oceanography, Population Dynamics, Behavior-Physiology, and Operations Research. With the exception of the Fishery-Oceanography Group, whose activities are concerned primarily with tuna ecology and tuna oceanography, all of the others are involved in various aspects of research on the industrial species of the California Current—anchovy, hake, saury, jack mackerel, Pacific mackerel, sardine, etc. The report which follows is concerned only with those research activities directly related to the interests of CalCOFI and is not intended as a comprehensive account of the research of the entire laboratory.

Most of CalCOFI-coordinated research at the Fishery-Oceanography Center is carried out by the *Population Dynamics Group,* which seeks to estimate the stock size and availability of latent resources and to demonstrate the effects of the fishery on recruitment, mortality and stock size of exploited fish populations. During this fiscal year, Dr. Paul Smith and biologists in this group participated in a full-scale cooperative oceanographic and biological survey of the California Current, the first such survey since 1966. For the first time, the surveys became international with the addition to the survey fleet of the research vessel, PROFESSOR DERYUGIN, from the Soviet laboratory TINRO in Vladivostok. For the second consecutive year, MILLER FREEMAN, research vessel of the Service's Biological Laboratory in Seattle, joined DAVID STARR JORDAN, research vessel of the Fishery-Oceanography Center and ALEXANDER AGASSIZ from Scripps Institution of Oceanography. The four-ship research operation was able, for the first time, to survey the whole of the spawning range of Pacific hake off the coast of southern California and Baja California. Preliminary analysis of the numbers and distribution of hake eggs and larvae taken with standard plankton nets indicate that about 3 million tons of adult hake were present in the 1969 spawning concentrations.

In an effort to develop hydroacoustic techniques for stock assessment, a series of three cruises was made on JORDAN by Dr. Smith and biologists in his group from August to November 1968, to investigate the use of sonar to map densities of targets over the transects of the CalCOFI grid. Now almost completed, an analysis of acoustic targets revealed that scattered targets are present over the entire range of the California Current with the heaviest concentrations occurring in the Los Angeles Bight during the January survey. A sonar survey taken in May and June 1969, from San Francisco to Cape San Lazaro, Baja California, indicated that about a million targets, probably individual schools of fish, inhabit the upper mixed layer of the sea during daylight hours. A new survey system has been designed, consisting of a towed body with transducers of three different frequencies for mapping fish schools in the upper 50 meters. This array is intended to provide target characteristics which can be used to distinguish schooled anchovy from other schooled fish and to estimate the size of individual fish within schools.

During the massive Santa Barbara oil spill in February 1969, Service biologists conducted a cruise on JORDAN into the area to assess effects of the oil on fish larvae and plankton. Samples taken from directly under the oil indicated that fish larvae were present in the usual numbers and kinds representative of the area at that time of year and it was concluded that the oil spill at that point had no major discernible effect on the planktonic biota.

New information on the aging of Pacific sardines is available from studies conducted on a large group of fish hatched at the Fishery-Oceanography Center in May 1968, and maintained in large aquaria. It has been found that growth in captivity compares favorably with growth estimates obtained from wild fish. The cooperative collection with California State agencies of data on the age structure of the anchovy populations from samples taken from the commercial catch has continued. A study of techniques for aging anchovies has resulted in a shift in approach which saves 50% in man-hours over the previous method.

Information obtained from a Service contract with the California Academy of Sciences and by agreement with Mexican fisheries agencies indicated that the anchovy landings from the Baja California fishery in 1968, are nearly the same as in 1967, while Pacific mackerel and jack mackerel landings remained low.

Research has also continued on elucidating the subpopulation structure of the anchovy. Indications from genotype analysis are that all anchovies south of Point Conception, in the southern California area, and at least as far south as Ensenada, Mexico, are drawn from a single homogeneous population.

The *Operations Research Group* is working to develop efficient tactical search tools for fishing vessels to understand how the biological characteristics of various species of commercial fish affect their reaction to fishing gear. In cooperation with the NMFS Branch of Economics, a study of the operating economics of the San Pedro wetfish fleet has been completed by this group. This study has shown that unless changes can be made in crew size, catch rate, and lay share percentage, the entry of new construction into the wetfish fleet will remain unprofitable.

One of the primary ways in which this group is working to solve some of the problems of the wetfish fleet is to reduce the manpower requirements for catching anchovy for reduction. During the past year a 10-inch Marco hydraulic fish pump has been placed aboard a wetfish boat to help eliminate mechanical brailing. Work has also been started to devise alternative seining techniques which will not require a power skiff, hence 1 or 2 less men.

In early July 1969, the MRC, acting on a subcommittee report, recommended the formation of a Wetfish Operation Pool to be made up of MRC, NMFS, California Department of Fish and Game, the Fisherman's Cooperative Association and labor to combine their resources and undertake a program of applied gear research. The MRC has now contracted with the Operations Research Group for a cooperative experiment to study methods of mechanizing the wetfish seining operation and negotiations have begun with the owners for the use of one wetfish boat to explore some of the methods suggested.

Sea surveys of the California Current have consistently indicated under-used fishery resources. During the past year biologists in the Operations Research Group have been investigating such potential fishery resources as shrimp, swordfish, basking sharks, and saury, the latter in cooperation with the Service's Exploratory Fishing Gear Research Base, Seattle. Saury, in particular, seems to offer some promise as an additional species for inclusion in the wetfish catch. With the Exploratory Fishing and Gear Research Base in Pascagoula, Mississippi, the Group has also been studying bioluminescence as an aid in night scouting for wetfish.

The experimental longline fishery for swordfish was started by this Group by inviting fishermen on a demonstration/experimental trip aboard the research vessel, DAVID STARR JORDAN, and by furnishing gear and assistance to the boats. This year the first commercial west coast longline trip was completed with 2.5 tons of swordfish caught. Although the catch was not spectacular, the hook rate of 0.8 fish/100 hooks set was encouraging, and a second vessel has since entered the fishery.

Scientists in the *Behavior-Physiology Group* are concerned with the behavior of larval, juvenile and adult fish and with the trophodynamics of the food chain of which the important commercial species of fish and invertebrates are a part. Principal emphasis of the Behavior-Physiology Group during the past year has been on the biology of larval fishes, particularly anchovy reared in the laboratory. Recent experiments have shown, for example, that at 22° C anchovy larvae can survive without food for 3 days after hatching or 1.5 days after absorption of the yolk. Best survival for anchovy larvae occurred when the density of food organisms was at a concentration of between 4 and 8 copepod nauplii per ml. The implication of these results is that the period of time which can elapse before the larvae must feed in order to survive after exhausting their yolk supply may be longer than expected and less critical in terms of survival.

A technique has been established for photographing fish larvae and their food which will make it possible to determine the feeding efficiency, the perceptive field for feeding, and to describe the feeding behavior of larvae of different sizes. Larval anchovies, 7–10 mm, were filmed with a high-speed camera and it was possible at higher photographic magnifications to resolve both the larvae and their food which ranged in size from 100–300 microns. These data will be used to determine plankton densities required for survival of larvae.

A study has been concluded which describes differential feeding of the anchovy on two sizes of crustaceans as a function of food density and indicates the density ratios at which the feeding attack will be directed exclusively at one of the organisms. After a satisfactory procedure had been established for culturing a unicellular algal flagellate, *Platymonas,* in the laboratory, feeding trials with the northern anchovy were made. The data indicate that large schools of anchovies respond immediately to *Platymonas* by increasing their swimming speed and filtering.

As part of a study of the mechanism and physiology of swimming in oceanic pelagic fish, a machine has been constructed and calibrated which will measure the swimming speeds of fish, 5–30 cm in length. Using a jack mackerel as the experimental animal, it was found that the frequency of tail-beat is not linearly related to fish length as has been previously supposed, but that the relation is logarithmic. It further appears that the relationship is essentially similar in all groups of teleosts tested—from goldfish to jack mackerel.

A series of experiments on the effect of temperature on hatching time, development, yolk utilization and growth of hake, jack mackerel, anchovy, and a number of other coastal pelagic marine species was completed. The data indicate that the rate of hatching and other related developmental processes triples over the 10° range (16–26° C) for the species studied. This information is vital for predicting biomass estimates from field egg and larval collections.

A study was begun on the effects of various physical conditions on the gonads of anchovies, beginning with different light and temperature regimes. From data accumulated thus far, it appears that ovary development is highly variable even under constant conditions and that eggs can develop to the yolked stage in a relatively short time.

An organism, the unarmored dinoflagellate, *Gymnodinium splendens,* has been found that is culturable in the laboratory, yet acceptable and nutritious to first-feeding fish larvae. During a series of experiments with this organism, anchovy larvae fed *Gymnodinium* survived 3 weeks beyond the mortality of starved larvae acting as controls.—*Alan R. Longhurst.*

REVIEW OF THE PELAGIC WET FISHERIES FOR 1968 AND 1969

The total wet-fish landings in California for calendar 1968 (57,646 tons) was the second lowest recorded since the failure of the sardine fishery. Only in the year 1965 (50,254 tons) were the fishermen less successful (Table 1).

During 1968, jack mackerel (27,834 tons) and squid (12,466 tons) catches were better than those recorded in the preceding two and four years, respectively but the northern anchovy (15,538 tons) catch was below expectations. The Pacific mackerel (1,567 tons) catch remained dismally low, despite a noticeable (about 300%) improvement over 1967. Only minimal amounts of Pacific sardine (62 tons) were taken for use as dead bait.

By contrast, the total 1969 landings (105,300 tons) were better and the highest recorded since 1958. Pacific sardine (53 tons) and Pacific mackerel (1,179 tons) were negligible and jack mackerel (25,961 tons) landings were only fair; however, squid (10,390 tons) landings were the third largest ever, and the northern anchovy (67,632 tons) catch exceeded all previous years.

During the fiscal period (July 1968–June 1969), 36 seiners fished in California waters. There were 23 "large" (60 feet and over) and 13 "small" purse seiners. Thirty-one of these vessels were based in San Pedro, two at Port Hueneme, and three sailed from Monterey. The largest Monterey seiner fished in southern California during part of the season.

Twenty lampara boats (excluding those seeking only live-bait) operated statewide, five were based at southern California ports and 15 at Monterey.

Pacific sardine

The moratorium on Pacific sardines remained in effect, but in 1969 was modified to provide for the taking of up to 250 tons annually for use as dead bait. This was passed by the Legislature in mid-year and became effective in November. By the end of the year, eight tons had been taken for this purpose, mostly from San Diego Bay.

The preliminary figures for the Baja California sardine catch indicate that a moderate drop occurred during the 1968–69 season (Table 2).

Northern anchovy

The California Fish and Game Commission again authorized a 75,000-ton reduction fishery, beginning August 1, 1968 (northern permit area), and September 15, 1968 (southern permit area), and ending May 15, 1969, in both areas.

Fishing began in the northern permit area on August 13, after a price agreement of $18/ton. Northern permit boats landed 2,354 tons through December, failed to land any fish in January, February or March, and caught only 382 tons during April and May, for a season total of 2,736 tons (Table 3).

The southern California fleet began fishing on October 17, after reaching a price agreement of $17/ton with a provision for increases based on increases in market quotations for meal. No increase was negotiated during this season. Southern California boats landed northern anchovies in each month of the season. Through December, 10,343 tons were landed, with an additional 3,404 tons being taken January through March. In April and May, fishing improved and 11,567 tons were added for a grand total of 25,314 tons (Table 3).

Until about the first of December the southern California reduction fleet (16 boats) operated primarily in the Anacapa Island-Port Hueneme area. Subsequently, and until the season closed on May 15, the majority of the catches were made within a triangular area bounded by Point Dume, Santa Catalina Island and Dana Point.

Live-bait catches showed an increase in 1968 over previous years, while the total 1969 catch approximated that of earlier years (Table 4). Since the live-bait catch is determined from voluntary records, these figures are relative and probably minimal.

Mackerel

The low Pacific mackerel catches (Tables 1 and 5) reflect the depressed status of the population. Most Pacific mackerel were taken incidentally with loads of jack mackerel. Jack mackerel catches, while up from the 1967–68 season, were still approximately 10,000 tons less than the previous 10 year mean. Most of the jack mackerel were taken near San Clemente Island and Cortes Bank, with lesser amounts coming from Santa Catalina and Santa Barbara Islands, and the inshore waters near San Pedro.—*David Ganssle*

TABLE 1

Landings of Pelagic Wet-Fishes in California in Tons; 1964–1969

Year	Sardine	Anchovy	Pacific Mackerel	Jack Mackerel	Herring	Squid	Total
1964	6,569	2,488	13,414	44,846	175	8,217	75,709
1965	962	2,866	3,525	33,333	258	9,310	50,254
1966	439	31,140	2,315	20,431	121	9,513	63,959
1967	74	34,805	583	19,090	136	9,801	64,489
1968	62	15,538	1,567	27,834	179	12,466	57,646
1969*	53	67,632	1,179	25,961	85	10,390	105,300

* Preliminary.

TABLE 2

Sardine Catch in Tons; 1964–1965 through 1968–1969

(Period June through the following May)

Season	California	Baja California	Total
1964–65	6,103	27,120	33,223
1965–66	719	22,247	22,966
1966–67	344	19,529	19,873
1967–68	71	27,036	27,107
1968–69	17	*14,044	14,061

* Preliminary June 1, 1968–March 31, 1969.

TABLE 3

Anchovy Landings for Reduction in the Southern and Northern Permit Areas; 1965–66 through 1968–69

Season	Southern Permit Area	Northern Permit Area	Total
1965–1966*	16,468	375	16,843
1966–1967†	29,589	8,021	37,610
1967–1968‡	852	5,651	6,503
1968–1969§	25,314	2,736	28,050

Seasons:

* November 12, 1965, through April 30, 1966.
† October 1, 1966, through April 30, 1967.
‡ September 15, 1967, through May 15, 1968.
§ August 1, 1968, through May 15, 1969.

TABLE 4

Commercial Landings and Live Bait Catch of Anchovies in Tons; 1964–1969

Year	Reduction	Other Commercial	Live Bait	Total
1964	0	2,488	5,191	7,679
1965	171	2,695	6,148	9,014
1966	27,348	3,792	6,691	37,831
1967	32,349	2,455	5,387	40,191
1968	13,795	1,743	7,176	22,714
1969*	65,214	2,419	5,538	73,171

* Preliminary.

TABLE 5

Jack and Pacific Mackerel Catch in Tons, 1964–1965 through 1968–1969

(Period May through April)

Season	Jack Mackerel	Pacific Mackerel
1964–1965	39,540	12,437
1965–1966	33,831	3,794
1966–1967	22,889	2,038
1967–1968	18,709	691
1968–1969*	30,101	1,644

* Preliminary.

PUBLICATIONS

1 JULY 1968–30 JUNE 1969

Abramson, Norman J., and Catherine L. Berude. 1969. Distribution of California angling effort in 1968. *Calif. Fish and Game, 55*(4) : 260–264.

Ahlstrom, Elbert H. 1969. Mesopelagic and bathypelagic fishes in the California Current region. *Mar. Res. Comm. Calif. Coop. Ocean. Fish. Invest., Rept., 13*: 39–44.

Alvariño, A. 1968a. Egg pouches and other reproductive structures in pelagic Chaetognatha. *Pac. Sci. 22*(4) : 448–492.

——1968b. The Tropico-equatorial zooplankton. *Fourth Latino-American Congr., Caracas (Venezuela), Nov., 1968, Proc.* (Abstr.)

——1969a. Atlantic Chaetognatha. Distribution and essential notes of systematics. (In Spanish.) *Spanish Inst. Oceanogr., Trab.*, (37) : 1–290.

——1969b. Zooplankton of the Gulf of Mexico, Caribbean Sea, immediate regions of the Pacific, and fisheries. *Fourth Nat. Congr. of Oceanogr., Mexico, Proc.* (Abstr.)

Baxter, J. L., J. D. Isaacs, A. R. Longhurst and P. M. Roedel. 1969. Review of activities: Report of the CalCOFI Committee. *Mar. Res. Comm., Calif. Coop. Ocean. Fish. Invest., Rept., 13*: 5–15.

Ben-Yami, M'nakhem, and Roger F. Green. 1968. Designing an improved California tuna purse seine. *Fish. Ind. Res. 4*(5) : 183–207.

Berger, W. H., and A. Soutar. 1970. Anaerobic basin sedimentation and differential preservation of plankton shells. *Geol. Soc. Amer., Bull., 81*(1) : 275–281.

Blunt, C. E., Jr. 1969. The jack mackerel (*Trachurus symmetricus*) resource of the eastern North Pacific. *Mar. Res. Comm., Calif. Coop. Ocean. Fish. Invest., Rept., 13*: 45–52.

Blunt, C. E., Jr., and Richard H. Parrish. 1969. The Pacific mackerel fishery: a summary of biological knowledge and the current status of the resource. *Calif. Dept. Fish and Game, MRO Ref.*, (69–7) : 1–25.

Brinton, E. 1969. Growth and reproduction of euphausiaceans (Crustacea) in waters of California and Baja California. (In Spanish) *Fourth Mexican Nat. Congr. Oceanogr.* (Abstr.)

Carlucci, A. F., and P. M. McNally. 1969. Nitrification by marine bacteria in low concentrations of substrate and oxygen. *Limnol. Oceanog., 14*: 736–739.

Carlucci, A. F., and Hazel R. Schubert. 1969. Nitrate reduction in seawater of the deep nitrite maximum off Peru. *Limnol. Oceanog., 14*: 187–193.

Carlucci, A. F., S. B. Silbernagel and P. M. McNally. 1969. Influence of temperature and solar radiation on the persistence of vitamin B_{12}, thiamine, and biotin in seawater. *J. Phycol., 5*: 302–305.

Carlucci, A. F., and S. B. Silbernagel. 1969. Effect of vitamin concentrations on growth and development of vitamin-requiring algae. *J. Phycol., 5*: 64–67.

Chow, Tsaihwa J. 1968a. Isotope analysis of sea water by mass spectrometry. *Water Poll. Contr. Fed., J., 40*: 399–411.

——1968b. Lead isotopes of Red Sea region. *Earth and Planetary Sci. Let., 5*: 143–147

——1970. Lead accumulation in roadside soil and grass. *Nature, 225*: 295–296.

Chow, Tsaihwa J., John L. Earl and Carrie F. Bennett. 1969. Lead aerosols in marine atmosphere. *Environ. Sci. and Tech., 3*: 737–740.

Chow, Tsaihwa J., and Carrie B. Snyder. 1969. Indium content of sea water. *Earth and Planetary Sci. Let., 7*.

Clemens, Harold B., and Glenn A. Flittner. 1969. Bluefin tuna migrate across the Pacific. *Calif. Fish and Game 55*(2) : 132–135.

Collins, Robson A. 1969. Review of the pelagic wet-fisheries for the 1967–68 season. *Mar. Res. Comm., Calif. Coop. Ocean. Fish. Invest., Rept., 13*: 11–12.

Cox, C. S., P. W. Hacker, B. P. Johnson and T. R. Osborn. 1969. Fine scale of temperature gradient. *Mar. Tech. Soc., Symp. Mar. Temp. Measurem., June 16, 1969, Miami Beach, Fla., Proc.*

Cox, C. S., Y. Nagata and T. Osborn. 1970. Oceanic fine structure and internal waves. *Tokyo Univ. Fish. Oceanogr. Lab., Dr. Uda's Commemorative Papers.*

Devereux, Robert F., John D. Isaacs and Feenan D. Jennings. 1969. Long-distance telemetry of environmental data for the North Pacific study. *Internat. Oceanol. Conf., Brighton, England, Feb. 16–21, 1969, Proc.*

Duffy, John M. 1968. Deformed lateral line in a jack mackeral, *Trachurus symmetricus* (Ayres). *Calif. Fish and Game, 54*(4) : 306.

Evans, M. W., John D. Isaacs and R. A. Schwartzlose. 1969. Atmospheric effects on the ocean as measured from deep-moored instrument stations. *Mar. Tech. Soc., Mar. Temp. Measurem. Symp., June 16, 1969, Miami Beach, Fla., Proc.*

Evans, M. W., R. A. Schwartzlose, A. M. Tubbs and P. W. Walker. 1969. Data from deep-moored instrument stations. 2. *Scripps Inst. Oceanogr., Ref.* (69–6) : 1–98.

Fager, Edward W. 1968. A sand-bottom epifaunal community of invertebrates in shallow water. *Limnol. Oceanogr., 13*(3) : 448–464.

——1969a. Production of stream benthos: a critique of the method of assessment proposed by Hynes and Coleman (1968). *Limnol. Oceanogr., 14*(5) : 766–770.

——1969b. Recurrent group analysis in the classification of Flexibacteria. *J. Gen. Microbiol., 58*: 179–187.

Fager, Edward W., and R. I. Clutter. 1968. Parameters of a natural population of a hypopelagic marine mysid, *Metamysidopsis elongata* (Holmes). *Physiol. Zool. 41*(3) : 257–267.

Fager, Edward W., and A. R. Longhurst. 1968. Recurrent group analysis of species assemblages of demersal fish in the Gulf of Guinea. *Can. Fish. Res. Bd., J., 25*(7) : 1405–1421.

Fitch, John E. 1969. Fossil records of certain schooling fishes of the California Current system. *Mar. Res. Comm., Calif. Coop. Ocean. Fish. Invest., Rept., 13*: 71–80.

Fitch, John E., and Robert J. Lavenberg. 1968. Deep-water teleostean fishes of California. Univ. Calif. Press, Berkeley, Calif. 225 p.

Fleminger, Abraham. 1967. Distributional atlas of calanoid copepods in the California Current region. Pt. 2. *Mar. Res. Comm., Calif. Coop. Ocean. Fish. Invest., Atlas*, (7) : 1–213.

——1968. An assessment of copepods in the international collection at IOBC. Cochin, India. *Inter. Oceanogr. Comm., n.s., Inf. Pap., 137*: 11–21.

Fleminger, Abraham, John D. Isaacs and J. Miller, 1969. Distributional atlas of zooplankton biomass in the California Current region. *Mar. Res. Comm., Calif. Coop. Ocean. Fish. Invest., Atlas*, (10) : 1–252.

Fullerton, E. C. 1969a. The California Fish and Game Code. *Mar. Res. Comm., Calif. Coop. Ocean. Fish. Invest., Rept., 13*: 101–102.

——1969b. New laws affecting fish and wildlife. *Outdoor California, 30*(1) : 10.

Gopalakrishnan, K., and E. Brinton. 1969. Preliminary observations on the distribution of Euphausiacea from the International Indian Ocean Expedition. *Nat. Inst. Sci. India, Bull*, pt. 2, (38) : 594–611.

Heimann, Richard F. G. (Comp.) 1969. California Dept. of Fish and Game sea survey cruises 1962; *ibid;* 1964. *Mar. Res. Comm., Calif. Coop. Ocean. Fish. Invest., Data Rept.*, (12) : 1–46; (13) : 1–48.

Hester, Frank J. 1968a. Underwater photography in the study of fish behavior. *Soc. Photo-Optical Instrument. Eng., Seminar on Underwater Photo-Optical Instrumentation Applications, Proc., 12*: 81–83.

——1968b. Visual contrast thresholds of the goldfish (*Carassius auratus*). *Vision Res. 8*(10) : 1315–1335.

Hubbs, Carl L., and Reizo Ishiyama. 1968. Methods for the taxonomic study and description of skates (Rajidae). *Copeia*, (3) : 483–491.

Hubbs, Carl L., and Leighton R. Taylor, Jr. 1969. Data on life history and characters of *Galeus piperatus*, a dwarf shark of Golfo de California. *Fiskeridirektor. Skrift., Ser. Havundesokelser. 15*: 310–330.

Hunter, John R. 1968. Fishes beneath flotsam. *Sea Frontiers 14*(5) : 280–288.

Isaacs, John D. 1967. The oceans and man. *Arizona Eng. and Sci.*, Dec.: 4, 6.

——1968a. Oceans without megohms (a twenty-year baptism of electronics by sea water—a report). *Inst. Electric. and Electron. Eng., Reg. Six, Conf., Portland, Ore., May 20, 1968, Proc.*

——1968b. Probing the birthplace of American weather. *NAVAL Res., Nov.-Dec.*: 1–12.

——1968c. The sea and man. *Explor. J. 46*(4) : 260–265.

——1969a. The nature of oceanic life. *Sci. Amer., 221*(3) : 146–162.

——1969b. The North Pacific study. *J. Hydronaut., 3*(2) : 65–72.

——1969c. Role of the NDBS in future variability studies of the North Pacific. *First UXCG Nat. Data Buoy Systems Sci. Adv. Meet., U. S. Coast Guard Acad., New London, Conn., 12–14 May, 1969, Proc.,:* 62–78.

Isaacs, John D. (Chairman). 1968. Report 68–4 of the Panel on Marine Activities. *NAS/NAE Comm. Adv. to the Environ. Sci. Serv. Admin. (ESSA).* (PRIVILEGED)

Isaacs, John D. (Co-Editor). 1968. California Cooperative Oceanic Fisheries Investigations, Report, vol. 12. *Calif. Mar. Res. Comm.,* Sacramento.

Isaacs, John D., with CalCOFI Committee, 1968. Partial review of and proposed program for research toward utilization of the California Current fishery resources. *Mar. Res. Comm., Calif. Coop. Ocean. Fish. Invest., Rept., 12:* 5–9.

Isaacs, John D., Chalmers Sherwin and Minos D. Generales. 1969. Science and technology: The driving force. *26th Ann. Inst. on World Affairs, Aug. 5–23, 1968, San Diego State College, San Diego, Calif., Proc.,:* 214–235.

Isaacs, John D., and Walter R. Schmitt. 1969. Stimulation of marine productivity with waste heat and mechanical power. *Cons. Int. Explor. Mer, J., 33*(1) : 20–29.

Ishiyama, Reizo, and Carl L. Hubbs. 1968. Bathyraja, a genus of Pacific skates (Rajidae) regarded as phyletically distinct from the Atlantic genus *Breviraja. Copeia,* (2) : 407–410.

Johnson, Martin W. 1968a. On phyamphion larvae from the Hawaiian Islands and the South China Sea (Palinuridae). *Crustaceana, suppl. 2:* 38–46.

——1968b. Palinurid phyllosoma larvae from the Hawaiian Archipelago (Palinuridea). *Crustaceana, suppl. 2:* 60–79.

——1968c. The phyllosoma larvae of scyllarid lobsters in the Gulf of California and off Central America with special reference to *Evibacus princeps* (Palinuridea). *Crustaceana, suppl., 2:* 98–116.

——1969. Two chelate palinurid larvae from Hawaiian and Philippine waters (Decapoda, Palinuridea). *Crustaceana, 16*(2) : 8–118.

Jones, James H. 1969. Processing of digital data logger STD tapes at the Scripps Institution of Oceanography and the Bureau of Commercial Fisheries, La Jolla, California. *U.S. Fish and Wild. Serv., Spec. Sci. Rept.: Fish.,* (588) : 1–25.

Kato, Susumu. 1969. Longlining for swordfish in the eastern Pacific. *Comm. Fish. Rev., 31*(4) : 30–32.

Knight, Margaret. 1968. The larval development of *Raninoides benedicti* Rathbun (Decapoda: Raninidae) with notes on the Pacific records of *Raninoides laevis* (Latreille). *Crustaceana, suppl., 2:* 145–169.

Kramer, David. 1969. Synopsis of the biological data on the Pacific mackerel, *Scomber japonicus* Houttuyn (Northeast Pacific). *U.S. Fish and Wild. Serv., Circ.,* (302) : 1–18.

Lasker, Reuben, and Lawrence T. Threadgold. 1968. "Chloride cells" in the skin of the larval sardine. *Exper. Cell. Res., 52:* 582–590.

Leong, Roderick J. H., and Charles P. O'Connell. 1969. A laboratory study of particulate and filter feeding of the northern anchovy *(Engraulis mordax). Can. Fish. Res. Bd., J., 26*(3) : 557–582.

Longhurst, Alan R. 1968a. Annual Report, FY 1968, BCF Fishery-Oceanography Center, La Jolla, California. *U.S. Fish and Wild. Serv., Circ.,* (303) : 1–32.

——1968b. The biology of mass occurrences of galatheid crustaceans and their utilization as a fisheries resource. *FAO Fish. Rept., 2*(57) : 95–110.

——1969a. How can the scientific community best contribute to the resolution of these varied problems? *Mar. Res. Comm., Calif. Coop. Ocean. Fish. Invest., Rept., 13:* 127–128.

——1969b. Pelagic invertebrate resources of the California Current. *Mar. Res. Comm., Calif. Coop. Ocean. Fish. Invest., Rept., 13:* 60–62.

Lynn, Ronald J., and Joseph L. Reid. 1968. Characteristics and circulation of deep and abyssal waters. *Deep-Sea Res., 15*(5) : 577–598.

McGowan, John A., and Takashi Okutani. 1968. A new species of enoploteuthid squid, *Abraliopsis (Watasenia) felis,* from the California Current. *Veliger, 11*(1) : 72–79.

MacGregor, John S. 1968. Fecundity of the northern anchovy, *Engraulis mordax* Girard. *Calif. Fish and Game 54*(4) : 281–288.

Mackie, A. M., R. Lasker and P. T. Grant. 1968. Avoidance reactions of a mollusc *Buccinum undatum* to saponon-like surface-active substances in extracts of the starfish *Asterias rubens* and *Marthasterias glacialis. Comp. Biochem. Physiol. 26*(2) : 415–428.

Messersmith, J. D., John L. Baxter and Philip M. Roedel. 1969. The anchovy resources of the California Current region off California and Baja California. *Mar. Res. Comm., Calif. Coop. Ocean. Fish. Invest., Rept., 13:* 32–38.

Miller, Robert Rush, and Carl L. Hubbs. 1969. Systematics of *Gasterosteus aculeatus,* with particular reference to intergradation and introgression along the Pacific Coast of North America: A commentary on a recent contribution. *Copeia,* (1) : 52–69.

Murozumi, M., Tsaihwa J. Chow and C. C. Patterson. 1969a. Chemical concentrations of polluted lead aerosols, terrestrial dusts and sea salts in the Greenland and Antarctic snow strata. *Geochimica et Cosmochimica Acta, 33:* 1247–1294.

——1969b. Lead, dust, and salt in firn and ice from Camp Century and Byrd Station. *Antarctic J., 4:* 218–219.

Okutani, Takashi, and John A. McGowan. 1969. Systematics, distribution, and abundance of the epiplanktonic squid (Cephalopoda, Decapoda) larvae of the California Current, April, 1954–March, 1957. *Scripps Inst. Oceanogr., Bull., Tech. Ser., 14:* 1–90.

Orcutt, H. G. 1969. Bottomfish resources of the California Current system. *Mar. Res. Comm., Calif. Coop. Ocean. Fish. Invest., Rept., 13:* 53–59.

Pearcy, William G., Gail H. Theilacker and Reuben Lasker. 1969. Oxygen consumption of *Euphausia pacifica:* the lack of a diel rhythm or light-dark effect, with a comparison of experimental techniques. *Limnol. Oceanogr. 14*(2) : 219–223.

Perrin, William F. 1969a. The barnacle *Conchoderma auritum* on a porpoise *Stenella graffmani. J. Mamm. 50*(1) : 149–151.

——1969b. Using porpoise to catch tuna. *World Fish. 18*(6) : 42–45.

Perrin, William F. and Carl L. Hubbs. 1969. Observations on a young pygmy killer whale (*Feresa attenuata* Gray) from the eastern tropical Pacific Ocean. *San Diego Soc. Nat. Hist., Trans., 15*(18) : 297–308.

Peterson, Richard S., Carl L. Hubbs, Roger L. Gentry and Robert L. DeLong. 1968. The Guadalupe fur seal: Habitat, behavior, population size, and field identification. *J. Mamm., 49*(4) : 665–675.

Radovich, John. 1968. Fishery rights and the law of the sea. *Outdoor California, 29*(3) : 6–7.

Reid, Joseph L. (Convener and editor). 1968. Symposium on wide-scale studies of the ocean. *Mar. Res. Comm., Calif. Coop. Ocean. Fish. Invest., Rept., 12:* 26–69.

Reid, Joseph L. 1968a. Oceanography. *In* The Americana annual 1968: 507–508. Americana Corp., New York.

——1968b. Physical oceanography. *In* Yearbook/Directory, 1962. *Oceanol. Internat., 3*(4) : 43–44.

——1969a. Oceanography. *In* Americana annual 1969: 512–513. Americana Corp., New York.

——1969b. Preliminary results of measurements of deep currents in the Pacific Ocean. *Nature, 221:* 848.

——1969c. Sea-surface temperature, salinity, and density of the Pacific Ocean in summer and in winter. *Deep-Sea Res., suppl., 16:* 215–224.

Reid, Joseph L., Henry M. Stommel, E. Dixon Stroup and Bruce A. Warren. 1968. Physical oceanography in the South Pacific, 1967. *Antarctic J., 3*(5) : 168–169.

Roedel, Philip M. 1969. A consideration of the living marine resources off California and the factors affecting their use. *Mar. Res. Comm., Calif. Coop. Ocean. Fish. Investi., Rept., 13:* 19–23.

Schott, Jack W. 1969. A technique for producing and mounting otolith wafers for age determination. *Calif. Fish and Game, 55*(1) : 86–88.

Schwartzlose, Richard A., and John D. Isaacs. 1969. Transient circulation event near the deep ocean floor. *Science, 165* (3896) : 889–891.

Scott, James M. 1969. Tuna schooling terminology. *Calif. Fish and Game, 55*(2) : 136–140.

Shannon, Walter T. 1969. The point of view of government: California looks to its ocean resources. *Mar. Res. Comm., Calif. Coop. Ocean Fish. Invest., Rept., 13:* 99–100.

Smith, Paul E., Robert C. Counts and Robert I. Clutter. 1968. Changes in filtering efficiency of plankton nets due to clogging under tow. *Cons. Perm. Int. Expl. Mer, J.,* 32(12): 232–248.

Soutar, Andrew, and John D. Isaacs. 1969. History of fish populations inferred from fish scales in anaerobic sediments off California. *Mar. Res. Comm., Calif. Coop. Ocean. Fish Invest., Rept., 13:* 63–70.

Taft, Bruce A. 1968. Path and transport of the Kuroshio south of Japan. *In* J. C. Marr (ed) Symposium on the Cooperative Study of the Kuroshio and Adjacent Regions (CSK). FAO, Rome. (Abstr.)

—— 1969. Review of: Upper waters of the Intertropical Pacific Ocean by Mizulsi Isuchuya. *Amer. Geophys. Union, Trans., 50*(12): 718–719.

Thrailkill, James R. 1969. Zooplankton volumes off the Pacific Coast, 1960 *U.S. Fish and Wild. Serv., Spec. Sci. Rept.: Fish.,* (581): 1–50.

Tranter, D. J., and P. E. Smith. 1968. Filtration performance. *In* D. J. Tranter (ed.) Reviews of zooplankton sampling methods. *UNESCO Monographs on Oceanographic Methodology,* pt. 1, chapt. 3, (2): 27–144.

Venrick, E. L. 1968. Seasonal cycle of oceanic diatoms. *Mar. Res. Comm., Calif. Coop. Ocean. Fish. Invest. Conf., Dec. 9–11, 1968, Catalina, Proc.,*: 28–29. (Abstr.)

——1969a. The distribution and ecology of oceanic diatoms in the North Pacific. *Ph.D. Thesis, Univ. Calif., San Diego.* 655 p.

—— 1969b. Recurrent groups of phytoplankton species in the North Pacific. *Mar. Res. Comm., Calif. Coop. Ocean Fish. Invest. Conf., Dec. 1–3, 1969, Cambria, Calif., Proc.,*: 29. (Abstr.)

Whitney, Richard R. 1969a. Inferences on tuna behavior from data in fishermen's logbooks. *Amer. Fish. Soc., Trans., 98*(1): 77–93.

—— 1969b. Schooling of fishes relative to available light. *Amer. Fish. Soc., Trans., 98*(3): 497–504.

Wood, Richard, and Robson A. Collins. 1969. First report of anchovy tagging in California. *Calif. Fish and Game, 55*(2): 141–148.

Wood, Richard, and Alec R. Strachan. 1969. A description of the northern anchovy live-bait fishery, and the age and length composition of the catch during the seasons 1957–58 through 1964–65. *Calif. Dept. Fish and Game, MRO Ref.,* (69-3): 1–69.

PART II

SYMPOSIUM ON POPULATION AND FISHERIES

Edited by JOHN D. ISAACS

Avalon, California

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Calif. Mar. Res. Comm., CalCOFI Rept., 14:21–22, 1970.

INTRODUCTION

JOHN D. ISAACS

This is the 19th Annual CalCOFI Conference or about the 30th of what was once called the Annual Sardine Conference, when the greatest practical problem of the eastern North Pacific was thought to be concerned mainly with that particular species. The meeting is under the sponsorship of the CalCOFI Committee, which is composed of Phil Roedel, John Baxter, Alan Longhurst, and myself. Each year it falls to one or another of this group to arrange these meetings.

This year it has been the responsibility of the Scripps Institution, and I am the general Chairman. We have arranged a symposium for this first day. For the second day, and morning of the third day there will be presented research reports, surveys, and the other individual and overall research activities of the CalCOFI group.

Today's symposium is for the purpose of placing this broad fisheries research program into a context. There could be a number of contexts into which the program could be placed and which would be suitable for such a symposium. For example, there are a number of purposes of fisheries research; recreational fisheries, and fisheries associated with luxury consumption, such as shrimp or tuna fisheries. We could profitably discuss the relationship of the CalCOFI Program with such activities. There is also, of course, the very real and underlying and vital purpose of such research as part of the general intellectual challenge of understanding this planet and its ability to be reconciled to mankind's needs.

There are also hypereconomic purposes of fisheries and fisheries research, such as the export of technology, that is, learning how to use the local fisheries, not solely as sources of domestic product, but as objects of study and experimentation so that one can apprehend opportunities elsewhere around the world, advise, and utilize them, acquire them and manage them in the most effective way. But today, among the possible purposes, we are addressing ourselves to a very fundamental one. We hope that we will be able to put into context fisheries as providing basic nutrient material for the people of this earth and thereby to elucidate the interrelationship between two great populations, that of people and that of marine fish.

Today's session is broken down into presentations of four principal elements of this interrelationship: (1) the nature of the earth's human population; (2) the food supplies of this planet; (3) the relationship of the marine fisheries in this planetary supply; and (4) the technology—how we are fitted for employing this supply—the management, technology, institutions, etc.

I hope that we do not have a highly structured presentation here. There will be adequate time for discussion from the floor. But, unless there is urgent reason to break in, we should hold questions until after each of the more or less formal presentations.

I would like to introduce this symposium with a quotation from the volume "Science and the Future of Mankind," published by the World Academy of Arts and Sciences from a paper by Richard M. Field. This is a quote from the first paragraph:

> "All human beings are animals and therefore depend on the material, natural resources which constitute their environment. Human beings should not try to conquer their environment but learn to live in harmony with it. Whether the earth was created for man or with man, they are interdependent correlated expressions of life, and it is either man's God-given or man's inevitable responsibility to explore, develop and distribute the earth's material, natural resources for the benefit rather than the ultimate impoverishment of himself and his fellow-men."

I agree with this, depending on his connotations of "animal," and this quotation exemplifies the spirit in which I hope we will approach this symposium.

I now introduce our first speaker, Dr. Samuel Preston, an economist, who received his doctorate from Princeton University. Dr. Preston was somehow talked into joining Dr. Kingsley Davis' group in Berkeley in the Department of Demography. It is very important to recognize the importance of the economic viewpoint in these matters of resources, and we are particularly fortunate to have Dr. Preston, an economist in demography, present this first part of our symposium on "World Population." Dr. Warren Wooster of Scripps Institution of Oceanography will be the discussant.

Calif. Mar. Res. Comm., CalCOFI Rept., 14:23–31, 1970.

WORLD POPULATION

SAMUEL PRESTON

The question of optimum population size is probably a major concern in fisheries resources, just as it is in demography. The principal difference, I suspect, is that many of you are concerned with ways to *increase* species population sizes, and can often do something about it, while demographers often seem to be plugging for a *decrease* in the human population, and are virtually powerless.

Little disagreement remains about the undesirability of the current rate of world human population growth. From almost any standpoint it is unsustainable for a very long period of time. From an academic viewpoint, one of the major bones of contention that remains is how one should go about *arguing* that the present rate of growth is too high. Should we point to limitations of the world's food supply, to the increasing air and water pollution and aggravations of urban living, or to the burden that rapid population growth places on struggling economies? I should say at the outset that my preference is for the latter approach. And I do want to stress that this debate over what does constitute the problem of population growth is not merely academic. The trouble with advocating the right thing for the wrong reason is that conditions may change in such a way as to permit opposite conclusions from two chains of reasoning that were convergent a moment before. If the population problem is not one of starvation, then we would obviously be wrong in concluding, after a revolutionary breakthrough in food production, that we can henceforth ignore population growth.

The clearest case against the current rate of growth, I think, is the economic burden it often entails. Pollution is really more a product of technological change than of population change, and crowding often seems to occur, at least in developed countries, because people prefer to live in crowded conditions, given the choice of a better job in an urban area or a poorer job in the country. And the problem of increasing world food production is difficult to consider apart from the problem of developing more efficient economies. Enthusiasm about even the most spectacular developments in aquiculture would have to be tempered by the difficulties involved in getting the food to the people in need of it and, sooner or later, developing a means for them to purchase it. Most of the potential for increasing world food production lies in land which is currently being farmed with backward techniques. This is not to say that the future role of the ocean in food production is negligible; but it is to suggest that the popular notion that the food salvation lies in the sea may be misleading, at least under present conditions.

A SKETCH OF WORLD POPULATION GROWTH

The subject of world population growth conveniently divides into three parts: what is known, what is expected, and what is hoped. We shall first consider what is known, or at least can be estimated. It is thought that at the time of Christ the world was inhabited by about a quarter of a billion people. Sixteen hundred and fifty years were required before the number of inhabitants doubled. In other words, during this long period of history the world's birth rate and death rate were closely balanced, with rates on the order of perhaps 45 annual births and 44.6 annual deaths per thousand people. Without any deaths the population would have doubled in about 15 years; this great multiplication was prevented by a continual series of famines, plagues, and epidemics. By 1750 the population had risen to about three-quarters of a billion. Only 150 years were required before this number doubled once again, so that by 1900 the world was inhabited by about one and one-half billion persons. The reason for the much more rapid rate of growth during this period is not very mysterious. In small part it was the opening up of new lands to European settlement, but the primary reason was a rising standard of living that permitted great improvements in sanitation and nutrition. Many of these improvements resulted from a revolution in methods of food production and distribution. Life expectancy at birth rose from perhaps 35 years in 1750 to 55 years in 1900 in the western countries. What had been a close balance between births and deaths was disrupted by man's increasing ability to alter his sursoundings for his own advantage.

This imbalance has become even more marked since 1900. The population has doubled once again, from 1.6 to 3.3 billion. Moreover, at the present rate of growth it will double again by the year 2000; the amount of time required for a population doubling is getting smaller and smaller. This is what is meant by the words ''population explosion,'' although the term is not especially apt. In an explosion the severest impact is felt at the moment of detonation, while the effects of world population growth are just beginning to be felt. Perhaps one of you could suggest a term which is equally dramatic but more suitable.

It has been asserted that man has upset the ecological balance of the universe. His natural enemy, the bacteria, has become less and less able to cope with man. This mortality improvement in western countries was spread over a relatively long period of time. Moreover, the economic changes which affected mortality also brought with them a fertility reduction.

A large decline in the birth rate has occurred in all western countries since the middle of the 19th Century. In the United States, for instance, a woman who survived to age 45 during the colonial period had eight children, on average; today she has less than three. Part of the reason for the drop in fertility is the mortality decline itself—fewer births are now necessary to insure a couple the same number of survivors, since many more births survive. A larger part of the reason is that married couples now desire fewer surviving children. The move from the farm to the city together with child labor laws have minimized the economic contributions of children, and women have found substitutes for childbearing to be increasingly attractive. So in western countries some of the population pressure that would have resulted from the mortality decline has been alleviated by a fertility reduction. This movement from a high mortality-high fertility population to a low mortality-low fertility population has been termed the "Demographic Transition," by demographers, of course.

Why, then, the sudden increase in rates of growth? The reason is that mortality improvements have recently been extended to "third-world" countries, primarily through effective public health measures rather than because of the lengthy process of economic change that occurred in the West. The speed of fall in death rates in many cases has been unprecedented in human history. A malaria eradication campaign in Ceylon succeeded in increasing the life expectancy from 43 to 52 years between 1946 and 1947, an improvement that typically required the better part of a century in the West. The death rate in Moslem Algeria fell from 42 per 1000 in 1946 to 13 per 1000 in 1952. The end result is not only an unprecedented population size in third-world countries but also unprecedented rates of growth, with birth rates remaining at the high level once necessary to insure population replacement, and death rates approaching the low levels realized in the West. In other words, these countries have undergone only the first half of the demographic transition. The world population is currently growing about 2.1 percent a year, and somewhat faster in the third-world countries. The figure in Table 1 should provide an idea of the size and rates of growth of the world's continents.

TABLE 1

Population and Growth Rates by Continent, 1965

	Estimated Population, 1965 (billions)	Estimated rate of natural increase, 1960–70 (annual percent increase) (assumption of "continued trends")
East Asia	.87	1.9
South Asia	.96	2.17
Africa	.31	2.7
Latin America	.25	3.4
Subtotal, "Third World Countries"	2.39	2.5*
Europe	.44	0.8
North America	.22	1.6
Oceania	.02	1.7
USSR	.23	1.8
Subtotal, Developed Regions	.91	1.3*
Total, World	3.30	2.1

* Weighted average.

Source: United Nations, Department of Economic and Social Affairs, *Provisional Report on World Population Prospects, as Assessed in 1963.* New York. 1964. ST/SOA/Ser. R/7.

TOWARD THE YEAR 2000

This leads to the second consideration: What trends in population size are expected in the near future? Simply assuming that the present rate of growth will continue provides an estimate of world population in the year 2000 which is double the current level. In actuality more sophisticated techniques of population projection are employed to make estimates, but in this case the assumptions about the most likely future course of mortality and fertility yield approximately the same estimate. Eighty-five percent of the increase anticipated in United Nations projections will occur in the continents of Latin America, Africa, and Asia. Between 1960 and 2000 the proportion of the world population living in these continents will increase from two-thirds to four-fifths. The population of Asia and Africa is expected to double, and of Latin America to triple. The population of Europe and North America is expected to increase "only" 35 percent. It should be noted that there is a large element of uncertainty about the present population of Mainland China, although it is probably not as uncertain as estimates of some of your fish populations, where about 20 percent of the world's population resides, so that any projections of her current population compound this uncertainty.

One consideration about future population growth is not generally recognized. Even if fertility rates show a dramatic and unexpected decline, the growth will still be enormous. The reason is that the average age of third-world populations is currently very low, as a result of their high fertility. In Costa Rica, 44 percent of the population is under 15 years of age, as opposed to 24 percent in Sweden. These large cohorts of young persons will shortly be entering their childbearing years, so that even with fewer children born per woman, the population birth rate is going to remain quite high. Even when the United Nations adopted what is considered to be a "low" fertility estimate, the world population was projected to increase to 5.4 billion by the year 2000. This is still an increase of 70 percent under very optimistic assumptions. On the other hand, if current mortality and fertility rates continue (that is, age-specific probabilities of dying or giving birth) then the population will increase to 6.8 billion by the year 2000. Just the *additional* inhabitants by that time would outnumber the current inhabitants.

What will be the effect of this tremendous expansion on human well-being? It is obvious that the relative rates of growth of developed and underdeveloped areas imply that the imbalance between the world's people on the one hand and resources and capital on the other will continue to increase. Per capita incomes in developed countries are currently growing faster than those in underdeveloped lands, tending to widen the relative discrepancy between the two blocs, to say nothing of the absolute discrepancy. The higher population growth rates of developing countries contribute in many ways to this increasing discrepancy.

First, the high fertility in underdeveloped lands produces a population with a high "burden of dependency"; that is, a population with almost as many members outside of labor-force age as inside. This results from the preponderance of the very young which we have noted earlier. Thus even if productivity per worker were as high in underdeveloped as developed countries, per capita incomes would be lower since each worker supports a larger family.

Secondly, of course, productivity per worker is *not* so high in underdeveloped areas. A worker typically has less land, capital, and education to work with. Land availability is not always a constraint, however; parts of Latin America, Africa, and Eastern Asia still have arable but uncultivated land. Some areas of the world like the northeast corridor of the United States and the colony of Hong Kong should convince us in any case that extremely high population densities—high ratios of people to land—are not inconsistent with high per capita incomes. In fact, per capita income in the northeast corridor is about $1,000 higher than in the rest of the United States. The biggest difficulty is not land but rather capital scarcity. What is needed most in developing countries is investment of capital in factories, roads, agricultural extension programs, irrigation, fertilizer plants, and education.

Whatever the historical reason for the current low ratio of capital to labor in developing countries, we can be fairly certain that rapid population growth is preventing any rapid improvements. For one thing, in a population with a high burden of dependency there is a tendency for a larger proportion of current output to be immediately consumed, thereby *reducing* the amount of investible resources. Second, an economy where the population is growing more rapidly must run faster merely to stay in the same place. If the labor force is growing three percent a year, the capital stock must grow three percent a year simply to keep productivity constant. Since the value of the capital stock is typically about three times the value of annual output, this means that nine percent of the annual output must be invested before any improvements in per capita income can be achieved. An investment proportion of nine percent is often the most a country can manage, particularly if it is laboring under a high burden of dependency. Thus high rates of population growth make high levels of investment imperative, while at the same time tending to reduce the supply of investible resources actually available.

Where does food fit into this picture? Quite obviously, if population is going to continue to grow at three percent per year in many countries, the food supply must grow that fast to prevent famines or at least increasing malnutrition. I do not want to seem to minimize these problems. A study by the Food and Agriculture Organization of the United Nations in 1967 found that 20 percent of the population in underdeveloped countries was undernourished—too few calories—and 60 percent was malnourished—too little protein. Malnutrition is known to cause a number of physical and mental disorders and contributes at least partially to the low productivity in many areas. To this extent a cheap, palatable, high-protein food supplement derived from fish might indeed help break one of the vicious circles of underdevelopment. But a moment's thought should convince us that the governments of developed countries are in no hurry to provide the resources necessary for such an extensive adventure. Foreign aid disbursements of the United States have been declining in recent years, not rising, and if you are really concerned with starvation, *per se,* you would probably not want to be put in a position of paying farmers to keep their land idle or opposing the expansion of funds for research in fisheries, which apparently has not kept pace with the expansion of interest in fish food.

Fortunately, there is also a vast potential for increasing food production in the underdeveloped countries themselves. The FAO, in an earlier estimate, predicted that world food production could be raised 50 percent simply by better use of fertilizer. Of course, fertilizer requires fertilizer plants, which require capital, whose availability is severely curtailed by population growth. Because of these interrelations, it is difficult to remove a discussion of food production from the context of overall economic development. That we may presently be nowhere near the upper limit of the earth's carrying capacity is indicated by Harrison Brown, who estimates that the earth might be able to feed fifty billion people. (We should note, however, that this apparently astronomical figure would be achieved in less than 200 years at the current rate of growth). I want to stress once again, however, that the undesirability of the current growth rate can be demonstrated without invoking limitations of food availability. Even though we might find a sudden solution to the world's food problem, it would not eliminate the world's population problem. Indeed, it might conceivably become more severe.

FERTILITY

This brings me finally to what is hoped, what course of events in the near future would be most desirable. It is probably evident by now that a fertility reduction ranks highest on the list. It is inconceivable and certainly undesirable that a government would adopt a policy of higher mortality, or even fail to invoke available public health measures that would continue to reduce mortality. The desire to avoid unnecessary death and misery is precisely what has directed attention to the population problem. The problem is obviously not solved by *generating* excessive death and misery. So of the two variables affecting a population's size, only one, the fertility level, is operational. In some cases even fertility is removed from this category for ideological reasons.

It is worthwhile first to examine whether fertility rates can be expected to fall in the natural course of events. We have already indicated that birth rates fell in western countries as incomes rose. But it is obvious that they did not fall into line with death rates; the difference between the two rates is still large enough to produce a rate of growth over 1 percent per year in most developed countries. Moreover, the level of per capita income at which fertility rates did begin to show significant declines is still well out of the reach of most developing countries. Consequently we cannot expect, in the absence of some unfamiliar influences, that fertility rates in developing countries will fall sufficiently to provide a tolerable rate of growth. Of course, a new element *is* present, namely the availability of cheap and efficient contraceptive devices. These provide a method of preventing birth which is much more satisfactory than the method of withdrawal upon which the western fertility reduction was based. Probably the most promising of the birth control devices are the intrauterine device (the IUD) and the birth control pill. The IUD is advantageous because it does not require constant maintenance. It can be inserted once and left in place if the woman's body can tolerate it. A major problem with the birth control pill is its price, but technological advances have been able to reduce the price down to about 15 cents per month when they are distributed on a mass basis. So the technological advances in death control have been more than matched by advances in birth control. The crucial difference is that public health measures can be adopted on a community basis and are universally welcomed, while contraceptive measures must be implemented by the much more numerous family units and are often resisted.

There is considerable controversy regarding the effectiveness of current world-wide efforts to reduce fertility. The intent of these efforts is, for the most part, to establish programs of "family planning." The central idea of family planning programs is to allow a woman to achieve her desired family size. In most cases this involves giving a woman the means to avoid unwanted pregnancies. Obviously this is best achieved by distributing contraceptives at a minimal cost. Family planning as an ideal is very hard to fault, on other than religious grounds. More than half of the people in the world live under governments that have adopted family planning, at least in principle. These include India, Pakistan, Malaysia, Indonesia, Singapore, Taiwan, South Korea, Iran, Kenya, and Communist China. The inclusion of Communist China in this list illustrates an earlier point. It is commonly assumed that one of the principal policy goals of Communist China is to maximize her military and industrial strength. Why, then, should it want to discourage population growth? The answer is that there is no scarcity of people but rather one of capital, and greater capitalization can be achieved by slowing down the rate of population growth.

Two countries that have adopted and implemented family planning programs—South Korea and Taiwan—have succeeded in reducing their birth rates noticeably, although their growth rates are still high. Another piece of evidence that suggests the potential usefulness of family planning is that sample surveys taken in 20 countries show, without exception, that substantial majorities of married couples want to restrict their childbearing. So it is quite evident that family planning has some potential usefulness in reducing birth rates. But the extent of this potential may be limited. Family planning is sufficient in the long run only if women desire the number of children necessary to replace themselves, and no more. Here sample surveys are much less encouraging. Women questioned in virtually every locality indicate that they desire, on the average, more than a replacement number of children. Even in Taiwan, where family planning has scored one of its successes, the growth rate is quite high, and the reason is not hard to uncover. The average Taiwanese woman desires about 4.5 children, enough to double the size of the population every generation. Likewise, in South Korea indications are that family planning, that is, contraceptives, have appealed for the most part to women 30–39 who already have four children, including two sons. In Tunisia the average number of children considered ideal is 4.3; in the Punjab over half of the visitors to family planning clinics had six or more children.

Nor do we have to leave the country to observe excessive childbearing desires. A Gallup Poll just published this past month showed that 45 percent of American women feel that the ideal family size is at least four children. By the way, the husbands were much more moderate. Only 35 percent of the husbands thought this was a good number. Five percent wanted zero. One could infer from all of these figures that permitting a woman to have the number of children she considers "ideal" is, in and of itself, seldom going to reduce the rate of population growth close to zero, a rate which is essential in the long run. Thus family planning, while it may represent an effective first step in the effort to reduce birth rates, can at the moment only be viewed as such. Kingsley Davis summarizes the difficulties very succinctly:

> "The term 'family planning' suggests that reproduction is being regulated according to some rational plan. And so it is, but only from the standpoint of the individual couple, not from that of the community. What is rational in the light of a couple's situation may be totally irrational from the standpoint of society's welfare." [1]

Alternative suggestions for reducing the birth rate usually entail a large amount of governmental interference in the decision-making process of couples. Several very imaginative solutions have been proposed, usually half in jest. One is to put a contraceptive into the water supply and sell the antidote at what would certainly be an extremely high price. Another suggestion is to allow each married couple two chits good for two children, which they could

[1] "Population Policy; Will Current Programs Succeed?" *Science*, 158(3802): 737, 1967.

use themselves or sell in a gigantic stock market—the government itself would sell enough additional chits through the market to insure exact population replacement. In both of these cases I think the price of the antidote in the water supply or the chit on the stock market would be very high, I would estimate probably somewhere between five and ten thousand dollars. If a couple desired six children it could still have them but only at a high price. Both of these schemes would generate a redistribution of childbearing from poorer to richer families, which many consider desirable.

A long time would be required before the American Congress, or any other, would even consider such visionary schemes. Nonetheless, it is not impossible to imagine journalists sometime in the 21st Century solemnly proclaiming this to be an idea whose time has come. In the meantime, there are several less radical proposals worth considering. One is the elimination of all present encouragements to fertility, such as income tax allowances, or dependency allowances in graduate fellowships. Another is the imposition of a marriage or birth tax. Abortions could be legalized, a step completely in line with the ideal of family planning. This is a very promising possibility; Japan's rapid fertility reduction was achieved largely through subsidized abortions, and abortion is a very common method of birth prevention in Latin America, despite its illegality. In at least two countries, Japan and Hungary, abortions outnumber live births. Of course, abortion raises moral questions that are somewhat more troublesome than contraceptives. The Catholic Church decided in 1869 that abortion would be equivalent to murder and has since successfully blocked numerous attempts to liberalize the abortion law despite the fact that in a recent Gallup poll, 83 percent of the American population favored some liberalization. The position of the Catholic Church receives little or no support from scientists. Dr. Robert Hall, Associate Editor of "Obstetrics and Gynecology," states that "scientifically the fetus is not a human being for the simple reason that it cannot survive even with outside help. An infant can survive with the help of an adult; an adult can survive on its own, but the fetus is dependent on its mother's womb." Perhaps the government could reimburse people for a sterilization operation, a method pursued in India. Or we could encourage women to work, a step which in eastern Europe has inadvertently reduced birth rates to the lowest levels anywhere in the world. This step would also help facilitate what many feel to be a necessary transition in values, from a society in which the family is one's primary source of satisfaction to one where a person's work, work associates, and neighbors begin to play a larger role.

SUMMARY

The recent reductions in mortality have introduced an enormous amount of excess capacity into the reproductive mechanisms of the human race. The result has been what by any standards must be termed an overproduction of human beings. Indications are that current efforts to reduce the birth rate will have to be supplemented by governmental measures that either directly regulate a couple's childbearing or provide strong incentives to infertility. Only if an unexpected change in attitudes toward family size occurs on a world-wide scale can family planning programs hope to reduce growth rates close to zero. Certainly the most troublesome piece of evidence in this regard is the fact that no nation on earth has been able to attain a zero growth rate for a period of any length without death rates which, by modern standards, are intolerable.

A Great Depression was necessary before the limitations of laissez faire capitalism were realized. Let us hope that a similar catastrophe is not necessary before laissez faire fertility is abandoned. To allow the situation to deteriorate until the earth can simply no longer support any more people would be an irresponsible gamble, that would in any case tend to depress the level of human well-being. Although the problem is currently most acute in developing countries, developed countries are in an ideal position to act as moral leaders by demonstrating that a nation *can* adjust to the new realities by reducing its annual stream of births.

REFERENCES

Coale, Ansley J. 1963. Population and Economic Development. *The Population Dilemma*, Philip M. Hauser, editor. Prentice-Hall, Englewood, N. J., pp. 46–69.

Cook, Robert C. 1965. World Population Projections, 1965–2000 *Population Bull.*, 21(4) : 73–99.

Davis, Kingsley. 1967. Population Policy: Will Current Programs Succeed? *Sci.*, 58(3802) : 730–739.

Dorn, Harold F. 1963. World Population Growth. *The Population Dilemma*, Philip M. Hauser, editor. Prentice-Hall, Englewood, N.J., pp 7–28.

Notestein, Frank. 1967. The Population Crises: Reasons for Hope. *Foreign Affairs*, 46(1) : 167–180.

DISCUSSION: Dr. Samuel Preston—WORLD POPULATION

Discussant: Dr. Warren S. Wooster

Wooster: Since I am not an expert on the subject of world population, there is a question I have, that might initiate some discussion. I hope there are other questions.

You make the point as an economist that the ultimate limitation on accommodation of people on the earth is capital rather than food. This implies that you could have the food if you could pay for it or provide the machinery to produce it. Is there enough surplus capital? As you say, our foreign aid is going down and, at the same time, I guess our investments abroad are going up. I don't know these rates, but suppose the existing capital were more equitably distributed, what would the situation be on bringing the development of the countries to a point where they could handle their own problems?

Preston: This is difficult to say for several reasons, one of which is that there are so-called increasing returns to capital. In a country which has a large amount of capital per worker, such as the United States, additions to the capital structure might provide for a larger increase in per capita income than would the same capital structure in an underdeveloped country. So perhaps the additions could be made in the United States and the benefits redistributed to the people outside the United States. This might be an ideal solution. Certainly there is an inequity—not really an inequity since it resulted from historical forces over which very few people alive had any control—but a redistribution of capital to the underdeveloped countries would double their incomes from what would raise ours only by 5–10 percent. So it is partly a distribution problem. The reasoning is that eventually these countries are going to have to generate enough annual investment to sustain themselves. However, we might help them get to that point now.

Wooster: We were discussing at breakfast the problem of the rates of all these things. The rate at which the developing countries could reduce fertility—and, as you say, you are not allowed to tinker with the mortality rate—versus the rate at which everything goes critical because there are just too many people for the food available. There is a recent statement saying the whole thing goes critical in 1975. Would you have any views on this, given that you seem so pessimistic about having the problem solved rapidly enough to do any good? When does the situation go critical?

Preston: That estimate I think is made by Paul Erlich based upon limitations of the world food supply, a position which I was implicitly arguing against. Perhaps the next speaker who is talking about world food production would have more informed views on the matter, but I think it is the consensus, at least among the people who know a little about it, the demographers, that food production certain has the potential to increase and this shows every time someone like Malthus tries to limit the growth rate of the human population by invoking the limitations of food supply; his predictions were proven wrong and there is no reason to expect that these predictions won't continue to fall short. I don't think that I could specify any one time at which the problem is going to become more severe. The question really is, is the situation in which six billion people live at a subsistence, near starvation, level worse than a situation where three billion people live at subsistence, near starvation, level? I would say that probably the situation where six billion people were at this level would be more severe because the additional capital and investments that would be necessary to get them out of this situation would be twice as hard to generate in that situation as it is currently.

Wooster: I have a feeling that, given the bad distribution, the mortality rate will begin to operate. We are getting richer and the developing countries are getting poorer per man. At some point this discrepancy is going to be intolerable and they are going to come and take it away from us. In the process, of course, the mortality rate is going to be high.

Isaacs: Of course, you mean *our* mortality rate.

Wooster: Whose ever.

McGowan: I can think of at least one limit on food production, namely the number of available carbon atoms in the world. Even if technological developments were such that we understood completely the mechanism of photosynthesis so that we could duplicate it and perhaps increase its efficiency, there is still just so much carbon available, and that's it!

Schmitt: What is the level?

Preston: Is it 50 billion, as Harrison indicated?

McGowan: I don't know, but I suppose that it could be estimated. You were saying that all these estimates have been wrong because food production has more than kept pace with population growth. Do you think that there is a limit?

Preston: Yes, I am sure there must be an upper limit but we are probably nowhere near it.

McGowan: There must be upper limits and that could be one of them. Another point is, how is it that the Japanese were able to introduce birth control so successfully? What is it about their society? Why did they accept it so readily?

Preston: That is a very important question, and for this reason Japan is a model not only of demographic transition, but of economic development.

McGowan: Yes, but how did they do it? It seems to me that their society is worth intensive study.

Preston: Well, it's a question to which there is almost no answer. I once had a professor of Economic Development, Sir Arthur Lewis, who is one of the world's authorities on ways to develop economies, and he attributed it to the "national energy" of the Japanese.

Whittington: One of the reasons Japan has been able to achieve the reduction in birth rate is the fact that less than one percent of the population is hampered by any moral theology as we are—about one percent are considered Christian in a population of nearly 100 million people. Birth control doesn't have any political opposition at all. Incidentally, Japan last year became the third industrial nation in the world.

Preston: We know that in Japan the process of demographic transition began with an agricultural revolution generating surplus off the land. We also know that there was some manpower available in Japan that is often not available in underdeveloped countries as a result of their landlord system. It was really the landlords of the rural countryside that led the agricultural revolution and provided the leadership for it. The surplus allowed people to live in cities and carry out manufacturing activities. It is also true that the lack of any religious constraints to fertility control is very much in evidence. As I say, the State almost provides a free abortion to any woman who wants it, and there are apparently more abortions than live births in Japan. They have about the lowest birth rate in the world, and obviously their low birth rate is certainly not going to constrain their economic growth.

Schmitt: Isn't it possible that Japan has reacted to its war defeat when it tried to gain lebensraum in the way Germany tried to expand into Russia? An underpopulated Australia was just too irresistible a target. I think the dashing of these attempts was probably the prime motivation. Japan is the country with the fewest tillable acres per person and despite its high rate of industrialization has a very low living standard. It is, I think, reacting to a crisis condition.

Preston: This is quite possible. The decline in birth rate accelerated dramatically after World War II, but it had been declining since about 1920 in Japan, so there was some reason already there in terms of the position in economic development, or whatever, that influenced the fertility rate. That may be the reason that the State provided the free abortions after World War II—meeting a great public demand—but it was after World War II that the great decrease began.

Alvariño: I think that education has a strong impact on birth control. People realize that to have children is a responsibility, not a privilege. The educated people in the Catholic countries of both Europe and Hispano-America do not follow the religious precepts on this particular matter. They do limit the number of their children to usually less than four. Apparently their intellectual, moral, and social values have some bearing on family size.

Preston: That is a good point. The earliest fertility reduction in the world occurred in France, which is essentially a Catholic country. Even in Latin America, as I indicated, abortion is the leading method of preventing births, and Latin America is essentially Catholic as well. So it is not necessarily true that one's national religion means that you can't pursue programs of fertility reduction. It does mean in many cases that you can't pursue them on a governmental level. Latin American governments have been slower than all other governments in the world to adopt programs of family planning, or whatever, and a large reason is that every time they try to do something, the Catholic Church puts up an intense amount of pressure and prevents it.

Chapman: I will make a point connected with distribution. It is often lost sight of that a very large part of the world population which suffers from protein malnutrition is that which is outside the money economy and we don't have any good mechanism for getting food from the money economy into the subsistence economy. I think this is something that activity must be directed toward. Presently the abundance of staple foods, cereals, sugars, carbohydrates of all sorts, and also of protein in the international market, is so great that the world market prices are depressed—but you can't get the stuff out of those channels into the subsistence economy where it is needed.

A second point, quite different, I have become sensitive to, in the last few months since I have been in contact with representatives of Qatar, Dubai, and Kuwait. They suddenly have a great deal of capital and Kuwait has been in this situation for some years. Capital is no problem; getting it used is really a social problem and it doesn't work out very well. Kuwait has found this out, Qatar is in the process of finding this out. It just doesn't work out well to take a bucket full of money around and leave it on the doorstep from time to time—there has to be some means provided for citizens to earn it or you have all kinds of social problems. This is another thing to be thought about in this connection.

Preston: Those points are both well taken. Both of the problems that are present could be solved, I guess, by a sufficient level of economic development to get everyone into the monied economy. That is, to have them producing something that is of value to someone else so that they could sell it and receive the money for it and then use the money to buy the necessary protein on the world market if they can't get it domestically.

Similarly in Kuwait, giving them money is no help because the country isn't producing anything else except oil, so that if the people wanted to buy anything, all they can buy is oil or else imports at fantastic prices. So that what they have to do is start some domestic based industries for production and in that case a redistribution from the big oil companies to the little man would succeed in raising the standard of living.

Evans: Is it not true that waste disposal and pollution may be as likely a population limit as is food?

Preston: I think it is and I mentioned that but I probably dismissed it too easily. While pollution is more a product of technological change than of population change, certainly if you have the same technology and you double the population then you are going to double the air pollution. I think air pollution is mostly a product of manufacturing activities which could be attributed to a change of technology, but water pollution is probably more closely related to the size of the population than to the level of technology.

Isaacs: You mentioned the possibility of establishing other sorts of rewards for the family group, or additional rewards other than having children. I've often wondered if, in this sort of symptomatic approach to the world population problem, there are not hidden implications that we overlook. The whole matter of the human being is a very complex one in psychology, motivation, etc. All of a sudden in a few generations we are going to try to change child bearing from something profoundly fundamental that for millennia was basically good and applauded by society to something that smacks of sin. I wonder if such a change can be made without grave psychological damage—not only to the parents but to the children. Perhaps the unrest of students is not unrelated to this increasing opinion that having children is bad.

Perhaps the whole problem will be dictated by some side effect. The bomb may be an unexpected one in an unexpected direction, rather than a population explosion in any simple ordinary sense.

Preston: Yes, I think tinkering with any set of social values has never been successful, except perhaps within institutions like the Church, but I think there has been no group of sociologists who sat down and decided to change the attitude of the world and went ahead and did so successfully. Personally I share the same fear of what would replace the family, and that is why I think that a better solution to these immediate problems of birth control would be a series of economic sanctions. Couples could still feel that child bearing is a worthwhile activity but expensive. This would be done by providing incentives to sterilization, dis-incentives to fertility, eliminating tax allowance, etc. Something is going to have to be done.

Isaacs: As an example of possible unexpected directions that tinkering may lead to, I have often wondered about the profound metamorphosis demanded of maturing children and its variation with family size. After all, the family is certainly a communal group by any definition—including, "to each according to his need—from each according to his ability." In our democracy we have insisted that each of the maturing members of the family group evolve or metamorphose to what we consider a higher level of independent democratic existence within the broader social group. This metamorphosis seems to me to be stimulated in large families and perhaps to be repressed in small ones. Hence as the family size continues to decrease and as there is a greatly lessened compulsion for this assertion of independence, it becomes easier for the young adult to hold onto the family type of relationship with society rather than to establish one of his independent contributions. The diminished family may thus lead to a sort of path of least-resistance socialism or communism. Indeed, this already may be taking place.

Powell: How do you work in the fact of the emotional makeup of a woman who often gets married to have a baby and hold a baby in her arms? This is not just to reproduce herself. These aren't just cold, scientific facts. A woman wants children. This is part of her nature—nothing she has been taught. It is something instinctive. How do you work in this factor?

Preston: Well there is something physiological, but I also think that child bearing, the level of child bearing, is partly decided, too, by the ideal of the society at a given moment, otherwise why have American women reduced their child bearing from 8 to less than three children? It is not a predetermined level which they have to seek out because of something physiological, it is also subject to some alteration by social values. But I would hesitate to fiddle around with the values because, as I said, I think other methods are available that could achieve the same goal.

Chapman: I want to broaden that thought a little bit and return to John's introductory remarks. It should really be considered without smirks that we are animals, that in the long hours of human evolution the thrust of environmental selection has been toward reproducing and existing as adults between the ages of 16 and 25. Now just in the latest seconds of human evolution, we want to change that whole emotional, physical, psychological basis and I don't think it is going to be easy. That is why we need a few humanists, a few sociologists, and other people working on these problems as well as economists. I am very glad to see economists get a better hold on this problem but I think we need these other disciplines.

Wooster: Actually, it is not that having children is going to be bad in this new world, but that it is a privilege rather than a right. It has been said that the trouble with family planning is that the planning is too small because it is purely on a family basis. But if the planning is to be done on some larger scale, this gets you into all sorts of difficult situations. There would be a master plan, saying how many babies each can have. Then there would be the question of who ought to have the babies. The high types ought to have lots of kids and the bad types ought not to have very many.

Isaacs: Which gets you into eugenics, and that is always unacceptable.

Wooster: One place where this operates to some extent is in Israel where they have a true socialistic system, in one sense. I visited one of the oldest kibbutzim in Israel some years ago where the children were all in dormitories, so to speak. They were sort of everybody's children and were segregated by ages the way they are in school. However, this was not working too well. They found that there was really a magic link between parents and their children and it wasn't the same for the children in the kibbutz where everybody were their parents. In fact, they are going back now and try to provide enough facilities for the individual families to have their children back in the family group on weekends. That is, of course, a very practical idea—to see your kids only from time to time.

Isaacs: This is a good example of the emotional factors that trouble the tinkerers. Does anybody really understand anything about these curious emotions associated with relatives? We put up with some bore because he is a cousin or something, and yet we'd kick him out of the house if he weren't. I have never quite understood this, although it is clear when the relationship is close, as with children. I think the example you give is an excellent one, Warren. It is clear in this case that regardless of how intensely the training was carried out to supersede the family, these relationships remained strong.

Johnson: Speaking partly of this psychological effect (short term), has anyone made any study of what effect Teddy Roosevelt's large family had on immediate birth control? Many of you may not remember this, as most of you are a lot younger than I am, but Roosevelt and his family were very much admired. I think he had eight or nine children.

Preston: I don't recall specifically seeing a reference to an effect, and I can recall what the declining birth rate curve looks like, but I don't remember seeing any break at that point. During Kennedy's administration, while he didn't have a large family himself, he radiated the values of large family life, yet the birth rate declined during his administration. In fact, it started about 1960 and declined throughout the sixties.

Wooster: A correlation of this occurred to my mind—a small group of oceanographers, those who are on the international circuit and see their children seldom, seem to have a rather large number of children. I started a study some years ago about the sex ratio of the children of oceanographers. At that time I was associated with Towny Cromwell, Roger Revelle, Gordon Riley, and Ray Montgomery. There was a heavy preponderance of female offspring, and I thought this could be the subject of a small piece of demographic research, in a broader context, perhaps.

Preston: I think that that has been noted before for other professional groups. I don't know what the reason is.

Isaacs: Dr. Preston, I am impressed by a number of the points you have made. One in particular I think you made very well is that the world's human population ecology is, for the moment, a rate limited rather than a gross limited process. That seems to be generally overlooked. We are always setting some sort of limitation on the total number of people in this world, and you point out very well and convincingly that the present and foreseeable problem is one of attaining feasible and compatible rates of all these things, per capita development, population growth rate, investment, and so on. It is not just the total gross food supplies, number of people, etc. This is an extremely important point, and I think you have made it very well.

The whole matter of the nature of the critical limits and critical processes is of vast importance. I know when I go through an atomic power plant, the most frightening dial of all of them, among all sorts that say "danger," "scram," and so on, the most frightening one is the dial in the middle that says "seconds to supercriticality." It sits there waving around about the 1,000 second mark, sometimes getting down to around five, and then no matter how rapidly one mentally calculates how many more neutrons are required for the thing to go supercritical, five seconds is frightening. We should have a big dial like this for the human population. We might find our moon technology of use in that. We could put the dial up there. Then every development, every crop, every birth could wiggle this huge hand a little bit one way or the other!

Well, we have had a very spirited discussion, and I want to thank the speaker for a fine presentation and a very interesting one. I thank the audience for their interesting comments and discussion.

Calif. Mar. Res. Comm., CalCOFI Rept., 14:32–42, 1970.

WORLD FOOD

WALTER R. SCHMITT

I want to express my gratitude to the previous speaker for pointing to the importance of economics in the food situation. I come to similar conclusions about the importance of the primary input, namely money. However, I disclaim any expertise as an economist.

INTRODUCTION

I have looked at the physical resources for food production only, but our discussion, I hope, will take us further afield to look at the inputs not only in terms of physical things but also in terms of skills, and money, as already mentioned. I have for this presentation diligently perused a three-volume study by the President's Science Advisory Committee (PSAC) "The World Food Problem," issued in May, 1967, by the White House. I think it strikes a realistic middle ground between the alarm of the Paddock brothers' "Famine—1975" and Ehrlich's "Population Bomb" on the one hand, and the optimism of many food specialists on the other. The Paddock brothers and Ehrlich disagree with the United States Department of Agriculture projection that world-wide famine will occur in 1984—they put it ahead to 1975 because they say food production is actually not going up as quickly as the Department of Agriculture predicted, while the population is growing faster.

It is time someone demolished an old Malthusian myth. One hundred and fifty years ago Malthus asserted that food production expands arithmetically and population geometrically. The geometric progression is easily demonstrated for the human population, but it can also be shown to hold for food production. If food did indeed expand linearly, the world must either have been in chronic surplus until now, an economic absurdity, or the population must have been held to *linear* advance through famine, which also is patently false. The conclusion is inevitable that, while food production may experience periods of linear advance or even decline, rapid expansion at times keeps food growth, resembling a step function, near the exponential population curve. There is thus nothing in the record that argues against the possibility of further rapid advances in food production.

George Borgstrom, known to you as the author of "Fish as Food," has also written "The Hungry Planet" published in 1965, in which he is a little more optimistic than the Paddocks or Ehrlich. On the other hand, we have rosier projections by advocates of some detail of food production, particularly protein from petroleum and things of this nature. However, I think that the PSAC Report is a fine penetrating realistic study that leads to many conclusions, some of which I hope to sketch out for you.

I will discuss briefly the global food situation in terms of distribution of food production, and nutritional status of some countries; briefly examine the important inputs such as water, fertilizer, and pesticides, as well as machinery, services, capital, and so on; run down the physical potential of earth for food; and discuss in greater detail the protein picture.

THE GLOBAL SITUATION

Table 1 shows you the distribution of food supplies and population in some of the great regions of Earth. I would like to bring your attention to North America, which with about seven percent of the world population is enjoying a huge supply in total and animal foods, and to the Far East, which is certainly

TABLE 1

Distribution of World's Population and Food Supplies, by Regions (1957–1959)

Regions	Percent of Population	Percent of Food Supplies		
		Total	Animal	Crops
Far East (incl. China, mainland)	52.9	27.8	18.5	44.2
Near East	4.4	4.2	2.8	5.5
Africa	7.1	4.3	2.8	6.3
Latin America	6.9	6.4	6.7	6.5
Europe (incl. USSR)	21.6	34.2	38.4	26.2
North America	6.6	21.8	29.2	10.4
Oceania	0.5	1.3	1.6	0.9
World	100.0	100.0	100.0	100.0

From H. A. B. Parpia and N. Subramanian in "World Protein Resources" p. 113, Am. Chem. Soc., Wash., D.C., 1966.

deficient in animal protein and barely makes it in crops. Some regions, like Latin America, seem to get their proper share of food supply in terms of population. Europe is pulling ahead in the food race. As a matter of fact, Europe is now facing a problem of overproduction, making it necessary to take land out of production and perhaps put it into parks and other uses. It is also contrary to the Paddocks' projections that this year we are experiencing a decline in the world trade of food products, which is primarily engendered by the good harvest in India due to the better than average monsoon season.

Maldistribution is also evident in Table 2 dealing with cultivated and potentially arable land. Look for instance at Column (5)—acres of cultivated land per person. In Asia that is 0.7, in Europe 0.9, and other regions exceed this level. Compare these figures with Column (6)—ratio of cultivated to potentially arable land. As one would expect, the continents with the lowest number of acres per person make the most complete use of that land. But there are areas like Africa and particularly South America which do not come close to utilizing their land potential. The PSAC study concludes that potentially arable land in the world is far greater than was originally assumed, namely about 24 percent of the ice-free land area. You see in the bottom row that twice, more than twice the presently cultivated land is available for potential cultivation. Competent cultivation of the tropics alone could contribute two billion acres, the PSAC study estimates.

TABLE 2

Present Population and Cultivated[1] Land on Each Continent, Compared with Potentially Arable Land

Continent	Population in 1965 (millions of persons)	Area in billions of acres			Acres of cultivated[1] land per person	Ratio of cultivated[1] to potentially arable land (percent)
		Total	Potentially arable	Cultivated[1]		
	(1)	(2)	(3)	(4)	(5)	(6)
Africa	310	7.46	1.81	0.39	1.3	22
Asia	1,855	6.76	1.55	1.28	.7	83
Australia and New Zealand	14	2.03	.38	.04	2.9	2
Europe	445	1.18	.43	.38	.9	88
North America	255	5.21	1.15	.59	2.3	51
South America	197	4.33	1.68	.19	1.0	11
U.S.S.R.	234	5.52	.88	.56	2.4	64
Total	3,310	32.49	7.88	3.43	1.0	44

From "The World Food Problem" V. II, p. 434. The White House. U.S. Govt. Printing Office, Wash., D.C., May, 1967.

[1] Our cultivated area is called by FAO "Arable land and land under permanent crops." It includes land under crops, temporary fallow, temporary meadows, for mowing or pasture, market and kitchen gardens, fruit trees, vines, shrubs, and rubber plantations. *Within this definition* there are said to be wide variations among reporting countries. The land actually harvested during any particular year is about one-half to two-thirds of the total cultivated land.

In this context a few figures from Georg Borgstrom [1] on countries' land shortage might be useful. Japan can till only .14 acre per person. The Netherlands is next with .23 ac/person. Then Egypt with .26. In fourth place is the United Kingdom with .34. China, with .40, is in 5th place. That compares with 2.6 ac/person in the USSR and United States, 5–6 in Canada and Australia. Notice that India is not among the most land-shy countries. One is tempted to correlate living standards with land and perhaps other resources. But Japan and England contradict such an attempt. For England the colonial past might provide an explanation. Japan, however, seems to point at work discipline, skill, and organization as better correlants.

To set the distribution of land resources against nutritional experience, let's look at Figure 1. The Group II countries, developed countries all, consume in excess of 3000 kilocalories per person per day. For Peru and India this is as low as 1930. Since Asians generally weigh less than Latin Americans, the Peruvians might actually be suffering more from the low

[1] The Hungry Planet, p. 5. MacMillan, New York, 1965.

caloric intake. The inside bar shows the protein experience, divided into animal and plant protein. Total protein requirement is about 1 gram daily per kilogram of body weight. Of this 60–70 grams for the average human being at least 20 grams should be animal protein, but you see that some Group I countries, with less than 10 grams, are certainly deficient in animal protein, while Group II countries with two and three times the minimum requirement indulge in luxury consumption of animal protein.

FAO has made projections on nutritional targets. In the short run they hope to achieve in the grossly deficient countries 15 grams of animal protein per person daily, in the long run 21 grams. This takes into account for these countries a better balance of amino acids in their plant proteins by AA fortification and by oilseed meal supplementation.

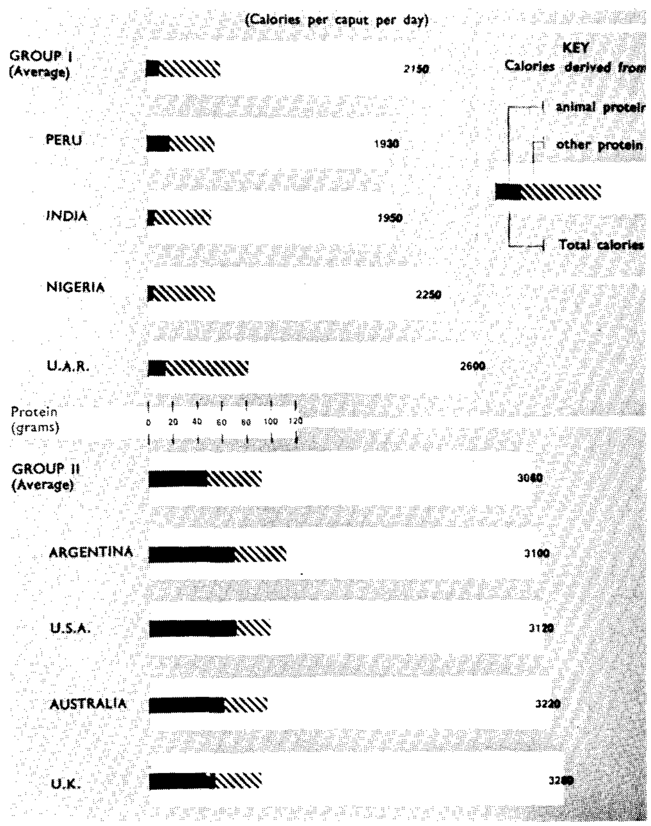

FIGURE 1. Contrast in nutritional status. Group I: Developing Countries, Group II: Developed Countries. *From* Pawley, W. H. 1963. Possibilities of increasing world food production. FAO, Rome. p. 15.

INPUTS, SERVICES, AND CAPITAL

In the next few minutes I would like to discuss some of the important inputs in the production of food—pesticides, fertilizer, equipment, know-how, etc., etc. Pesticide use correlates directly with crop yield. Japan, with the highest yields in the world, applies pesticides at a per acre level seven times greater than the United States. I did not expect this in view of the relative lack of pesticide pollution alarm in that country. Europe is also ahead of the United States in pesticide use but slightly, and in the use of fertilizer the situation is similar: Japan 1st, Germany 2nd, Europe 3rd, United States 4th.

An interesting picture emerges when we look at the cost of fertilizer in terms of crop value. Take, for instance, rice. A bushel of rice buys a certain quantity of fertilizer in Egypt; let's call it Q. The same bushel of rice produced in India buys 2Q's of fertilizer. In the United States, 4Q's. We are, however, not enjoying the cheapest fertilizer. Pakistani rice affords 4.5Q's—quite extraordinary—and Japan is on top with 5.5Q's.

Time magazine reported a little exotic experiment where in the breeding of seed, or the production of seed, the application of sound—namely music—was beneficial. Under 5–12-kilocycle sound, the resultant seed is tripled in weight and produces four times more potential grain-bearing shoots, possibly due to improved pollination by mechanical shock vibration. Cows also seem to be contented when serenaded and give more milk.

The infrastructure necessary to support an expanding food production requires not only the inputs we have touched on so far, pesticide and fertilizer, and the breeding skills that go into genetic improvement of plants and animals, but also requires a lot of roads and trucks and mechanical power. Figure 2 gives you available power on a per hectare basis, inclusive of animal and human power. You see that Japan is doing much better than the United States, and so is England. Japan's high power rating is mostly due to use of small, below 8 HP tractors in their garden farming, while the United States employs large machinery units servicing thousands of acres. It is quite evident here that developed countries use mechanical power in agri-

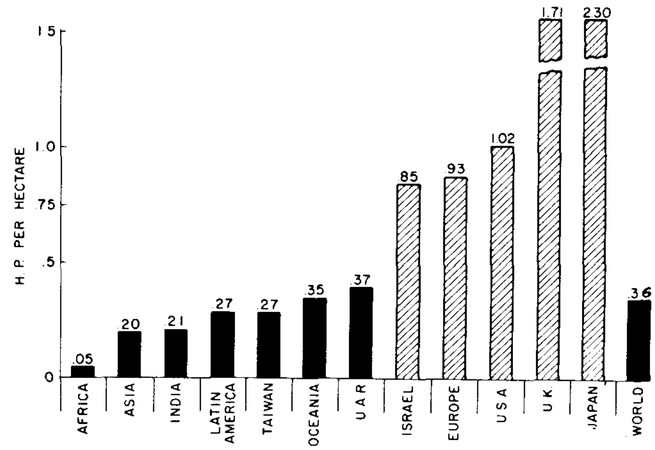

FIGURE 2. Power available for agricultural field production 1964–65. (Arable land and land under permanent crops). *From* The world food problem. V. III, p. 177. The White House. U.S. Govt. Printing Office, Washington, D.C., May 1967.

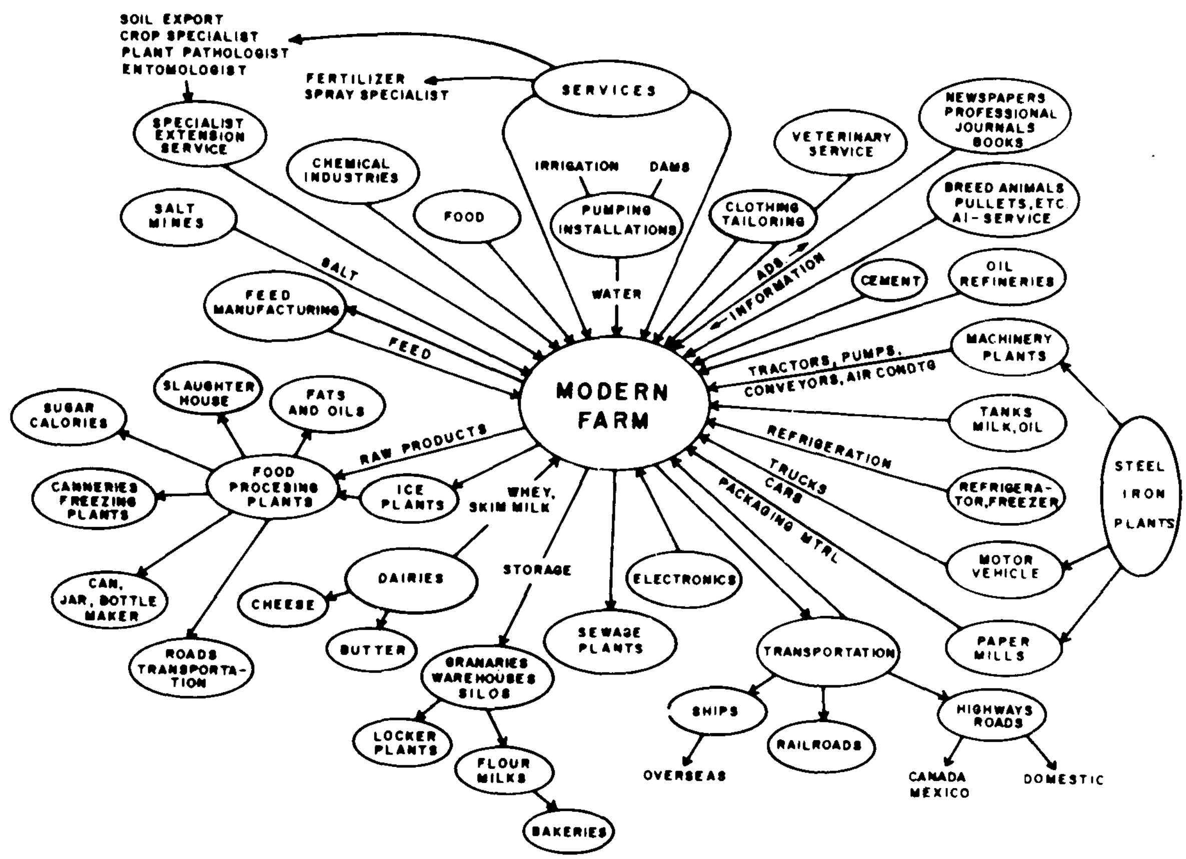

FIGURE 3. The modern farm. A modern farmer leaves all food and feed transportation, most of the storage, and almost all processing to outside enterprises. He brings to his farm most fuel, fertilizers and other chemicals; even a substantial part of his own food is purchased. A modern farmer needs the help of a number of non-farm-employed people in order to be able to produce. Producing food therefore involves far more people than the labor force on the farm. *From* Borgstrom, Georg. The hungry planet. MacMillan Press, N.Y.

culture at many times the rate of underdeveloped countries.

The PSAC report says much about the desirability of enhancing water supplies for irrigation, and while this is a very expensive part of the total improvements for more food, it is a very essential one. I have deduced by indirect means, namely from the potential expansion of hydro-electric power, that the earth's rivers may ultimately irrigate three times as much acreage as they do presently, or about 3×10^6 km ^{2}. Pakistan gives us a fine illustration of the difference between incompetent and competent irrigation. Prior to World War II that country, which practices almost total irrigation agriculture, was a food exporter. Incompetent irrigation led to root fouling and alkalization of the soil on account of high water tables, turning food exports into imports. Invited United States experts, among them Professor Isaacs and Dr. Revelle, recommended that tube wells and drainage canals be installed to permit aeration of the root zone and the flushing of the accumulated salts. This has lead now to a positive export balance again.

In addition to the wells drilled by the Pakistani Government, the farmers have also installed wells at their own cost, from $1500 to $2000 per well. Since these wells paid off in about two years as promised, farmers have been willing to consider and carry out this self-improvement program. This demonstrates, contrary to a widespread notion, the willingness of farmers, even in underprivileged countries, to accept innovations and change when the potential benefits are large enough.

I am only touching on some of the many and complex factors in the whole food improvement picture. Figure 3 puts this all together, perhaps not very clearly. The modern farm, from which the developed countries get their food, makes use of a wide range of inputs—services of many kinds, irrigation systems, fuel and machinery, refrigeration equipment, and so on. It even buys food from retail outlets. The processing of its raw products is done outside. The subsistence farm, on the other hand, has very little outside assistance available to it, and when we compare farm worker productivities we probably should count in all this outside manpower on which the modern farm depends.

In discussing what needs to be done to make subsistence farming and the entire economy more productive, the PSAC study concludes that "The scarcest and most needed resource in the developing countries is the scientific, technical, and managerial skill needed for systematic, orderly decision-making, and implementation." The task to meet even minimum nutritional targets is a large one. This is perhaps best seen from the following comparison: between 1935 and 1962, 21 underdeveloped countries averaged a 0.3 percent annual increase in beef, corn, and rice production. But PSAC suggests that a 4 percent growth rate is necessary over the next twenty years to meet these targets,—an order of magnitude change. The projected capital cost to achieve this for all underdeveloped countries runs to $80 billion over the next 22 years. Of this India requires $30 billion, primarily for irrigation (10), machinery (6.2), trucks (4.5), and fertilizer (3.3 billion dollars).

As Dr. Preston pointed out already, this calls for a 5.5 percent growth rate in these countries' national economies in order to expand the required infrastructure. Dr. Revelle has estimated a $20 billion capital infusion per year, including native capital, to meet this challenge.

EARTH'S FOOD POTENTIAL

Some time ago Professor Isaacs and I looked into the natural capacity of Earth to produce organic matter. The estimates, portrayed in Figure 4, are divided into a marine and terrestrial portion. Despite the land's 1 : 2.5 areal disadvantage, it seems to outproduce the sea. Actual plant and animal harvests are indicated for both realms, and in the sea's case compared with a potential that is equivalent to the productivity at the first carnivore level. It is doubtful that this potential will ever be approached by the fisheries because of the organisms' wide dispersion, unless extensive high-seas cultivation would become feasible in the future.

In Table 3 are listed a few maximal aquacultural yields under a variety of conditions. The extremely high figure for mussels includes, of course, the weight of their shells. If we compare these yields with the rate of harvesting Peruvian anchovy, which at 350 kg per hectare annually is the most prolific gathering operation in the world, we see that improvements by an order of magnitude may be possible in favorable areas.

The inferior position of the marine plant harvest (Figure 4) is of course due to the generally small size of marine plants and their relative indigestibility for man. In the center of the figure the dietary demand by an eventual world population of 10 billion are sketched in for perspective.

There appears to be ample room for increasing natural productivities since sunlight is inefficiently utilized. For instance, I have elsewhere [2] calculated that after all physical limiting factors save solar radiation would be ameliorated, conventional agriculture has a tenfold potential for product expansion. In this, full pest and disease control would double crops, fertilization also two times, shifting some pasture and technical cropland and using potentially arable land, at least 1.5 times; irrigation competently applied, 1.7 times; and reducing losses in processing, storage, and transportation by half, 1.2 times. In such efforts the principle of synergism should be observed, which says that the combined benefits of these measures are greater when applied simultaneously than when applied separately.

I have left out of this consideration the cultivation of tropical soils, particularly in the rain forests and in the adjacent areas that have some dry season, because its technology is not yet fully mastered. When eventually applied—and this depends perhaps primar-

[2] Schmitt, W. R. 1965. The planetary food potential. Annals, *New York Acad. Sci.* 118(17): 645-718.

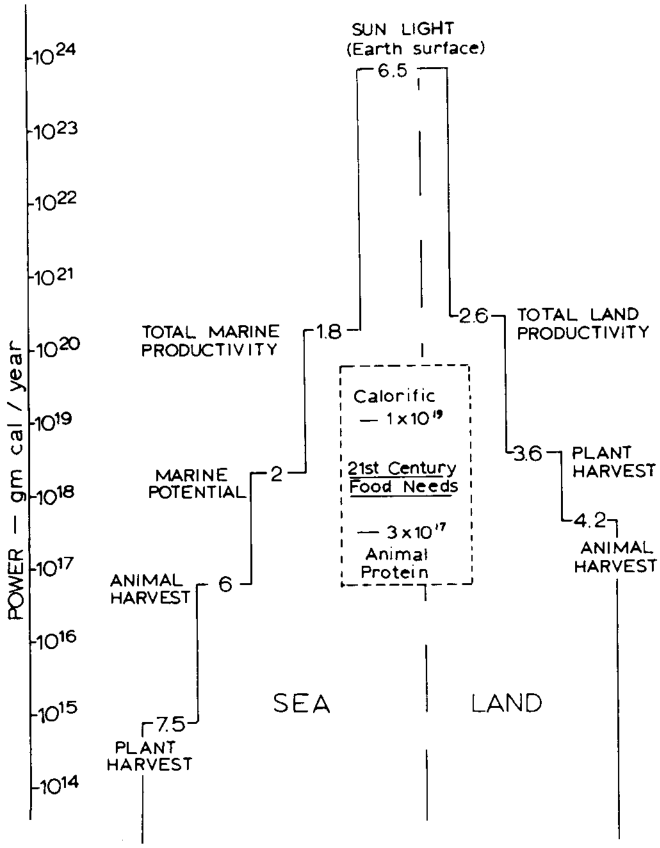

FIGURE 4. Marine and terrestrial food energy.

ily on providing roads and trucks, supplies, comfort and health, etc., through a high degree of infrastructure—these areas alone might double the present world food production.

THE PROTEIN PICTURE

In the last section I would like to examine in some detail what can be done to upgrade protein nutrition where deficient. Lack of a good amino acid balance leads to grossly impaired health with withering limbs and bloated belly, as we see in the picture in Figure 5. On the right is the same child one year later, having received a proper diet including protein from fish. Of course, you can't see what she really looks like under all of this prettifying paraphernalia: smile, clothing, even the tricycle seems to come along with the protein.

The names given to conditions of malnutrition are quite descriptive. *Sugar babies, Annam obesity,* and *weaning damages* speak for themselves. *Kwashiorkor* is an African word meaning red baby. Dr. Alvariño and I reviewed a film made in Guatemala for possible showing tonight that deals with malnutrition in that country. This movie actually did not make a point of animal protein shortage there, but rather charges the incidence of malnutrition to dietary ignorance. Three families are portrayed, a poor one from the country, two from the city, one poor and one middle class. All babies do well until they are weaned. After that the last family is o.k. because it is nutritionally informed. The poor city family also gets by because medical attention eventually arrests incipient trouble. But the

TABLE 3

Selected Ranges of Aquacultural Yields Per Year

(In Kilograms Per Hectare and Dollars Per Hectare, Except as Noted)

Type of cultivation	Location	Yield	Approximate wholesale value of annual crop
Oyster			
Common property resource (public grounds)	United States	9	38
Intensive cultivation, heated hatchery, larval feeding	United States	5,000	21,000
Intensive care, hanging culture	Japan*	20,000	23,100
Mussels			
Intensive care, hanging culture	Spain*	300,000	49,000
Shrimp			
Extensive, no fertilization, no feeding	Southeast Asia	1,000	1,200
Very intensive, complete feeding	Japan	6,000	43,000
Carp			
Fertilized ponds, sewage ponds	Israel	500	600
	Southern Germany	500	
Fertilized ponds, accessory feeding	Israel	2,100	
Sewage streams, fast running	Indonesia*	125,000	
Recirculating water, intensive feeding	Japan	100†	114†
Catfish			
Ponds, no fertilization or feeding	Southern United States	200	70
With fertilization and feeding in slowly flowing water		3,400	2,400 (net profit 300)
Milkfish			
Brakish ponds, extensive management	Indonesia	400	
With fertilization and intensive care		2,000	600
Trout			
Cement raceways, intensive feeding, rapid flow	United States	170†	168†

* Values for raft culture and comparable intensive practices based on 25 percent of the area being occupied.
† Per liter per second.
From Bardach, J. E., 1968. Aquaculture. Sci., 161 (3846):1104.

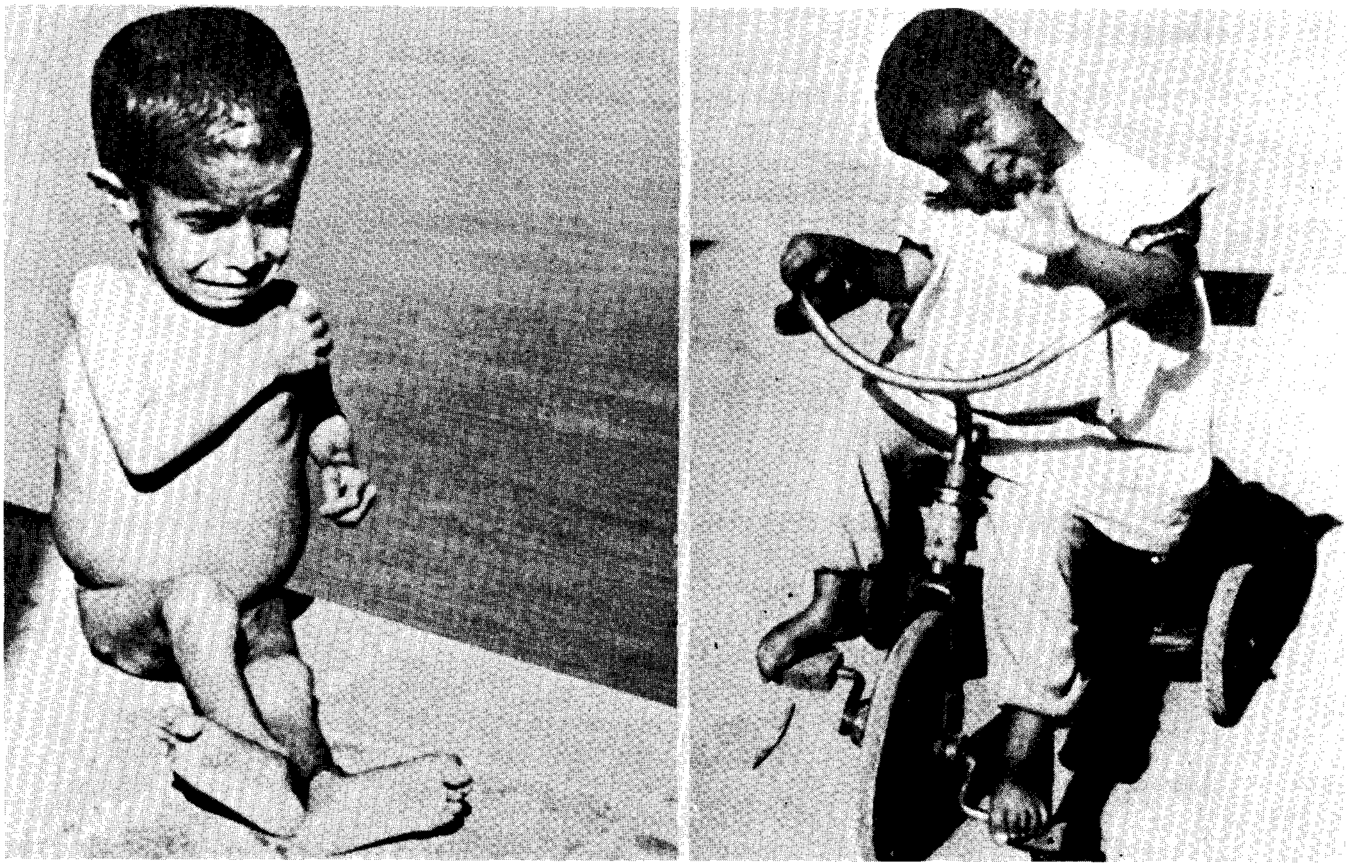

FIGURE 5. One year of proper diet, including protein from fish, separates these two pictures of the same girl in Iran. *From* Jebsen, J. W. 1962. Fish in nutrition. *Ed.* E. Heen and R. Kreuzer. Fishing News (Books), London.

rural family has neither dietary savvy nor help of any kind, and when the weanling develops spotted limbs and diarrhea from its almost purely starchy diet, it is taken off food entirely.

The difference between the protein value of various food stuffs is nicely demonstrated in Table 4 on essential amino acids (AA) contents. The standard used here, egg protein, is pretty ideal though unnecessarily high in methionine and cystine (not shown). If no make-up AA were available during the same meal time, one food's protein would be utilized only to the level of its minimum AA component—beef 70, fish 79, soybean 53, and so on. This then imposes an additional metabolic load to excrete everything above that value which the already malnourished person can ill afford. Unfortunately, this is too often the case. For foodstuffs in combination, the benefits are considerable. You can readily see from this list that fish and rice give a very fine AA balance.

TABLE 4

Percentage of Ideal Concentration of Essential Amino Acids Observed in Typical Proteins [1,2]
(Using Egg as 100 Percent)[3]

Foodstuffs	Histidine	Threonine	Valine	Leucine	Iso-Leucine	Lysine	Methionine	Phenyl-alanine	Tryp-tophan
Beef	157	90	73	87	84	141	84	70	92
Fish muscle	124	96	86	106	105	148	100	79	109
Soybean meal, low fat	138	80	76	89	97	111	53	95	127
Whole rice	81	78	88	91	84	52	106	89	118
Whole wheat	100	67	62	78	64	44	78	91	109
Cottonseed meal	128	61	69	67	64	57	53	107	118
Whole corn	119	76	76	167	103	38	97	89	55
Peanut flour	100	57	66	79	66	57	25	88	72
Dried roast beans	104	79	78	78	89	106	62	89	73
Sesame meal	106	81	67	70	63	38	53	78	93

1 Data mainly taken from Hopper, T. H., Amino acid composition of foodstuffs. *In:* Altschul, A. M. (ed.) Processed plant protein foodstuffs, New York, Academic Press, 1958. 955 p. pp. 877–891.
2 Data mainly taken from Heinz (H.J.) Company. The Heinz handbook of nutrition: a comprehensive treatise on nutrition in health and disease. Rev., 2d ed. New York, McGraw-Hill, 1965. 462 p.
3 *From* "The World Food Problem" V. II, p. 315. The White House. U.S. Govt. Printing Office, Wash., D.C., May, 1967.

TABLE 5

Major Oilseeds Used as Food

Species	Botanical Name	Protein Content (Av.), %	Oil Content (Av.), %	World Production, 1000 Metric Tons	Major Producing Countries	Problems in Processing as Food
Soybean	*Glycine max.*	42	20	35,000[a]	U. S., China	Antitrypsin factors Hemagglutinin factor
Peanut	*Arachis hypogea*	27	48	14,800[b]	India, Senegal, Nigeria	Aflatoxin
Cottonseed	*Gossypium*	30	30	20,600[b]	U.S., India, USSR, Mexico, UAR, Brazil, Pakistan	Gossypol, malvalic acid, aflatoxin
Sesame	*Sesamum indicum*	25	50	1,500[b]	China, India, Sudan, Mexico	Fiber, oxalate
Sunflower	*Helianthus annus*	30	40	6,840[b]	USSR, Argentina, Uruguay, South Africa, Turkey	Fiber
Coconut	*Cocus nucifera*	8[c]	65[c]	3,200[b, c]	Philippines, Indonesia, Ceylon, India, Malaysia	Fiber

[a] Estimated for 1965.
[b] *(6)*.
[c] Dried meats (copra).
From Milner, Max, 1966. World Protein Resources. Am. Chem. Soc., Wash., D.C., p. 54.

Supplementing the three staples shown here with oilseed meals is moderately beneficial. This is, of course, the basis of a truly vegetarian diet, but I suspect that many vegetarians are kidding themselves and us in that they accept such animal products as eggs, milk, and its derivatives, even sea food. The use of oilseed for food is quite a big business, as is evident in Table 5. Some 80 million tons, containing 24 million tons of protein, or about one quarter of the total protein demand, are globally produced for this purpose. The oilseed products are sold for 12–40 cents per pound of protein, not exactly cheap. Some also contain toxins in troublesome concentrations, requiring costly extraction and posing problems of food adulteration if fortification levels are high. Despite such drawbacks, they have won wide acceptance. An estimated 10 percent of the Japanese' protein intake is supplied by various soybean meal products named Tofu, Miso, Shoyu, and Natto. Perhaps one-tenth of the Indonesians eat 100 grams per day of Tempeh, also made from soybeans. A similar portion of Guatemalans use Incaparina, a protein meal made from cottonseed under United Nations auspices, either occasionally or regularly. And in Hong Kong, a soft drink, Vita soy, with 6 grams protein to the bottle and vitamin enriched, has captured 25 percent of the soft drink market even though it tastes like liquid library paste.

We in fish research are, of course, partial to another high grade protein supplement, namely MPC, or FPC as it is more widely known. The objectives of MPC are twofold: first, to supply an inexpensive high grade protein of wide versatility to malnourished people, and secondly, to utilize for food marine species not in great dietary demand. Although MPC is not yet in commercial production, it is clear that it will not be competitive with other protein products, as from oilseeds, for instance. It is also facing resistance on culinary grounds. MPC would, however, extend fishing pressure to presently unwanted species and thus achieve a desirable ecological balance that would be requisite if the marine potential in Figure 4 were to be approached. Already, severe dislocations among many exploited fish stocks are apparent, as we will hear from Dr. Chapman.

Referring back to Figure 5, we see lysine particularly deficient despite methionine's negative bias. Lysine is now being produced by fermentation with select microorganisms on substrates of molasses and corn steep liquor. This process has replaced a purely synthetic chemical approach. However, some of the other AA are chemically synthesized. Total world production figures are unavailable; in the United States in 1964 about 3000 tons of AA were manufactured. They are selectively added to certain foods and feeds staples. AA fortification not only allows exact tayloring of proteins, but may well be cheaper than supplementation with MPC or SBP (soybean protein). The PSAC people report that at 25 cents per pound MPC, 15 cents per pound SBP, and $1, $1.5, and $2 per pound of lysine, threonine, and tryptophan, selective AA fortification of rice, wheat, and corn is 30 percent cheaper than MPC supplementation and ten percent cheaper than that with SBP. There is, moreover, impairment of the staple's flavor and functional quality if MPC exceeds six percent and SBP two percent.

By far the most exciting development with respect to AA balance has been the breeding of two corn varieties—Opaque 2 and Floury 2—that are double in lysine and 1.65 times in tryptophan. Children, fed a diet with Opaque 2 corn as sole source of protein at 2 grams protein per kilogram of body weight daily, retained nitrogen as well as a control group using skim milk for protein. I think that such genetic enhancement of AA balance is at least as potentially beneficial as the recently developed dwarf varieties of wheat (in Mexico) and rice (in the Philippines) for high yield and sturdiness.

There are a few other ways to expand the protein supply that I want to mention briefly. For one, we have what collectively can be called Single Cell Protein, that is yeast, bacteria, or fungi cultures utilizing all manner of organic and inorganic substrates. Laboratory work with cultures has made us aware of their enormous capacity for growth, but in practice we encounter unsolved problems of production, processing, and nutritional quality. Also, at 20 to 40 cents per pound of protein, these proteins are not competitive with more palatable preparations. More expensive yet are algal proteins, as that from chlorella at 70 cents per pound when cultured pure, and even then questions remain with respect to digestibility, palatability, and toxicity. Sewage has been considered as substrate of algal cultures and would bring down the cost sharply, but such products would not be suitable for direct human consumption. Rather, we could envision algae as an intermediary link in a double symbiotic system such as shown in Figure 6. Here the output is in conventional products, at the same time that the primary objectives, sewage treatment, water re-use, and recycling of nutrients, become achievable.

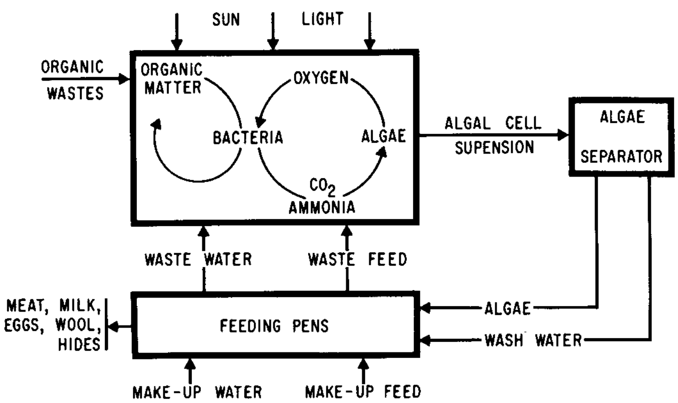

FIGURE 6. Algal culture linked with livestock feeding pens. *From* Schmitt, W. R. 1965. The planatary food potential. *Annals New York Acad. Sci.* 118:696.

Some research is now being directed toward the extraction of leaf protein through pulping and pressing. The cost seems to be quite reasonable at around ten cents per pound of protein; however, their acceptability is not well known.

Most of the protein supply measures I have discussed thus far involve human intervention in varying degree. There are situations in which the opposite approach can be more fruitful. In the tropical lands of Africa, for instance, the husbandry of temperate zone livestock is often plagued with animal diseases (e.g., rinderpest) to which the imported animals are more susceptible than the native game. Returning the range to the latter, especially ungulates, while exercising a modicum of range management, can not only increase the yield despite the game's generally smaller size, but also be quite profitable. A 50-square mile area in Rhodesia was harvested of 60 tons of game at a £3200 profit. The same area's cattle potential is estimated at 50 tons at £500 profit.[3] In this way the high losses to disease (30 to 40 percent) could well be halved for a 25 percent increase in animal protein, possessing higher meat quality and traditional acceptance. And most of the work with urea-fed cattle should be equally applicable since most of the game species of interest are ruminants. Africans, incidentally, make the most efficient use of these animals' protein by milking and bleeding them. For the world, milk is the single largest source of animal protein and accounts in part for the toleration of the Indian cattle.

How successful novel approaches toward better protein nutrition will be depends on many factors. Supply is not enough. In the underdeveloped countries, which all lie in tropical or subtropical climates, better systems of cultivation, harvesting, processing, distribution, storage, and marketing must evolve. If I were to single out the, to my mind, most promising way to combat malnutrition speedily, it would be AA fortification of cereals and/or genetic breeding for AA balance. The malnourished, largely vegetarian peoples would, I think, readily accept such an improvement and might even remain unaware of it culinarily.

CONCLUSIONS

Perhaps some alarm about the world food situation stems from an underestimate of our globe's tremendous physical potential for food. I have indicated this to be at least ten times the present utilization. With the exception of rainforest and high seas cultivation, the technology for food expansion is well in hand. Also, historically, food production has kept pace with population advance, by and large. However, the latter is now so rapid that only the economies of developed countries can meet the necessary rate of expansion. Since populations in the underdeveloped countries grow faster yet, and at the same time lack a sound economic base, they are doubly penalized. We are thus faced with a distribution problem, not so much in physical resources as in capital, skills, attitudes, infrastructure, and so on. The attainment of these under adversely high and still accelerating population growth rates is the world's principal dilemma and is not likely to succeed without drastic birth rate limitation. What the underdeveloped countries must do in the agricultural and economic sectors, Roger Revelle, now Director of Population Studies at Harvard, sums up in this way:[4]

"If the people of the poor countries are going to get enough to eat, they must practice market-oriented agriculture; and there must be overall economic development. They cannot concentrate, as they have always done in the past, on the relatively simple problem of improving subsistence agriculture. They must urbanize, industrialize, develop their entire economies. At the same time they must create the research and teaching institutions, the transportation and communica-

[3] The World Food Problem, V. II, p. 269. The White House, May, 1967.

[4] Revelle, R. R. 1968. International Cooperation in Food and Population, International Organization, 23(1): 366.

tions systems, the incentives for farmers, and the social conditions required for modern, scientifically-based agriculture.

"These are not problems that can be solved in a year or ten years. The solution will take at least two generations. They must be approached not as in the past with short-term, quick payout programs or with gimmicks of various kinds, but with realistic, long-continued, large-scale action. Any review of these problems shows that they cannot be solved without very great contributions from the developed countries."

In all this nothing has been said about pollution or environmental degradation. In its global aspects this is a fairly recent concern. An expanding world agriculture, employing fertilizer and pesticides as intensely as Japan or Germany do, and the pollution peril from the accompanying industrialization, will certainly multiply the present dangers to the world's ecology. The mode of attack that R. Revelle inveighs above in the interest of viable peoples and economies will need to incorporate strong environmental safeguards in order to maintain a viable planet.

DISCUSSION: Walter R. Schmitt—WORLD FOOD

Discussant: Professor John D. Isaacs

Isaacs: In listening to Walter's excellent presentation and in relating it to the remarks of the first speaker, Dr. Preston, I have been attempting to put in mind just what is the position of the scientist in these problems. It is very much, I think, as we have found in the research on the fish of this coast. We can show what is scientifically possible, the engineer and technologist can show how to do it, and then whether it is done results from a different set of inputs and a different set of people involving economic, political, social relations, and a whole bevy of other matters. In this case that Walter has discussed, the scientist can show what is the potential of a planet to support people. The engineer, that is the agricultural technologist, food technologist, etc., can show how it can be done. Whether or not it is done is quite outside of the control of the scientist or technologist.

The scientist and technologist produce a degree of assurance that there are openings and potentials. The better the scientist documents the potential, the more pressure there develops for these things truly to be done. The more there are mistakes of advice the more uncertainty and reluctance is generated in the undertaking of new developments.

So, I think that the major scientific input into resource utilization is overall assurance and guidance. Of course there are also the many scientific aspects involved in the individual steps of putting developments into operation. The scientific product is thus assurance, and this assurance for obvious reasons should be as strong, meaningful, and unequivocal as possible. Where the scientific input is not, humanity is done a disservice. One way that a disservice is done is to be proven demonstrably wrong by lay people. As members of an advanced western society, U.S. society, scientists often tend to take a "holier than thou" attitude, as though lay people really don't know anything about their own problems. I am impressed by the occasions when simple people have shown surprising insight. As an example, there are a number of cases where they have not continued to accept and cultivate hybrid corn for the very good reason that the groups of hybrid corn that were introduced mainly increased the yield of starch rather than protein and hence were precisely what was not needed. These people recognized this deficiency though perhaps through not very sophisticated scientific tests—the flour didn't hang together to make good tortillas or something of this nature—so they went back to their own native seed. We have seen here today that the starch component of some of these hybrid corns has principally been increased, not the protein, and we should be impressed that these native people recognized that before we did.

There is abundant evidence that the customs of natives may be of very profound significance. A friend of mine who spent some years in Egypt tells a remarkable story of dead donkeys there. I will briefly relate it. He became curious that he never saw a dead donkey in Egypt, as there were plenty of donkeys, and they surely were not eaten. With much difficulty he broke through the communication barriers, which exist to the scientist in all these countries in talking to the man in the field. It slowly and finally developed that there was a great tradition about dead donkeys, and he discovered that these people clearly knew much about trace element chemistry. There was a ritual in which the rib cage was put under the plants that obviously suffered from conditions now known as resulting from phosphate deficiencies; the liver was put under the plants that showed the symptoms of copper deficiencies; the flesh was put under those with nitrogen needs, and so on even to the genitals for the plants that suffered sulphur deficiency. So for more than 2000 years these people in Egypt have practiced trace element chemistry in their agriculture.

When I look at these lists of foods and their amino acid contents, I wonder if perhaps some of the simple processing of foods broadens the amino acid spectrum.

As you know, herbivorous animals convert the vegetable protein into the full range of amino acids that we have been discussing as "animal protein," but they do not do this solely by themselves. The principal synthesis is carried out by symbiotic microorganisms in their digestive tract. These and other microorganisms are quite capable of manufacturing "animal protein."

Perhaps the human race, in developing foods that have been acted upon by microorganisms, such as fish sauce, poi, leavened bread, etc. have partly compensated outside of their bodies for their poverty of inner symbionts. We perhaps should look at these as sorts of symbionts external to the human digestive system which aid in protein conversion. I see little evidence that we have considered it possible that people developed these fermented foods for the very real purpose of improving their amino acid intake, and I believe that most of the analyses of diet are of the input food material rather than of the finished products. Perhaps the primitive chefs are better than we think, and the introduction of baking powder has been sinful.

Of course, finally looking at the examples of how we should not develop a "holier than thou" approach, we have our own nutritional illogic and problems, as everybody knows, while we eat our eggs, drink our milk, and put ourselves into early graves with our own American sacred chickens and cows and our own sacred dairy industry. The picture of the healthy American person is a rosy-cheeked individual with high blood pressure, atherosclerosis, and a big glass of enriched milk in his hand. Clearly we would be more sensible and much better off, and anybody from India or any other country whom we advise could argue this, that the sensible thing to do would be to catheterize our cows and drink blood rather than the milk. The dairy industry could be changed over instantaneously to deliver bottles of warm blood each morning for breakfast. I believe that regardless of the logical case that could be made for us, say by some of the nations *we* are advising, it is quite possible that we wouldn't like that. We have our own "sacred cows." Looking at these other countries then, we must realize that there are things that they don't like even though they are logical. We die prematurely and illogically well-fed, while others die prematurely and illogically ill-fed. I am, of course, not arguing against helping where we can. We should consider such help of extreme importance, but I *am* arguing that we should enter such advice with a consciousness that the food customs may have more meaning than is immediately apparent, and that much more enters into these matters than logic. We are not in a strong position when it comes to logic, ourselves.

Chapman: I was caught by the modern farm and all the things around it. I think this points out a lesson that we don't always abide by, that when you take the modern farm and transplant it into a society where all the little gimcracks are not available, it doesn't work worth a darn and this applies to a modern fishing boat and applies to a lot of other modern things. Take it out of context in which it is developed and used very efficiently and put it into another social context, it doesn't work well at all.

Isaacs: Walter pointed that out. It is an important factor that you have emphasized. I wonder if there is a kind of biogenetic law in these developments also, that in the ontogeny the phylogeny must be recapitulated. As you try to introduce modern developments into Pakistan, for example, it is clear that you just can't superimpose them on the country—there has to be some sort of a shorthand repetition of the kind of development our forefathers went through.

Longhurst: This is being brought out by people like Duboise looking at the African agricultural economy where they maintain that what they require first is buffalo rather than tractors. Walter, in your tabulation of power available for agriculture in these various places, has anybody taken into consideration animal power in agriculture?

Schmitt: Yes, the PSAC Study gives such a breakdown. Of the world average of .36 hp/ha, 12% is animal power and 7% is human power, while in Asia it is 50% and 25% respectively. These range from practically nil/nil in the United States to 23% and 42% in Taiwan and 69% and 27% in India, respectively.

Isaacs: In regard to the totality of the development being the difficulty, in Pakistan it isn't adequate just to throw some fertilizer on the ground, you must apply more water. As soon as these are done, you get weeds, and the native crops are incapable of competing with weeds. Now with all the weeds, you have to cultivate intensively. To do this, crops must be in rows. Thus you can't hand broadcast the seed, so you must have seeders, and improved seed, then herbicides and insecticides, and on it goes. Everything really, as we have developed it in our society, has to go together. You can't start out with one single part effectively.

Mackett: You mentioned it would take an investment of $80 billion to modernize subsistence agriculture. Was this annually?

Schmitt: No, this was a 22-year total. It would require about $300 million a year initially, rising to $4 billion a year at the end of this phase. This is in an attempt to meet the minimum nutritional targets over this period. It also allows for population growth and infrastructure development in the underdeveloped countries.

Chapman: This sort of a figure has no meaning to business people. For instance, what is the pay out? What are you likely to get in return for the capital? You can quite easily take $25 million and build a good size fishery and have your $25 million back at the end of 10-12 years.

Schmitt: I don't think that we can apply in an aid program the usual profit yardstick. A viable world cannot be maintained on gross disparities of living standard, especially not at a time of instant communication. The rich countries are still exploiting the poor through adverse trade, and the gap is widening. While per capita income expressed in dollars is not a good measure of living standards on account of artificial exchange rates, I think we are agreed on the need for full money market economies in place of subsistence economies, and this requires massive infusion of low-profit capital. Perhaps this can only be accomplished with a world currency or full currency convertibility.

Ahlstrom: I was wondering about some of the projections you made for the future, the rapid drive of urbanization that is picking up land for freeways and for peoples' cultures. Has this been projected? This is going to take an awful lot of good land.

Schmitt: No, I don't think this has been accounted for. But perhaps with the increase in soil knowledge, one can reclaim or put to use some of the marginal lands that have so far not been included in the potentially arable land category.

Chapman: I would like to see some of the data that backed up this business of withdrawal of land versus desirability of urbanization. As an example, the whole Los Angeles area was worth nothing—it was made fruitful and then urbanized, but you certainly can't feel that Los Angeles was hurt very much agriculturally.

The area in the northeast corridor, very poor land covered with scrub forest, is being scraped and made into suburb, and I am not sure the suburb won't be a better use for it.

Schmitt: I think Benny Schaefer, in a discussion, made a good point with respect to land use. As long as an outside supply of food is available, the best land use is industrialization. The profits generated by such an operation can buy more food than can be grown on any particular piece of land.

Isaacs: I have been astonished by two cases:

(1) Everybody shouted how disastrous it was to mine the water around the region of Phoenix and after what actually happened it became clear that this was what they should have done. Now Phoenix is there and they have an industrial city which draws in water from other and more expensive sources.

(2) In the case of Pakistan the British knew perfectly well a hundred years ago that they had to put in an adequate drainage system, otherwise if agriculture continued they would develop water logging and salination. Economically you could not put in these drainage systems at the outset. It was not profitable. Pakistan did not become an industrial nation.

How do you predict all of this? One case should have carried on despite this apparent disruptive disastrous approach, and in the other one, a disaster actually developed. We are in a quandary; we can't be overly conservative in these matters but we also must! I have no answers.

Thank you very much, Walter.

Calif. Mar. Res. Comm., CalCOFI Rept., 14:43–56, 1970.

WORLD FISHERIES

WILBERT McLEOD CHAPMAN

The subject given me to discuss, World Fisheries, is delightfully broad and vague. The subject can be treated from numerous viewpoints. I intend to touch on several of these viewpoints in a cursory manner and then speculate a little on the future, some of the problems that it may bring, and some solutions that may be applied to those problems. All of the Statistics cited come from Yearbook of Fishery Statistics, FAO, Vol. 23, Fishery Commodities 1966 (1967) and Vol. 24. Catches and Landings 1967 (1968).

World catch of aquatic products is recorded by FAO in terms of round live weight of fish and shellfish in metric tons, with whales excluded, and this format is generally followed by writers and speculators on the subject. I will follow it too. It should not be forgotten, however, that whales of all sorts are still caught in substantial numbers. Of the large whales (blue, fin, sperm, etc.,) FAO records 51,593 taken in the 1966/67 season; of the smaller whales (minke, pilot, etc.), 7,951 in 1967, and of dolphin, porpoise, etc., about 7,000 tons. Thus, in terms of live weight, the total whale catch may still come to somewhere between 1.5 and 2.0 million metric tons, which amounts to about the same level as the total world yield of fish and shellfish in 1850 as estimated by Moiseev (1965). While the main product from whales is still edible and other oils, whale meat has been increasingly used since the end of World War II for direct human consumption and otherwise, especially in Japan.

The world fish catch approximately doubled to four million tons by 1900 and reached about 9.5 million tons in 1913 before the outbreak of World War I. This was the period of introduction of the steam engine to larger fishing craft and the development of the otter-trawl, particularly in the north-east Atlantic. In most of the world fishing remained on a subsistence basis.

There was material interruption in fish production, particularly adjacent to Europe, during World War I and recovery and growth were slow, being still about 10 million tons in 1932 (Meseck, 1968). Growth in production was then rather rapid until the outbreak of World War II, reaching about 21 million tons in 1938. This was the period noted for the expansion of use of internal combustion (and particularly diesel) engines in fishing vessels, the use of ice on a large scale at all levels in the fish trade from vessels at sea to the retail store, the beginning of freezing at sea, the large-scale manufacture of fish meal and its use in animal husbandry, substantial increases in the canning of fish in hermetically-sealed containers, and expansion in world trade of fishery products with increased ease of transportation not only at sea but internally in the developed countries of the northern hemisphere.

Again, there was an interruption of fish production during World War II, with it sinking to perhaps 15 million tons during the peak of hostilities (or lower, the statistical systems being disrupted also), rising back to 18 million tons in 1947 (Meseck, 1968) as nations rebuilt their fisheries as rapidly as they could, and then back to the 1938 level in 1950, when 21.1 million tons were landed.

There then began an unprecedented rise in world fish production. By 1960 world landings had very nearly doubled, to 40 million tons, in 1965 were at 53.5 million tons, and in 1967 had reached 60.5 million tons.

This was the period when a great many innovations came into the fish trade at all levels. These included widespread freezing of fish at sea; extensive use of the diesel engine in fishing vessels; the widespread use of synthetic fibers in webbing, ropes, etc.; the rapid extension of various acoustic devices for locating fish; the use of hydraulic power on vessels through winches, power blocks, line haulers, to markedly reduce physical labor inputs at sea. At the processing end machinery was introduced to fillet, skin, and dress fish mechanically at sea and ashore; automatic filling machines were adopted with much improved efficiency growing also in other parts of the canning line; sharp freezing processes, with improved machinery, became widespread; machinery for fishmeal manufacture became much improved and diversified, as did the whole fish-meal producing business, including economies of size. In transportation and merchandizing, shipment of frozen goods on a worldwide basis became commonplace, air transport of high-unit-cost delicacies began, bulk shipment of fish meal commenced, and the marketing of fish at the wholesale level gravitated to larger and firmer hands. Technological change is still moving swiftly through the fish trade, as it is through most of the rest of the economy, with resultant improvement in quality and diversity of product at lower relative cost.

PRODUCTION BY REGIONS

Fish and shellfish production has increased by different rates and magnitudes in different regions of the world. This will be traced only since 1957, which is the period most marked by change.

In Oceania production has gone from 110 to 200 thousand tons in the past ten years, but still amounts to only about 0.3 percent of the world production.

Production in Africa has increased from 2,130 to 3,739 thousand tons in this period but its share of total world production has decreased from 6.4 percent to 6.2 percent.

Production by U.S.S.R. is larger than for all Africa and has increased from 2,621 thousand tons in 1958 to 5,777 thousand tons in 1967. Russia's percentage of total world catch in the same period has increased from 7.9 percent to 9.5 percent.

Production in North America has stayed reasonably constant, being 3,990 thousand tons in 1958 and 4,300 thousand tons in 1967 (it had reached 4,490 thousand tons in 1962). North America's share of world catch has shrunk from 12 percent in 1958 to 7.1 percent in 1967.

The sharpest increase has been achieved by South America, where production in 1958 was 1,630 thousand tons and in 1967, 12,140 thousand tons. South America's share of world catch increased from 4.9 percent in 1958 to 20.1 percent in 1967. The increase came mostly in Peru and Chile.

European catches have increased steadily in the period from 7,750 thousand tons in 1958 to 11,820 thousand tons in 1967 when, for the second time, it fell behind South America. Europe's share of world catch has actually dropped from 23.4 percent in 1958 to 19.5 percent in 1967.

The great expansion in world production has been by Asia whose catches went from 14,940 thousand tons in 1958 to 22,580 thousand tons in 1967, but Asia's share of the world catch fell from 45.0 percent in 1958 to 37.7 percent in 1967. This was because of the great surge forward in South American production.

PRODUCTION BY SEPARATE NATIONS

The production of fish and shellfish by country is extremely skewed toward the high producers. In 1967 the biggest producer (Peru) took 17 percent of the world catch and the largest two (Peru and Japan) took 30 percent between them. The largest five fish producers (Peru, Japan, Mainland China, U.S.S.R., and Norway) took 54 percent of the world catch, the next five largest producers (U.S.A., South and South West Africa, Spain, India, and Canada) took 13 percent of the catch, and the third five largest producers (Indonesia, Denmark, Chile, U.K., Iceland) took 8 percent of the world catch. Thus about 11 percent of the countries of the world accounted for about 75 percent of the world production of fish and shellfish in 1967. The catches of these fifteen countries are set out in Table 1. The figures for Mainland China are FAO's best guess, not reported on by the nation since 1958, and then probably on an inflated basis. The catches cited by Indonesia do not have a secure statistical base. The other statistics are probably pretty accurate. They are, at least, all that are available.

TABLE 1

Landings of Fish and Shellfish by 15 Major Countries, 1967, Metric Tons, Round Weight

Peru	10,110,200
Japan	7,814,000
M. China	5,800,000 (1958)
U.S.S.R.	5,777,200
Norway	3,214,000
Subtotal	32,715,400
U.S.A.	2,384,100
S. and S.W. Africa	1,664,400
Spain	1,430,600
India	1,400,400
Canada	1,289,800
Subtotal	8,149,300
Indonesia	1,201,800 (1966)
Denmark	1,070,400
Chile	1,052,900
U.K.	1,026,100
Iceland	896,300
Subtotal	5,247,500

PRODUCTION BY SOCIAL AND ECONOMIC CLASS

Writers, and the United Nations apparatus, divide the countries of the world roughly into two categories, which are called developed or developing, industrialized or underdeveloped, rich or poor, or some such suitable pairing of terms. An examination of this dichotomy quickly establishes the fact that it is not the industrialized countries, which were the strong fishing countries of the pre-war period, that are developing their fish production most rapidly in the post-war period.

If production statistics for ten of these industrialized countries of Europe and North America (U.S.A., U.K., Germany, France, Canada, Netherlands, Italy, Denmark, Belgium, and Sweden) are combined it will be seen that their total production in 1938 was 6,423.6 thousand tons; in 1958 7,367 thousand tons; and in 1967 8,106 thousand tons, giving in 1967 a 9 percent increase in the previous ten years, and a 24 percent increase over the preceding thirty years (Table 2).

On the other hand if one takes the catch of thirty countries of the developing world combined (Morocco, Senegal, Ghana, Sierra Leone, Tanzania, Uganda, Zambia, Liberia, Madagascar, Cuba, Mexico, Panama, Argentina, Chile, Colombia, Guyana, Peru, Venezuela, Ceylon, Taiwan, Hong Kong, India, Indonesia, Korea, Malaysia, Pakistan, Philippines, Thailand, South Viet Nam, and Poland), it will be found that they were 5,915.7 thousand tons in 1958, and ten years later were 20,973.3 thousand tons, nearly a quadrupling. Since these statistics include those of Peru and Chile (both developing countries) where fish production has increased extraordinarily, it might be felt that this comparison was slanted. If the catches of those two countries are removed from both the 1958 and 1967 columns, the combined catches of the remaining countries is 4,928 thousand tons in 1958 and 9,810 thousand tons, or nearly a doubling in ten years, which is considerably better than the highly industrialized countries have done (Table 3).

TABLE 2

Landings of Fish and Shellfish in Selected Industrialized Countries, 1938, 1958 and 1967, Metric Tons, Round Weight

Country	1938	1958	1967
U.S.A.	2,360,100	2,703,400	2,384,100
United Kingdom	1,198,100	999,000	1,026,100
Germany	777,200	725,400	661,500
France	643,600	611,800	820,000
Canada	838,600	1,007,600	1,289,800
Netherlands	256,200	313,800	314,600
Italy	181,000	245,700	337,300
Denmark	97,100	598,000	1,070,400
Belgium	42,500	64,000	63,900
Sweden	129,200	238,000	338,300
Totals	6,423,600	7,367,000	8,106,000

TABLE 3

Landings of Fish and Shellfish in Selected Countries of the Developing World, 1958 and 1967, Metric Tons, Round Weight

Country	1958	1967
Morocco	172,700	258,000
Senegal	85,900	173,700
Ghana	30,900	110,100
Sierra Leone	17,700	33,600
Tanzania	55,000	118,400
Uganda	54,700	88,400
Zambia	26,900	38,500
Liberia	1,400	11,800
Madagascar	25,500	40,200
Cuba	21,900	63,000
Mexico	163,900	350,300
Panama	6,800	72,100
Argentina	84,200	240,900
Chile	225,800	1,052,900
Colombia	25,000	57,300
Guyana	3,500	13,900
Peru	961,200	10,110,200
Venezuela	78,300	107,200
Ceylon	40,700	115,600
Taiwan	229,700	458,100
Hong Kong	69,500	86,900
India	1,064,600	1,400,400
Indonesia	691,000	1,201,600(1966)
Korea	403,600	749,100
Malaysia	139,900	367,100
Pakistan	283,700	417,000
Philippines	447,300	769,200
Thailand	196,300	849,400
South Viet Nam	143,000	380,500
Poland	145,100	338,900
Total	5,915,700	20,973,300

PRODUCTION BY KINDS OF FISH

The relative proportion of fresh water and diadromous fishes; marine fishes; crustacean, molluscs, and other invertebrates; and other things such as seals, miscellaneous animals and plants, in the total world catch has remained remarkedly stable over the years, always dominated by marine fish. Marine fish have proportionately increased slightly over the years, being 71.9 percent of the catch in 1938, 72.7 percent in 1958, and 77.6 percent in 1967. The variation has been within that range. The proportion of fresh water and diadromous fish in the catch has declined slightly from 16.7 percent in 1938 and 1958 to 13.6 percent in 1967, with only one year (1948) being slightly outside that range with 13.2 percent. The category crustacea, molluscs, and other invertebrates formed 8.7 percent of the catch in 1938, then rose to 10.1 percent in 1948, from which it has slowly and steadily declined (8.9 percent in 1958 and 7.4 percent in 1967). The category "other" (seals, and miscellaneous animals and plants) was never large and has declined rather steadily from the high point of 2.7 percent of total world catch in 1938 to 1.4 percent in 1967.

It has been in the category marine fishes that the big expansion of production has taken place in the past ten years, going from 24.12 million tons in 1958 to 46.94 million tons in 1967.

Substantially all the crustacea, mollusca, and other invertebrates also come from salt water and their catches have increased from 3.26 million tons in 1958 to 4.48 million tons in 1967. Although the increase in the net physical yield of these has been modest, they are such high cost items that this increase has brought more than one billion dollars of extra income to shrimp and lobster fishermen around the world over that period. A substantial part of the fish in the fresh water and diadromous category (salmons, some trout, some smelts, alewives, some sturgeon), also are raised in the ocean, even though they come back to fresh water to spawn. This category has increased in yield from 5.56 million pounds in 1958 to 8.22 million pounds in 1967. Thus in 1967 the total production of marine animals and plants comprised at least 90 percent of the total fish and shell fish catch of the world, and the relative proportion was increasing with the years.

In the category of marine fishes the startling expansion has been in the group of herring-like fishes (herring, sardines, anchovy, and the like). Production went from 7,250 thousand tons in 1958 to 19,680 thousand tons in 1967. This was dominated by increased catch of one species of anchovy off western South America which went from 777 thousand tons in 1958 to 10,530 thousand tons in 1967. This in turn was dominated by the fabulous growth of the anchovy fishery in Peru whose yields increased from 737 thousand tons in 1958 to 9,825 thousand tons in 1967. This one-species-fishery so dominated the world fishery scene that when production from it dipped in 1965, total world fish production figures leveled off from their steady rise since the end of World War II and some writers (Mikhaylov, 1968) gained the impression that world fish production had begun to level out.

The herring-like fishes thus dominate world fish and shellfish catch, providing nearly $\frac{1}{3}$ of it. The next largest category totally and in growth is FAO's category of unsorted and unidentified fishes, which rose from 5,280 thousand tons in 1958 to 8,290 thousand tons in 1967. Since a share of these are certainly herring-like fishes, these sorts of animals certainly provide more than $\frac{1}{3}$ of the world catch of fish and shellfish. It is likely that this will be the case in the near future, as these sorts of fish, feeding as they do on the plants of the ocean or the animals one stage removed therefrom, are the most abundant fish in the world. This statement is made not only on the basis of theory but on the basis of observed large underutilized resources of them, such as the anchovy of

Southern California, the anchovy and sardine of the Gulf of Mexico, the sardinella of West Africa and Angola, the anchovy and sardinella of the Arabian Sea, the sardinella of Northwest Australia, etc.

The other group of fishes that has shown sharp increase in production over the past ten years are the cod-like fish (cods, hakes, haddocks, pollacks, etc.). Their production increased from 4,490 thousand tons in 1958 to 8,150 thousand tons in 1967 (nearly a doubling). There was an increase of half a million tons in cod catch during this period, but the big increases in this category were in hakes and Alaska pollack, which before this period were classed more or less as trash fish. The hake catch of the world increased from 323 thousand tons in 1958 to 1,483 thousand tons in 1967, more than a quadrupling. Most of this increase went to the frozen fish market, with much of it going into the frozen fish block market. The production of Alaskan pollack went from 345 thousand tons in 1958 to 1,735 thousand tons (an increase by a factor of five). Most of this went to the minced fish market of Japan, but a fair part of it also went into the frozen fish market of Russia. Much of it was caught off the United States.

There are probably 24,000 species of fish in the world other than those included in the three categories of herring-like, cod-like, and unsorted or unidentified species referred to above. Most of these occur in the ocean. The recorded production of all other fishes aside from these three categories was 7,100 thousand tons in 1958 and 9,820 thousand tons. The increase in all of these catches was, thus, about 2,720 thousand tons in this period of time, or about half the increase in catches of cod-like fishes, and about a quarter of the increase in catch of herring-like fishes.

The major increase in this "all-other" category was in mackerels, the catch of which went from 532 thousand tons to 2,027 thousand tons. Sharp increase of mackerel catch was noted in Japan, where it went from 268 thousand tons in 1958 to 687 thousand tons in 1967, and in South Africa, where it went from 20 thousand tons in 1958 to 139 thousand tons in 1967. The most startling increase in mackerel catches, however, was in Norway where it went from 15 thousand tons in 1958 to 867 thousand tons in 1967. This was almost an accidentally discovered fishery resulting from using acoustic locating devices and deeper and longer purse-seines for herring (made possible by the introduction of synthetic webbing and power block) which dipped into the deeper swimming mackerel schools. Most of the production went into fish meal.

While there was also some increase in the worldwide catch of sea perch, sea basses, etc., (2,250 thousand tons in 1958 and 3,140 thousand tons in 1967), the catches of other groups of fishes held level or declined during this decade. The group of flat fishes (flounders, plaice, halibut, turbot, etc.), actually declined somewhat. The main increases in the sea perch-bass category was in catches of sea perch from the Pacific (mostly Japanese and Russian catches in the Northeast Pacific which reached their peak in 1965), and from sand lances in Denmark (which went from 75 thousand tons in 1958 to 208 thousand tons in 1967).

One may roughly summarize the rapid growth of fisheries in the last decade, then, by saying that the major increases were in the production of herring-like fishes (mostly anchovy for fish meal raw material) and of the cod-like fishes (mostly hake and Alaskan pollack for the frozen fish trade). Other sharp increases were in production of sea-perch (for the frozen fish trade) which appears to have passed its peak, and in mackerel and sand lance (most of which went for fish meal).

While their total tonnage of production is submerged in the much greater tonnages of marine fish production, some additional mention should be made of what has been going on in the production of crustaceans and molluscs because (a) several of these are delicacies that bring very high income to the fishermen who land them and (b) some of them represent very large underutilized resources (squid and octopus, shrimp and prawn, and some sorts of crab), or are luxury products susceptible to mariculture (oysters, mussels, clams) because they can bear its cost.

Crustacean production, as a whole, increased from 850 thousand tons to 1,350 thousand tons in 1968. Among the sharp increases were king crab (rising from 64 thousand tons to 134), and shrimp (440 thousand tons to 690). Other increases were noted in other marine crabs and other marine crustacea. Market demand for crustacea is increasing sharply (frozen king crab meat sells for $8,000 per ton), known underutilized resources of considerable size exist, and it is inevitable that further increase will come quickly in this category. The application of new technology in handling frozen products, and in air transport of sea foods as well as in processing these products, is beginning to have effect.

The mollusc category is particularly interesting. It has increased from 2,070 to 3,080 thousand tons in this ten-year period. Squid represent one of the largest underutilized resources of the world ocean. The flesh is delicious but there is market resistance in much of the world because of the look of the animal, and old wives' tales. Nevertheless, production of squid increased from 466 to 750 thousand tons in this period. Octopus bear even worse connotations than squid, are equally delicious, and there are substantial underutilized resources of them known. Production increased from 70 to 80 thousand tons in this decade.

Mussels (166 to 275 thousand tons) and oysters (639 to 829 thousand tons) are particularly susceptible to mariculture and their increased use on a worldwide basis is steady, as noted by the above figures. This is not true in the United States where mussels are not much eaten and where most of the vast original oyster beds have been wantonly destroyed by unwise or lacking conservation measures.

CHANGING PATTERNS OF USE

There have been consistent changes in the worldwide pattern of use of fish and shellfish over the years that are interesting in the slowness, steadiness, and persistence of the trends. The FAO Yearbook of Fishery Statistics for fishery commodities, 1967 (Vol.

25), is not yet available and the following statistics are from Volume 23 (1966), but the trends have undoubtedly persisted through 1967.

The largest single use still is for fresh marketing, but the relative use for this purpose has dropped off steadily since 1938 when 52.9 percent of production was used in this form until 1966 when only 31.1 percent was used for this purpose. The downward trend has developed slowly, with 44.6 percent used fresh in 1958.

The old, traditional ways of preserving fish for later use (drying, smoking, salting, etc.), have also steadily fallen off in favor over the years. In 1938 27.1 percent of world production was used in this fashion, whereas in 1966 only 14.3 percent was so used. The trend of drop-off in this use has speeded up since 1958, when 22.0 percent of production was used in this fashion.

The overwhelmingly largest change in trend of usage over the years has been as raw material for fish meal. In 1938, 8.1 percent of world production was used in this fashion. The disruptions of World War II decreased this use somewhat, so that it was only 7.7 percent in 1948. Since then the increase has been steady (except for a slight dip in 1965 because of perturbations in Peru) and since 1958 it has been rather sharply upward. In 1958, 13.0 percent of total world fish and shellfish production was used for this purpose, and by 1966 a full 31.2 percent of production (only slightly less than for fresh marketing) was so used.

The other steadily increasing use for fish and shellfish has been in the frozen form. None was recorded as used in this manner in 1938 (although small volumes of higher-priced items such as steelhead trout, halibut, oysters, and a few others had been produced for such use in the United States for twenty years before that and some, such as frozen steelhead, had been in international trade between the west coast of the United States and France). By 1948, 5.1 percent of world production was noted as being used in this fashion. This use has grown steadily and slowly since then, with 12.3 percent of world production being used in this fashion in 1966.

Undoubtedly the slow, but steady, increase of use of fish and shellfish in the frozen form has been an attribute not only of the slowness of change in eating habits generally, but also the slow-spread change in provision of refrigeration facilities in the long line of production through the supply channel from the fishing vessel to the consumer's kitchen. The big growth of this use has been in the United States and Canada where, since the end of World War II, the spread of facilities for handling frozen food in the grocery trade and in the home has been broad, enabling the shipment and purchase of frozen fish quite easily throughout the continent. This custom is beginning to spread in England and throughout Europe (eastern as well as western). In South Europe, West Africa, and some other places, frozen fish is produced aboard ship increasingly and permitted to thaw during transportation to the point of retail sale. This does not produce a very good product, but the practice grows nevertheless. In West Africa there was scarcely a pound of frozen fish sold in 1960, and by 1967 volume had increased to over 200,000 tons.

The proportion of fish used for canning has held rather constant through this 30-year period. In 1938, 7.1 percent of production was used in this form, and the same was the case in 1948. The percentage used for this purpose since has risen somewhat, but has vacillated in a close range between 9.5 percent (in 1956 and 1957) and 8.4 percent in 1963. It was 8.8 percent in 1966.

The category miscellaneous purposes (mostly waste products) has decreased steadily in consequence from a high level of 5.1 percent of production used for these purposes in 1938 to 1.7 percent in 1966, as greater portions of this went into reduction for animal feeding, the canning of pet foods, etc.

In terms of actual, rather than relative, use, the consumption of fish and shellfish in the fresh state increased from 14.8 to 18.0 million tons from 1958 to 1966, the amount used in the frozen form went from 2.8 to 7.0 million tons in this period, the amount used in the smoked, salted, dried, or cured form went from 7.3 to 8.1 million tons, the amount used for canning grew from 3.0 to 5.0 million tons, the amount used for making fish meal shot up from 4.3 to 17.7 million tons, and the amount used for miscellaneous purposes has been kept level in the FAO statistical system at 1 million tons during the entire period.

THE FUTURE MARKET

There is a great deal of talk heard these days about solving the protein malnutrition problems of the world, and public health, social, and economic problems attributable thereto, by Food from the Sea. Most of this is done by people who do not know the least thing about what they are talking about either from the standpoint of people, fish, or the ocean, or how to get these things working together. Most of the response is from similarly uninformed people who point out that only 1 percent of man's food comes from the water, fisheries development is not economically practical anyway, and that the limit of the ocean's ability to produce food is near at hand (Scott, 1968; Ceres, 1968).

One must keep in mind, when talking about food, that, in relation to the current food distribution systems, there is a surplus of proteins and carbohydrates. Protein and carbohydrates from vegetable sources and cereal grains are moving into international markets in such volume presently that such proteins are at 14-year lows on price, and prices of such staple carbohydrate sources as cereal grains and sugar are at 20 to 30-year lows. These commodities are frequently selling on the international market at well below the cost of production. Sugar presently can be had on some of the world markets at half the cost of production. France is presently negotiating the sale of its surplus wheat, stimulated by government subsidy, in Asia at well below the cost of production. More examples could be given (Dean, 1968).

The problem is distribution. Distribution of food is through three main channels—commercial marketing where a money market exists, governmental give-away programs, and subsistence economies where the consumer raises or catches what he eats or barters these products with his near neighbors.

A major part of the world's human population lives in a subsistence economy. No government or groups of governments, are sufficiently strong enough economically to give sufficient foods into these populations living on subsistence economies to meet their minimum needs over and above their own productivity. There has been no means devised yet to get food from the commercial marketing economy into subsistence economies which have nothing to exchange for the food.

The ocean is a poor place to look for the total food requirements of many people, but it is an excellent source of the most critical element—high quality animal protein. The reason is that, although the total primary production of plants in the sea is about the same as on the land, the plants of the sea are mostly microscopic plankton, with fast growth rates, short longevity, and low standing crops that are not amenable to economic harvesting or processing. They also are not amenable to cultivation in bulk terms competitive with land sources of carbohydrates. The major food harvest of the sea has been, is, and will be animals one or more steps above the plants in the ocean's food chain (Bogorov, 1965; Schaefer, 1965, 1968).

Schaefer (*loc. cit.*) has made computations describing the ability of the ocean to produce high-quality animal protein. They may be summarized thus. The waters of the world presently yield a harvest of about 60 million tons of fish and shellfish per year, and provide about 15 percent of the world's supply of animal protein. The average human per capita requirement for animal protein is about 15 gr. per day, or 5.5 kg. per year. This is contained in about 37 kg. (or 81 lbs.) of ordinary marine animals. Thus if there were no waste, and the protein were evenly distributed, the present world population of about 3.5 billion people could obtain all of their necessary animal protein from about 128 million tons of marine animals, or a little more than twice present production. There is general agreement among scientists that known ocean resources are capable of supporting sustainable yields of at least 200 million tons per year. This would provide the protein requirements, in terms stated above, of about 6 billion people. Schaefer calculates, further, that using the total probable potential yield of protein from the ocean at the second trophic level above plants, enough is available to supply the requirements of a 6 billion population by somewhere between 9 and 34 times.

Thus the problem is not availability of protein being produced by the ocean. The problem is tapping the ocean protein production for products that people will buy and eat at prices they can afford in the money (or commercial) section of the world's economy, or providing improved facilities in the sustenance economy for people to catch and use what they need. Work proceeds actively on all of these levels. Here we will deal only with the activity in the money economy sector, but not forgetting the important efforts made by UNDP, FAO, many bilateral governmental programs, and many programs of governments internally to improve the production of fish for immediate use in the sustenance economy.

FISH MEAL

As noted above, the prime growth in fish production since World War II has not been for filling direct human nutrition requirements at all, but has been for fish meal used in animal nutrition. The overwhelmingly largest part of this production has been used in poultry and pork production. The production of fish meal on a worldwide basis has come from about 579,000 tons in 1948 (Peterson, Giertsen, and Co., 1966) to 4,350,000 tons in 1967 (Groben, 1968).

This use is entirely contingent on competitive prices in the market. The three prime end variables are the rate of consumption of poultry, eggs, and pork. The second level of competition is between fish meal and other sources of equivalent protein nutritional value. An example is soya meal plus methionine which is equivalent in nutritional value to fish meal and is chosen as a feed ingredient in a particular geographic location primarily on the basis of price but also on convenience and other economic characteristics.

In the decade under examination (1958–1967), worldwide production of fish meal has come from 1,360 to 4,350 thousand tons (Groben, 1968). Assessing the above factors as well as he can, Groben believes a world fish meal production of 6.0–6.5 million tons is possible by 1975. This would be a drop in market growth and is perhaps conservative. This two million ton increase in fish meal demand equates with about 11 million tons of round weight extra fish catch over the next eight years. This equates roughly with the whole fish meal output of Peru and Chile. It cannot be had from that resource (anchovy) which is producing presently at about top sustainable level, or a little beyond.

Other resources will require to be opened to production, such as the sardinella of the Arabian Sea, the anchovy of southern California, the anchovy and sardine of the Gulf of Mexico, the sand lances of the North Atlantic, etc.

The use of fish for direct human consumption in all forms (fresh, frozen, canned, cured) increased from 28 to 38 million tons in the period 1958–1966, or at the rate of a little better than one million tons per year. There is no reason to expect that this rate of gain will be less in the next decade than it was in the last. One can perhaps expect modest or little gains in the period in the use of cured and fresh fish, with rather larger gains in use of canned fish, and the most gain in the use of frozen fish, if the pattern of the last decade (and actually the last three decades) persists.

CONVENIENCE FOODS

The trend to use fish in the frozen form began in the most affluent countries as an attribute of the spread of the mechanical means of preserving frozen foods through the distribution chain and into the home. It is continuing to grow in the more affluent countries and to spread geographically as affluence, and the machinery which goes with it, spreads. In the most affluent countries this form of use has spread ever more rapidly with the increased use of convenience foods that require little preparation before eating. This has led to the use of frozen fillets, and then to the frozen block of fillets which can be further processed into fish sticks, fish portions, fish sandwiches, etc. These may be retailed still frozen in either cooked, breaded, or uncooked form. Companion to this is the growth in use of frozen shrimp in various forms and frozen crab meat and molluscs. Similar patterns of use seem to be developing in the poorer countries as they become more affluent.

A trend is now beginning in North America for the increased use of frozen seafoods as a component of frozen ready-prepared dinner meals and it seems likely that this newer use of such things as shrimp, crab, tuna, etc., in such convenient, ready-to-cook and serve form will continue to increase steadily in volume.

FISH PROTEIN CONCENTRATE

For a number of years there has been a dream in the mind of nutritionists and similarly interested people that the very abundant and underutilized smaller animals of the ocean could be processed into a defatted, dehydrated fish protein concentrate that would be stable as to flavor and odor in storage for long periods of time and be easy and cheap to store and transport. In essence this would be fish meal manufactured to human food hygiene standards, and with substantially all the fats removed, so that it would be substantially neutral as to odor, flavor, and light in color. It could be added to formulated foods such as breads, pastas, gruels, mushes, soft drinks, and other forms of staple consumption of carbohydrates so that the staple food would be nutritionally well-rounded and sufficient.

The dream is real. The product can be, and has been, produced by several means. A great deal of research is under way currently under various auspices in the United States, Canada, Russia, Sweden, South Africa, Chile, and elsewhere on the technology, and on the adaptation of laboratory means of production to commercial plant scale level. It is, however, still a dream. The only market presently available is for nutritional studies and government public health programs that involve the use of only a few thousand tons of FPC per year and in which the product is given away.

If the product gets developed to the level where an 80 percent protein fish protein concentrate that is water soluble and is odor and flavor free becomes commercially available at prices close to 25 cents per pound, then it is likely to come into commercial use in formulated foods as an expander, or substitute, for dried skim milk, soya concentrate fortified with methionine, and proteins from other vegetable sources such as oil seeds similarly fortified with appropriate synthetic amino-acids. It seems likely that such commercial use of FPC will begin in the United States and Canada within the next five years, and may assume noticeable proportions within the next decade.

This development is coming along at the same time that food habits in the United States are changing in the direction of increased use of formulated foods, which is a logical extension of the already very large market for convenience foods, that need little preparation before serving.

The resources available in the ocean for such FPC production are enormous. All of the things now used as raw material for fish meal would be suitable raw material for FPC, and it is likely that FPC manufacturing will be conducted together with fish meal production. Entirely aside from the small fishes such as anchovy and sardine available for such purposes, smaller crustacea such as red crab, krill, etc., would also make suitable raw material. The size of the known resources available for such production is indicated by the amount of krill thought to be available in the Antarctic alone. It is estimated conservatively that this one kind of animal in that region alone could support a sustainable fishery of 100 million tons a year.

THE SHAPE OF THE IMMEDIATE FUTURE

As noted above, despite all of the concern in the United States, whose domestic fishery has been stagnating in growth for thirty years, production of world fisheries has been increasing for twenty years at a much more rapid rate than the increase of the human population or than that of land agriculture. It continues to grow at about the same rate as it has for the past twenty years.

If the growth of production of fish and shellfish on a worldwide basis continues at an annual rate of 4 percent increase (which is a little slower than its growth rate since 1948), production will be about 86 million tons in 1976 and about 123 million tons in 1986. Both anticipated market demand and resource availability make this projection appear to be reasonable, and perhaps conservative.

The income to fishermen from the 60 million ton production of 1967 was a little better than $9 billion. Presuming stability of price (and there will be, of course, increase) fishermen's income would be about $13 billion in 1976 and somewhat more than $18 billion in 1986. It is interesting to compare this with the highly publicized value of petroleum production from the sea bed, which currently runs at about $4 billion per year, and will be some time in catching up with the value of fish and shellfish catches.

The highly publicized mineral resources of the sea bed produce less than $50 million of product per year.

Roughly speaking, fish products triple in value between the landing and retail prices. Thus, translating the above to retail levels, the retail value of fish products should be about $27 billion in 1967, $39 billion in 1976, and $54 billion in 1986. Thus the economic effect of fishery development is not nominal, and this is one of the prime reasons why both developing and industrialized countries (both worried about foreign exchange balance) put in so much effort in fishery development both by their own efforts and through multi-lateral means. This is likely to continue.

AQUACULTURE

In some quarters the subject of aquaculture has taken on the flavor of religious argument in recent years. The difficulty in dealing with the subject in brief compass is that both the true-believers and the iconoclasts have some truth on their side.

The one point that requires constant remembering is that animal protein from the ocean has no particular *nutritional* attributes better than those of animal protein produced from land animals. Both provide that balance of amino-acids which the human body requires in some measure to keep in good health. On straight out nutritional qualities anchovy protein is no more, or less, valuable than pig or cow protein. Also it is no more valuable in this sense than protein from vegetable sources (soy, oilseed press cake) fortified by appropriate synthetic amino-acids.

Accordingly, in the low-cost bulk animal protein market the product of aquaculture is unlikely to ever be of much importance. There is too much wild stock in the ocean which can be landed profitably at prices of 1 cent or less per pound. I do not know of any aquatic animal that can be raised by aquaculture in much volume at costs as low as 10 cents per pound.

Except for the provision of bulk, low-cost animal protein, however, aquaculture has more or less a place at all other levels of the protein market.

In the sustenance economy aquaculture has a place in the home farm pond. This has never yet been a matter of much importance outside the region of paddy-rice culture because such essentially wild culture without management is not very productive, and when management is applied the costs go up so that the production must compete in the money economy. Experiences by governments in West Africa, for instance, have not been very fruitful (Kimble, 1960). As an experienced FAO field expert told me in Nigeria one time, people who are not sophisticated enough to take care of cows and chickens cannot be expected to be proficient in the much more highly sophisticated business of raising fish in ponds.

In situations where the ponds are close to market and there is no processing, storage or transportation costs of consequence between the producer and the consumer, pond production of fish can be both profitable and locally important from the standpoint of protein nutrition. This is quite important in the area of paddy-rice culture through southeast Asia, and in the vicinity of the temple ponds of India.

A number of carps, among other fishes, are particularly amenable to fresh-water pond culture and in regions where there is a market for this sort of fish (through much of Asia, Central Europe, Israel) they form the basis for both a lucrative and highly productive pond culture. As this pond culture is made more sophisticated by proper management, fertilizing, feeding, breeding of stocks, use of several species in the same pond, etc., the productivity per unit area or pond becomes quite high, but costs also are such that the end product is not cheap. This sort of culture has been raised to particularly high levels of efficiency in Taiwan and in Russia (Ryther, Bardach, *et al.*, 1968).

Aquaculture, both fresh water and marine, has a particular role to play in the luxury and semi-luxury field of the money market economy. Mussels, oysters, salmon. trout, eel, cat fish, shrimp, yellowtail, pearls, and other such delicacies and desirables are raised in more or less volume for this high-value market in Japan, United States, and Europe, and in many instances the aquaculture is quite sophisticated. Considerable quantities of food are produced in this manner. For instance, Japan produces somewhat more than 30,000 tons of oyster meats per year through aquaculture, somewhat more than 30,000 tons of catfish are produced per year through pond culture in the United States, etc. In all cases the cost of production and end product is rather high.

For instance, the catfish farmer in the United States receives for his product something more than $600 per ton, about midway between the prices received for their products by tuna and shrimp fishermen.

In essence, aquaculture can not be expected to yield very much of the three to four million tons of additional fish and shellfish production the world will demand each year for the next generation, but in some situations its expansion can be quite useful from the nutritional viewpoint, and in several situations it can be quite lucrative from the profit standpoint in the money economy.

Research and development projects in aquaculture should be closely reviewed from the standpoint of cost-effectiveness with other means of producing the same desired results.

NOURISHING THE POOR

Unfortunately the great bulk of humanity that suffers from protein malnutrition lies outside the money economy and they are very hard to get at because they have nothing to trade for the abundant protein available in the money economy and on the international market. It is not readily apparent how the very abundant protein resources of the sea can be got to these great masses of people any more easily than the available surpluses of vegetable proteins that still depress the international protein markets, or than through solving the general problem of getting them into the money market.

A particularly sharp (but no unique) example is provided by Peru. Its fish production has risen from 84 thousand tons in 1948 to 10,110 thousand tons in 1967. Its domestic consumption of fish has risen from about 20 to 155 thousand tons per year in the same period of time, which is not a bad rate of growth. Yet the very large population of Peruvians living in the high Andes suffers generally from protein malnutrition and probably is not as well off nutritionally as it was in the days of the Inca empire. This population is largely outside the money economy and cannot buy the cheapest product of the coastal fisheries, which are the cheapest and most voluminous of any country in the world. The product of these enormous fisheries is made into fish meal and sold in Europe, North America, Japan, and elsewhere in the world primarily for chicken feed.

Another example is provided by Upper Volta where protein malnutrition is rampant. Its government wants a fishery pre-development survey and assistance from FAO and UNDP in fishery development. There is only one substantial river in Upper Volta, and it has no sea coast. From the standpoint of other equally pressing demands on such funds as they have available for fishery development, this is not a very cost-effective place for FAO and UNDP to allocate much such funds, although the need is admittedly great. Upper Volta sits astride one of the ancient but still well-used trade routes along which flows the dried freshwater fish from the upper Niger delta to the coast, and the fish from the prolific coastal fisheries going into the interior. Plenty of fish is available in Upper Volta; the people who need it nutritionally do not have the money to buy it.

Great hopes have been held out that fish protein concentrate will bring relief to these protein malnutrition problems among these numerous very poor people outside the money economy. It is difficult to see how this can be realized on practical levels. In very large parts of the world where this situation exists the odor and flavor of rancid fish is not only not objected to, but is an added attraction to spice up the tasteless rice, or cassava, or other bland carbohydrate dishes. In such instances it would be considerably cheaper and more practical to provide dried anchovy or sardine without going through the rather expensive manufacturing process of making bland FPC. But the people who need the protein have nothing to trade for either.

Although most of the increased fish production from the world ocean has been consumed by the industrialized nations there has been a great deal of increased availability of fish protein also to the very poor. The increased fish consumption in Peru is a case in point. This could not have occurred in the absence of a large export fishery which supported by its earnings the fishery development required for this purpose. The whole of Table 2 also illustrates this point.

FAO and a number of bilateral fishery assistance schemes are often criticized because time and money is spent on providing synthetic webbing, outboard motors for canoes, experts in pond-culture, uneconomically small cold-stores and iceplants, and similar not very cost-effective activities for increasing fish production. It is true that the same amount of money and effort spent elsewhere and otherwise would produce more fish and shellfish, but these activities at the village level in mostly sustenance economies brings local relief to protein malnutrition problems that is of more than casual consequence. It also frequently starts the village into the money economy, and brings it within range of more practical assistance.

All of this is not very satisfying to those who wish to solve the very serious problem of protein malnutrition among pre-school children and lactating mothers outside the money economy quickly. Aside from the slow process of bringing them into the money economy no very satisfactory scheme has been found except provision of needed food by government largesse, and this is not anywhere nearly adequate to need. Fish protein concentrate can be useful in such give-away programs but they are not sufficient to solve the problem in near time.

DEVELOPING FISHERIES

In the United States it is not generally realized how much government money goes into developing fisheries. This has begun to be effective in recent years as the Special Fund of the United Nations Development Program through its executing agency, the Food and Agriculture Organization of the United Nations, and has increasingly improved its methodology and support. At present there are about 25 of these longish term fishery development projects in train through which the recipient nation provides matching funds. Perhaps as much as $20 million per year is now being administered in this form by FAO Department of Fisheries. Some assistance to this activity is now being experienced through capital loans from the International Bank for Reconstruction and Development. This has already been effective in building the long-range fisheries of Taiwan and Korea.

On another scale entirely, many industrialized, or semi-industrialized countries spend large sums in building up their sea fisheries as state enterprises (in socialist countries) or in subsidizing private enterprise in fishing in non-socialist countries. Russia has purportedly invested $4 billion in building up its worldwide fish production from the war's end up to 1965, and allocated about $3.2 billion to this purpose under the current five-year plan. Poland, East Germany, Rumania, and Bulgaria have also made considerable steps along this line. In the western world Norway, England, Italy, Spain, and Canada have subsidized fish production considerably. Various bilateral programs have been more or less effective, such as the Indo-Norwegian project, the Colombo plan projects in Ceylon, the German project in Thailand, the Russian projects in Somalia, Yemen, Cuba, Egypt, and Senegal, the French and EEC projects in Ivory Coast and Congo Brazzaville, United States projects in West Pakistan and India, etc.

Government money is still increasingly flowing into fishery development projects on a worldwide basis and this can be expected to continue to increase for a rather long while to come. An essential reason for this is that the resources of the sea not only produce rather cheap animal protein that is badly needed and desired on a broad world-wide basis, but these resources of the high seas under international law are the common property of all nations and freely available to all only for the cost of harvesting. By increasing its harvest of them the individual nation can improve the nutritional base of its people without the use of foreign exchange (except for fishing gear and vessels it cannot make itself), or earn foreign exchange with which to buy other things it wants or needs.

MANAGING FISHERIES

This common property nature of the high seas ocean resources not only gives rise to peculiar economic considerations in fishery development, but leads to a vast and increasing array of resource management problems as among the sovereign nations who are owners of the resources. Resources of the high seas are the private property of an individual only when reduced to his possession. The private fisherman operates on the high seas not under rights that pertain to him under international law, but under rights that pertain to the sovereign whose flag his vessel wears. The use of the high seas falls under international law. Individuals are frequently the objects of international law, but only sovereign nations are its subjects.

All users of the common pastures of the high seas want to maximize their possibility of using it, few wish to provide the funds or restraint required to manage the use of these resources wisely. What is owned by everybody is not very well taken care of by anybody.

These factors have given rise to numerous conflicts among nations over time, and still do. There are three main proposals currently under debate in the international community to handle these increasing problems:

a. Turn the whole problem over to the United Nations. Nobody yet has figured just how to do this on a practical basis, or to demonstrate that the United Nations might be able to handle it better than the problem is handled now.
b. Split up ownership of the high-seas resources among the nations, keeping in mind that agriculture never prospered very well until the common pastures were put under private ownership. A major problem is that many major resources are highly mobile. This solution might well stir more conflicts than it settles.
c. Perfect the present system of international and intergovernmental fisheries commissions through which the immediately concerned nations attempt to apply conservation regulations in high seas fisheries. This subject is too complicated to review here, and has been recently treated by Chapman (1967, 1968).

It may be stated, however, that increased fishing effort on the high seas exacerbates these fishery management questions. The rise in production of fish and shellfish from 20 to 60 million tons per year has more than tripled these problems and their consequences. A rise in production to 86 million tons in 1976 and to 123 million tons in 1986 will exacerbate all of these problems sharply and seriously, bringing more major resources under need of conservation management and bringing increased conflicts because of lack of knowledge as to what to do and lack of desire to do it anyway.

THE APPLICATION OF SCIENCE AND TECHNOLOGY TO THE PRODUCTION OF FOOD FROM THE SEA

Great progress has been made in the last 100 years, and particularly in the past decade, in accumulating knowledge and understanding of the natural processes of the ocean, the atmosphere, and the biological resources of the ocean—together with the dynamic relationships among these factors. Scientific publications and committee reports on these subjects now come in the mail faster than they can be read.

Nevertheless, the need for such knowledge and understanding accrues more rapidly than the latter develops in both fishery conservation and development.

In fishery conservation a few simple parameters are required for each population of fish to make possible rational management of the use of the resource. It is necessary to know something of the general biology of the species, the rate of recruitment, the rate of growth, the rate of mortality, and the part of the latter resulting from fishing effort.

The difficulty is that variation in environmental factors, both biological and physical affect the rate of recruitment, sometimes the rate of growth, and frequently the rate of mortality in substantial manners. In almost no instance is the relationship of variations in these environmental factors and these vital statistics of the population known well enough to account for effects, much less predict them.

In particular we have only the slightest ideas of the paths, and effects, of transfer of energy through the multitude of pathways and recycling in the web of life in the ocean. We do not understand in any cases in detail what happens to the other populations when we heavily fish one kind of animal out of a complex group, which we normally do. Thus the task of managing the use of living resources of the sea is largely a game of educated guessing, with the guessers not being very well educated.

In fishery development we do not yet have very good ways of measuring the size of a population of animals aside from indirect measurements resulting from applying a fishery to it. Methods derived from various acoustic devices, and inferring population strength from relative abundance of young in the plankton are useful, but rather crude.

Changes in strength and transport of major ocean currents are known to affect materially the strength and transport of upwelling that brings nutrients to the surface layers of the ocean and supports the waxing and waning of ocean life. Changes in strength of lower atmosphere wind currents are known to affect in a major way the strength of upper ocean currents. Nothing of this is known with enough precision to predict any part of it for more than a few days ahead of time, or to understand effects either on currents or resource fluctuations. No system of global measurements is in being to gather the information needed to construct theory from which interpretations and predictions can be made. Accordingly such theory does not exist able to yield useful interpretations or predictions.

Because of this ignorance, generally referred to by the name ecology, use of the living resources of the sea is still in the hunting stage of neolithic times. In a very few cases it has emerged to the range management stage, and only in inconsequential areas has it come to the point where crude agricultural management is possible or desirable.

FISH AND STRATEGY

Quite aside from the effect of national fish production on the foreign exchange balance, the contribution of such production to the national food budget, and the national economy (none of which appear to be of much concern to United States policy makers), there are two other strategic elements of national posture in which fisheries play a sufficient role to be mentioned briefly:

a. Controversies over jurisdiction over fisheries lying in the adjacent high seas prevented agreement on the breadth of the territorial sea at the Law of the Sea Conferences in 1958 and 1960. These controversies are unlikely to be settled peacefully without a material expansion in ocean research to elucidate their root causes.

b. Who controls the sea may control the world. In conditions like those presently existing where Naval power cannot be used except in an extremity, who uses the sea most may come the closest to controlling it. The United States has permitted the decay of its use of the sea by civilian industry (merchant marine and fisheries) steadily since World War II with consequent decay to its posture.

THE CONDITION OF UNITED STATES FISHERIES

The condition of United States fisheries can be briefly summed up:

The total annual supply of fish and shellfish available for use in the United States was just 3 million metric tons in 1950 and in 1967 is just short of 7. Thus the use of fish and shellfish for all purposes in the United States has increased sharply since the war both absolutely and per capita. The per capita use in the United States (about 70 lbs. per year) is now among the highest in the world (Fisheries of the United States, 1967).

The supply of fish and shellfish to the United States market has come increasingly from imports. In 1950 they provided 25.1 percent, and in 1967, 71.1 percent. The United States has become the largest and most lucrative market for fish and shellfish in the world. In 1928 these imports were valued at $39 million, in 1950 at $198 million, and in 1967 at $727 million.

The most recent estimate by U.S. Bureau of Commercial Fisheries experts of the resources of fish and shellfish available in our near coastal waters indicates supplies adequate to produce about 20 million tons per year on a sustainable basis (Pruter, 1968).

The United States flag fishing fleet has averaged producing about 2.5 million tons per year for the last thirty years; the U.S. market continues to grow, and presently uses well more than twice the product of the U.S. fleet; resources available are sufficient to support yields about eight times those presently taken and about three times what is consumed per year. Foreign fishermen, mostly from Europe and Asia, actually take almost as much off the United States coast per year as do those of the United States.

There appears to be scope for the much vaunted United States business know-how and skills in applying science and technology to production problems in improving the yield of United States flag fishing vessels.

LITERATURE CITED

Bogorov, V. G. 1965. Quantitative Assessment of Sea Flora and Fauna. DAN, 162(5).
Ceres. 1968. FAO Review, 1(4): 55.
Chapman, W. M. 1967. The State of Ocean Use Management. FAO Fisheries Reports (46), Suppl. 1: 1–17.
——. 1968. The Theory and Practice of International Fisheries Commissions and Bodies. Proc. 20th Ann. Sess. Gulf and Caribbean Fish Inst., Inst. Mar. Sci., Univ. Miami, July, 1968: 77–105.
Dean, R. H. 1968. Address to International Association of Seed Crushers Conference, Washington, D.C., 26 September, 1968: 1–8.
FAO. 1967. Yearbook of Fishery Statistics. 23, Fishery Commodities 1966.
——. 1968. Yearbook of Fishery Statistics. 24, Catches and Landings 1967.
Groben, H. 1968. *Die langfristigen Entwicklungstendenzen auf dem Weltfishmehlmarkt.* Infn. Fischw. Auslds., Heft 10. October, 1968, Bonn-Hamburg: 1–12.
Kimble, G. H. T. 1960. Tropical Africa. Two volumes. Twentieth Century Fund, 1960, II: 44.
Meseck, G. 1968. Signification of the World Fishery for the Food Economy under special Consideration of Asia. *In* Possibilities and Problems of Fisheries Development in Southeast Asia, German Foundation for Developing Countries, Berlin, Sept., 1968: A2–A53.
Mikhaylov S. V. 1968. Outline of World Ocean Future, Priroda, Moscow, (6): 24–31.
Moiseev, P. A. 1965. The Present State and Perspective for the Development of the World Fisheries, FAO/EPTA (1937-II): 69–83.
Peterson, P. 1961. *Fish Meal Production and Trade in the World.* Future Developments in the Production and Utilization of Fish Meal, FAO, II: 1–64.
Pruter, A. F. 1968. The Supply of Living Sea Resources in the Future of the Fishing Industry of the United States. Univ. Wash., Publ. in Fisheries, N.S., IV: 102.
Ryther, J. H., and J. E. Bardach, *et al.* 1968. The Status and Potential of Aquaculture. Two volumes. American Inst. of Biol. Sci., Wash., D.C.
Schaefer, M. B. 1965. The Potential Harvest of the Sea. Trans. Am. Fish. Soc., 94(2): 123–128.
——. 1968. Economic and Social Needs for Marine Resources. *In* Ocean Engineering (Brahtz, ed.), John Wiley and Sons, New York: 6–37.
Scott, Anthony D. 1968. Fisheries Development and National Economic Development: 335–345.
U. S. Bureau of Commercial Fisheries. 1968. Fisheries of the United States, 1967. C. F. S. (4700): 1–101.

DISCUSSION: Dr. Wilbert McLeod Chapman—WORLD FISHERIES

Discussant: Dr. Alan R. Longhurst

Longhurst: I think we have about 15 minutes to discuss this contribution, and I have just one or two points to make.

Wib said that he very strongly believes in the continued increase of world landings at something like the present world rate over the next few decades, and I wonder whether I ought to ask him to rehash this a bit in the light of the fact that a very high percentage of our present landings comes from a very small number of species and the landings by species are skewed in a manner similar to the distribution of landings among countries.

I brought some figures here that show that in 1965 nearly 60 percent of the world's landings of fish came from 12 species-groups, if you group the mackerels and jack mackerels separately. These 12 species-groups run: Peruvian anchovy, Atlantic cod, Atlantic herring, South African sardine, mackerels as one group, jack mackerels as one group, the Alaska pollack, haddock, red-fish as a group, menhadens as a group, North Pacific herring and European pilchard. Of these species, I know of 5 which are in serious trouble, and I would like to ask Wib what his opinion is, in general terms, about maintaining the catches which we have now, while projecting our future increases in landings.

Chapman: My feeling is that there will be opened up the use of new resources. As an example, what has been going on in the last 5 years is a great expansion and use of hake on a world-wide basis. There is still some room for hake expansion, especially in the Chilean area. I frequently refer to the sardinella of the Arabian Sea area, which is a big resource, but there are a lot of other herring-like fishes available there too—really about 50 species—but the sardinella is the prominent one. The anchovy of the Pacific Ocean is a fair sized resource. There is still considerable room for development in sardinella of West Africa and northern part of Angola, and anchovy in that region too, I believe. And this is what I think is going to happen, is that the market pressure, the market demand for fish, is going to continue to be along about the same trend as we have—it requires opening up new resources and also the maintenance of the resources that we have now at the level of nearly maximum sustainable production. I think we are losing out on cod in the Atlantic. Menhaden has already gone over the hill; the California sardine did. As to the Peruvian anchovy, we may have enough grasp of this to hang on to it. The two problems must go hand in hand, opening up new fisheries to fill the demand and maintaining what we've got.

Isaacs: What about elasmobranchs?

Chapman: They don't amount to much in total, John. They form about 2 percent of production and they don't increase much. Not very abundant anywhere.

Isaacs: They're also some of the competitors of ours; this may be their most important aspect.

Chapman: Quite. We haven't really done anything about weeding out competitors. We don't even know what competition is. We think of competitors mainly from a standpoint of nuisance. The dog fish along this coast is really a nuisance, but nobody thinks of it as a competitor except a few scientists.

Longhurst: I am not sure I share your optimism, that we could maintain the base we've got, although it's a very good idea to hold this very optimistic outlook and to think that while moving on to a new species we will continue to build our total catch. Really our record doesn't seem to be awfully good in maintaining exploited species on a long-term basis, particularly in international or interstate fisheries.

Chapman: I agree.

Longhurst: This seems to be a very central problem, and very, very intractable.

Chapman: I agree because mostly you are dealing with humans and they are hard to get along with.

Carry: Speak a little louder so the *guests* in the back can hear?

Chapman: I said humans are hard to get along with, and you highlighted my statement. It is hard enough to understand fish but to understand humans is beyond comprehension.

Longhurst: If I might put one more question to the speaker before we open it up for general discussion—

You speak about a technological revolution in fisheries starting in the early 50's with new sorts of gear and vessels, and so on. Has anybody measured, on a global basis, the increase in fishing effort that all this implies. I have the feeling, just reading the trade literature, that we are increasing our effort and technological pressure on stocks much faster than we are increasing our landings, both on a global basis and on single fisheries.

Chapman: The only fellow in the world that I know, that has been dabbling with this problem, is Paul Adams, with the OECO in Paris, and he has now gotten pretty good statistics coming in from all European vessels and what they are producing and so forth. I don't think anybody else is paying any attention to this at all.

Longhurst: I think it is a very serious thing too.

Chapman: I do too.

Bullis: Commenting on your point about the resources base, I think this rapid growth over the last 20 years hasn't been concentrated on established species. In my region (Gulf of Mexico) 70 percent of the shrimp production is based on species that weren't harvested 20 years ago; 50 percent of the menhaden are species that weren't harvested 20 years ago; the same with 50 percent of the snapper production. This is contributing very heavily to the expanding world production and I think the big question is one of how much farther can we go into this unutilized species group category?

Chapman: Another good example is provided by the Gulf of Alaska. All of the added productions that have come from there in the last 10 years have been of species that weren't used before. Now we are getting into the pandalid shrimps and they're going to be a good sized resource. There are technological as well as marketing improvements that have made this development possible. The use of minced fish (surumi) in Japan is what made the increase in pollack fishing practical. This makes a good fish-product raw material and so there has been a big expansion. I am not saying I'm optimistic or pessimistic, but how I think things are going to go. Really I am predicting on the basis of how it has gone in the last 20 years and the thing that is surprising to me is how steady these trends have been when you look over a 30-year period.

Preston: The point is, I suppose, there isn't an infinite number of new resources. Considering conservative estimates of these and the difficulties in managing the ones you have, you may top off somewhere around 250 million tons per year.

Chapman: I have been going along with this 200–250 million tons production level but I don't believe it at all because of what Harvey just said. By the time we get to producing 100 million tons per year out of the ocean instead of 50 million tons, you are going to be looking at the whole mass of living matter in the ocean with a different set of market demands. You may be thinking of *krill,* for instance, of which perhaps 100 million tons a year are available—keeping in mind that mysids now form the raw material for a large direct human consumption business as fish sauce in Thailand and Japan.

What we think of in the United States is tuna and shrimp and halibut and cod and salmon, but there are a lot of different animals in the ocean that you can get hold of pretty cheap that make fairly good eating and the market keeps changing steadily. We should dip into these other resources.

McGowan: It bothers me a little bit that one of these so-called new resources, that you mentioned, California anchovy, is not a new resource at all in an energetic sense. It is a replacement for an old resource, the California sardine, that had been fished out. I very much suspect that if you want to maintain the present levels of fishing on all the species that we are using now, plus spread to new ones, that somehow, the calories and materials formerly utilized by the crops we are taking out are going to be shunted somewhere else and it is very likely to go through species that are absolutely useless to us—salps, for instance; they turn much of their carbon intake into cellulose.

Bullis: Isn't it as likely though, that it could go to something that would be a little bit better?

McGowan: Who knows? Nobody on God's green earth can tell you that. At the present time there is no reason, that I know of, to believe that the trophic resources that formerly went into "useful" populations will be switched to other species of equal usefulness to man. This is a very important question in ecology and much more work needs to be done on it.

Chapman: Well, what we are trying to get at a bit in this exercise of the IDOE, is to push the research into that field we keep talking about but not doing much about. That is ecology. Actually I would prefer to phrase it "the transfer of energy through the web of life."

We do nothing about this presently and these questions you bring up are the very real ones and I think are pressing very hard on our whole foundation of knowledge presently.

McGowan: I think we have overextended it, as a matter of fact.

Isaacs: Just taking that bare bones of your statistics there, with the 2 percent increase on fisheries a year, this is then falling behind the rate of population increase. Of course, that doesn't say that it isn't contributing in a particular way to those people that need the food.

Chapman: I think the quickest way you can get anchovy into Europeans anyway, is to run it through chickens.

Isaacs: This always sounds inefficient at first—wouldn't you like to comment on this?

Chapman: Well the transfer of essential amino acid by chickens is approximately 1 to 1, keeping in mind, however, that you are using up grain in the process. But from the amino acid standpoint you don't lose anything running it through chickens—also catfish—which are a hair better.

Isaacs: One thing that was brought up was the matter of subsidy in other countries—you might comment on some comparable subsidies between farmers and fishermen and their relative productivity.

Chapman: The only thing I can say is that the farmers, everywhere in the developed world, are pretty heavily subsidized. Fishermen, by and large, don't have as large a subsidy as farmers do and this is becoming more and more of a problem and particularly in the developing world. The Europeans are increasingly subsidizing their fishermen. The three most recent very sharp examples of this in western Europe are Spain, Italy, and Greece where very substantial subsidies are being granted. From the economic standpoint, straight out, what it is being done for is to save foreign exchange.

Longhurst: Also recently in Great Britain, when distant-water trawl fisheries began getting into real trouble, the immediate answer was an increase in Government subsidies.

Farris: If I understood what you said, the expanded world fisheries aren't going to do a doggone thing for the poor people, but the rich people are going to have a better diet nutritionally, more conveniently packaged out of this whole ball of wax.

Chapman: That is approximately what I said. That is the way it has been running.

The interesting thing that I failed to say was anything about the Peruvian example. The consumption of fish domestically in Peru has increased from some 20 thousand tons per year to 155 thousand tons per year over a 10-year period and it is going up quite steadily. This is a sharp increase. This would not be possible in Peru if it were not for the export fisheries which bring enough money into the business to permit the bonito and other food fisheries to be expanded, and produce food for local consumption. This is so in a number of these developing countries where they are hitting heavily on fisheries for export in order to earn foreign exchange. What this is doing is building up the whole structure of their fishing industry because of the capital coming back into it, producing fish cheaper for home consumption than would otherwise be the case. Ceylon is a good example, Thailand is a good example, Malaysia is a good example. But there is no way to stimulate fisheries to really help poor folks only, with heavy subsidization. Poor folks are pretty nearly beyond help.

Isaacs: I think there are some very important points to the problems here and an immense amount of discussion is possible on almost any single one. We certainly have never paid much attention to the effects of a fishery of a species on its competitors or predators, or even on behavioristic groups within the population. With the U.S. tendency for highly selective fisheries, such interaction may be even more immediately important than in the less selective cases. In the long run these latter, of course, may give rise to even more profound reactions—an ocean of only salps and medusae is repulsive.

We have introduced a great number of such open subjects in this symposium. Perhaps we can discuss some of them further this afternoon.

I suggest right now we have a coffee break.

Calif. Mar. Res. Comm., CalCOFI Rept., 14:57–66, 1970.

WORLD FISHERY TECHNOLOGY

HARVEY BULLIS

Thank you, Mr. Chairman. Two aspects to my comments should be explained. First, if Wib Chapman had talked for another ten minutes, he would have covered my talk beautifully, and second, they made me promise that it would be sufficiently controversial to give plenty of opportunity for debate.

I am going to have an entirely different cast to my presentation than the previous three speakers, who I think did a beautiful job of providing the group an objective perspective. I have never been able to do this with the question of fishing technology. I find myself deeply immersed in it, with highly subjective feelings on the subject, and I am afraid you are going to find all of my comments tainted. With these comments, I will start off with a rather terse statement that I don't think we have anything that can be given the categorical term of WORLD FISHERY TECHNOLOGY.

Mechanization, increased vessel size, increased power, synthetic fibers, are transitional elements in world fisheries. To categorize them as a technology in a static sense is misleading. In a sense, fishing technology has developed as it was needed.

If we look to the future, there are indications that the present technology is not going to be adequate. Our fisheries are in transition, either moving toward adequate or inadequate technology. I would say the groundfish fisheries in New England and perhaps the Pacific Northwest seem to be moving toward inadequacy while others such as our tuna fisheries are moving in a satisfactory direction. Fishing technology responds to a long list of social and economic factors. These dictate how successful technology will be. Value-of-catch factors say that high value of a product permits great inefficiency and a very low-value product demands very high efficiency. An example in our area of ownership claims on resources or on environments that produce resources would be the menhaden fishermen versus the sportsfishermen controversy. So, regardless of fishing efficiency and abundance and availability, social controversy has a strong bearing on whether or not the menhaden fishing operation in a particular area is "successful." Another example—a small commercial fishery for snook in Florida was recently legislated out of business. Whereupon sportsfishermen started selling snook to the market and you can buy as many snook as you could before. Instead of two or three commercial operations, we now have 5,000 or 6,000 sportsmen producing the catch.

Since you were so kind as to donate coho salmon to the Great Lakes, we can see what has recently happened. The position of the State is that this is a sport species. Since sportsfishermen can't seem to catch them, the State has moved in and established a State-run commercial fishery. We have market systems that frequently work against the fisherman. In the system that says to buy cheap and sell high, the fisherman sits right at the bottom of the pile. When production is the highest, the prices are the lowest.

So, fisheries technology operates within wide parameters of availability, proximity, values, skills, materials, subsidies and supports, restriction, and management. To develop a concept of WORLD FISHERY TECHNOLOGY is too confusing to attempt at the present time. But if we did, I think we would see that the strategy or tactics of one country or possibly one region is not necessarily successful elsewhere. Things like need for food in the homeland, demand for special products, foreign investment opportunities, and need for foreign exchange all have a tendency to shape technology.

From this point on, I would like to view it from the interests of the producing segment of the United States industry.

Here we see strange phenomena. In the Western Hemisphere there is an interesting range of the fishing effectiveness. The lowest catch-per-man per year is about 500 pounds. This is in the Netherlands Antilles and applies to full-time fishermen. In contrast, is the high catch-per-man of about 3,000 tons in the industrial trawl fishery in the Gulf of Mexico. However, regardless of how effective or how efficient a particular piece of fishing equipment may be, the fisherman is responding to a series of economic pressures. In Puerto Rico we found that in spite of the rather depressing levels of catch that were coming out of certain areas, the fishermen wanted no assistance in increasing the catch. They maintained that if the circumstances warranted, they could do this without help from the Government. While the Government wanted to give them free nets, free boats, etc., they had sort of tuned themselves to certain size landings, certain volumes, that they could bring in without upsetting the market price. They could catch a lot more fish but, by keeping the landings at a certain level, they could maintain a price level that they figured was a fair return for their effort. Until the entire marketing scheme could be changed, they were not about to move out of this position. I think we could find a number of more subtly disguised examples in our United States fisheries.

So try to look at what "success" means in fishing technology in the United States. There is always some relationship to profit but not necessarily to maximum profit potential. A producing segment that is tuned to the marketing system is not anxious to adopt a new system. In fact, there is fear on the part of some fishermen of new and more efficient systems. They are going to upset the apple cart!

So, from a positive point of view, I would say that we could probably do much better if there was proper motivation. There are wide areas of fishing technology that haven't been explored. In taking a rather broad look, if it is possible to do so, at the success stories in United States fisheries, there are criteria that seem to emerge. One would be having the value of the catch retain some parity to production costs. The shrimp fisheries in the Gulf of Mexico are an example. If shrimp prices had not gone up to where they are right now, most of our shrimp fishery would be on the rocks. The other, and perhaps more important, is the adaptability of the production units to change. An example would be the purse seine revolution on the tuna fisheries. The willingness of the industry to make a major technological change when it did probably averted disaster.

Another example of adaptability to change was brought up in the discussion of Wib's paper; broadening the resource base. Certainly in the Gulf, this is the basis of the success in the fisheries over the last 20–30 years rather than any gear technology innovations.

Some more personal ideas are perhaps best expressed in some of the programs that we are conducting. I would now like to get into the area of controversy that you asked of me and explain what we are trying to do in the development of a vast latent stock of fish and the techniques that we are using to assist the industry in expanding production in this area. In very general terms the matrix of this program is wrapped around four generalized roles. These are to broaden the resource base by identifying and assessing latent stocks; particularly in looking for new grounds for commercially established species and identifying populations of unused species that would seemingly offer marketing compatibility with species that are being utilized that could be slipped into a marketing structure without creating serious problems. So our goals are (1) to identify those species groups that show innovative investment opportunities, (2) to provide improved time and space intelligence for the established commercial species, (3) improvement of extraction technology, and (4) to evolve good communication with the industry to effectively implement the adoption and development of the above.

The calico scallop project is perhaps familiar to you. The initial role of this project was to help a group of fishing vessel owners who had found themselves in a technological bind. Their vessels were no longer large enough for effectively competitive trawling for shrimp.

In the following I will present a series of figures that, hopefully, will illustrate some of our activities.

Figure 1 shows the catch taken in a typical 15-minute drag of an 8-foot tumbler dredge on the scallop beds off east Florida.

Figure 2 is an example of superimposing a grid on an aerial photograph for estimating school size. There are no reliable methods of estimating stock size of unexploited species. The biological tools at our disposal pretty much depend upon monitoring the exploitation of the species. We are dealing with about 40 species, all considered surface schoolers. Of the 40 species, only one is being harvested—menhaden. Our catch data for the past 20 years indicate that menhaden is not the most abundant species in the Gulf. There is no way to determine the margin of error in estimating school size. We have conducted a number of experiments with professional fish spotters. They are working on menhaden with a 50% error factor. As soon as they move off to the other 39 species, we operate with error factors on orders of magnitude of 5 or 10 or 20 times. Much of the effort of fisheries development in the Gulf area is delineating the pelagic stocks of coastal pelagic schoolers in particular. In the last 3–4 years, we have more or less submerged all of our other activities to try to develop new techniques for quick survey and assessment of schooling species.

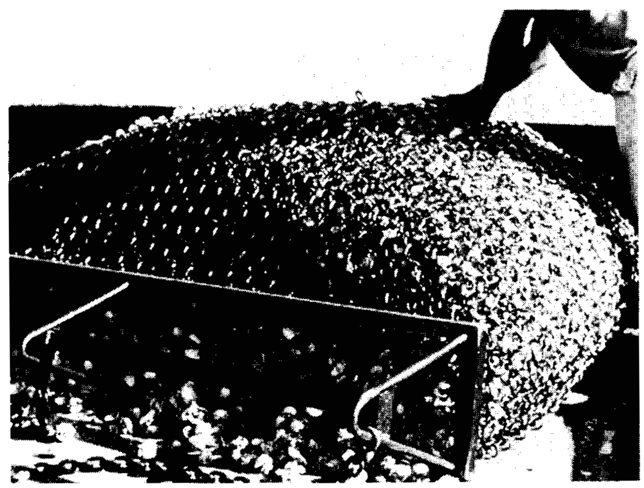

FIGURE 1. Calico scallop taken in a typical 15-minute drag of an 8-foot tumbler dredge on the scallop beds off east Florida.

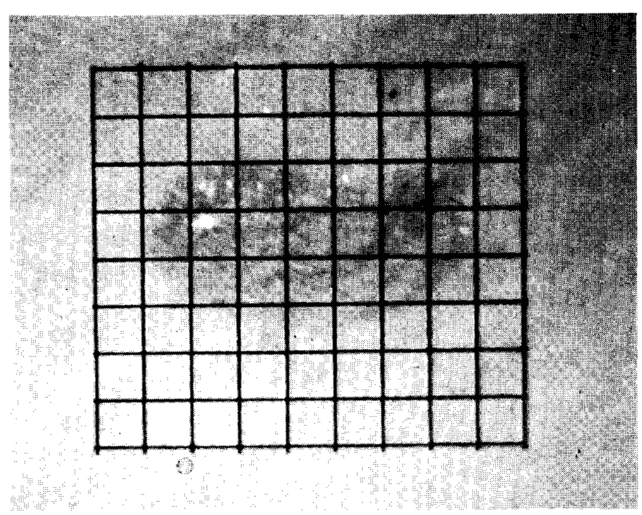

FIGURE 2. An example of superimposing a grid on an aerial photograph for estimating a school size.

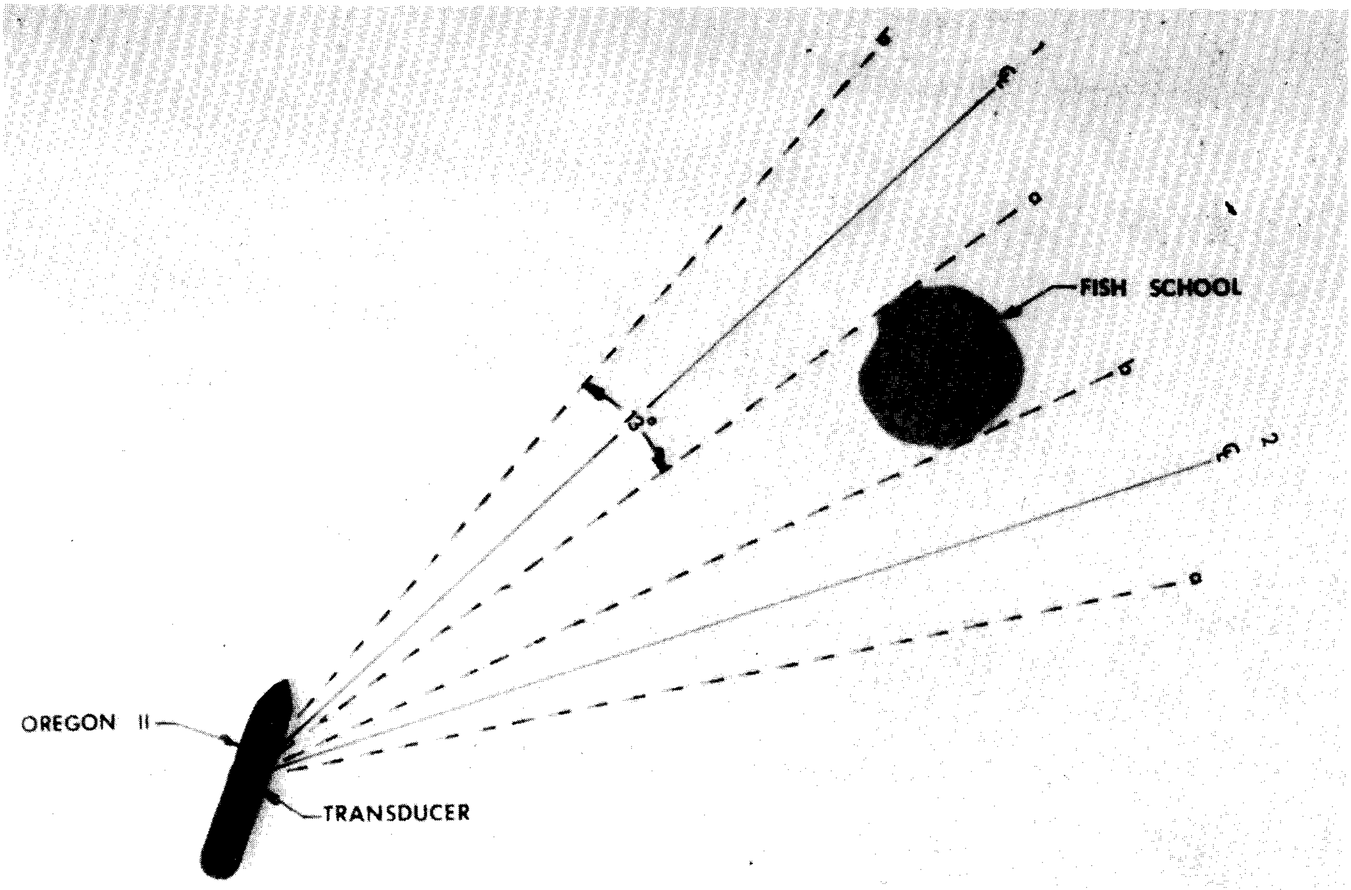

FIGURE 3. Sonar profiling of a fish school with a variety of frequencies and pulse lengths.

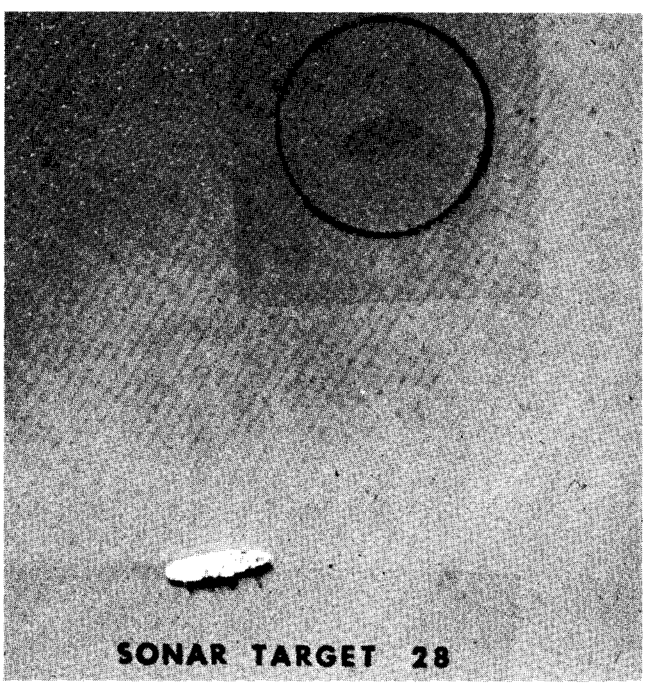

FIGURE 4. Aerial photography associated with sonar profiling target.

Signal penetration studies have been conducted by picking up a fish school on sonar, profiling it with a variety of frequencies and pulse lengths as depicted in Figure 3, and conducting simultaneous aerial photography (Figure 4) to get definitive horizontal profiles of the school.

Next, I would like to read a few pages that I have clutched out of a recent talk that explains in some detail one of the perhaps most exciting prospects for future fisheries survey technology. The National Aeronautics and Space Administration has undertaken, as you know, an extensive study to determine the feasibility of developing a satellite system to survey the resources of the earth. The study is now being conducted to determine the feasibility of utilizing remote sensors aboard both aircraft and spacecraft to assess aspects of our minerals, forest, water, agriculture, and other resources. These sensors operate on the principle that each object on earth reflects, absorbs, and emits energy—electro-magnetic radiation—in a manner characteristic of the object's physical and molecular strings, giving each its own special signature. One group of sensors, multispectral cameras, reports the special distribution of electromagnetic radiation from the target over some narrow portion of the spectrum. Other sensors, such as scanning spectrometers, measure intensity and spatial distribution of this radiation as a function of wavelength over the entire spectrum from the ultraviolet through the visible into the non-visible infrared and microwave regions.

Intriguing questions then arise as to the possibility of applying these new technologies to such earthbound applications as fisheries resources, survey, and assessment. We have initiated a program directed toward the application of remote sensing technology to the problem of pelagic fishery resource assessment —particularly the location, identification, and quantification of surface and near-surface fish stocks. Because of the complexities of the problem and the inherent limitation in each method considered, a number of approaches have been taken. The initial effort of this program was to determine the feasibility of utilizing aerial photography in conjunction with ground crew observations as a means of obtaining quantification and qualification data on known pelagic fish stocks. More than 1,000 schools have been photographed using black-and-white, color, infrared, and various photo combinations. Sixty-five of these schools were sampled to determine size and species composition. Simultaneous sonar soundings were also obtained on a number of schools in an effort to determine subsurface configurations and density. These have shown that the position and surface configuration of fish schools may be obtained in very precise terms from high altitude photography. Selected photographs are now being subjected to color separation and isodensitometric analysis to determine the relationships which may exist between color, tone sensities, species, and school size respectively. The aerial photogrammetric studies are limited in certain respects, due to problems of water penetration and subtle color differences associated with some schools. Multispectral photographic techniques may be used, however, to detect these subtle differences and provide greater depth penetration by excluding those spectral regions which contribute little or nothing to the inclination content of the photograph. Black and white as well as color films are inherently sensitive to large portions of the electromagnetic spectrum.

In case of fish schools in their natural environment, the color differences which may be used to locate and identify certain species may very easily be lost in the background reflectivity of the scene and hence pass undetected upon examination of the photograph.

Multispectral photography separates the reflected radiation into a number of wavelength bands which have been pre-selected to yield maximum differentiation between the target and the background. This is accomplished by using narrow band filters which cover only the area of spectral difference and thus enhance to provide greater contrast between the target and background. A series of multispectral experiments were conducted by Long Island University, under contract to our Laboratory, during the past summer to determine the feasibility of using these techniques to locate and identify surface and near-surface fish schools.

Initially, the wavelength bands for greatest depth penetration were determined for two regions in the northern Gulf area. Special narrow band filters were developed to look at those parts of the spectrum which would give the greatest depth penetration for these waters. A series of test flights were then made over the areas using a 4-lens multispectral camera system in high speed emulsions. 15-x120-foot target areas consisting of red, blue, yellow, and gray scale panels were placed in the scene and served to evaluate the performance of the sensors for underwater penetration and as a control for the analysis on imagery. Schools photographed during these experiments were sampled to provide ground truth data on size and species composition. We have received only a preliminary report on these studies so far but the indications are that we are getting excellent separation of the fish school from the environment and this particular study has indicated that high altitude photography has a potential in survey and assessment projects.

Many pelagic species may be identified on the basis of color or distinctive pattern—the red color of menhaden schools which is identifiable from visual observation, for example. These characteristics are commonly used by commercial spotters to locate schools. The use of colors, or of spectral differences, by the commercial spotter to identify species suggests that spectral analysis of the reflected radiation will reveal characteristic spectral signatures which may then be used to locate and identify fish schools in their environment, at least under special conditions. During September of this year the Pascagoula Laboratory and TRW Systems recorded spectral reflection measurements on 15 schooling species in the north Gulf. Measurements were made on single fish, fish in small groups, and impounded fish schools using TRW spectrometers. The spectral reflectance measurements were obtained under natural lighting conditions from both surface vessels and stationary oceanographic platforms. And again, these data are presently under analysis by TRW. However, we have received a preliminary report from them that shows that this has a possibility for species identification.

Another approach to the problem of locating and measuring pelagic fish stocks which appears to have good potential is the use of low-level light sensors such as image intensifiers which record bioluminescence or "fire" as referred to by fishermen.

The Florida Spanish mackerel fisheries serve to illustrate the potential of this method. In Florida this fishery is carried on chiefly with gill nets and haul seines at night. The fish are sighted by the fire in the water, which is the result of a number of fish schools which cause luminescent organisms in the water to glow momentarily. Rapidly swimming fish cause these organisms to luminesce, outlining their bodies with light and leaving trails of light. Schools of mackerel containing 5–10 tons can be identified by individual flashes of bioluminescence. This fire can be seen with the naked eye on moonless nights; however, it is also possible to pick it up on cloudy nights or, in any circumstance, less than full moonlight. During the past three months a series of tests have been conducted using huge intensifiers on loan from the Night Vision Laboratory at Fort Belvoir. Intensifiers used in these

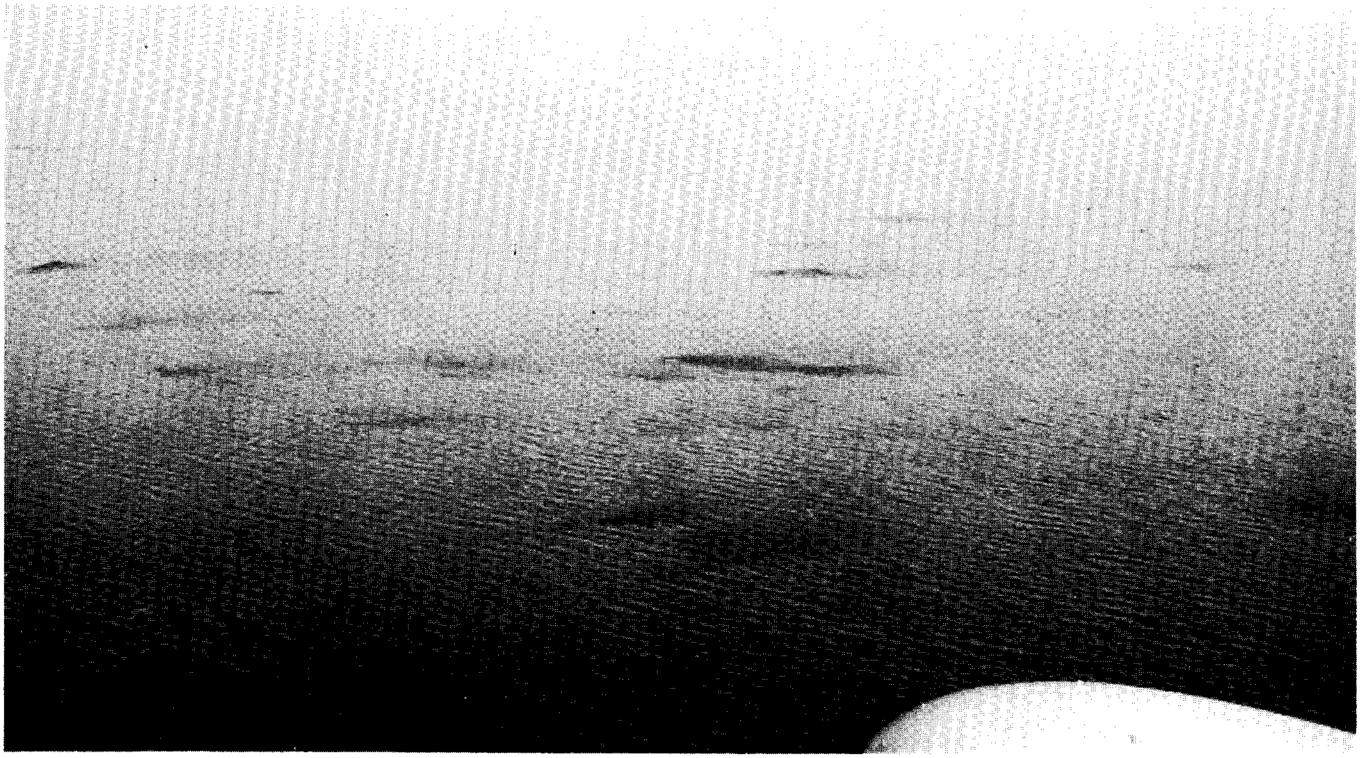

FIGURE 5. Thread herring schools off the west coast of Florida in normal summer.

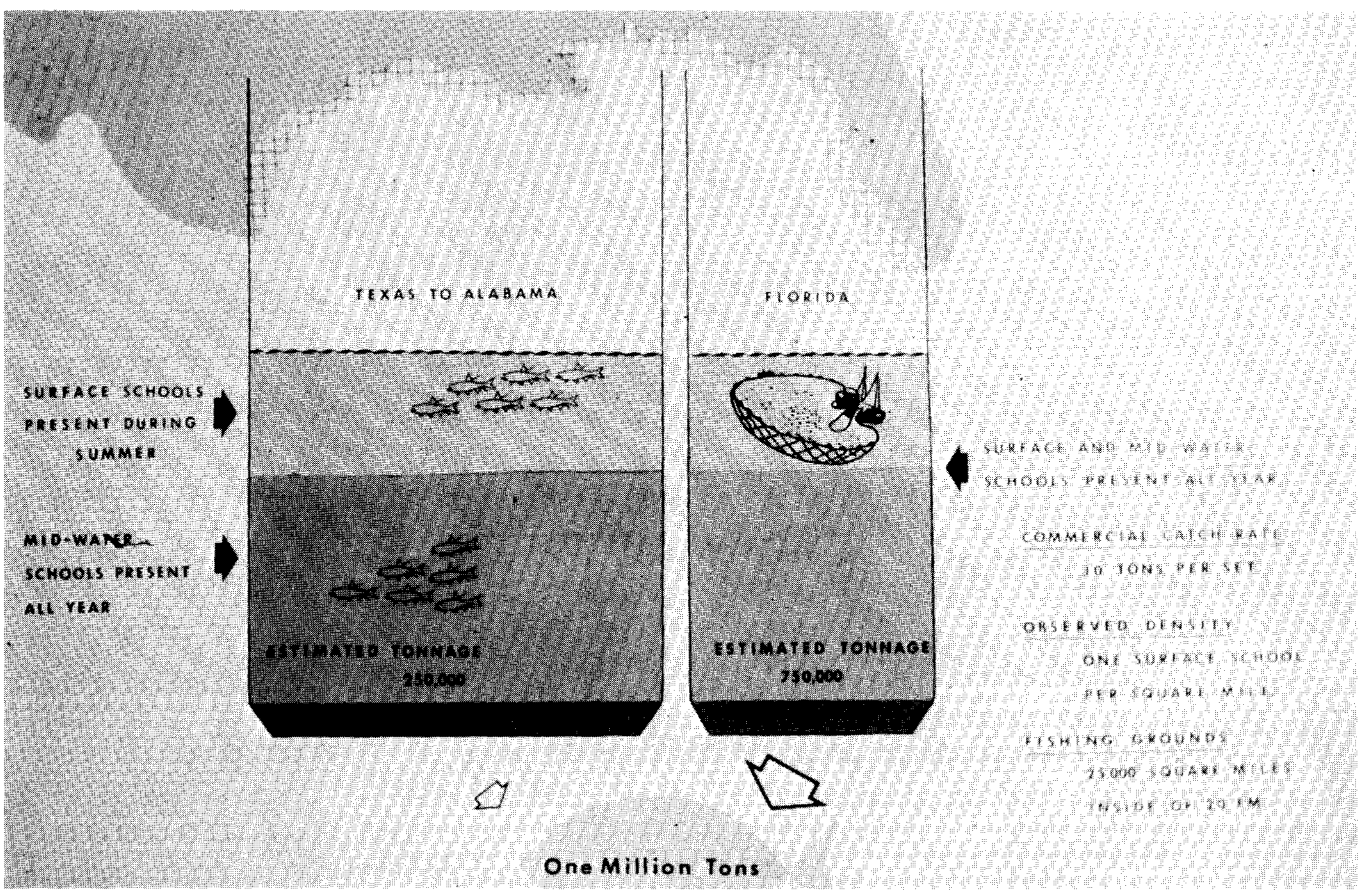

FIGURE 6. Estimate of school count and tonnage of thread herring off Florida's west coast.

initial studies amplify the ambient light and, in the case of bioluminescence, they emit light 40,000 times that seen with the naked eye. Observations have been made using a closed circuit TV system coupled with the intensifier of fish schools, individual fish, and in water masses with low concentration of luminescent organisms. Results of these tests dramatically show that low-level light sensors may be used effectively from high altitudes as a means for locating and possibly identifying pelagic fish stocks over large oceanic areas.

Now let me resume the presentation of my photographs. Figure 5 shows a number of thread herring schools off the west coast of Florida, a very common sight throughout the summer months in that area.

After three years of aerial spotting on the west coast of Florida we came up with an estimated school count and, by sampling estimated school size and simple multiplication, came up with some figures (Figure 6).

Several menhaden schools are visible in Figure 7.

Our first attempt to use aerial infrared film produced this startling image (Figure 8). Here are anchovy schools off the coast of Louisiana, Mississippi, and Alabama.

Later on in the studies when we were working on thread herring stocks off southwest Florida, we happened to have a shallow-water sonar study of fish that were hiding in the sediment clouds. At the time there were a number of vessels in the area fishing for thread herring. It was impossible to see any of the schools from the air. Figure 9 shows these boats being set under sonar direction from our vessel. This particular set hauled about 115 tons of thread herring. None of these schooling phenomena could be observed visually at the time. So again this opens up some intriguing possibilities of analysis of high-altitude photo reconnaissance of the coastal waters.

In Figure 10 a sonar scanning directly ahead of the vessel running through turbid water is reproduced. Each one of these lines is a separate fish school—very heavy concentrations of thread herring schools along the coast here. Very typical of the west coast of Florida in summer months.

We have been announcing that there have been large quantities of fish in this area for many years, but professional fish spotters maintain that the schools (based on menhaden fishing) are too small to set on. They do not show enough color. In Figure 11 is shown a very small school, about 75 feet in diameter. We had to pay a seiner $300 to come over and put his seine around the school and that school yielded 100,000 pounds of thread herring.

The oil slick phenomenon, as perhaps many of you know, has been under investigation by Barringer Corporation in Toronto for the last few years. They managed to interest NASA in the possibility that they could determine spectral signatures in these oils and

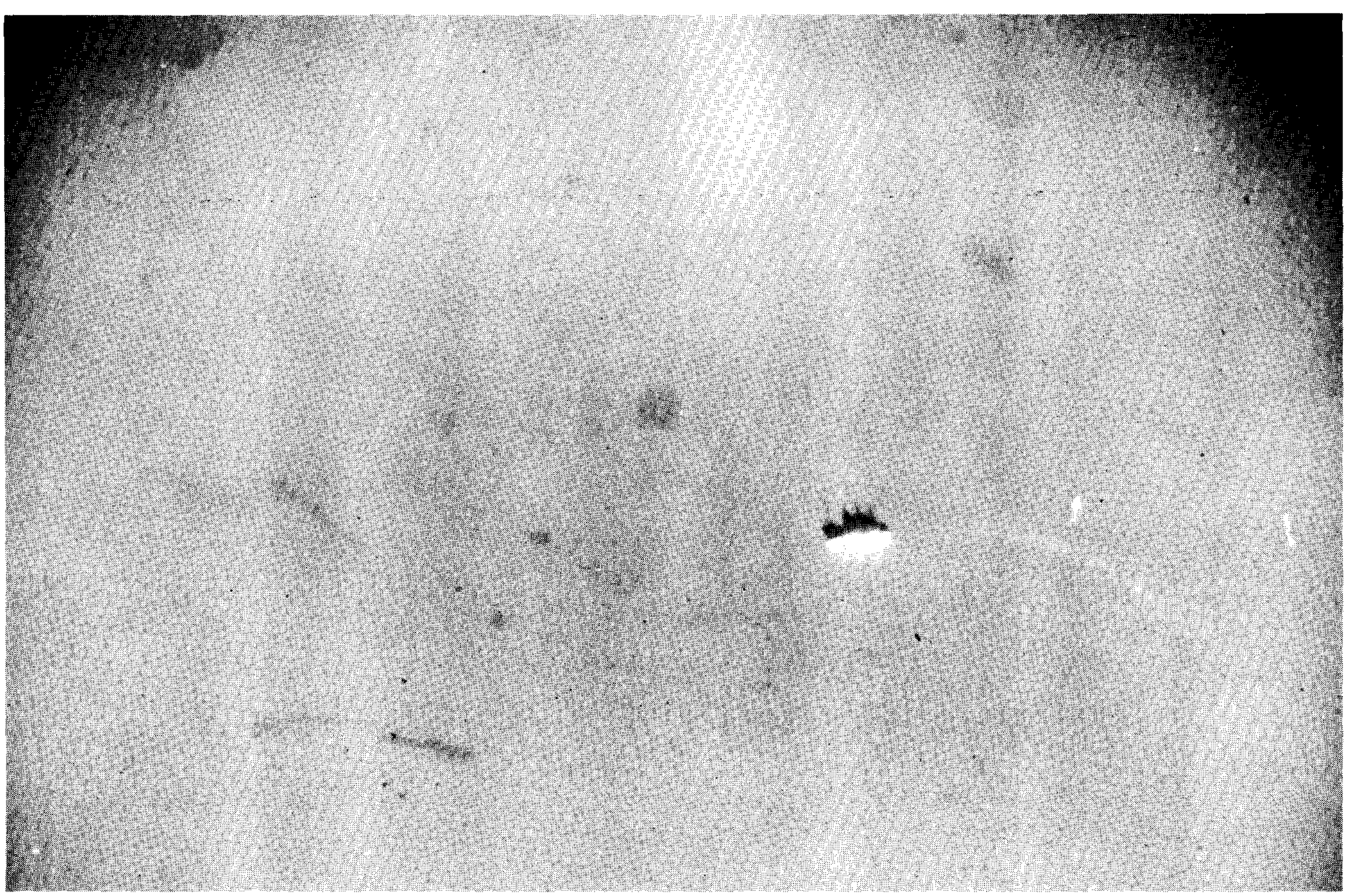

FIGURE 7. Menhaden schools.

were able to do it in the ultraviolet area of the spectrum, only trouble being that ultraviolet has little application for high altitude use because of atmospheric interference problems. Anyway, once it appeared we had a real-time relationship with the surface oil slicks and fish schools, we went back and examined our photographic library, and came up with large numbers of indications of the oil slick phenomenon in association with schools.

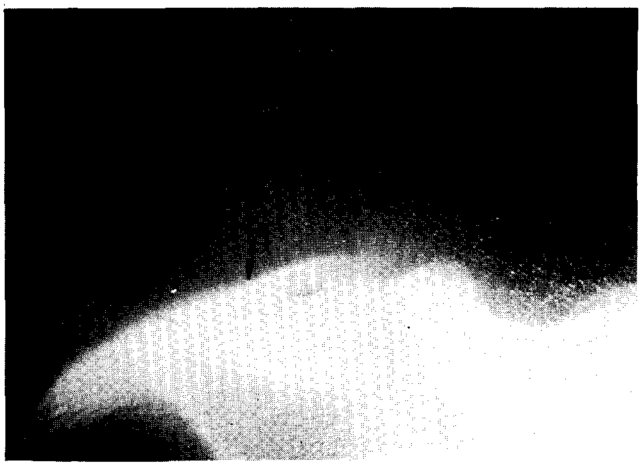

FIGURE 8. Infrared film images of anchovy schools in Gulf of Mexico.

Significantly, Barringer found that fish oil slicks differ from mineral oil slicks in that they have no color. They show (1) an opaque feature as in Figure 12 if you change the angle or (2) a glossy feature as in Figure 13. However, the color was identical to the surrounding environment. Mineral oil slicks have color characteristics and can be easily identified.

We looked at a number of species to see if we could find out which oils in the particular fish created the slicking phenomena. Fish oils apparently have characteristic absorption peaks, and those for mullet are plotted in Figure 14.

We found this immense school of 30-pound king mackerel (Fig. 15). We notified the local fleet of gill netters who extracted more than two million pounds from this single school. Previous year total landings from the west coast of Florida were under 1.2 million pounds.

Figure 16 shows a prototype bioluminescence detector based on equipment developed by the Army. The contract to develop this equipment costs the same as the entire BCF budget this fiscal year.

Here in Figure 17 is one of the first direct photographs of bioluminescence. This is a small school of Spanish mackerel seen from an altitude of about 80 feet. It was just barely visible with the naked eye, and here we are viewing it on a TV screen.

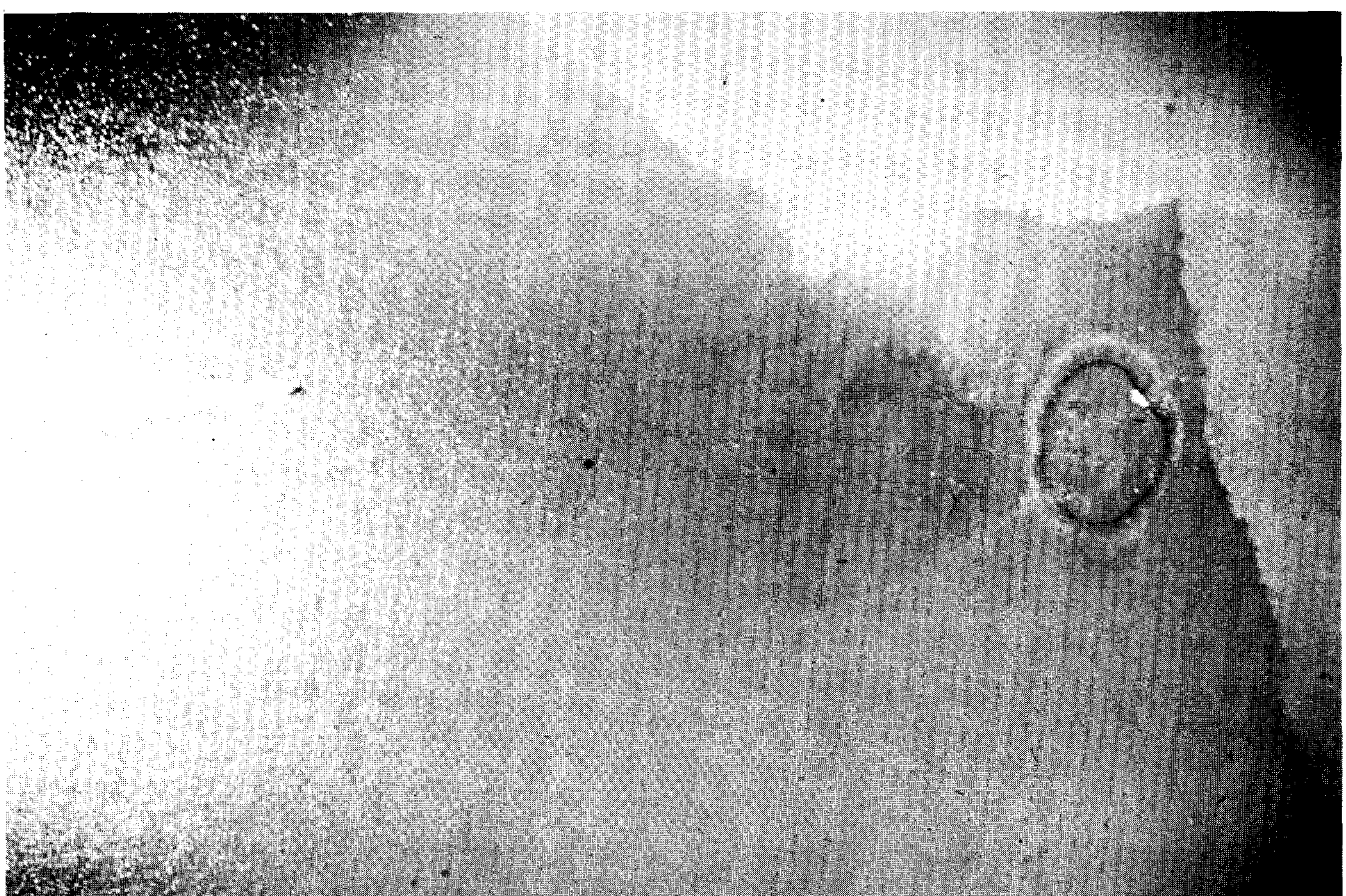

FIGURE 9. Sonar directed set around thread herring schools obscured by sediment cloud.

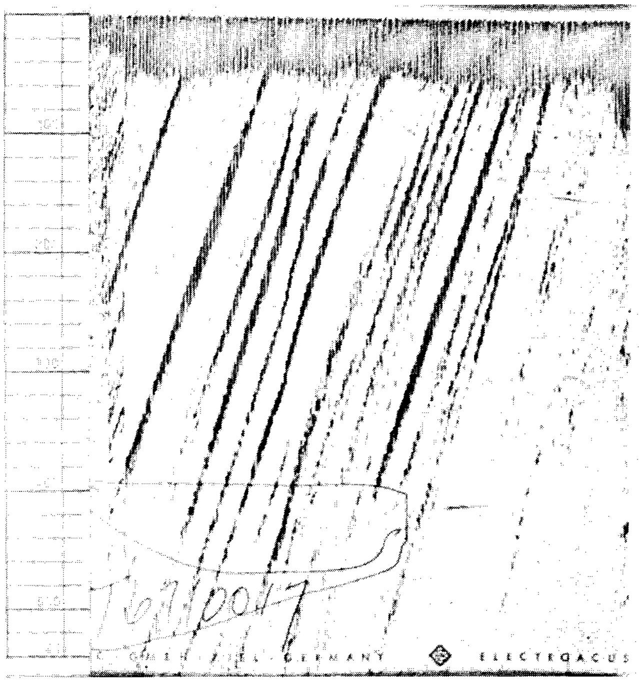

FIGURE 10. A sonar scanning directly ahead of the vessel running through turbid water.

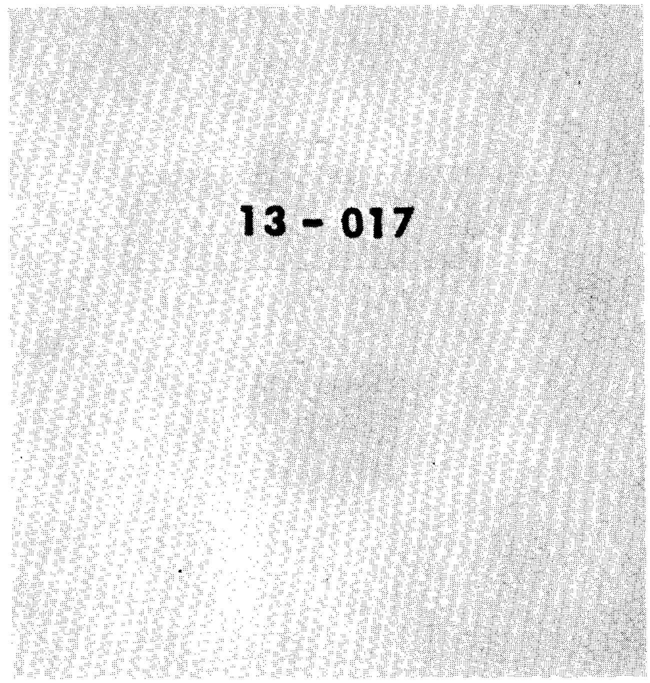

FIGURE 11. A small thread herring school, 75 feet across, that yielded 100,000 pounds.

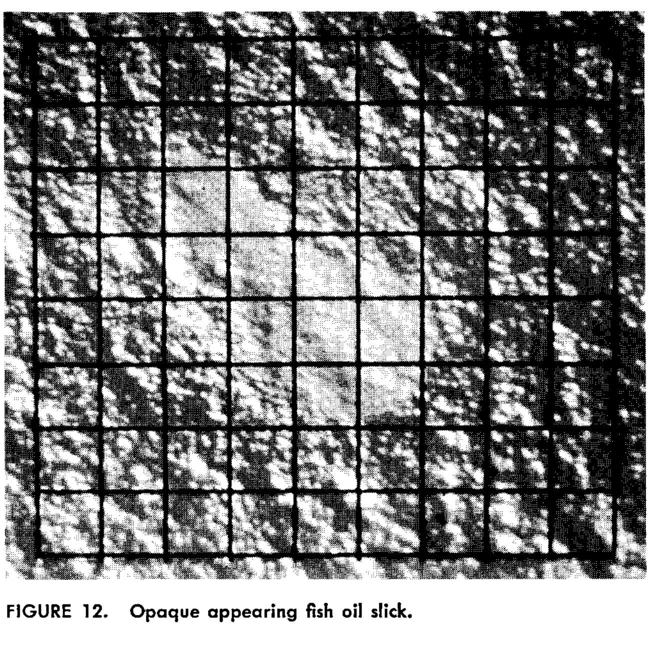

FIGURE 12. Opaque appearing fish oil slick.

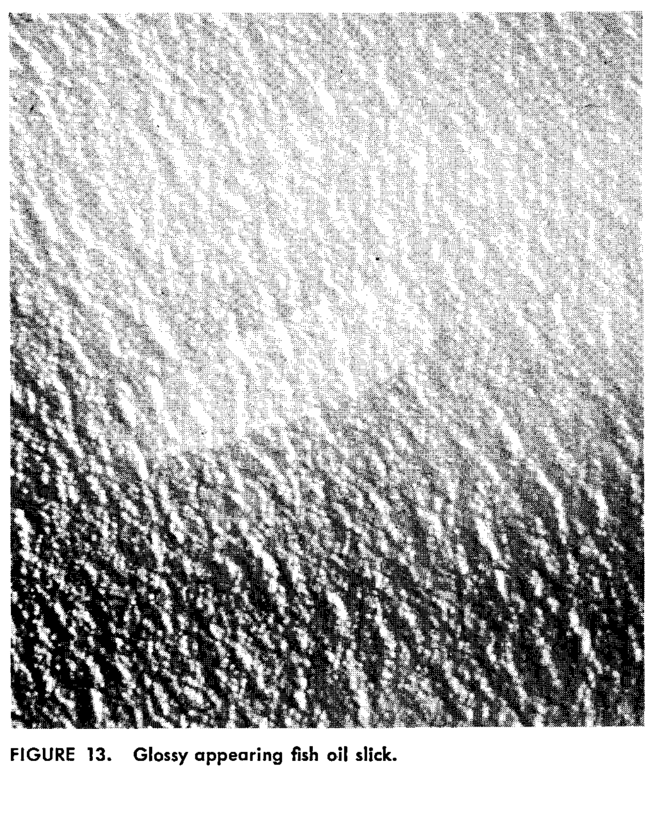

FIGURE 13. Glossy appearing fish oil slick.

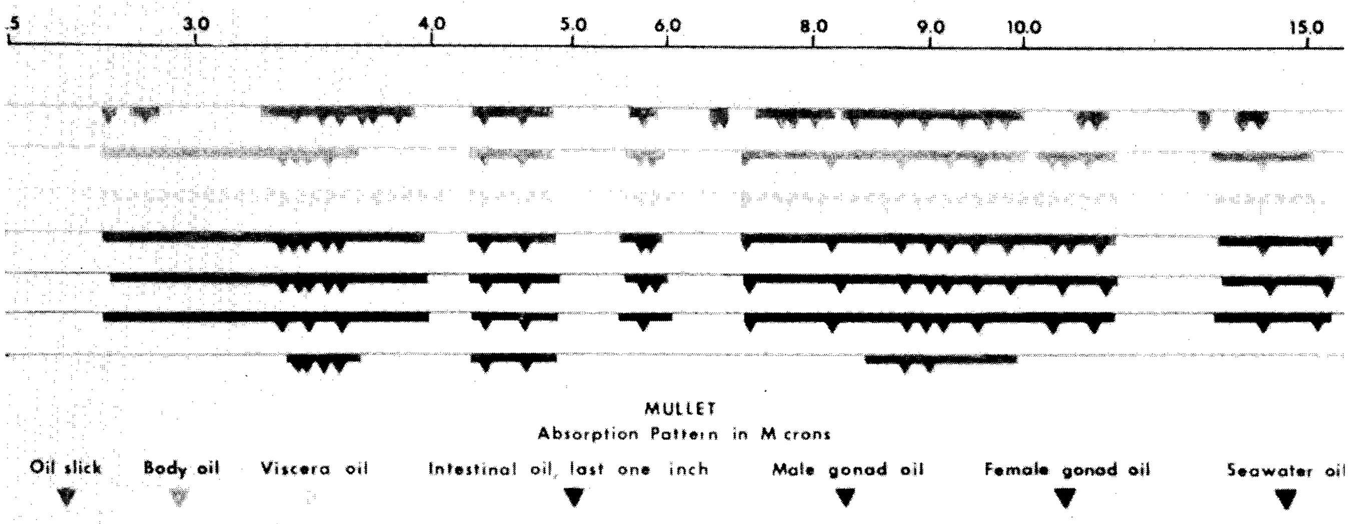

FIGURE 14. Absorption peaks of mullet oils.

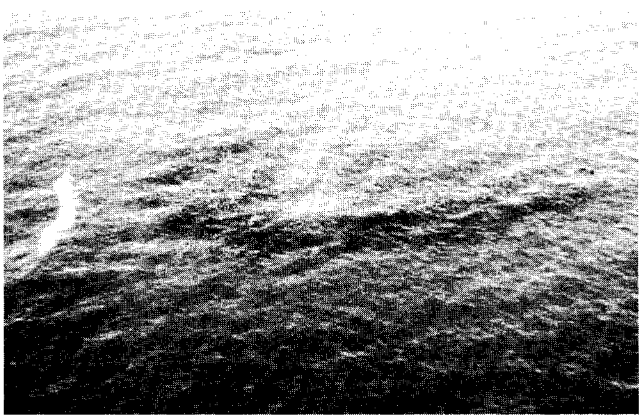

FIGURE 15. King mackerel school that yielded two million pounds.

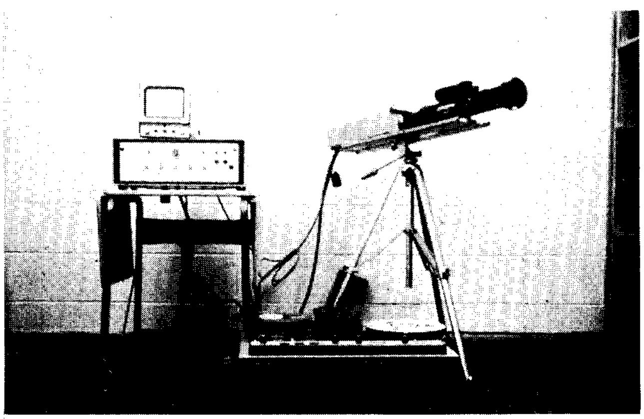

FIGURE 16. Prototype of newly developed bioluminescence detector.

DISCUSSION: Harvey Bullis—WORLD FISHERY TECHNOLOGY

Discussant: Phil M. Roedel

Roedel: A couple of comments before we get to the questions.

It has been interesting to me that in the last year or two all of our discussions with industry in California, and we have had many of them, have homed in on the need for exploratory fishing, gear development, and economic surveys as the most important things that Government can do today for the California fishing industry. Not that they regard what we are doing as unimportant—just that they feel that we, for a variety of reasons, are not carrying out work in these areas that the industry feels could result in a great deal of help to them.

With respect to sea surveys of pelagic fish, we in the Department of Fish and Game are at least guardedly optimistic that the techniques that are now being developed with our research vessel, the ALASKA, will pay off. The preliminary results in population size estimates for anchovies have been gratifyingly close to those developed by Dr. Ahlstrom through his egg and larva study.

With that, I think I will throw it open to general questions. Perhaps Dr. Chapman, from the initial remark, has first priority.

Chapman: No question.

——: Would the image intensifier work in the water that doesn't have phosphorescence?

Bullis: Yes. The point is that it amplifies light. This particular unit amplifies this light 40,000 times. We are now testing a unit that amplifies 90,000 times with much better optics. The capability exists to go farther with this. The difficulty is that we are operating this as a charity case. If it were not for the goodwill of other governmental agencies turning over this equipment to us, we couldn't afford to buy the off-on switch.

Chapman: Another thing is that water without luminescence in it hasn't much fish in it, ordinarily.

Bullis: Actually, this is a very preliminary estimate of what this equipment can do. We think that the equipment is so sensitive that you might be better off in areas of low bioluminescence. Most of the luminescent organisms we are dealing with are dinoflagellates and these have a very short period to their phenomenon. You can see that in the last two figures. The fish outlines very nicely. When it is frightened and takes off at a rapid swimming rate, it leaves a trail of fire behind it. If you had heavy bioluminescence in an area, then you could tune your instrument down and compensate for it, but the point is, even at very, very low levels, well below what you can see with the naked eye, the equipment is still able to record it.

——: Have you identified the source of the particular oils on the surface?

Bullis: No. We examined the stomach contents and the last inches of the gut, fecal matter, head oil, tissue oil, liver oil, and gonad oil. The spectral characteristics of each were very different. The testes, the ovaries, the stomach contents, the fecal matter, and body oils each had definable characteristics.

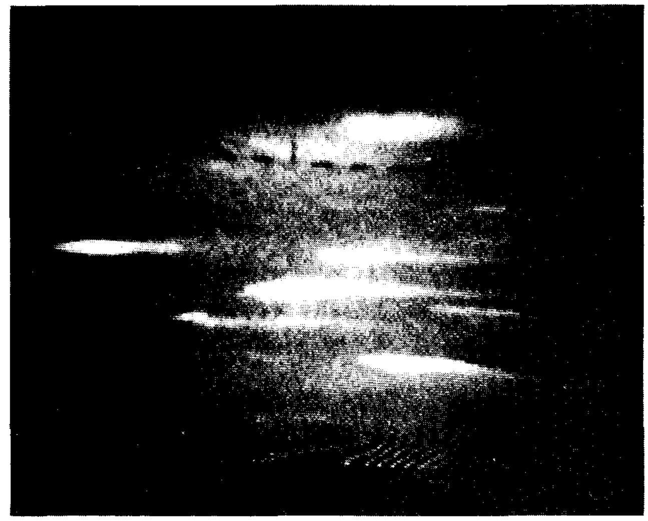

FIGURE 17. Bioluminescence associated with small school of Spanish mackerel.

——: Is it the same for all species of fish?

Bullis: No.

——: Stomach contents must vary depending on what it's been eating?

Bullis: The stomach content, yes. This is a hodgepodge and we examined a few of these and it didn't seem to be a very important consideration.

Isaacs: This oil phenomenon is an interesting one and I am delighted that you are working on it. I have read several times that fishermen could detect these oil films on the surface and also that the petrels are adapted to picking up oil droplets on the surface over fish that are being fed on by predators. At least one book also has referred to oil produced by the predators on these fish.

Bullis: One of the intriguing things about these oil slicks: Barringer found out that they had a very short duration, break up into small lenses very quickly, and then emulsification takes place rapidly. I suppose you could compare this to the joke about alligator eggs.

Isaacs: May I make a comment that goes back quite a bit in these discussions? I was rather astonished—no, not astonished, it sounded quite realistic—at this tendency of fishermen not wanting to accept greatly improved fisheries. This is an interesting matter because it tends, of course, to keep the poor, poor. How do you account for this? Is it that if a more effective fishery is developed that they will not be a part of it because they don't have the capital or because their boats are not adaptable to it? What is it?

Bullis: I think there are too many things that are acting here to pick out why this condition exists.

Chapman: Oh Harvey, it's the same thing with fishermen as it is with scientists, they don't want to think and they don't want to change.

Calif. Mar. Res. Comm., CalCOFI Rept., 14:67–70, 1970.

GENERAL PANEL DISCUSSION

SYMPOSIUM ON POPULATION AND FISHERIES

Panel: ISAACS, SCHMITT, PRESTON, CHAPMAN, BULLIS

Isaacs: I have been impressed throughout this symposium, more impressed than I have been previously, by the great separation between classes of nations. I am brought back to a statement by Abdul Salam, Scientific Advisor to the Government of Pakistan, an extremely intelligent man, who holds a chair in theoretical physics at the University of London. Dr. Salam once introduced such a discussion as this by saying that over a thousand years ago two medical books were written by a great Indian physician. The first was entitled ''The Diseases of the Rich,'' and the second, ''The Diseases of the Poor.'' He pointed out that these are even more applicable today than they were a millennium ago, and not only to individuals but to nations.

Look at this curious set of diseases that we have, in which our stocks of food are clogged, as Dr. Chapman points out, in our money market; in which we cannot reasonably reap our own fish except by those fisheries that have escaped from our immediate control, such as the tuna fishery; in which we lack money to buy such things as image intensifiers or on-off switches for important practical research; and in which we develop technologies that neither we nor a more primitive people can use.

I was impressed when Mr. Bullis was relating the tale of Jesus Christ appearing before two fishermen, as you remember, telling them to drop their nets on the other side of the boat. As several people have pointed out, Peter and Paul obviously were horrified by the results. They had caught far too many fish, and they didn't want so many fish. Their net was being torn up, it was giving them a lot of work, and they said, if you remember, being quite awed by this nevertheless, ''Lord, we are but simple folk. Depart from us.''

In some of his analyses of the Bible, Shaw paints a gloomy picture of these people with fish all gilled in their nets, nets ready to carry away, the boat ready to swamp, and so forth; no wonder they quit their business. Some of our technology that we attempt to impose on simple people must have some of this same effect.

With that remark and with the impression I get that there seems to be little development that seems likely to break through these barriers and make food of the marine realm available to the people who need it, I will leave all these gentlemen open to your slings and arrows and questions.

Farris: After hearing all the papers today, it seems to me that the most important thing is: how do we get these impoverished people off the dime so they can buy the fish that we can obviously find?

Chapman: We want to get them *on* the dime so they can buy the fish.

Preston: Obviously, a lot of thought is being given to the problem, and it is not as though nothing is being done. It is not true that in most cases underdeveloped countries now have a negative growth rate in their per capita GNP. In fact the growth rate is positive and in some cases quite high, but typically less than it is in the West. It is the discrepancy between the two blocks that has increased; it is not that they are going backward in absolute terms. I think the general consensus of opinion is that a revolution in agricultural techniques is required to get enough products that could be sold on a market, and thereby acquire some of the advantages of modern living. Getting a taste of what is possible in a modern economy provides some incentives for the continuation of the growth, but it requires starting out in most cases with an intensive governmental effort to increase the rate of agricultural productivity by agricultural extension, fertilizer, plants, and the like.

Isaacs: Within the developing countries? Yes. However, Ayub says that agricultural subsidy by a government of an agrarian country is an incongruity. The national economy depends on the agriculture to start with. Introduction of technical aid is, of course, something else.

Preston: What happens is that one country begins to export its agricultural produce and in turn can import some of the capital equipment necessary for industrialization. The produce is not just being consumed within the country, but some is left over for export.

Chapman: Another thing is that it all needs a little bit of patience. These things are moving ahead really quite rapidly compared with history—with previous time periods. I run around the world a good deal and I am always surprised when I go back through a place. Everything's still going to hell in a hand basket, but on a higher economic level than it was the last time. It is much the same thing in San Diego with the tuna fishermen—the most prosperous of the fishermen in the world that I know of, and they have enormous economic problems. They just ring their hands when they see you coming down the street. No tuna fisherman, in the 30 years that I have been acquainted with the business, has ever been happy economically. He's been going broke on a higher scale all the time.

West Africa, your country, Alan, in the 10 years I have been acquainted with it, has moved ahead economically enormously, but now everybody knows they have trouble. Ten years ago, they didn't know they had trouble.

Powell: As far as agriculture is concerned, how are you going to develop all the arable land and make it really economically productive at a maximum production factor without becoming socialistic in the world. Take the farmers down in Mexico where each man owns his little plot of land. How are you going to bring maximum production about without having some real big problems?

Preston: I am not sure you haven't answered your own question. It is true in many cases that some form of governmental interference, particularly in the area of land reform, is productive. Latin America is a very good example and Mexico a particularly good one. Mexico is probably in the best shape of any Latin American country now, at least excluding those with good mineral resources. And the consensus is, I think, that they underwent a very successful land reform. They took a lot of land away from the large land owners who were using the land less productively for grazing or something like that, and turned it into food production and thereby generated the beginnings of the process of development.

So it may indeed be true. It is true, socialism has obvious connotations, but I think more governmental interference is going to be necessary in some cases.

Isaacs: I always wonder about this sort of thing, because in that case the big land holders were not using the best land, and there are other cases where land holdings are so small that the best methods cannot be applied to it.

Chapman: I am going to raise another question. If you do better being socialistic why not be socialistic?

Powell: This doesn't matter, but you are going to have to farm on a large-scale basis with mechanized equipment to get your maximum productivity, aren't you?

Schmitt: I would dispute this because Japan has the highest yields with the smallest plots.

Isaacs: And Russia, of course, gets the biggest production off the small garden plots given to its individuals, rather than in the big communal operations.

Schmitt: It is horticulture, almost, in Japan, with highly intensive manpower application and mechanical power, as I showed you on the illustration. I think it is not necessarily true that you have to go to large holdings. Land reform, I think, is a desirable feature of national development because the farmer needs to participate in that yield increase and that economic reaping. If it goes to the landlord, he will remain unmotivated.

Isaacs: An old Arabian saying is that the best fertilizer is the owner's footprint on the ground.

Longhurst: If you have big land owners that are not utilizing land, probably you will have some form of socialism taking it away and redistributing, and yet—

Preston: You need a strong central government, whether it's socialistic or capitalistic.

Chapman: The revolutionary doesn't want any government at all. Another factor in this too, John, is that when Walter puts up charts and so forth, this is fine, you can see what is going on, but when it comes down to managing the use of a piece of land or an area of land or a country, there come such highly diverse problems that you can't treat them generally.

I think really the cocoa farms of the Ashanti tribe in Ghana are not quite the same as the rice paddies of southeast Asia. Every different society, and every different type of agriculture is of very high diversity. One can't generalize.

Isaacs: But you can establish some general constraints on the possibilities.

Smith: I've been going practically depressive just listening first of all to Ehrlich, then I read someone else who is very hopeful, and then I hear Dr. Preston here and then I read Borgstrom,—quite frightening. I wonder, something that both Borgstrom and Schmitt left out of their considerations, I think, is the availability of water. I have heard a lot about these problems, but I think water pollution must be considered as most crucial and that we must press, in developed and underdeveloped countries, for high quality waters.

Schmitt: I agree. I discussed irrigation without stressing its full potential importance. The Pakistan example illustrates the eminence of water. We are not yet moving toward a proper economic utilization of water. In the southwest, for instance, here in our own country, a study at the University of New Mexico by N. Wollman, showed that we could gain far greater economic returns from water use than we do presently, either by domestic residential use or even by recreation. They pay much better for water than does irrigation. So perhaps large shifts are necessary. Most of the $80 billion expense that I quoted for the development of the underdeveloped countries' agriculture is in water supply, provision of dams—

Smith: Where is the water coming from?

Schmitt: The Indian peninsula is certainly a well-watered region.

Smith: We are providing water at a higher rate than it is being replaced.

Isaacs: Only in a few places and we are also wasting it. We are stuck with some curious anachronisms as you may know. The cheapest water in the world, that is priced the lowest, is in the Sacramento Valley where the State has to supply water to farmers at $1 an acre foot, by far the cheapest material on the face of this earth. This allows them to raise very low-level crops, fodder crops—much of our water is tied up in this sort of a way. Also the solutions to problems of cultivating the well-watered regions of the world, the places that have more than adequate natural rainfall, have never been effectively attacked, never been re-searched. Then, of course, there is the whole interesting matter of saltwater agriculture and some of the new information on hydroponics of using ordinary crop plants grown in sea water. This seems to be successful if you just keep the water sufficiently stirred. And then my favorite, of course, my favorite little piece of marine resource, the little DNA molecule, that tells salt-tolerant plants how to desalinate sea water using the atomic energy of the sun. We have never taken this gene out of the sea and tried to breed it into crop plants, so that there can be useful salt-tolerant plants for the ubiquitous problem of salinity of irrigated arid regions and also for the direct irrigation by sea water.

Preston: Could I address myself to something other than the water question which you raised? An inconsistency exists in the predictions about whether disaster is imminent in 10 years and whether we can go up to 50 billion people. They are really based on a different set of assumptions. People like Ehrlich, I think, assume that institutions and techniques are *not* going to change. In that case we are going to have a problem. But obviously, if it is possible to increase the world food production by a factor of 10, whether we are going to have a problem in 15 years or so really depends on the rate of change. Institutions in these countries themselves have made estimates like that, maybe perfectly correct, and maybe a pessimistic approach is what is necessary. The only argument that is currently being made is that a rapid rate in population growth itself may make institutional changes inevitable, which can't be easily discounted, but I think world opinion is for trying to achieve these changes in another way.

Schmitt: I am very certain that these changes will come about before 10 times the food is necessary and the institutional changes that Dr. Preston hints at, they are already taking place.

The Vietnam war may well be the last military confrontation for both East and West. We are actually moving into a humanistic age with more adequate allocation of resources to the real problems of the world, and particularly gratifying to me was the appearance this summer in Russia of Andrei D. Sakharov's *Progress, Coexistence, and Intellectual Freedom.* Sakharov, an eminent Soviet nuclear physicist, says in this privately distributed manifesto among other things: "International affairs must be completely permeated with scientific methodology and a democratic spirit, with a fearless weighing of all facts, views, and theories, with maximum publicity of ultimate and intermediate goals, and with a consistency of principles.

"Specialists are paying attention to a growing threat of hunger in the poorer half of the world. . . . What is involved is a prognosticated deterioration of the average food balance in which localized food crises merge into a sea of hunger, intolerable suffering and desperation, the grief and fury of millions of people. This is a tragic threat to all mankind.

"It is apparently futile only to insist that the more backward countries restrict their birthrates. What is needed most of all is economic and technical assistance to these countries. This assistance must be of such scale and generosity that it is absolutely impossible before the estrangement in the world and the egotistical, narrow-minded approach to relations between nations and races is eliminated. It is impossible as long as the United States and the Soviet Union, the world's two great superpowers, look upon each other as rivals and opponents.

"A fifteen-year tax equal to 20 percent of national incomes must be imposed on developed nations. The imposition of such a tax would automatically lead to a significant reduction in expenditures for weapons. Such common assistance would have an important effect—that of stabilizing and improving the situation in the most underdeveloped countries, restricting the influence of extremists of all types.

"Mankind can develop smoothly only if it looks upon itself in a demographic sense as a unit, a single family without divisions into nations other than in matters of history and traditions.

"The problem of geohygiene (earth hygiene) is highly complex and closely tied to economic and social problems. This problem can therefore not be solved on a national and especially not on a local basis. . . . Otherwise, the Soviet Union will poison the United States with its wastes and vice versa. At present, this is a hyperbole. But with a 10 percent annual increase of wastes, the increase over 100 years will be multiplied 20,000 times."

Parrish: What about our petroleum reserves?

Isaacs: We have two hundred years of recognized reserves for present consumption rates at the moment, and the recognized reserves seem to be growing rather rapidly. If we had time, I would show you an interesting extract from the old book some of you were raised with, the Book of Knowledge, 1912 edition. It relates the then common opinion of how soon we were going to run out of petroleum fuel because of the rapid increase in use in trains and boats and all the new fangled automobiles around, and that by the year 1946, all petroleum would be exhausted. The man that writes this, however, possesses a lot of inner confidence, for when he finishes relating the current opinion, he says—and he has turned out to be correct—that he thinks as we learn more about petroleum and how it was formed we will learn more about how to look for it; we will find greater reserves; and even after that when we finally run out of petroleum—as he says we inevitably will—by then he says that we will have unlocked the marvelous power in radium. Of course, that was the only radioactive material they knew at the time.

And now the new discovery is apparently of petroleum and petroleum-bearing formations in the deep sea. The writer of this old article turns out to be correct—we may be able to increase petroleum production for any length of time that any of us here have reason to worry about.

McGowan: None of these conversations make any sense to me. I have heard several others and read several others on population problems and no one has come up with tangible solutions. Sooner or later there is going to be a population problem no matter how much food you produce and it is easy to calculate when that will happen. For instance, we could literally populate the earth. It doesn't require a very sophisticated calculus to do that.

Isaacs: They calculate it every 10 years, John, and there is always a group of people who say their calculations didn't turn out to be correct, but that this must make the inevitable fiasco more terrible. I agree with you that there are limits, but dire predictions have gone on for hundreds of years. The human race seems to continue to solve these problems.

Schmitt: Obviously Malthus would not have made his statement about geometric populations growth and arithmetic food growth had food supply not been at a danger level. Certainly there was no considerable surplus of food around. Therefore, 150 years ago at the time of Malthus, we should draw the food production as tangent to the population growth at that time. This would by now leave the food production adequate for perhaps 10 percent of the people. Obviously, food production has grown geometrically as well. It must have jumped repeatedly in response to technological innovations, even though many segments in its curve advance arithmetically, but certainly the sum total of it is a geometric growth in food production.

McGowan: Are you talking about the population problem?

Preston: No, the food problem. There is a difference between the food and the population problem.

McGowan: And what is that difference? I guess I didn't get it.

Preston: Well, the population problem merely relates to the restrictions placed on the ability of a country to develop into part of the modern world.

Chapman: We in the western world are getting ahead of the game.

Preston: Many countries are not getting ahead fast enough for their own wishes. I guess there is some limitation in the total food supply, but that doesn't mean we're anywhere near that at the moment. It is really a quite different matter, I think, than the population problem although they are always discussed in the same terms.

McGowan: And I think they should be.

Isaacs: All these calculations can be applied to the American Indian. Using his particular production methods he was overpopulated.

McGowan: Could very well have been. Of course his population growth rate became negative, and ours is not and it never will unless something is done.

Chapman: One other factor, John, looking back in history, we aren't doing too bad now because we are worried about our condition. It certainly isn't as bad for mankind generally as it was 100 years ago, and 300 years ago it was a heck of a lot worse. There have been periods in history when things were going along pretty well, but they have been very few and very temporary. We have worried that the dollar was going to pot, but during my lifetime the general economic welfare of the human race has been a hell of a lot better than any period in history of which I have read, and it's measured rather well by the increase in population. For a long period of history population didn't increase very fast. The reason it didn't was because things were tough.

Hardwick: Without worrying about the physical necessities of food, we can produce these for any number of people; however, there are aesthetic problems and psychological problems and physiological problems—people begin to act differently in a crowded environment, in an urban environment, and I don't know whether you can say people act like rats or not, but if you put rats in a cage and let them reproduce until they are crowded, they become completely abnormal. This also seems to happen to human populations. I know I grew up in a rural area, and people there act a lot different.

Isaacs: I often wonder why we are so tied down to urban populations anyway. We keep saying that we have to save our cities. Are there no alternatives?

Preston: People like to live in cities, that's why there are cities. People enjoy them.

Chapman: Well, the great unpopulated areas of the United States are Pennsylvania, New Jersey, Maryland. Fly over this, and very little of it is populated. Most of it is bum timberland full of deer, more deer now than when the white man came.

Isaacs: Also when you take off from Calcutta, which is a teeming mass of people, overpopulated in a way people think is the prototype of the future, what do you fly over? You fly across four hundred solid miles of almost unpopulated jungle.

Longhurst: Yes, but how are people from Calcutta going to live in this jungle?

Chapman: Alan, what you want to do is live in a big city all by yourself.

Isaacs: I feel that we have opened up endless avenues for discussion, that we could go on like this for the whole 3-day session, but I think we should bring this symposium to a close at this time. I wish to thank the panel and the participants for a spirited and valuable session. I thank the speakers for four most unusually perceptive, penetrating, and provocative presentations.

I will not attempt to summarize, but I believe that important characteristics of the broad problems have been very powerfully developed. Dr. Preston's points on relative rates of population growth and economic development; Wib's discussions of the economic constraints; Walter's on total potential and on alternatives; and Dr. Bullis' on the open-ended possibilities of technological advances in fisheries.

I thank you all.

PART III

SCIENTIFIC CONTRIBUTIONS

Calif. Mar. Res. Comm. CalCOFI Rept., 13:73–75, 1970.

FORMATION OF A FALSE ANNULUS ON SCALES OF PACIFIC SARDINES OF KNOWN AGE

MAKOTO KIMURA
National Marine Fisheries Service, Fishery-Oceanography Center
La Jolla, California 92037

Pacific sardines, *Sardinops caerulea* (Girard), were reared from hatching through the first year of life at the Fishery-Oceanography Center, La Jolla, California. The availability of these fish has allowed the study of growth in length and weight and the formation of accessory ring and annulus on scales of sardine of known age to compare with measurements of field-captured fish.

Sardine eggs were obtained on May 9, 1968, off San Diego, California. They were transferred to the Fishery-Oceanography Center aquarium and placed in a clear, thin-walled polyethylene bag which was suspended in sea water in a 3,500-gallon pool. The polyethylene bag, about 1 meter deep and 1 meter diameter, was used to confine the newly-hatched larvae to a small area of facilitate feeding. An air stone in the bag kept the water gently in motion. Light was constant, provided by a 1,000-watt mercury vapor lamp over the tank.

After 2 days between 16° and 18° C. the eggs hatched into larvae about 4 mm. long. The procedure of feeding changed as the fish grew. The larvae were fed a variety of wild plankton organisms, until the 11th day when their diet was supplemented with live brine shrimp, *Artemia salina*, nauplii. After 28 days the larvae were released into the pool. The food was changed to frozen brine shrimp and size #1 trout food at 52 days. During the first 2 months only a minimum amount of water was added to the pool periodically to flush off the surface scum. At the end of 2 months a constant flow of ambient sea water was maintained in the pool. At the beginning of the third month, the amount of food fed per day was set at 10 percent of the calculated total weight of the fish in the tank; a decision based on a study of food utilization by young anchovy, *Engraulis japonicus* (Temminck et Schlegel), by Takahashi and Hatanaka (1960). The average weight of the fish was obtained from monthly samples and the number of fish estimated until December when they were counted as they were being transferred to another pool.

The larvae were sampled frequently through the first 2 months (Figure 1) to obtain empirical data on their rate of growth. A total of 646 specimens were measured to the nearest half-millimeter SL during this period. From the third month on, samples were measured at 30-day intervals. The laboratory fish were smaller than fish obtained from the Pacific coast bait fisheries during the 1938–39 season (Walford and Mosher, 1943a) through November. After November their lengths were similar.

Two rings formed on the scales during the first year of life of the aquarium reared sardines (Figure 2). The first ring (accessory) formed between August and September 1968. The second ring (annulus) formed between December 1968 and January 1969. Both rings had all of the usual characteristics of an annulus. The second ring was considerably easier to see than the first ring.

Figure 3 illustrates several factors that may be related to formation of the rings. Formation of the accessory ring is associated with the period of maximum growth. Formation of the annulus ring occurs immediately prior to the onset of rapid growth during the late winter 1969. None of the other factors appear to be related to formation of the rings.

At the time of annulus formation the fish were about 7.5 to 8.5 months old and averaged 101 to 105 mm. SL, respectively. Back-calculated L_1 lengths on a random selection of scales from the December through March samples averaged 100.0 mm. SL. However, on their first actual birthdate the sardines averaged 124.5 mm. SL, nearly 25 percent greater actual observed length than their first year back-calculated length. At the time of the accessory ring formation the fish were about 4.5 to 5.0 months old and averaged 81.8 mm. SL.

Other investigators have reported two rings per year on scales taken from similar species. Aikawa (1940) reported that two rings formed on the scales of the Japanese sardines, *Sardinia melanosticta* (Temminck et Schlegel) per year. Davies (1958) found that two rings formed during the first year of life on scales taken from commercially caught South African pilchard, *Sardinops ocellata* (Pappe).

Formation of an accessory ring on scales of laboratory reared Pacific sardines during their first summer of life is cause for concern. If similar accessory rings form on scales of fish in their natural environment, considerable error in assigning ages to fish may result. Preliminary analysis of historical data and re-examination of previously read scales indicates that this type of error in aging has occurred. We are attempting to develop quantitative techniques for distinguishing between accessory rings and annuli.

ACKNOWLEDGMENTS

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REFERENCES

Aikawa, Hiroaki. 1940. On the age and race of the Japanese sardine, *Sardinia melanosicta* (Temminck et Schlegel). *Rec. Oceanogr. Works Jap* 2 (1) : 81–112.

Davis, D. H. 1958. The South African pilchard (*Sardinops ocellata*). Preliminary report on the age composition of the commercial catches, 1950–55. *Div. of Fish., Cape Town, Union of South Africa, Invest. Rep.* (33) : 1–244.

Takahashi, Masao, and Masayoshi A. Hatanaka. 1960. Experimental study on utilization of food by young anchovy, *Engraulis japonicus* (Temminck et Schlegel). *Tohoku J. Agr. Res.* (11) : 161–170.

Walford, Lionel A., and Kenneth H. Mosher. 1943. Studies on the Pacific pilchard or sardine (*Sardinops caerulea*). 2. Determination of the age of juveniles by scales and otoliths. *U.S. Fish and Wildl. Serv., Spec. Sci. Rep.*, (20) : 1–19 (including tables and figures). Reissued in Spec. Sci. Rep. Fish. (15) : 31–95, 1950.)

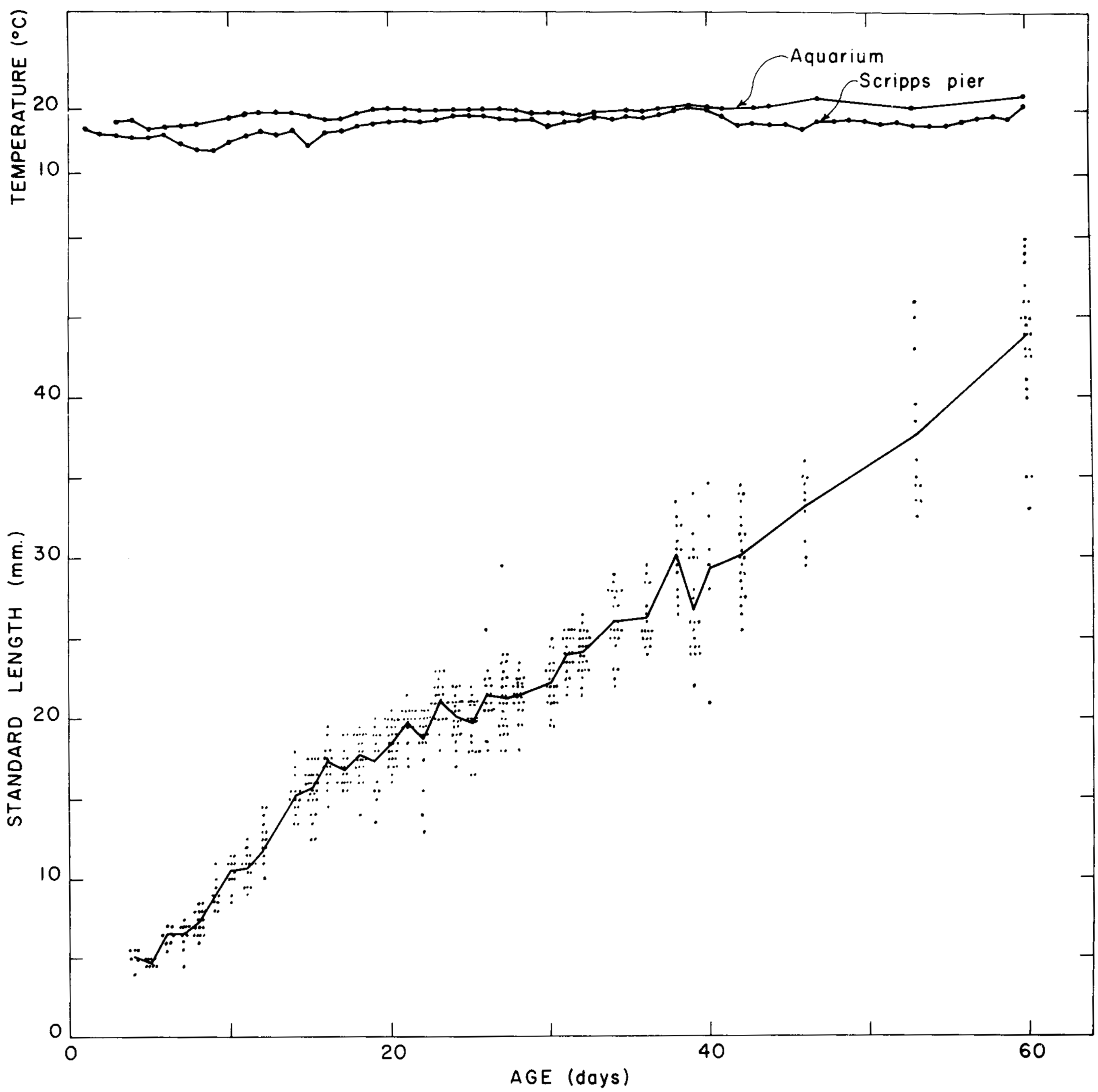

FIGURE 1. Standard lengths of the aquarium reared sardines during the first 2 months of life. The solid line connects the average lengths of the fish sampled on any one day. Scripps pier and the aquarium water temperatures are shown in the upper graph.

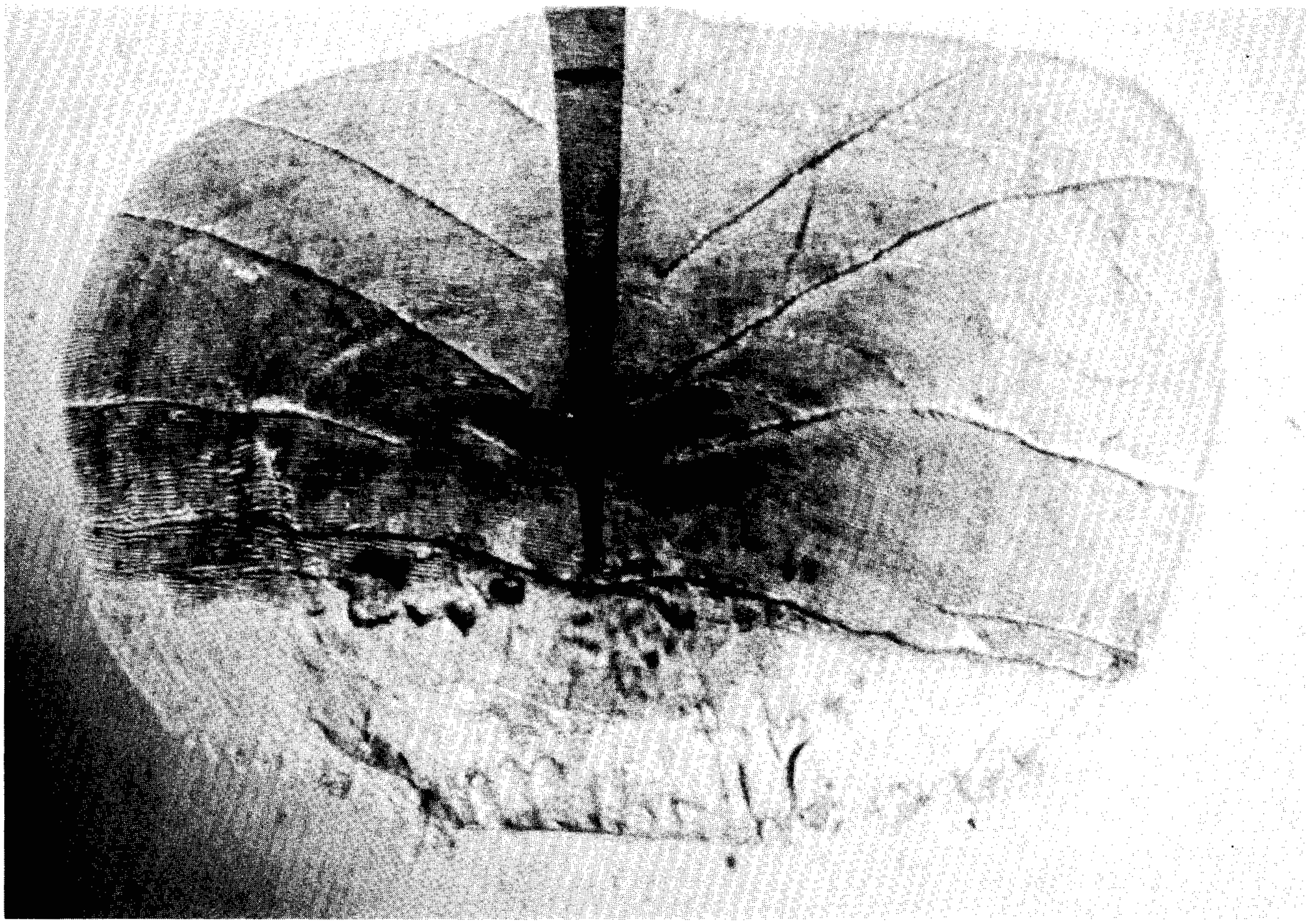

FIGURE 2. A typical scale from one of the aquarium reared sardines sampled in its tenth month of life, March 3, 1969. The dark marks drawn on the scales indicate the accessory check (inner mark) and the first annulus.

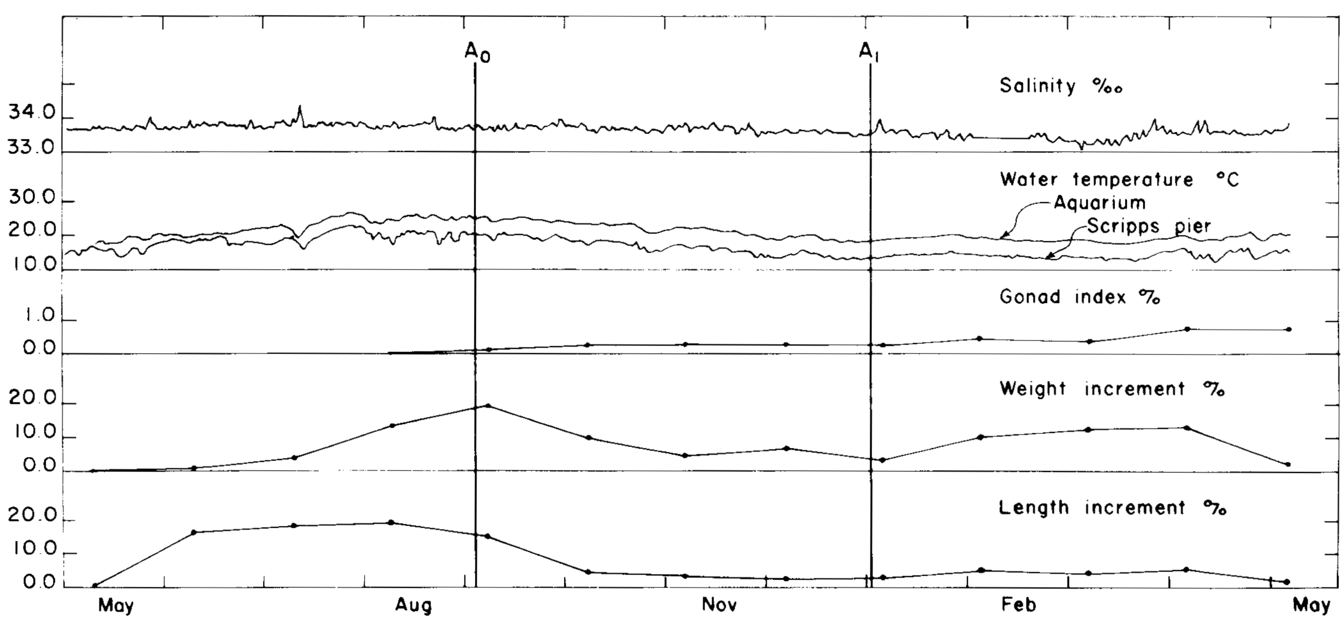

FIGURE 3. Average monthly length increment in percent of the average standard length at the end of 1 year, average monthly weight increment in percent of total weight at the end of 1 year, gonad index (weight of gonad in percent of body weight), along with water temperature and salinity. Periods of formation of the accessory check and the annulus are indicated by the vertical lines A_0 and A_1 respectively.

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FEEDING LARVAL MARINE FISHES IN THE LABORATORY: A REVIEW

ROBERT C. MAY [1]
Scripps Institution of Oceanography
La Jolla, Cailfornia

INTRODUCTION

Interest in rearing marine fishes under laboratory conditions has intensified during the past decade, and there is every reason to believe that this trend will continue. The larval stages of marine fishes are being investigated experimentally because of their inherent biological interest, their importance in determining recruitment in adult fish populations, and their central place in problems associated with large-scale fish culture. The greatest difficulty in attempts to rear marine fishes through the larval stage has frequently been to provide a suitable food—that is, a food which the larvae will consume and grow on and which can be supplied in sufficiently large quantities. The literature on rearing marine fishes is scattered, in several languages, and in some cases not readily accessible, and a comprehensive review emphasizing feeding has not appeared until now. This review summarizes the attempts to feed larval marine fishes in the laboratory which have been described in the literature from 1878 through 1969, in the hope that such a review will aid persons who undertake similar work in the future.

Several previous reviews contain information relevant to the problem of feeding larval fishes. Hertling's treatise on rearing marine fishes (Hertling, 1932) includes a section on feeding, but investigators now will find his discussion of little help, partly because at the time he was writing, relatively little work had been done on rearing beyond the yolk-sac stage under laboratory conditions. Morris (1955) confined his discussion of nutrition in marine fish larvae to a consideration of Pütter's theory that dissolved organic matter is an important source of nutrition for fishes, an hypothesis which has so far not been definitively tested in larval fishes. Morris (1956) described rearing experiments with 17 species of California fishes and included a lengthy discussion of various food types. Hirano and Oshima (1963) reviewed methods of feeding the larvae of a variety of marine animals, including selected examples of attempts to feed larval fishes, and supplied valuable data on the sizes of various potential food organisms. Shelbourne (1964) described his extensive work with the plaice and gave an account of the historical development of marine fish culture. Blaxter (1965) discussed the feeding ecology of herring larvae, integrating data from the laboratory and the field, and Blaxter and Holliday (1963), reviewing the biology of the clupeids, summarized information on the larvae of this well-studied family of predominantly marine fishes.

The present review will summarize previous attempts to feed the larvae of marine fishes in the laboratory by presenting 1) a list of all food types used in the studies reviewed, and 2) a general discussion of the major food types. Only reports describing the rearing of larvae hatched from eggs in the laboratory are considered here, and reports of rearing in large, uncontrolled bodies of water such as ponds, are excluded. Also excluded, of course, are studies dealing with the rearing of fishes which have no free-swimming larval stage. A number of papers have appeared during the 1960's concerned with the physiology and behavior of marine fish larvae; although they frequently include mention of feeding in the laboratory, most of them have been omitted here since the methods used are usually described in greater detail in other papers more specifically concerned with rearing techniques.

One of the drawbacks of reviews of this kind is that they necessarily oversimplify the original work and thus may be misleading if not used properly. When dealing with reports—many of which are sketchy almost to the point of uselessness—of experiments conducted under vastly different conditions with a variety of species, comparisions are difficult and generalizations risky. If a particular food type was used in the past without success, it is still possible that it will prove useful for another species of fish or for the same species under different conditions. Also, several different approaches to the problem of feeding may prove equally fruitful. A case in point is the rearing of the sole, *Solea solea*: Fabre-Domergue and Biétrix (1905) reared sole using a flagellate as first food and, later, wild plankton from which the larvae selectively preyed upon other fish larvae and ignored copepod nauplii; nevertheless, Flüchter (1965) obtained excellent results by feeding larvae of this species only *Artemia* nauplii.

The emphasis of the present review on feeding is not meant to imply that other factors are not important for the successful rearing of larval fishes, or that larval survival in the studies reviewed was solely dependent upon the choice of food. Providing a suitable food is a sine qua non in any rearing attempt, but a host of other significant factors are operating in the complex artificial environment of the larvae. The importance of such factors is evident, for example, in Blaxter's (1968a) observation that although over 90% of the herring larvae in his experiments were feeding well, only 25–35% survived yolk-ab-

[1] National Marine Fisheries Service Fellow. This work was done at the National Marine Fisheries Service Fishery-Oceanography Center, La Jolla, California.

sorption. Also, it is not uncommon to find dead larvae with food in their guts. A discussion of factors other than food is beyond the scope of the present review, and persons interested in the details of the studies reviewed here must consult the original papers.

LIST OF FOOD TYPES

Table 1 lists the food types which have been used in all papers included in the review. For convenience the living organisms other than wild plankton have been arranged taxonomically under four main headings: *Protista: planktonic forms; Protista: nonplanktonic forms; Metazoa: planktonic forms;* and *Metazoa: nonplanktonic forms.* In a few cases the designations *planktonic* and *nonplanktonic* are somewhat arbitrary. Nonliving foods and "prepared aquaria" have been placed under the heading *Miscellaneous.*

TABLE 1

Foods Used in Attempts to Rear the Larvae of Marine Fishes

Food	References
WILD PLANKTON	Antony, 1910; Blaxter, 1968, 1969; Blaxter and Hempel, 1961; Budd, 1940; Cunningham, 1893–95a & b; A. Dannevig, 1948; H. Dannevig, 1897; Dannevig & Hansen, 1952; David, 1939; Fabre-Domergue & Biétrix, 1897, 1905; Garstang, 1900; Ivanchenko & Ivanchenko, 1969; Kramer & Zweifel, 1970; Lebour, 1925; Meyer, 1878; Mito et al., 1969; Morris, 1956; Okamoto, 1969; Orcutt, 1950; Richards & Palko, 1969; Schach, 1939; Schumann, in Bardach, 1968; Yamamoto & Nishioka, 1952
PROTISTA: PLANKTONIC FORMS	
Chlorophyta	
Loxophyceae	
Platymonas subcordiformis	Orcutt, 1950
Halosphaera minor	Blaxter, 1969
Chlorophyceae	
Chlamydomonas sp.	Bishai, 1961; Blaxter, 1962, 1969; Gross, 1937; Qasim, 1955, 1959
Dunaliella primolecta	Blaxter, 1969
Dunaliella salina	Fabre-Domergue & Biétrix, 1905
Dunaliella sp.	Blaxter, 1962; Budd, 1940; Delmonte et al., 1968; Morris, 1956
Chlorella stigmata	Qasim, 1955
Chlorella sp.	Blaxter, 1962
Stichococcus sp.	Morris, 1956
Pyrrophyta	
Cryptophyceae	
Cryptomonas maculata	Blaxter, 1969
Desmophyceae	
Prorocentrum micans	Blaxter, 1969; Gross, 1937, Lasker et al., 1970; Qasim, 1955
Dinophyceae	
Gymnodinium splendens	Lasker et al., 1970
Oxyrrhis marina	Morris, 1956
Oxyrrhis sp.	Kasahara et al., 1960
Protoceratium reticulatum	Lasker et al, 1970
Fragilidium heterolobum	Lasker et al., 1970
Crysophyta	
Xanthophyceae	
Olisthodiscus sp.	Blaxter, 1969
Chrysophyceae	
Isochrysis galbana	Qasim, 1955, 1959
Monochrysis lutheri	Forrester, 1964
Chromulina pusilla	Qasim, 1955

TABLE 1—Continued

Foods Used in Attempts to Rear the Larvae of Marine Fishes

Food	References
Bacillariophyceae	
Coscinodiscus concinnus	Hertling, 1932
Coscinodiscus radiatus	Gross, 1937
Skeletonema costatum	Blaxter, 1962; Forrester, 1964; Gross, 1937; Kurata, 1956, 1959
Thalassiosira sp.	Gross, 1937
Lauderia borealis	Blaxter, 1969
Rhizosolenia sp.	David, 1939
Chaetoceros sp.	David, 1939
Biddulphia mobiliensis	Hertling, 1932
Ditylum brightwellii	Blaxter, 1969
Nitzschia closteium	Orcutt, 1950
Nitzschia sp.	Bishai, 1961; Blaxter, 1962; Budd, 1940
"Diatoms"	David, 1939; Rubinoff, 1958
Eumycophyta	
Ascomycetes	
"Yeast"	Klima et al., 1962; Morris, 1956
Taxonomy uncertain	
"Natural and cultured phytoplankton"	Klima et al., 1962
"Raw cultures of phytoplankton"	Dannevig, 1948
"Cultures of single species of green algae and naked flagellates"	Dannevig, 1948
"Phytoplankton"	Bishai, 1961; Ivanchenko & Ivanchenko, 1969
"Plankton algae"	Runnström, 1941
"Algae"	Fabre-Domergue & Biétrix, 1897
"Monadinen"	Kotthaus, 1939
"Vegetarian diet"	Soleim, 1942
PROTISTA: NONPLANKTONIC FORMS	
Cyanophyta	
"une nostocacee"	Fabre-Domergue & Biétrix, 1897
Chlorophyta	
Enteromorpha sp.	Kotthaus, 1939
Chrysophyta	
"Filamentous brown diatom"	Fabre-Domergue & Biétrix, 1897
Ciliophora	
Ciliata	
Euplotes sp.	Fabre-Domergue & Biétrix, 1897
Philaster digitiformis	Fabre-Domergue & Biétrix, 1897
Stylonychia sp.	Kasahara et al., 1960
Taxonomy uncertain	
"Filamentous algae"	Delmonte et al., 1968
"Cultured infusorians"	Fabre-Domergue & Biétrix, 1897
METAZOA: PLANKTONIC FORMS	
Aschelminthes	
Rotifera	
Brachinous plicatilis	Hirano, 1969; Mito et al., 1969; Okamoto, 1969
Mollusca	
Gastropoda	
Crepidula sp. "larvae"	Rubinoff, 1958
Bulla gouldiana veligers	Lasker et al., 1970
Haminoea vesicula veligers	Lasker et al., 1970
Navanax inermis veligers	Lasker et al., 1970
"Nacktschnecken" (? nudibranch) larvae	Kotthaus, 1939
Pelecypoda	
Mytilus californianus "larvae"	Morris, 1956
Mytilus sp. trochophores	Blaxter & Hempel, 1961; Okamoto, 1969; Schach, 1939
Mytilus sp. "larvae"	Dannevig, 1948; Kotthaus, 1939; Kurata, 1956
Ostrea edulis "larvae"	Dannevig, 1948
Crassostrea gigas "larvae"	Hirano, 1969
"Oyster" trochophores	Okamoto, 1969
Annelida	
Polychaeta	
Chone teres trochophores	Kurata, 1959
Pomatoceros sp. "larvae"	Dannevig, 1948
Nereis sp. eggs	Cunningham, 1893–95b
"Minced worms"	Cunningham, 1893–95a

TABLE 1—Continued

Foods Used in Attempts to Rear the Larvae of Marine Fishes

Food	References
METAZOA: PLANKTONIC FORMS —Continued	
Arthropoda	
Crustacea	
Artemia salina nauplii	Bishai, 1961; Blaxter, 1962, 1968; Blaxter & Hempel, 1961; Budd, 1940; Chirinos de Vildoso & Chuman, 1964; Dannevig, 1948; Dannevig & Hansen, 1953; Delmonte et al., 1968; Fahey, 1964; Fishelson, 1963; Flüchter, 1965; Forrester, 1964; Fujita, 1957, 1965, 1966; Gross, 1937; Hirano, 1969; Joseph & Saksena, 1966; Kasahara et al., 1960; Klima et al., 1962; Kramer & Zweifel, 1970; Kurata, 1956, 1959; McHugh & Walker, 1948; McMynn & Hoar, 1953; Mito et al., 1969; Molander & Molander-Swedmark, 1957; Morris, 1956; Okamoto, 1969; Orcutt, 1950; Qasim, 1955, 1959; Richards & Palko, 1969; Rollefsen, 1939; Rubinoff, 1958; Schumann, in Bardach, 1968; Shelbourne, 1964; Shojima, 1957; Soleim, 1942
"Cladocera"	Gross, 1937
Daphnia pulex eggs	McMynn & Hoar, 1953
Daphnia sp.	Blaxter, 1965; Bückmann et al., 1953
"Copepods"	Bishai, 1961; Bückmann et al., 1953; Fishelson, 1963; Gross, 1937; Hirano, 1969
"Copepod nauplii"	Kasahara et al., 1960; Kotthaus, 1939
Tigriopus californicus nauplii	Fahey, 1964
Tigriopus fulvus nauplii	Bishai, 1961; Budd, 1940; Orcutt, 1950
Tigriopus fulvus adults	Blaxter, 1965, 1968; Morris, 1956
Tigriopus sp. "young stages"	Blaxter, 1962
Tisbe sp.	Blaxter, 1962
Balanus balanoides nauplii	Blaxter, 1962, 1968; Dannevig, 1948; Qasim, 1955, 1959; Shelbourne, 1964; Soleim, 1942
Balanus glandula nauplii	Morris, 1956
Balanus amphitrite albicostatus nauplii	Hirano, 1969; Kasahara et al., 1960
Neomysis japonicus "young"	Kasahara et al., 1960

TABLE 1—Continued

Foods Used in Attempts to Rear the Larvae of Marine Fishes

Food	References
Echinodermata	
Echinoidea	
Dendraster excentricus eggs or larvae	Morris, 1956
Strongylocentrotus purpuratus eggs or larvae	Budd, 1940; Morris, 1956; Orcutt, 1950
Tripneustes esculentus eggs or larvae	Richards & Palko, 1969
Arbacia sp. eggs or larvae	Deuel et al., 1966; Rubinoff, 1958
"Fertilized sea urchin eggs"	Fujita, 1965
Asteroidea	
Asterias sp. eggs	Blaxter, 1962
Urochordata	
Ascidian larvae	Fabre-Domergue & Biétrix, 1897
Chordata	
Fish larvae	Fabre-Domergue & Biétrix, 1905
METAZOA: NONPLANKTONIC FORMS	
Aschelminthes	
Nematoda	
Anguillicula sp.	Blaxter, 1962
MISCELLANEOUS	
Prepared aquaria	Bishai, 1961; Delmonte et al., 1968; Heuts, 1947; Klima et al., 1962; McHugh & Walker, 1948
Finely ground trout food	Richards & Palko, 1969
Powdered fish foods	Rubinoff, 1958
Commercial fish-fry foods	Blaxter, 1962; Delmonte et al., 1968; Klima et al., 1962
Cooked chicken egg yolk	Bückmann et al., 1953; Fabre Domergue & Biétrix, 1897; Fishelson, 1963; Fujita, 1966; Heuts, 1947; Ivanchenko & Ivanchenko, 1969; Klima et al., 1962; Kurata, 1959; Morris, 1956; Nikitinskaya, 1958
Water-soluble vitamin compounds	Klima et al., 1962
Liver of shore crab, *Carcinus maenas*	Bishai, 1961
Minced shrimp and crab meat	Kurata, 1959
Crushed mussel	Fabre-Domergue & Biétrix, 1897
Homogenates of *Mytilus*, periwinkle, *Fucus* and kelp	Ivanchenko & Ivanchenko, 1969
Liver-skim milk	McMynn & Hoar, 1953
Human blood	Klima et al., 1962

DISCUSSION OF THE MAJOR FOOD TYPES

Wild plankton. One of the most widely used sources of food for larval fishes has been plankton taken from natural waters, referred to here as wild plankton. Wild plankton is usually collected by tows with a plankton net, although Schumann (work described in Bardach, 1968) collected plankton at night with a submerged pump to which plankters were attracted by a light, and concentrated the plankton with a series of filters. Prior to feeding the plankton to the larvae, it is common practice to strain it through netting of a mesh size which passes only those organisms which the larvae can feed upon. This performs the additional function of removing most potential predators from the plankton. Meyer (1878), however, noted poor survival and growth among herring larvae which were given plankton strained through cloth and found that normal growth was resumed when unstrained plankton containing large numbers of copepods was administered. It would seem obvious that as the larve grow the size range of the plankton used as food should be increased. The plankton supplied to larval fishes usually contains a mixture of organisms, and authors who describe the use of wild plankton in rearing experiments, often list the dominant organisms in the plankton. Some also give information on which plankters were eaten by the larvae, based either on analyses of gut contents or on observations of feeding behavior. Copepods, copepodites and copepod nauplii frequently dominate in wild plankton and often constitute the main food of the larval fishes (Garstang, 1900; Lebour, 1925; Schach, 1939; Blaxter, 1969), but many other types of organisms may be present (*cf.* Blaxter and Hempel, 1961; Blaxter, 1968a), and herring and plaice larvae are reported to have selectively fed upon larval molluscs in wild plankton (Meyer, 1878; Dannevig, 1897). Blaxter (1969) had more success with offshore than with inshore plankton in rearing experiments with larval sardines.

Wild plankton has proved to be an excellent source of food for larval fishes in the laboratory, as might be expected since it contains the same food which fish larvae feed on under natural conditions. Plankton collected in the sea was the mainstay of the successful early attempts to rear marine fishes (Meyer, 1878; Dannevig, 1897; Garstang, 1900; Fabre-Domergue and Biétrix, 1905; Anthony, 1910) and is still being used in rearing for experimental purposes (Schumann, in Bardach, 1968; Blaxter, 1968, 1969; Ivanchenko and Ivanchenko, 1969; Richards and Palko, 1969; Kramer and Zweifel, 1970).

However, despite the proven effectiveness of wild plankton as a food source, its use has serious disadvantages which make it unsuitable in many instances. Among these disadvantages are: 1) the seasonality and highly variable quality and quantity of wild plankton; 2) the dependence of plankton collection on weather conditions; 3) the time-consuming nature of collecting plankton; 4) the mixture of food types in the plankton which makes controlled feeding experiments difficult; and 5) the difficulty of removing from the plankton all organisms which may prove harmful to the fish larvae. Because of such drawbacks, much effort has been expended in the search for larval-fish foods that can be cultured in the laboratory. The long list of food types presented in Table 1 testifies to this fact.

Phytoplankton. Of the many attempts described in the literature to feed phytoplankton to larval fishes (Table 1), very few have met with any success. In several experiments various types of phytoplankters were ingested by fish larvae, yet the larvae survived no longer than starved controls (Gross, 1937; Orcutt, 1950; Qasim, 1955, 1959; Bishai, 1961; Blaxter, 1969); this suggests that at least certain types of phytoplankters are nutritionally inadequate for larval fishes. Schach (1939) found that yolk-sac herring larvae kept in water thick with phytoplankton acquired a "green mass" in their guts, presumably from ingesting phytoplankton, but these larvae did no better than larvae kept in clear water, and both groups began feeding on zooplankton 4 days after yolk-absorption.

In the first successful attempt to use phytoplankton as a larval fish food, Fabre-Domergue and Biétrix (1905) found that newly-hatched sole larvae, *Solea solea,* ate *Dunaliella salina* cultured from salt marshes but soon switched to carnivorous feeding. Hertling (1932) stated that the armed bullhead, *Agonus cataphractus,* could be reared by feeding the early larvae on diatoms, and Runnström (1941) claimed to have kept herring larvae alive for 6 weeks on "plankton algae," but these authors supplied few details. Kasahara *et al.* (1960) fed early larvae of the black porgy, *Mylio macrocephalus,* on the naked dinoflagellate *Oxyrrhis* but soon changed over to animal foods. Lasker et al. (1970) gave the only detailed description of rearing for prolonged periods using phytoplankton alone. They reared the northern anchovy, *Engraulis mordax,* for 19 days (when the experiments were purposely terminated) with good growth and survival, using the naked dinoflagellate *Gymnodinium splendens* as the sole food, and in one experiment kept a larva alive for 34 days on this phytoplankter. Growth and survival were somewhat better, however, when molluscan larvae were supplied along with the *Gymnodinium.*

Artemia nauplii. Perhaps the greatest breakthrough in feeding techniques was the discovery by Rollefsen (1939, 1940) that the plaice, *Pleuronectes platessa,* could be reared from hatching through metamorphosis with nauplii of the brine shrimp, *Artemia salina* L., as the only food. This is an extremely convenient source of food, since the nauplii hatch readily when the dried eggs are placed in water, and the eggs can be stored for long periods and used when needed. Unfortunately, not all fish larvae are able to take *Artemia* nauplii as a first food because of their relatively large size (length 0.4 mm, width with appendages folded 0.35 mm; from Blaxter, 1962). Hirano and Oshima (1963) pointed out that larvae of different fish species begin taking *Artemia* nauplii at different sizes. For example, the puffer, *Fugu rubripes,* eats *Artemia* nauplii when it is 4.1 mm long; *Mylio macrocephalus* and the flatfish, *Liopsetta obscura* at 5 mm; the halfbeak, *Hemiramphus sajori,* at 6–6.5 mm; and the Pacific herring, *Clupea pallasii,* at 9–10.5 mm (Hirano and Oshima, 1963). Fishelson (1963) reported that *Blennius pavo* of 3.5 mm total length will consume *Artemia* nauplii, and Flüchter (1965) found that *Solea solea* larvae 3 to 4 days old, i.e., ca. 5 mm total length, began to eat this food. These differences are undoubtedly related to differences between species in morphometry and mouth size (see Schumann, in Bardach, 1968), and perhaps also to the use of different strains of *Artemia* with different sized nauplii. Rosenthal and Hempel (1970) wrote that among young herring, the success of prey-catching maneuvers was higher with *Artemia* nauplii than with wild plankton, and they attributed this to the greater visibility of *Artemia* (Blaxter, 1968b) and to its sluggish escape response.

Certain flatfish larvae appear to do very well on an exclusive diet of *Artemia* nauplii. Shelbourne (1964) reported good survival (66%) through metamorphosis for plaice larvae feeding on *Artemia* alone, and Flüchter (1965) fed sole larvae on *Artemia* and obtained 80% survival through metamorphosis, and growth comparable to that of larvae in the sea. *Artemia* nauplii alone have also been used successfully to feed larval *Fundulus heteroclitus* (Joseph and Saksena, 1966), *Fundulus majalis* (Fahey, 1964), *Aulorhynchus flavidus* (Morris, 1956), *Sebastes pachycephalus nigricans* (Fujita, 1957), two cottid species (Morris, 1956), four species of artherinids (McHugh and Walker, 1948; Morris, 1956; Chirinos de Vildoso and Chuman 1964), and *Fugu pardalis* (Shojima, 1957). They have frequently been used to supplement other food types (e.g. Dannevig and Hansen, 1952; Blaxter and Hempel, 1961; Blaxter, 1962, 1968a; Fishelson, 1963) or to feed older larvae (e.g. Dannevig, 1948; Kasahara *et al.,* 1960; Schumann, in Bardach, 1968; Okamoto, 1969; Kramer and Zweifel, 1970).

Riley (1966) has shown in a controlled experiment that the survival and growth of plaice larvae feeding on *Artemia* nauplii are markedly affected by the amount of food available. He found that surplus food increased the survival beyond first feeding; but very high feeding levels were detrimental to the larvae after feeding had become established, since they caused fouling of the water and promoted the growth of bacteria and ciliates. Flüchter (1965) recommended extremely high concentrations of nauplii (20,000 per liter) for first-feeding sole larvae. The necessity of high concentrations of food for young larvae is also strongly suggested by Rosenthal's (1969b) finding that first-feeding herring larvae were successful in only 1% to 10% of their strikes at prey.

A rather substantial body of evidence indicates that *Artemia* nauplii alone will not sustain the growth and survival of clupeid larvae over long periods. Dannevig and Hansen (1952) found that older larvae of the Atlantic herring, *Clupea harengus,* did not grow on an exclusive diet of *Artemia.* Blaxter and Hempel (1961) and Blaxter (1962) also had little success using only *Artemia* to feed *C. harengus,* and Blaxter (1968a) was unable to rear herring beyond 25 mm on *Artemia.* McMynn and Hoar (1953) and Kurata (1959) reared the Pacific herring *Clupea pallasii* only to 10.2 and 14.5 mm, respectively, on *Artemia* alone. An explanation for this phenomenon may be that the digestive system of the larval clupeid is incapable of fully digesting the nauplii of *Artemia.* Rosenthal's (1969a) observation that *Artemia* nauplii are much more resistant to digestion by larval *C. harengus* than are copepods supports this explanation. Attempts to feed *Artemia* nauplii on phytoplankton in order to make them more nutritious (Dannevig and Hansen, 1952; Morris, 1956; Blaxter, 1962) appear to have met with little success, although Rosenthal (1969b) fed herring larvae of 15 mm total length and larger on *Artemia* which had been reared on cultured *Dunaliella* to ca. 1.8 mm in length. Despite the evidence for the nutritional inadequacy of *Artemia* nauplii for clupeid larvae, Blaxter (1962) found that 10–12 mm herring which had previously fed on *Artemia* nauplii survived up to twice as long without food as larvae which had fed on *Balanus* nauplii.

Certain technical problems are associated with the use of *Artemia* nauplii. Care must be taken to avoid placing eggshells in rearing containers along with the nauplii, as they may be eaten by fish larvae in place of nourishing food and the larvae may starve as a result (Morris, 1956). Rosenthal (1969a) observed one herring larva which took almost nothing but *Artemia* eggs. Blockage of the gut by *Artemia* eggshells has been reported in young seahorses (Herald and Rakowicz, 1951). As *Artemia* nauplii grow, they may become too large for the fish larvae to eat; they also become less nutritious as their yolk is consumed, a change which is indicated by transition from a deep orange to a whitish coloration (Morris, 1956). Morris stated that fish larvae which fed on older *Artemia* nauplii "did not prosper," and he recommended that uneaten nauplii be removed from rearing tanks each day.

Other crustaceans. Nauplii of the barnacle *Balanus* sp. are smaller than *Artemia* nauplii (Hirano and Oshima, 1963) and have been used to feed larval *C. harengus* (Soleim, 1942; Dannevig, 1948; Blaxter, 1962, 1968a), *Pleuronectes platessa* (Shelbourne, 1964), *Blennius pholis* and *Centronotus gunnellus* (Qasim, 1955, 1959) and *Mylio macrocephalus* (Kasahara *et al.,* 1960; Hirano, 1969). Barnacles have a short spawning season, however, and this limits their usefulness as larval fish food (Blaxter, 1962, 1968a). Blaxter (1965, 1968b) found that herring larvae required more light to feed on *Balanus* nauplii than on *Artemia* nauplii, presumably because the former are smaller and more transparent.

Since nauplii of calanoid copepods are frequently the dominant organisms in the guts of larval fishes caught at sea (e.g., Lebour, 1920), they would appear to be a natural choice as a food for use in laboratory fish-rearing. But copepod nauplii have never been cultured on a large scale for the purpose of feeding larval fishes, probably because of the technical difficulties of producing sufficient numbers. Kotthaus (1939) harvested nauplii which hatched from eggs carried by adult copepods collected in plankton tows, but he worked on a rather small scale. Kasahara *et al.* (1960) listed copepod nauplii as one of the foods they used but did not say how the nauplii were obtained.

Morris (1956) stated that nauplii of the spray-pool harpacticoid *Tigriopus* sp. are thigmotactic and hence not available to larval fishes, and most recorded attempts to use them as food have met with no success (Budd, 1940; Orcutt, 1950; Bishai, 1961; Blaxter, 1962). Nevertheless, Fahey (1964) mentioned, without further elaboration, that he reared *Bairdiella chrysura, Alosa pseudoharengus,* and *Mugil caphalus* using mass-cultured first and second naupliar stages of *T. californicus* as food. Certain other crustaceans such as young mysids (Kasahara *et al.,* 1960) and adult *Tigriopus* (Morris, 1956; Blaxter, 1965, 1968a) have been used to feed older larvae.

Mollusc larvae. The larvae of certain molluscs are attractive food sources because of their availability and small size (most under 0.2 mm, many under 0.1 mm—see Loosanoff and Davis, 1963; Hirano and Oshima, 1963) and have been used successfully several times, especially to feed very young larvae. Most such experiments have employed the larvae of bivalve molluscs, which generally hatch as trochophores and later develop into veligers. Kurata (1956) found mussel larvae an excellent food for early larvae of the flatfish *Liopsetta obscura,* and Okamoto (1969) gave mussel and oyster trochophores to early red sea bream, *Pagrus major,* larvae. Morris (1956) describes a procedure for obtaining eggs from the California mussel, *Mytilus californianus.* Dannevig (1948) used oyster larvae successfully to feed smaller larvae of several fish species, and Hirano (1969) reared *Mylio macrocephalus* using oyster larvae as the first food. Gastropod larvae, which in most cases hatch as veligers, have been used much less frequently than bivalve larvae. Lasker et al. (1970) found that the veligers of three species of opisthobranch gastropods were too large to be taken by first-feeding anchovy larvae but that they increased the growth rate and survival of older larvae which had fed first on a dinoflagellate. May (unpublished data) reared the atherinid *Leuresthes tenuis* through metamorphosis using veligers of the gastropod *Bulla gouldiana* as the sole food, with a survival of 16.7 percent through metamorphosis.

Other living foods. Kasahara et al. (1960) fed the hypotrichous ciliate *Stylonichia* sp. to larval *Mylio macrocephalus* 3-3.5 mm in length. (It is interesting in this connection that Kotthaus (1939), Schach (1939), and Bishai (1961) considered hypotrichous ciliates as undesirable contaminants in rearing experiments with herring and even suggested that they may have attacked and killed larvae.) The use of the rotifer *Brachionus plicatilis* to rear larval fishes has been reported recently by Japanese workers (Hirano, 1969; Mito *et al.*, 1969; Okamoto, 1969) who offered it to first-feeding or very young larvae.

Kurata (1959) found that first-feeding *Clupea pallasii* larvae took trochophores of the sabellid polychaete *Chone teres* in preference to *Artemia* nauplii, which were larger; but he considered *C. teres* as an unsuitable food source, because its spawning season was very short and the trochophores settled quickly. Cunningham (1893–95b) fed *Nereis* eggs to larval plaice with very limited success.

Several workers have tried echinoderm larvae as larval fish foods. Morris (1956) reared the sciaenid *Geneonymus lineatus* beyond yolk-absorption by feeding first with eggs and larvae of the sand-dollar *Dendraster* and later switching to *Artemia* nauplii. In their successful rearing trials Rubinoff (1958), Fujita (1965) and Richards and Palko (1969) offered sea urchin eggs or larvae (along with other foods) to larval fishes but did not state whether this food was taken to a significant extent.

Bruun (1949) cited the common use of nematodes for feeding freshwater tropical aquarium fishes and suggested that they might be a suitable food for marine fish larvae. But Blaxter (1962) tried the nematode *Anguillicula* sp. as a food for herring larvae without success, and Korovina (1962), working in freshwater, reported that the hard skin and sharp extremeties of larval nematodes (*Panagrelus redivivus*) injured the digestive tract of *Coregonus* larvae and killed them. Riley (1966) found free-living nematodes in the detritus on the bottom of some of his tanks which were occasionally taken by plaice post-larvae.

Algae growing on the walls of rearing containers was eaten by advanced herring larvae (Kotthaus, 1939) and by 8-day-old gobies (Delmonte *et al.*, 1968), and "slime" on tank walls was browsed off by plaice larvae in sufficient quantity to color the gut brown in larvae which had a restricted supply of *Artemia* nauplii (Riley, 1966).

Fabre-Domergue and Biétrix (1905) found that sole larvae soon began to feed on other larval fishes, including especially sprat larvae but also larvae of their own species. Schumann (in Bardach, 1968) attributed a 50% reduction in the number of Pacific mackerel larvae, *Scomber japonicus*, during the first 9 days after hatching, to intraspecific predation; he also found that Pacific barracuda fry, *Sphyraena argentea,* are exclusively piscivorous at a length of 4.5 mm.

Series of food types. Some Japanese investigators have developed rather complicated feeding schedules in which progressively larger food types are offered to the growing fish larvae, there being periods of overlap to eliminate abrupt transitions from one food type to the next (Kasahara *et al.*, 1960; Hirano, 1969; Okamoto, 1969). For example, Okamoto (1969) fed *Pagrus major* the following succession of foods: oyster and mussel trochophores, *Brachionus plicatilis,* barnacle nauplii, *Artemia* nauplii, zooplankton, annelid larvae, shrimp meat, and finally fish meat—the administration of each new food type overlapping for several days that of the previous type.

Prepared aquaria. In some rearing attempts workers have allowed a flora and fauna to develop in the rearing containers prior to introduction of the fish eggs or larvae. These "prepared aquaria" usually contain attached algae, phytoplankton, zooplankton, and ciliates. Growth of the biota has been encouraged by adding fertilizers and vitamins (Delmonte *et al.,* 1968) and by placing the tanks in direct sunlight (Schach, 1939; Heuts, 1947; Bishai, 1961). Unfortunately, authors who describe such aquaria rarely specify exactly what organisms are in them, and it is impossible to tell from their accounts which items served as food for the fish larvae. After the fish larvae hatch, specific food items are usually added to prepared aquaria, such as egg yolk (Heuts, 1947) or *Artemia* nauplii (McHugh and Walker, 1948). The flora in prepared aquaria seems to maintain chemical equilibrium in the water by stabilizing pH and O_2 tension and taking up fish metabolites. This role of green plants was appreciated by some of the early investigators: Garstang (1900) placed one of his rearing containers in direct sunlight and added green algae (*Ectocarpus*) "as a means of aerating and purifying the water," and Fabre-Domergue and Biétrix (1902) used algae to assure *"d'une part l'oxygénation continue du mileu, d'autre part l'élimination d'une proportion de déchets nuisibles impossible à éviter."* Shelbourne (1964) incorporated *Enteromorpha* into closed systems of sea-water circulation for the specific purpose of stabilizing water chemistry.

Schach (1939) and Bishai (1961) siphoned food organisms into their rearing containers from tanks which were essentially prepared aquaria, containing phytoplankton and copepods and placed in sunlight. Kotthaus (1939) and Schach (1939) both had *Enteromorpha* growing in their rearing containers, and Kotthaus achieved success only in containers which received some direct sunlight during the day.

Nonliving foods. Food types in this category are attractive because of their great convenience, but they present the difficulty that uneaten food accumulates on the bottom of the rearing container and decays rapidly, fouling the water. Anthony (1910) considered artificial foods unsuitable due to the decay problem, and Fabre-Domergue and Biétrix (1905) believed that running water was necessary when artificial foods were used. By far the most widely used non-living food has been cooked chicken-egg yolk made into fine particles. Fabre-Domergue and Biétrix (1897) were apparently the first to try this food source, and Heuts (1947), Fishelson (1963), Fujita (1966), and Ivanchenko and Ivanchenko (1969) have used it successfully. Egg yolk has served primarily as a food for newly-hatched larvae, and larvae are soon given living food such as wild plankton (Ivanchenko and Ivanchenko, 1969) or *Artemia* nauplii (Fishelson, 1963; Fujita, 1966). Nikitinskaya (1958), Kurata

(1959), and Ivanchenko and Ivanchenko (1969) were able to keep *Cluepea pallasii* alive only for short periods on egg yolk alone. Heuts (1947) fed egg yolk to stickleback larvae in prepared aquaria, but it is not clear how long he continued to administer the yolk. Bückmann *et al.* (1953) and Fishelson (1963) observed that particles of egg yolk were consumed by larvae only when the particles were moving in water currents, such as are set up in aquaria by a stream of air bubbles. Korovina (1962) noted that egg yolk, especially in excess, tended to pollute the water during rearing trials in fresh-water with *Coregonus* larvae.

Delmonte *et al.* (1968) successfully fed newly-hatched goby larvae in prepared aquaria on commercial fish-fry foods, although they noted a tendency for the uneaten food to decay; Blaxter (1962) and Klima *et al.* (1962) had no success with such foods. Bits of meat (squid flesh, crab meat, chopped fish, etc.) are unsuitable for young larvae (Kurata, 1959; Bishai, 1961), but very advanced larvae commonly have eaten such items (e.g. Dannevig, 1948; Kasahara *et al.*, 1960; Blaxter, 1965, 1968; Hirano, 1969). Blaxter (1965), however, found that the feeding rate of herring larvae 22–40 mm in length was higher on live *Tigriopus* than on pieces of squid flesh, which indicates that even advanced larvae prefer live food.

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REFERENCES

Anthony, R. 1910. The cultivation of the turbot. Proceedings of the 4th International Fishery Congress, Washington, 1908, Pt. 2. *Bull. U.S. Bur. Fish.* 28:861–870. (Translation.)

Bardach, J. E. 1968. The status and potential of aquaculture, particularly fish culture. Vol. 2, Part III, Fish culture. Amer. Inst. Biol. Sci., Washington, D.C., 225 pp. (Pages 22–29 of this work describe the rearing experiments of G. O. Schumann.)

Bishai, H. M. 1961. Rearing fish larvae. *Bull. Zool. Soc. Egypt.* (16): 4–29.

Blaxter, J. H. S. 1962. Herring rearing—IV. Rearing beyond the yolk-sac stage. *Mar. Res. Scot.*, (1): 18 pp.

——. 1965. The feeding of herring larvae and their ecology in relation to feeding. *Calif. Coop. Oceanic Fish. Invest., Rept.*, 10: 79–88.

——. 1968. Rearing herring larvae to metamorphosis and beyond. *J. Mar. Biol. Ass. U.K.*, 48: 17–28.

——. 1968b. Visual thresholds and spectral sensitivity of herring larvae. *J. Exp. Biol.*, 48: 39–53.

——. 1969. Experimental rearing of pilchard larvae, *Sardina pilchardus*. *J. Mar. Bio. Ass. U.K.*, 49: 557–575.

Blaxter, J. H. S., and G. Hempel. 1961. Biologische Beobachtungen bei der Aufzucht von Heringsbrut. *Helgol. wiss. Meeresunters.*, 7: 260–284. (English summary.)

Blaxter, J. H. S., and F. G. T. Holliday. 1963. The behaviour and physiology of herring and other clupeids. *Ad. Mar. Biol.*, 1: 261–393.

Bruun, A. Fr. 1949. The use of nematodes for larval fish. *J. Cons. Int. Explor. Mer*, 16: 96–99.

Bückmann, A., W. Harder and G. Hempel. 1953. Unsere Beobachtungen am Hering, *Clupea harengus* L. *Kurz. Mitt. fischereibiol. Abt. Max-Plank Inst. Meeresbiol.*, (3): 22–42. (English summary.)

Budd, P. L. 1940. Development of the eggs and larvae of six California fishes. *Calif. Dept. Fish Game, Fish Bull.*, (56): 50 pp.

Chirinos de Vildoso, A., and E. Chuman. 1964. Notos sobre el desarollo de huevos y larvas del pejerry *Odontesthes (Austromenidia) regia regia* (Humboldt). *Bol. Inst. Mar. Peru*, 1: 3–31. (English summary.)

Cunningham, J. T. 1893–95a. The life-history of the pilchard. *J. Mar. Biol. Ass. U. K.*, 3: 148–153.

——. 1893–95b. Experiments on the rearing of fish larvae in the season of 1894. *J. Mar. Biol. Ass. U. K.*, 3: 206–207.

Dannevig, A. 1948. Rearing experiments at the Flødevigen seafish hatchery 1943–1947. *J. Cons. Int. Explor. Mer*, 15: 277–283.

Dannevig, A., and S. Hansen. 1952. Faktorer av betydning for fiskeegenes og fiskeyngelens oppvekst. *Fiskeridir. Skr., Ser. Havundersøk.* 10(1): 36 pp. (English summary; English translation of pp. 6–16, the section on herring: translation no. 415, Marine Laboratory, Aberdeen, Scotland.)

Dannevig, H. 1897. On the rearing of the larval and post-larval stages of the plaice and other flat fishes. *Rep. Fish. Bd. Scot.*, 1896, Pt. 3: 175–193, pl. IV.

David, L. R. 1939. Embryonic and early larval stages of the grunion, *Leuresthes tenuis*, and of the sculpin, *Scorpaena guttata*. *Copeia*, (2): 75–81.

Delmonte, P. J., I. Rubinoff and R. W. Rubinoff. 1968. Laboratory rearing through metamorphosis of some Panamanian gobies. *Copeia*, (2): 411–412.

Deuel, D. G., J. R. Clark and A. J. Mansueti. 1966. Description of embryonic and early larval stages of bluefish, *Pomatomus salatrix*. *Trans. Am. Fish. Soc.*, 95: 264–271.

Fabre-Domergue and E. Biétrix. 1897. Recherches biologiques applicables à la pisciculture maritime sur les œufs et les larves des poissons de mer et sur le turbot. *Ann. Sci. Nat. (Zool.)*, 8 Sér., Tome 4: 151–220.

——. 1902. Appareil à rotation pour l'élevage des œufs de larves des poissons marins. *C. R. Ass. Franç. Av. Sci. Sess.* 30, 1902, Pt. 2: 577–582.

——. 1905. Développement de la Sole *(Solea vulgaris)*. Introduction à l'étude de la pisciculture marine. Travail du Laboratoire de Zoologie Maritime de Concarneau. Vuibert et Nony, Paris. 243 pp.

Fahey, W. E. 1964. A temperature controlled salt-water circulating apparatus for developing fish eggs and larvae. *J. Cons. Int. Explor. Mer*, 28: 364–384.

Fishelson, L. 1963. Observations on littoral fishes of Israel. II. Larval development and metamorphosis of *Blennius pavo* Risso (Teleostei, Blenniidae). *Israel J. Zool.*, 12: 81–91.

Flüchter, J. 1965. Versuche zur Brutaufzucht der Seezunge *Solea solea* in kleinen Aquarien. *Helgol. wiss. Meeresunters.*, 12: 395–403. (English summary.)

Forrester, C. R. 1964. Laboratory observations on embryonic development and larvae of the Pacific cod *(Gadus macrocephalus* Tilesius). *J. Fish. Res. Bd. Canada*, 21: 9–16.

Fujita, S. 1957. On the larval stages of a scorpaenid fish, *Sebastes pachycephalus nigricans* (Schmidt). *Jap. J. Ichthyol.*, 6: 91–93. (In Japanese with English summary.)

——. 1965. Early development and rearing of two common flatfishes, *Eopsetta grigorjewi* (Herzenstein) and *Tanakius kitaharai* (Jordan et Starks). *Bull. Jap. Soc. Sci. Fish.*, 31: 258–262. (In Japanese with English summary.)

——. 1966. Egg development, larval stages, and rearing of the puffer, *Lagocephalus lunaris spadiceus* (Richardson). *Jap. J. Ichthyol.*, 13: 162–168. (In Japanese with English summary.)

Garstang, W. 1900. Preliminary experiments on the rearing of sea-fish larvae. *J. Mar. Biol. Ass. U.K.*, 6: 70–93.

Gross, F. 1937. Notes on the culture of some marine plankton organisms. *J. Mar. Biol. Ass. U.K.*, 21: 753–768.

Herald, E. S., and M. Rakowicz. 1951. Stable requirements for raising sea horses. *Aquar. J.*, 22: 234–242.

Hertling, H. 1932. Die Züchtung von Meeresfischen für wissenschaftliche und praktische Zwecke. *In* E. Abderhalden (ed.), Handbuch der biologische Arbeitsmethoden., Abt. 9, Teil 6, Heft 2: 195–366.

Heuts, M. J. 1947. Experimental studies on adaptive evolution in *Gasterosteus aculeatus* L. *Evolution*, 1: 89–102.

Hirano, R. 1969. Rearing of Black Sea Bream larva. *Bull. Jap. Soc. Sci. Fish.*, 35: 567–569, 603–604. (In Japanese with English summary.)

Hirano, R., and Y. Oshima. 1963. On the rearing of larvae of marine animals with special reference to their food organisms. *Bull. Jap. Soc. Sci. Fish.*, 29: 282–297. (In Japanese.)

Ivanchenko, L. A., and O. F. Ivanchenko. 1969. Transition to active feeding by larval and juvenile white sea herring (*Clupea pallasii* Natio *Maris-albi* Berg) in artificial conditions. *Dokl. Biol. Sci.*, 184: 207–209. (Translated from *Dokl. Akad. Nauk S.S.S.R.*, 184: 1444–1446.)

Joseph, E. B., and V. P. Saksena. 1966. Determination of salinity tolerances in mummichog (*Fundulus heteroclitus*) larvae obtained from hormone-induced spawning. *Chesapeake Sci.*, 7: 193–197.

Kasahara, S., R. Hirano and Y. Oshima. 1960. A study on the growth and rearing methods of black porgy, *Mylio macrocephalus* (Basilwesky). *Bull. Jap. Soc. Sci. Fish.*, 26: 239–244. (In Japanese with English summary.)

Klima, E. F., I. Barrett and J. E. Kinnear. 1962. Artificial fertilization of the eggs, and rearing and identification of the larvae of the anchoveta, *Cetengraulis mysticetus*. *Bull. Inter-Amer. Trop. Tuna Comm.*, 6: 155–178.

Korovina, V. M. 1962. The diet of broad whitefish larvae during transition to active feeding. *Nauchn.-Tekh. Byul. Gos. Nauchn.-Issled. Inst. Ozernogo i Rechnogo Rybn. Khoz.*, 15: 57–61. (Biol. Abstr. 44—17809)

Kotthaus, A. 1939. Zuchtversuche mit Heringslarven (*Clupea harengus* L.). *Helgol. wiss. Meeresunters.*, 1: 349–358.

Kramer, D., and J. R. Zweifel. 1970. Rearing and growth of anchovy larvae (*Engraulis mordax* Girard) as influenced by temperature. *Calif. Coop. Occanic Fish. Invest. Rept.*, 14: 84–87.

Kurata, H. 1956. On the rearing of larvae of the flatfish, *Liopsetta obscura*, in small aquaria. *Bull. Hokkaido Reg. Fish. Res. Lab.*, 13: 20–29. (In Japanese with English summary.)

——. 1959. Preliminary report on the rearing of the herring larvae. *Bull. Hokkaido Reg. Fish. Res. Lab.*, 20: 117–138. (In Japanese with English summary.)

Lasker, R., H. M. Feder, G. H. Theilacker and R. C. May. 1970. Feeding, growth and survival of *Engraulis mordax* larvae reared in the laboratory. *Mar. Biol.*, 5: 345–353.

Lebour, M. V. 1920. The food of young fish. No. III (1919). *J. Mar. Biol. Ass. U.K.*, 12: 261–324.

——. 1925. Young anglers in captivity and some of their enemies. A study in a plunger jar. *J. Mar. Biol. Ass. U.K.*, 13: 721–734.

Loosanoff, V. I. and H. C. Davis. 1963. Rearing of bivalve molluscs. *Adv. Mar. Biol.*, 1: 1–136.

McHugh, J. L. and B. W. Walker. 1948. Rearing marine fishes in the laboratory. *Calif. Fish and Game*, 34: 37–38.

McMynn, R. G. and W. S. Hoar. 1953. Effects of salinity on the development of the Pacific herring. *Canad. J. Zool.*, 31: 417–432.

Meyer, H. A. 1878. Biologische Beobachtungen bei künstlicher Aufzucht des Herings der Westlichen Ostsee. Weigandt, Hempel and Parey, Berlin. (Translation in *Rep. U.S. Comm. Fish.*, 1878, Pt. 6: 629–638.)

Mito, S., M. Ukawa and M. Higuchi. 1969. On the development and rearing of the larvae of a flounder, *Kareius biocoloratus* (Basilewsky) with reference to its spawning in the culturing pond. *Bull. Nansei Reg. Fish. Res. Lab.*, 1: 87–102. (In Japanese with English summary.)

Molander, A. R., and M. Molander-Swedmark. 1957. Experimental investigations on variation in plaice (*Pleuronectes platessa* L.). *Rept. Inst. Mar. Res. Lysekil, Ser. Biol.*, (7): 45 pp.

Morris, R. W. 1955. Some considerations regarding the nutrition of marine fish larvae. *J. Cons. Int. Explor. Mer*, 20: 255–265.

——. 1956. Some aspects of the problem of rearing marine fishes. *Bull. Inst. Oceanogra. Monaco*, (1082): 61 pp.

Nikitinskaya, I. V. 1958. On the onset of active feeding of the larvae of *Clupea harengus pallasi*. Val. *Zool. Zh.*, 37: 1568–1571. (In Russian with English summary.)

Okamoto, R. 1969. Rearing of red sea bream larvae. *Bull. Jap. Soc. Sci. Fish.*, 35: 563–566, 603. (In Japanese with English summary.)

Orcutt, H. G. 1950. The life history of the starry flounder, *Platichthys stellatus* (Pallas). *Calif. Dept. Fish. Game, Fish Bull.*, (78): 64 pp.

Qasim, S. Z. 1955. Rearing experiments on marine teleost larvae and evidence of their need for sleep. *Nature* (Lond.), 175: 217–218.

——. 1959. Laboratory experiments on some factors affecting the survival of marine teleost larvae. *J. Mar. Biol. Ass. India*, 1: 13–25.

Richards, W. J., and B. J. Palko. 1969. Methods used to rear the thread herring, *Opisthonema oglinum*, from fertilized eggs. *Trans. Am. Fish. Soc.*, 98: 527–529.

Riley, J. D. 1966. Marine fish culture in Britain. VII. Plaice (*Pleuronectes platessa* L.) post-larval feeding on *Artemia salina* L. nauplii and the effects of varying feeding levels. *J. Cons. Int. Explor. Mer*, 30: 204–221.

Rollefsen, G. 1939. Artificial rearing of the fry of sea water fish. Preliminary communication. *Rapp. et Proc.-Verb., Cons. Int. Explor. Mer*, 109, Pt. 3; 133.

——. 1940. Utklekking og oppdretting av saltvannfisk. *Naturen*, (6/7): 197–217.

Rosenthal, H. 1969a. Verdauungsgeschwindigkeit, Nahrungswahl und Nahrungsbedarf bei den Larven des Herings, *Clupea harengus* L. *Ber. Dt. Wiss. Komm. Meeresforsch.*, 20: 60–69. (English summary.)

——. 1969b. Untersuchungen über das Beutefangverhalten bei Larven des Herings *Clupea harengus* L. *Mar. Biol.*, 3: 208–221. (English abstract.)

Rosenthal, H., and G. Hempel. 1970. Experimental studies in feeding and food requirements of herring larvae (*Clupea harengus* L.) *In* Steele, J. H. (ed.), *Marine Food Chains*. Univ. Calif. Press, Berkeley, pp. 344–364.

Rubinoff, I. 1958. Raising the atherinid fish *Menidia menidia* in the laboratory. *Copeia*, (2): 146–147.

Runnström, S. 1941. Quantitative investigations on herring spawning and its yearly fluctuations at the west coast of Norway. *Fiskeridir. Skr., Ser. Havundersøk.*, 6(8): 71 pp.

Schach, H. 1939. Die künstliche Aufzucht von *Clupea harengus* L. *Helgol. wiss. Meeresunters.*, 1: 359–372.

Shelbourne, J. E. 1964. The artificial propagation of marine fish. *Adv. Mar. Biol.*, 2: 1–83.

Shojima, Y. 1957. On the development of eggs and rearing of larvae of a puffer, *Fugu (Higanfugu) pardalis* (T. and S.). *Sci. Bull. Fac. Agr. Kyushu Univ.*, 16: 125–136. (In Japanese with English summary.)

Soleim, P. A. 1942. Årsaker til rike og fattige årganger av siid. *Fiskeridir. Skr., Ser. Havundersøk.*, 7(2): 39 pp. (English summary.)

Yamamoto, G., and C. Nishioka. 1952. The development and rearing of hatched larvae of North Pacific Cod (*Gadus macrocephalus* Tilesius). *Spec. Publ. Jap. Sea Reg. Fish. Res. Lab., on the third anniversary of its founding:* 301–308. (Translation no. 402, Fish. Res. Bd. Canada.)

Calif. Mar. Res. Comm., CalCOFI Rept., 14:84–87, 1970.

GROWTH OF ANCHOVY LARVAE (*ENGRAULIS MORDAX* GIRARD) IN THE LABORATORY AS INFLUENCED BY TEMPERATURE

DAVID KRAMER AND JAMES R. ZWEIFEL
National Marine Fisheries Service, Fishery-Oceanography Center
La Jolla, California

INTRODUCTION

The northern anchovy (*Engraulis mordax* Girard) spawns between 13° and 17° C off California and occasionally at warmer temperatures. Growth rates of larvae are unknown for this species yet these data are needed for estimating the size of the spawning population. This report describes a method for rearing larval anchovies in the laboratory and the effect of two temperatures, 17° and 22° C on their growth rates.

REARING AT 17° C

Anchovy eggs for two experiments at 17° C (17-I and 17-II) were collected in the ocean off San Diego, California. In each experiment 2,000 eggs of approximately the same stage of development were put into the tank and hatched almost synchronously. The larvae were sampled as soon as possible after all eggs were hatched and sampling continued through 23 days in 17-I and 35 days in 17-II (Table 1, Figures 1 and 2).

A rectangular glass tank, 183 cm long by 71 cm wide by 38 cm high, was used for rearing the anchovy larvae. It contained 380 liters of sea water and was sprayed inside with a non-toxic, glossy black epoxy paint against which the larvae could be seen and which allowed them to detect their food (Blaxter, 1962; Shelbourne, 1964). The tank was built into a deep water table which served as a water bath in which temperature was maintained at ±0.5°C with a mixing valve (Lasker and Vlymen, 1969).

TABLE 1

Size ranges and mean lengths ($\bar{x}$) of anchovy larvae reared from hatching in two 17° C experiments (17-I and 17-II) and one 22° C experiment (S.D. = standard deviation)

	17–I				17–II				22°			
Age (days)	Number of larvae sampled	Size range of sample (mm)	$\bar{x}$	S.D.	Number of larvae sampled	Size range of sample (mm)	$\bar{x}$	S.D.	Number of larvae sampled	Size range of sample (mm)	$\bar{x}$	S.D.
0	10	2.9– 3.4	3.2	0.17	10	2.5– 3.5	3.2	0.30	—	—	—	—
1	10	3.5– 4.0	3.7	0.16	10	3.2– 3.9	3.6	0.22	7	2.5– 3.3	2.9	0.28
2	10	3.3– 4.0	3.7	0.24	6	3.0– 4.2	3.7	0.43	12	3.1– 3.7	3.4	0.17
3	10	3.6– 4.1	3.9	0.13	9	3.5– 4.0	3.8	0.21	12	3.4– 4.9	3.7	0.46
4	11	3.4– 4.2	3.8	0.22	—	—	—	—	11	3.7– 4.6	4.0	0.26
5	10	3.5– 4.5	4.0	0.25	7	3.7– 4.8	4.1	0.33	15	2.9– 5.4	3.9	0.74
6	10	3.6– 4.8	4.1	0.32	—	—	—	—	9	4.2– 6.3	5.2	0.70
7	10	3.8– 5.1	4.3	0.46	10	3.9– 5.0	4.6	0.42	12	3.8– 6.9	5.6	0.80
8	10	3.9– 5.8	4.7	0.67	—	—	—	—	8	6.0– 7.8	7.0	0.57
9	9	4.5– 6.7	5.8	0.73	—	—	—	—	—	—	—	—
10	10	4.4– 6.7	5.7	0.77	10	4.5– 8.4	6.4	1.15	5	7.1– 9.0	8.1	0.74
11	10	4.9– 7.7	6.6	0.83	—	—	—	—	—	—	—	—
12	10	5.7– 8.4	7.2	0.79	13	4.3– 9.2	6.7	1.47	5	8.5–11.9	10.0	1.53
13	11	6.1– 9.4	7.6	1.06	—	—	—	—	—	—	—	—
14	10	7.5– 9.6	8.8	0.64	15	6.3–11.1	9.1	1.47	5	8.0–11.4	9.8	1.34
15	10	5.8– 9.1	8.2	1.03	—	—	—	—	5	11.3–14.3	12.8	1.18
16	10	7.7–10.5	9.2	0.76	6	6.4–10.3	8.0	1.30	—	—	—	—
17	10	6.1–11.7	9.5	1.80	—	—	—	—	8	10.0–15.4	13.3	2.01
18	10	7.6–12.3	10.5	1.23	9	6.8–13.4	10.4	2.09	—	—	—	—
19	—	—	—	—	—	—	—	—	—	—	—	—
20	9	7.9–13.7	11.8	1.74	7	5.5–13.3	9.6	2.74	—	—	—	—
21	—	—	—	—	—	—	—	—	—	—	—	—
22	10	10.2–16.0	12.6	1.78	10	7.9–17.3	12.4	2.49	—	—	—	—
23	—	—	—	—	—	—	—	—	—	—	—	—
24	—	—	—	—	15	10.0–17.0	13.3	2.07	—	—	—	—
25	—	—	—	—	—	—	—	—	—	—	—	—
26	—	—	—	—	6	9.4–18.4	14.4	2.96	—	—	—	—
27	—	—	—	—	—	—	—	—	—	—	—	—
28	—	—	—	—	10	10.0–18.9	15.3	2.70	—	—	—	—
29	—	—	—	—	—	—	—	—	—	—	—	—
30	—	—	—	—	—	—	—	—	—	—	—	—
31	—	—	—	—	9	11.0–19.8	15.6	2.81	—	—	—	—
32	—	—	—	—	—	—	—	—	—	—	—	—
33	—	—	—	—	—	—	—	—	—	—	—	—
34	—	—	—	—	12	9.8–20.7	17.4	3.15	—	—	—	—

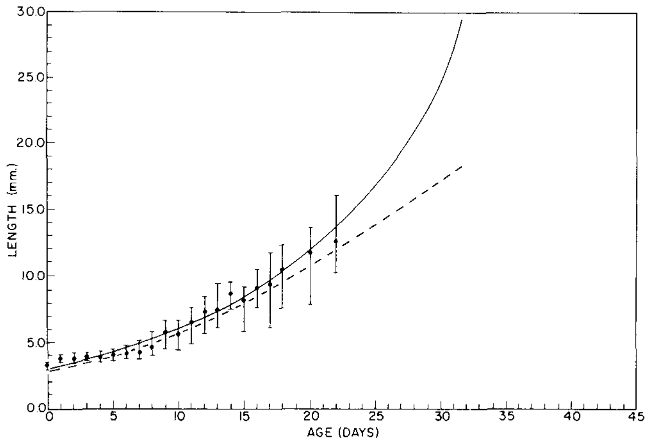

FIGURE 1. Growth of anchovy larvae reared from hatching for 23 days (17-I) at 17° C. Solid line is based on the equation

$$l_t = l_o e^{ct}$$

broken line was obtained by fitting the Gompertz model to the data (see text). The mean length and range are shown for each sample (see Table 1).

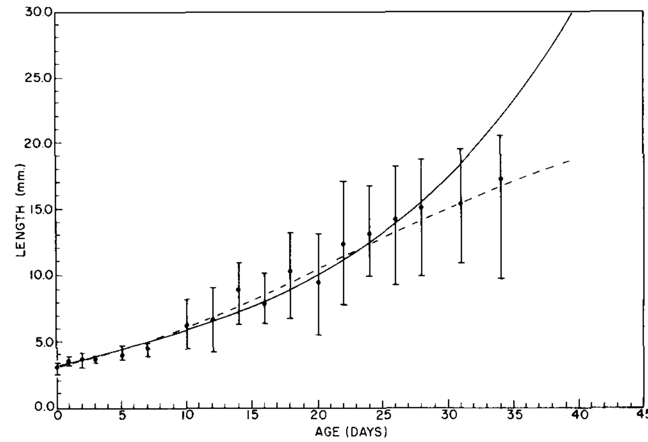

FIGURE 2. Growth of anchovy larvae reared from hatching for 35 days (17-II) at 17° C. Solid line is based on the equation

$$l_t = l_o e^{ct}$$

broken line was obtained by fitting the Gompertz model to the data (see text). The mean length and range are shown for each sample (see Table 1).

Daylight fluorescent lights were used to illuminate the rearing tank. The main light, centered over the tank was set on a diurnal schedule—12 hours on and 12 hours off. In order to avoid sudden reaction by the larvae to the tank lights' going on and off, the room lights were turned on 1 hour before the tank lights went on and turned off 1 hour after the tank lights went off. Light at the surface of the water in the tank averaged 44 ft-c with the tank and room lights on and 32 ft-c with only the room lights on. The room in which the experiments were conducted had walls which did not reach the ceiling (Lasker and Vlymen,

TABLE 2

Feeding of anchovy larvae reared in two 17° C experiments (17-I and 17-II)

Experiment	Feeding schedule	Larvae: Age (days)	Larvae: Size range (mm)	Diet: Kind[2]	Diet: Approximate size range (width in μ)	Diet: Average food density[1] (no/ml)
17-I	Every day	2–15	3.3– 9.1	Plankton Copepod nauplii	70– 90	0.4
		16–17	7.7–11.7	Plankton Copepod nauplii Copepodites Brine shrimp nauplii[3]	70–120 200–500	2.0
		18–22	6.1–16.0	Brine shrimp nauplii	200–500	0.8
17-II	Every other day	2–16	3.0–10.3	Plankton Tintinnids Copepod nauplii	50– 90	2.3
		18–22	6.8–17.3	Plankton Tintinnids Copepod nauplii Copepodites	50–130	2.2
		24–31[4]	10.0–19.8	Plankton Tintinnids Copepod nauplii Copepodites Copepods	50–190	2.6
		33	—[5]	Brine shrimp nauplii	200–500	1.0

[1] Calculated as homogeneous dispersion but only upon addition to tank (see text).
[2] Predominant types.
[3] Supplement to plankton.
[4] On day 28 brine shrimp nauplii only—no plankton collection.
[5] No sample of larvae.

1969). Consequently when the tank and room lights were off 3 ft-c of light illuminated the surface of the tank from lights in the adjoining corridor.

The main diet for the anchovy larvae for most of each experiment was plankton collected with an 80-μ mesh net in Mission Bay, San Diego. Food size, controlled by mechanical straining through various size meshes, was determined and maintained for different sizes of larvae as nearly as possible in accordance with the data of Arthur (1965) and Berner (1959) (Table 2).

As noted in Table 2, densities of food organisms were calculated as though for homogeneous dispersions in the tank but only for the times when they were introduced. Once in the tank, plankters concentrated in the brightest areas, usually near the surface of the water and at the sides and bottom of the tank so it was never possible to determine the true density of plankton. In experiment 17-II, food organisms totalled more than a million at each feeding and remained available to the fish larvae for as long as 2 days after each addition of plankton. Food densities were classed as adequate or inadequate by the sighting of larvae feeding on plankton or by the incidence of food in the guts of sampled larvae. Using these criteria, feeding incidence was noted as "low" in 17-I and "high" in 17-II.

REARING AT 22° C

The larvae sampled at 22° C were from a mass-rearing experiment conducted by G. O. Schumann with techniques similar to those described by Longhurst (1968). No data is available on the numbers of eggs put into the tank, the feeding schedule, nor the numbers of organisms added to the tank with each feeding. The larvae were sampled only on the days shown in Table 1 and as depicted in Figure 3.

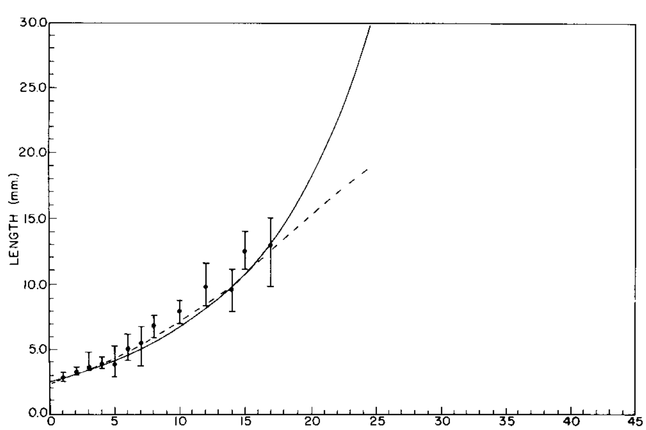

FIGURE 3. Growth of anchovy larvae reared from hatching for 18 days at 22° C. Solid line is based on the equation

$$l_t = l_o e^{ct}$$

broken line was obtained by fitting the Gompertz model to the data (see text). The mean length and range are shown for each sample (see Table 1).

GROWTH

Growth in these experiments can be expressed by the equation

$$l_t = l_o e^{ct}$$

where
l_t = length at time t
l_o = length at hatching
c = instantaneous growth rate expressed as mm/mm of length

In 17-I $l_t = 2.739e^{.0718t}$
In 17-II $l_t = 3.24e^{.0555t}$
In the 22°C experiment $l_t = 2.543e^{.0972t}$

These curves are illustrated by the solid lines in Figures 1, 2, and 3 respectively.

Although these simple logarithmic curves fit the experimental data well, extrapolation is dangerous since growth rates are known to decrease with age. Laird (1969) showed that a Gompertz model characterized by the set of differential equations

$$dW(t)/dt = \gamma W(t)$$
$$d\gamma/dt = \alpha\gamma$$

or $W(t) = W_o exp\{A_o/\alpha[1-exp\ (-\alpha t)]\}$

where
W_o = weight at time 0
A_o = growth rate at time 0
γ = instantaneous growth rate
α = instantaneous change in γ

describes the early growth processes of a large number of organisms in which growth is fundamentally exponential (implied by the normal binary fission of cells) and undergoes some intrinsic (as opposed to environmental) exponential retardation by some unknown physiological mechanism. This equation was fitted to our experimental data using the length-weight relationships of the data of Lasker et al. (1970) where $W = b \log l^k$ provided a better fit for premetamorphic larvae than does the classic allometric formula $W = bl^k$ for which weights must be estimated.

The iterative least squares estimates were obtained by minimizing the expression

$$\sum_{1}^{n}\left[l^k - l_o^k exp\{A_o/\alpha[1-exp(-\alpha t)]\}\right]^2$$

with respect to l_o, k, A_o, and α. It was found that k close to 6.0 provided the best fit. Therefore a common $k = 6.0$ was used for all sets and the estimated values for b were

.00070 in 17-I
.00084 in 17-II
and .00049 in the 22° C experiment.

The growth rate at 22° C was about 1.75 times that in 17-II but it is not possible to make a definite conclusion about the higher rate at 22° C. Absolute food densities and food availability were not known in the 22° C experiment since rearing was not continued through metamorphosis. The most tenable hypothesis for the more rapid rate at the higher temperature is that as a consequence of greater activity the larvae fed more frequently and increased feeding produced a higher rate of growth. Although there is no experimental evidence for this mechanism in larval fishes it has been demonstrated for the post juvenile stages of a serranid, *Epinephalus guttatus* (Menzel, 1960) and a cichlid, *Cichlasoma bimaculatum* (Warren and Davis, 1967). Other variables such as the use of continuous light and a larger container may also have been responsible for or contributed to the higher growth rate.

The higher rate of growth in experiment 17-I with lower food densities than in 17-II may have been the result of selective early mortality of smaller larvae which were unable to find sufficient food and thus, by such mortality, benefited the larger larvae by increasing their available food supply. Another view is that the larger larvae may have been better able to seek out the scarce food items and benefit from them while the smaller larvae could not and ultimately died.

REFERENCES

Arthur, D. K. 1956. The particulate food and the food resources of the larvae of three pelagic fishes, especially the Pacific sardine, *Sardinops caerulea*. Ph.D. Thesis, *University of California, Scripps Institution of Oceanography*: 231 pp. (Typewritten).

Berner, L., Jr. 1959. The food of the larvae of the northern anchovy *Engraulis mordax*. *Inter-Amer. Trop. Tuna Comm., Bull.*, 4(1) : 1–22.

Blaxter, J. H. S. 1962. Herring rearing—IV. Rearing beyond the yolk sac stage. *Mar. Res. Scot.*, (1) : 1–18.

Laird, A. K. 1969. The dynamics of growth. *Res./Develop.*: 28–31.

Lasker, R., H. M. Feder, G. H. Theilacker and R. C. May. 1970. Feeding growth, and survival of larval anchovies reared in the laboratory. *Mar. Biol.*, 5: 345–353.

Lasker, R., and L. Vlymen. 1969. The experimental sea-water aquarium of the Bureau of Commercial Fisheries Fishery-Oceanography Center, La Jolla, California. *U.S. Fish and Wildl. Serv. Circ.*, (334) : 1–14.

Longhurst, A. R. 1968. Bureau of Commercial Fisheries Fishery-Oceanography Center, La Jolla, California, Fiscal Year 1968. *U.S. Fish and Wild. Serv. Circ.*, (303) : 1–32.

Menzel, D. W. 1960. Utilization of food by a Bermuda reef fish. *J. Cons.* 25 :216–222.

Shelbourne, J. E. 1964. The artificial propagation of marine fish. *Adv. mar. Biol.*, (2) : 1–83.

Warren, C. E., and G. E. Davis. 1967. Laboratory studies on the feeding bioenergetics, and growth of fish, p. 175–214. *In* S. D. Gerking (ed.) The biological basis of fresh-water fish production. John Wiley & Sons, Inc., New York.

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THE SAURY AS A LATENT RESOURCE OF THE CALIFORNIA CURRENT

PAUL E. SMITH AND ELBERT H. AHLSTROM
National Marine Fisheries Service, Fishery-Oceanography Center
La Jolla, California 92037
and
HAROLD D. CASEY[1]

INTRODUCTION

An American fishery on the Pacific saury (*Cololabis saira* Brevoort) of the California Current has been considered intermittently over the last three decades. Recently, interest in the eastern Pacific stocks has increased due to rising prices and diminished catches of this species in the western Pacific. Japanese, Soviet, and American exploratory research on this species in the eastern Pacific has been intensified during the past several years. As yet no fishery has developed on this species in the California Current region. It is the purpose of this paper to review two bodies of data on saury abundance collected on cruises of the California Cooperative Oceanic Fisheries Investigations (CalCOFI) conducted jointly by the University of California, Scripps Institution of Oceanography and the U.S. Department of Commerce's National Marine Fisheries Service Laboratory, La Jolla, California. Night-light observations of juvenile and adult sauries were recorded from September 1950 through December 1958 and have been published through December 1955 (Ahlstrom and Casey, 1956). In addition, saury eggs have been sorted from oblique plankton tows since February 1950, and the results to December 1955 have been published in the same report. That portion of the saury data on observations and planktonic eggs which has not yet been published is appended to this paper (Appendix Tables I and II). Sea survey cruises conducted since 1950 (Heimann, 1969) have yielded information on saury observations (Eberhart, 1954). Basic oceanographic data related to the plankton tows and night-light stations are in "Observations of the Pacific Ocean" series (Staff, Scripps Institution of Oceanography) and specific information on the plankton tow data are available by reference to Thrailkill (1969). Information on saury eggs from eight cruises in the mid-Pacific between 1956–57 have been provided by the National Marine Fisheries Service Biological Laboratory, Honolulu, Hawaii (Appendix Table III).

In addition to summarizing current data collected by surveys in the California Current area, we will attempt to answer the following questions:

> What is the range of natural fluctuations in abundance of Pacific saury in the California Current survey area, and what seasons or areas within the California Current area are the most likely for scouting for fishable saury concentrations?

We will first deal with estimates of abundance of the saury spawning population as determined from collections of their eggs on CalCOFI surveys.

DISTRIBUTION OF SAURY EGGS WITHIN THE CALCOFI SURVEY AREA OFF CALIFORNIA AND BAJA CALIFORNIA

Our data on occurrence and abundance of saury eggs has been obtained from plankton hauls on CalCOFI survey cruises between February 1950 and December 1966. Data on occurrence of saury eggs are summarized for these years in a composite map (Figure 1). Frequency of occurrence is shown for stations occupied most frequently in the CalCOFI pattern: these lie between station lines 60–137, with offshore coverage to station 90 on lines 60–120 and to station 60 on lines 123–137. In the remainder of the pattern only positive and negative stations for saury eggs are indicated.

Information summarized on this map is based on 23,284 plankton hauls of which 2,429, or 10.4%, contained saury eggs. Total standardized number of saury eggs was 51,900 or 21.37 per positive haul.

Sampling and survey techniques have been most recently summarized by Ahlstrom (1966, p. 1–5). Briefly, a 1-m diameter net with 0.55-mm apertures is towed obliquely from approximately 140-m to the surface at a vessel speed of about 2 knots. During a haul the net moves 3–4-m forward for each meter of ascent. A flow meter in the mouth of the net is used to estimate the volume of water strained during each haul. For comparability, fish eggs and larvae obtained in each haul are standardized to the number under 10 square meters of sea surface. The standard haul factor usually is about three.

The area represented by a station in the CalCOFI grid, most commonly, is 20x40 nautical miles. Inshore stations, however, are more closely spaced and may represent as small an area as 4x40 nautical miles, offshore stations, particularly those seaward of station 70 usually represent an area of 40x40 nautical miles, or even a greater area if seaward of station 90.

Saury eggs did not occur with equal frequency throughout the CalCOFI survey area (Figure 1). They were taken less frequently at inshore stations in all parts of the pattern and at stations occupied off central and southern Baja California.

[1] Formerly with the National Marine Fisheries Service, now with the San Diego City Schools System.

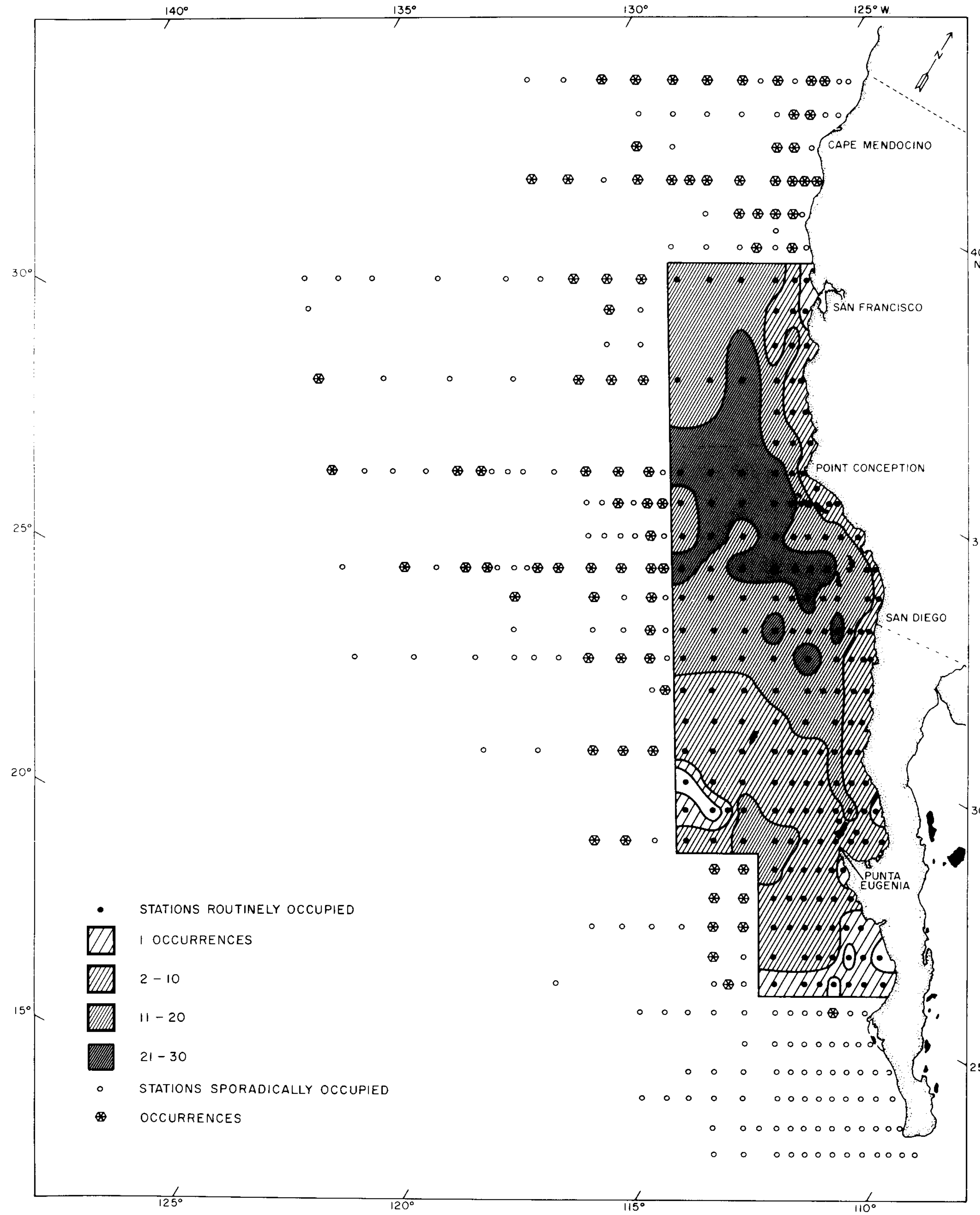


FIGURE 1. Saury egg occurrences 1950–1966.

TABLE 1

Occupancies of plankton stations made on CalCOFI survey cruises, 1950–66, summarized by area and month.

Station lines	Month												Total all months
	01	02	03	04	05	06	07	08	09	10	11	12	
40– 47	7	--	12	32	25	19	54	29	13	6	--	--	197
50– 57	20	10	10	25	23	56	50	26	13	13	--	--	246
60– 67	147	10	10	216	126	145	229	54	47	155	23	22	1184
70– 77	146	33	29	224	149	169	231	56	32	138	26	28	1261
80– 87	366	230	186	460	306	325	444	160	100	346	143	150	3216
90– 97	432	286	243	565	440	410	579	192	139	463	130	183	4062
100–107	403	233	222	536	386	335	493	139	73	361	38	96	3315
110–119	429	269	266	555	388	340	503	188	171	375	34	91	3609
120–127	367	213	228	429	276	250	416	165	113	334	56	88	2935
130–137	345	146	172	403	201	174	352	130	57	295	54	47	2376
140–147	122	60	52	94	--	30	10	31	11	33	40	18	501
150–157	109	43	36	66	--	27	--	19	14	21	35	12	382
Total	2893	1533	1466	3605	2320	2280	3361	1189	783	2540	579	735	23,284

TABLE 2

Occurrence (positive hauls) for saury eggs on CalCOFI survey cruises, 1950–66, summarized by area and month.

Station lines	Month												Total all months
	01	02	03	04	05	06	07	08	09	10	11	12	
40– 47	1	--	0	2	0	3	11	0	3	1	--	--	21
50– 57	0	1	1	5	0	16	5	3	1	1	--	--	33
60– 67	3	0	1	42	42	45	26	7	0	1	0	0	167
70– 77	8	4	6	81	65	60	19	5	1	1	0	0	250
80– 87	36	31	30	157	120	73	28	6	9	15	3	5	513
90– 97	42	52	53	168	141	83	33	13	2	12	4	2	605
100–107	41	39	36	113	57	43	12	6	1	11	2	0	361
110–119	32	26	29	74	35	42	7	2	0	3	2	2	254
120–127	34	16	20	36	36	17	10	4	0	0	2	0	175
130–137	12	0	4	11	10	7	5	0	0	0	0	0	49
140–147	1	0	0	0	--	0	0	0	0	0	0	0	1
150–157	0	0	0	0	--	0	0	0	0	0	0	0	0
Totals	210	169	180	689	506	389	156	46	17	45	13	9	2429

TABLE 3

Percentage of positive hauls for saury eggs on CalCOFI survey cruises, 1950–66, summarized by area and month.

Station lines	Month												Total all months
	01	02	03	04	05	06	07	08	09	10	11	12	
40– 47	14.3	--	0	6.2	0	15.8	20.4	0	23.1	16.7	--	--	10.7
50– 57	0	10.0	10.0	20.0	0	28.6	10.0	11.5	7.7	7.7	--	--	13.4
60– 67	2.0	0	10.0	19.4	33.3	31.0	11.4	13.0	0	0.6	0	0	14.1
70– 77	5.5	12.1	20.7	36.2	43.6	35.5	8.2	8.9	3.1	0.7	0	0	19.8
80– 87	9.8	13.5	16.1	34.1	39.2	22.5	6.3	3.8	9.0	4.3	2.1	3.3	16.0
90– 97	9.7	18.2	21.8	29.7	32.0	20.2	5.7	6.8	1.4	2.6	3.1	1.1	14.9
100–107	10.2	16.7	16.2	21.1	14.8	12.8	2.4	4.3	1.4	3.0	5.3	0	10.9
110–119	7.5	9.7	10.9	13.3	9.0	12.4	1.4	1.1	0	0.8	5.9	2.2	7.0
120–127	9.3	7.5	8.8	8.4	13.0	9.8	2.4	2.4	0	0	3.6	0	6.0
130–137	3.5	0	2.3	2.7	3.6	4.0	1.4	0	0	0	0	0	2.0
140–147	0.8	0	0	0	--	0	0	0	0	0	0	0	0.2
150–157	0	0	0	0	--	0	--	0	0	0	0	0	0
All hauls	7.3	11.0	12.3	19.1	21.8	17.1	4.6	3.9	2.2	1.8	2.2	1.2	10.4

TABLE 4

Numbers of saury eggs (standard haul summations) obtained on CalCOFI survey cruises, 1950–1966, summarized by cruise.

Month of cruise	Year																	Total
	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	
January	--	62	28	240	297	38	219	0	7	40	319	89	142	194	189	244	3391	5,499
February	925	594	265	219	491	444	401	315	49	15	135	--	--	--	--	--	83	3,936
March	104	521	95	260	366	39	387	0	20	39	84	--	--	--	--	--	--	1,915
April	827	187	580	606	404	1339	532	4600	671	192	748	322	158	132	877	619	250	13,044
May	149	271	1032	881	1137	2469	615	737	909	511	30	--	--	--	--	--	2666	11,407
June	110	248	408	1040	476	267	270	161	4050	208	9	--	--	--	--	--	401	7,648
July	25	125	186	460	57	3775	5	63	38	114	3	155	23	64	161	77	77	5,408
August	97	7	5	226	0	70	0	0	0	35	50	--	--	--	--	--	0	490
September	59	12	23	22	--	599	0	0	0	0	0	--	--	--	--	--	0	715
October	0	28	2	3	0	82	56	0	0	33	442	66	92	205	79	6	0	1,094
November	498	3	6	4	--	4	5	5	0	9	--	--	--	--	--	--	0	534
December	--	0	--	0	97	0	46	0	0	64	--	--	--	--	--	--	3	210
Total	2794	2058	2630	3961	3325	9126	2536	5881	5744	1260	1820	632	415	[1]595	[1]1306	[1]946	6871	51,900

[1] Many special inshore stations included in appendix tables are omitted in these totals.

In order to more quantitatively document areal differences in occurrence and abundance of saury eggs, the CalCOFI grid was subdivided into 12 regional groupings, each comprising a cardinal and two ordinal lines. Thus lines 40, 43, and 47 were grouped together, lines 50, 53, and 57, etc.

These data are presented in three tables: Table 1 summarizes the areal and temporal distribution of station occupancies, Table 2, the areal and temporal distribution of occurrences (positive hauls) for saury eggs, and Table 3 summarizes the frequency of occurrences of saury eggs (percentage of positive hauls) by month and area. Frequency of occurrence of saury eggs is highest off central and southern California (station lines 60–67 through 90–97), decreasing progressively off Baja California to 2% positive hauls on lines 130–137, 0.2% positive hauls on lines 140–147, and 0% positive hauls on lines 150–157.

Temporally, the frequency of occurrences of saury eggs was highest during the spring months. April–June (19.4%) and lowest during the fall months, October–December (1.7%). The month with the highest frequency of occurrence on the average was May (21.8%). During January through July saury eggs were taken on all cruises made with the exception of 5701 and 5703. During August through December saury eggs were obtained on about 60% of the cruises, although only in 2.3% of the collections.

Data on the number of saury eggs collected during each monthly cruise (Std haul totals) are given in Table 4, and a companion table summarizes the number of occurrences (positive hauls) of saury eggs, Table 5.

Tables 1–5 summarize data from all stations occupied on regular CalCOFI cruises during 1950–1966. In Figure 1, we delimited a smaller area as that occupied on CalCOFI cruises with greatest regularity. This area extends between station lines 60–137 and from shore to station 90 on all lines except 123–137; for the latter, coverage was from shore to station 60. This area covers approximately 209,150 square miles. In the analysis that follows our detailed estimates of abundance of sauries are for this basic CalCOFI area. Most CalCOFI stations fall within this area (20,645 of 23,284), Table 6.

TABLE 5

Numbers of positive hauls for saury eggs obtained on CalCOFI survey cruises, 1950–1966, summarized by cruise.

Month of cruise	Year																	Total
	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	
January	--	10	8	10	14	2	14	0	1	9	32	18	13	23	9	26	21	210
February	13	25	10	11	19	16	25	3	8	5	20	--	--	--	--	--	14	169
March	12	29	18	20	32	6	34	0	4	2	23	--	--	--	--	--	--	180
April	17	32	47	57	54	22	37	33	68	29	56	54	32	26	25	73	27	689
May	24	39	42	61	49	35	38	53	68	57	4	--	--	--	--	--	36	506
June	26	42	43	67	35	12	24	14	55	27	3	--	--	--	--	--	41	389
July	8	26	17	24	6	3	2	8	7	16	1	5	3	1	7	14	8	156
August	7	1	2	22	0	3	0	0	0	7	4	--	--	--	--	--	0	46
September	6	1	2	3	--	5	0	0	0	0	0	--	--	--	--	--	0	17
October	0	2	1	1	0	3	2	0	0	9	2	7	7	2	7	2	0	45
November	3	1	2	1	--	2	2	1	0	1	--	--	--	--	--	--	0	13
December	--	0	--	0	2	0	2	0	0	4	--	--	--	--	--	--	1	9
Total	116	208	192	277	211	109	180	112	211	166	145	84	55	[1]52	[1]48	[1]115	148	2,429

[1] Many special inshore stations included in appendix tables are omitted in these totals.

TABLE 6

Summary of number of stations occupied and number of positive hauls for saury eggs on CalCOFI survey cruises, 1950–66, in the basic CalCOFI pattern and in adjacent areas.

Area	Total number stations occupied	Number positive hauls(P)	Percent positive hauls
Basic CalCOFI pattern: lines 60–137	20,645	2,255	10.9
Lines 40–57 (all stations)	443	54	12.2
Lines 60–120 (stations seaward of station 90)	881	103	11.7
Lines 123–137 (stations seaward of station 60)	432	16	3.7
Lines 140–157 (all stations)	883	1	0.1
	23,284	2,429	10.4

The eggs of the Pacific saury are quite distinctive. Their shape is unusual for pelagic fish eggs, being ovoid rather than round. They are spawned in clusters, the eggs being held together by filaments characteristic of the species.

Saury eggs are neither evenly nor randomly distributed. A number of factors contribute to patchiness in their distribution. The saury is a schooling fish that sometimes occurs in massive concentrations. Although the size of spawning aggregations of sauries are not known they probably remain in schools during spawning—hence spawning fish are clustered rather than randomly dispersed. The eggs are spawned in clusters, and although the eggs tend to become disassociated during their long incubation period, large clusters of eggs are sometimes collected. Hence, patchiness is likely to be on at least two scales.

The consequences of this are that 1) a sample can be taken in an 800 square mile area which has a number of eggs per 10 square meters which is too large to be characteristic of the entire 800 square miles, and 2) a sample from an area can be taken which contains no eggs even though that same 800 square mile area does contain eggs. Since we want some idea of the amount of variation from each source, we have separately identified the proportion P of the samples which have saury eggs and D the number of saury eggs per positive sample. The rationale behind this separation is that the precision of the proportion P can be evaluated by the binomial distribution. The density D has a frequency distribution which is complicated by adherence of some eggs, dispersal of some others, and schooled spawning behavior of the adults. To further complicate the frequency distribution the long incubation time (see below) implies that this distribution will change with time.

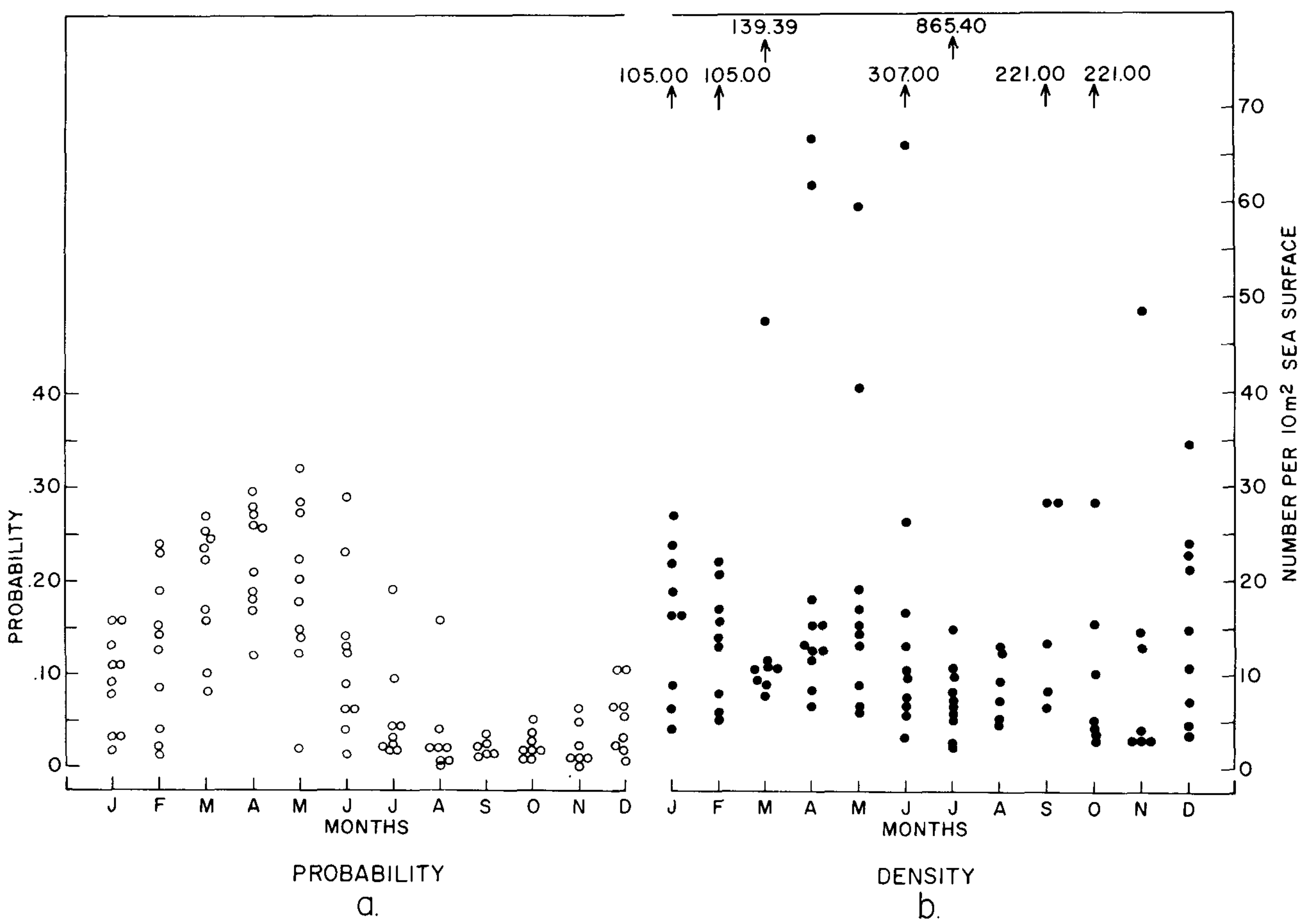


FIGURE 2. The seasonal succession of bimonthly average probability of occurrence (a) and bimonthly average density of eggs per 10 m^2 in positive tows (b).

The probability P is usually less than 0.05 (Table 3) during several months in the autumn of each year and is usually greater than 0.15 several months in the spring. An example of the 95% confidence limits of these probabilities with 250 samples is approximately

P	*Limits*
0.05	0.03–0.09
0.15	0.10–0.20
0.25	0.20–0.31

(Snedecor and Cochran, 1967, page 6). The seasonal succession of "P" is shown in Figure 2a.

In Figure 2b D, the density of eggs per 10 m^2 in positive samples, is shown to be rather erratic and the seasonality is not as pronounced as is the probability of positive sample (2a). The occurrence of samples with a large density are neither frequent nor regular. The large individual samples are not anomalous: they are here assumed to be too infrequent to be properly represented in the bimonthly density averages. These large rare samples usually coincide with periods with high probability of positive samples. This is as would be expected but there is no indication from Figure 2b that the preponderance of high density samples occurs at any one time of year. For these reasons we will stabilize the average number of eggs per 10 m^2 sea surface for positive samples.

FECUNDITY

A thorough study of the fecundity of the Pacific saury in our region has not been made. MacGregor (pers. comm.) has estimated from a few samples that females contain 22.7 eggs in the *maturing size mode* per gram of body weight. There is no evidence that the male-female number or weight ratio varies from unity, so we assume the fecundity per spawning batch to be 11.35 eggs per gram of adult in the CalCOFI area. If the fecundity is too high, our biomass estimates will be proportionately low, or vice versa. If the biomass of males is less than that of females, our spawning biomass estimates will be too high.

An important consideration in treating fecundity data is the number of spawning batches matured per female per year. Hatanaka (1956a, pages 235–237) found three size modes of ova in fully matured ovaries, with modal sizes of 0.6, 1.1, and 1.9 mm. The time required to mature the middle batch after the largest was spawned was assumed by Hatanaka to require approximately 2 months. Lacking more precise information on the average maturation times between spawning batches, we are accepting Hatanaka's determination of approximately 2 months. This is perhaps the most critical datum in converting estimates of egg abundance to estimates of spawning population biomass. Although each monthly cruise is assumed to represent 30 days, and two adjacent cruises 60 days—actual coverage of stations are made about 1 month apart, on the average. Since it is unlikely that successive modes of ova would mature as rapidly as 30 days, we undoubtedly are sampling different segments of the spawning population during any two successive monthly cruises.

DEFINITION OF SYMBOLS

N—Number of stations occupied during a cruise within a specified survey area, such as the basic CalCOFI area.

P—Number of positive hauls for saury eggs obtained during a cruise within a specified area.

S—Standard haul total of saury eggs obtained in a collection.

D—The number of saury eggs spawned per day in a standard area, representing 10 m^2 of sea surface.

A—Weighting factor for area. For the purposes of this paper we use an average weighting factor for area. For the basic CalCOFI survey area, this is derived by dividing 7.17×10^{10} by N.

T—Weighting factor for time. For the purposes of this report, a cruise is assumed to represent 30 days.

C—Estimate of the number of saury eggs in a specified survey area during a given cruise.

I—Incubation time of saury eggs in days. Precise information on incubation time as related to temperature is not available. Dr. Grace Orton (pers. comm.) observed that saury eggs required 9–10 days to develop to hatching when kept in the laboratory in a finger bowl. We are assuming that saury eggs require 10 days incubation time on the average.

B—Estimate of the biomass of spawning fish (males and females) in metric tons.

ESTIMATING ABUNDANCE OF SAURY EGGS

The primary estimate of abundance of saury eggs we wish to make is abundance in the basic CalCOFI area. This area covers 209,150 square miles or 7.17×10^{10} standard areas.

The formula for calculating abundance of eggs within a specified survey area during a given cruise is

$$C = D \cdot P \cdot A \cdot T$$

We have used two estimates of D in our calculations, both averages. The estimate we consider the more reliable is that based on total collections made over a 17-year period.

$D_t = \Sigma S$ for all cruises $/\Sigma P$ for all cruises times I,

$$\text{or } D_t = \frac{51{,}900}{2429 \times 10} = 2.137$$

$D_y = \Sigma S$ for a given year $/\Sigma P$ for the same year times I.

ESTIMATES OF SAURY EGG ABUNDANCE AND BIOMASS OF SPAWNERS IN THE BASIC CALCOFI AREA, 1950–1966

Estimates of egg abundance are made for the two best adjacent months of each year. During the period of quarterly cruises 1961–1965, the April estimate has been doubled, to obtain a 2-month abundance estimate. The basic CalCOFI area with respect to station lines (60–137) was covered on most cruises used for abundance estimates, exceptions being 5504, 5704, 6004, 6605, and 6606. When a portion of the CalCOFI area, usually lines 60–77, was covered on only one of the two cruises, we have adjusted for the missing coverage by assuming occupancies and positive hauls to be identical to those obtained on the more complete cruise. Hence, all estimates are based on coverage of the complete basic CalCOFI area. However, stations occupied outside the basic CalCOFI area, such as on lines 40–57 or 140–157 are not used; for this reason adjusted N, is usually smaller than the original N value of a cruise, and similarly adjusted P is usually smaller than the original P value of a cruise.

The estimates of egg abundance contained in Table 7, use the formulation C = DPAT in the following manner.

D is standardized to 2.137 eggs per standard area per day of spawning (D_t as previously defined).

P—positive hauls for saury eggs, adjusted as above described.

A—weighting factor for area. This basic CalCOFI pattern contains a surface area of ca. 7.17×10^{11} m^2 or 7.17×10^{10} standard areas. For a given cruise $A = 7.17 \times 10^{10}$/adjusted N.

T—weighting factor for time: 30 days.

As previously noted, the number of saury eggs spawned per batch per metric ton of males and females is standardized at 1.135×10^7. Hence, an estimate of the spawning biomass is obtained by dividing the estimates of egg abundance for two consecutive months by the value for fecundity.

Estimates of the spawning population biomass range from 88.6 thousand metric tons to 266,000 metric tons, a range of three times. Average biomass during the 17-year period was 182.0 thousand metric tons. Estimates based on years with monthly cruises are somewhat less variable, ranging from 142,000 metric tons to 266,000 metric tons, and average 198,000 metric tons or approximately 220,000 short tons.

We are making several assumptions in equating estimates of number of saury eggs in the CalCOFI area to the biomass of spawners. We assume that the total saury spawning population in the survey area will spawn during the peak 2-month period. We also are assuming that during a 2-month period, each female will have spawned only one batch of eggs.

$$B = \frac{C_1 + C_2}{1.135 \times 10^7}$$ in which C_1 and C_2 are monthly estimates of egg abundance for the two adjacent months of each year with the highest number of occurrences (positive hauls) of saury eggs.

One important factor, egg mortality, is not applied in this formulation, because we have no reasonable estimate of this rate. The effect of its omission will be to underestimate the number of eggs spawned. To adjust for mortality during the embryonic period, the eggs would have to be aged and corrected to the number at the instant of spawning.

TABLE 7

Estimates of number of saury eggs spawned within the basic CalCOFI area during the two best months of each year, and of the biomass of spawners, 1950–66.

Year	Month	Lines occupied	Total stations N	Adjusted N	Positive stations P	Adjusted P	A (standard areas $\times 10^8$)	C (estimate of number eggs $\times 10^{10}$)	Estimate of biomass of spawners $\times 10^3$ metric tons
1950	May	40–130	129	84	24	20	8.51	109.1	217.5
	June	40–130	106	73	26	22	9.77	137.8	
1951	May	60–137	127	111	39	30	6.42	123.5	242.8
	June	60–157	170	117	42	39	6.09	152.1	
1952	April	60–137	155	152	47	47	4.69	141.4	216.3
	May	60–137	187	184	42	42	3.87	104.2	
1953	May	60–137	203	162	61	57	3.92	143.4	266.5
	June	60–137	196	192	67	67	3.70	159.1	
1954	April	60–137	196	195	54	54	3.65	126.4	207.8
	May	60–137	205	204	49	49	3.48	109.5	
1955	April	80–137	134	149	22	27	4.72	81.7	149.0
	May	60–137	184	183	35	35	3.90	87.4	
1956	April	60–157	178	151	37	37	4.72	112.0	172.7
	May	40–137	239	202	38	37	3.54	84.0	
1957	April	80–157	207	183	33	48	3.90	119.9	210.0
	May	60–137	205	205	53	53	3.48	118.4	
1958	April	60–137	267	233	68	64	3.07	126.1	229.2
	May	60–137	232	232	68	68	3.07	134.0	
1959	April	60–147	250	224	29	29	3.18	59.2	141.7
	May	60–137	261	247	57	55	2.88	101.6	
1960	March	73–137	163	184	23	31	3.87	76.9	146.4
	April	40–157	342	240	56	47	2.96	89.3	
1961	April	60–137	240	199	54	44	3.60	101.4	178.7
1962	April	60–140	247	202	32	27	3.54	61.3	108.0
1963	April	60–140	245	200	26	22	3.57	50.3	88.6
1964	April	60–137	224	211	25	24	3.38	51.9	91.5
1965	April	63–137	237	220	73	70	3.24	145.3	256.0
1966	May	80–137	195	235	36	52	3.05	101.6	170.4
	June	60–103	135	235	41	47	3.05	91.8	
									182.0

Spawning Outside the Basic CalCOFI Area

We have a number of sources of information on saury spawning outside the basic CalCOFI area. On some cruises stations were occupied off southern Baja California (station lines 140–157), on many cruises stations were occupied seaward of the basic CalCOFI pattern on station lines 60–137 (Figure 1 and Table 6), and on about 10 percent of the cruises stations were occupied off northern California (station lines 40–57). Only one haul of 883 made off southern Baja California contained saury eggs, hence spawning in this area is inconsequential. Stations occupied seaward of station 60 on lines 123–137 were only slightly better—3.7 percent contained saury eggs. The area seaward of station 90 on lines 60–120 is an important spawning area for the saury. We propose to divide this extensive area into two subareas for deriving estimates of abundance: 1) Area A—station lines 60–120, stations 95–120; 2) Area B—station lines 60–100, stations 130–200. Average size of the saury spawning population is estimated at 100,000 metric tons in Area A, 70,000 metric tons in Area B during the two spring months, April–May (Table 8). The average size of the saury spawning populations in the basic CalCOFI area during April–May is estimated to be 173,000 tons. Inasmuch as these estimates cover the same time period, the offshore population can be assumed to be distinct from that in the basic CalCOFI area, hence these estimates are additive.

The two best months for saury eggs off northern California (station lines 40–57) are June and July. The average size of spawning populations during these months is estimated to be 62,000 metric tons. The spawning population could be made up, in part, of fish which have migrated into this area from the south or offshore subsequent to the April–May spawning.

TABLE 8

Estimates of average saury egg abundance and biomass of spawning populations in areas seaward of basic CalCOFI area or off northern California.

	Number stations	P	Area (× 10³) sq. miles	A	DPAT (× 10¹⁰)	Biomass × 10³ metric tons
Areas seaward of basic CalCOFI area						
Area A (station lines 60–120, stations 95–120)						
April	174	32	91.2	2.674	54.9	100
May	64	19	91.2	4.888	59.5	
Area B (station lines 60–100, stations 130–200)						
April	51	8	166.4	11.192	57.4	70
May	17	1	166.4	33.576	21.5	
Areas off northern California						
Northern California (station lines 40 to 57)						
June	75	19	78.8	3.602	43.9	62
July	104	16	78.8	2.597	26.6	

TABLE 9

Saury spawning off Oregon, 1949.

	April	May	June	July	August	September	Total
Stations occupied off Oregon on CalCOFI cruises in 1949							
Station line 1	--	5	--	10	10	--	25
Station line 2	--	6	--	10	10	10	36
Station line 3	10	10	--	9	10	10	49
	10	21	--	29	30	20	110
Positive hauls for saury eggs off Oregon in 1949							
Station line 1	--	0	--	0	7	--	7
Station line 2	--	0	--	1	4	3	8
Station line 3	0	2	--	1	2	1	6
	0	2	--	2	13	4	21

Estimate of abundance of saury eggs off Oregon in 1949.

Month	Number stations occupied	P	Area × 10³ sq. miles	A	PADT	Biomass × 10³ metric tons
July	29	2	96	11.35	14.6	93
August	30	13	96	10.98	91.5	

Ordinarily CalCOFI surveys do not extend to the north of California. However, three lines of stations off Oregon were occupied wholly or in part during five cruises of 1949. The majority of occurrences of saury eggs were obtained on the August cruise: 13 positive hauls out of 30. Only eight additional hauls contained saury eggs out of the remaining 80 obtained during 4904, 4905, 4907, and 4909. An estimate of the abundance of spawning fish off Oregon in July–August 1949 amounts to 93,000 metric tons. Inasmuch as the spawning season off Oregon is later in the year than off California, we cannot be certain that the spawning population is wholly distinct from that off California. More limited coverage off Oregon was obtained in 1950. Seven of 33 hauls made off Oregon in August and September 1950 contained saury eggs. (Table 9.)

The most systematic coverage of the eastern north Pacific to the north of 20° N latitude was obtained on the NORPAC Expedition of August 1955 (Figure 3). Saury eggs were obtained at 15 stations of 196 in the portion of NORPAC covered by CalCOFI research vessels. In addition, saury eggs and/or larvae were taken in hauls made by NMFS Honolulu Biological Laboratory's ships between 30° and 50° N and 155° and 180° W (Figure 4, Appendix III). About half of the positive records fall within the comprehensive CalCOFI pattern, illustrated in Figure 1: the remainder are interesting additions to our information on distribution of saury eggs.

In summary the average estimate of the size of the saury spawning population within the basic CalCOFI area between San Francisco, California, and Pt. San Eugenio, Baja California, is 182,000 metric tons when based on egg abundance during the two best months of each year, 173,000 metric tons if based on average abundance during April–May. The saury population offshore from the basic CalCOFI area (station lines 60–120) is estimated to be equally large, averaging 170,000 metric tons during April–May. An estimate of the average spawning population off northern California, station lines 40–57, during the two best months in that area amounts to 62,000 metric tons. Our best estimate from off Oregon of 93,000 metric tons is based on our coverage during July–August 1949. If the spawning population in all four regions were separate, the average biomass would exceed 500,000 metric tons. This does not include the offshore portions of the population between 40° to 50° N latitude that extends out to at least mid-ocean (180° W) and probably completely across the Pacific.

AVAILABILITY

One of the authors (Casey) has prepared a draft of a manuscript in which arbitrary quantities have been assigned each kind of observation recorded on night stations under working lights. The senior author (Smith) has conducted personal night-light observations in November 1968 and May 1969 over

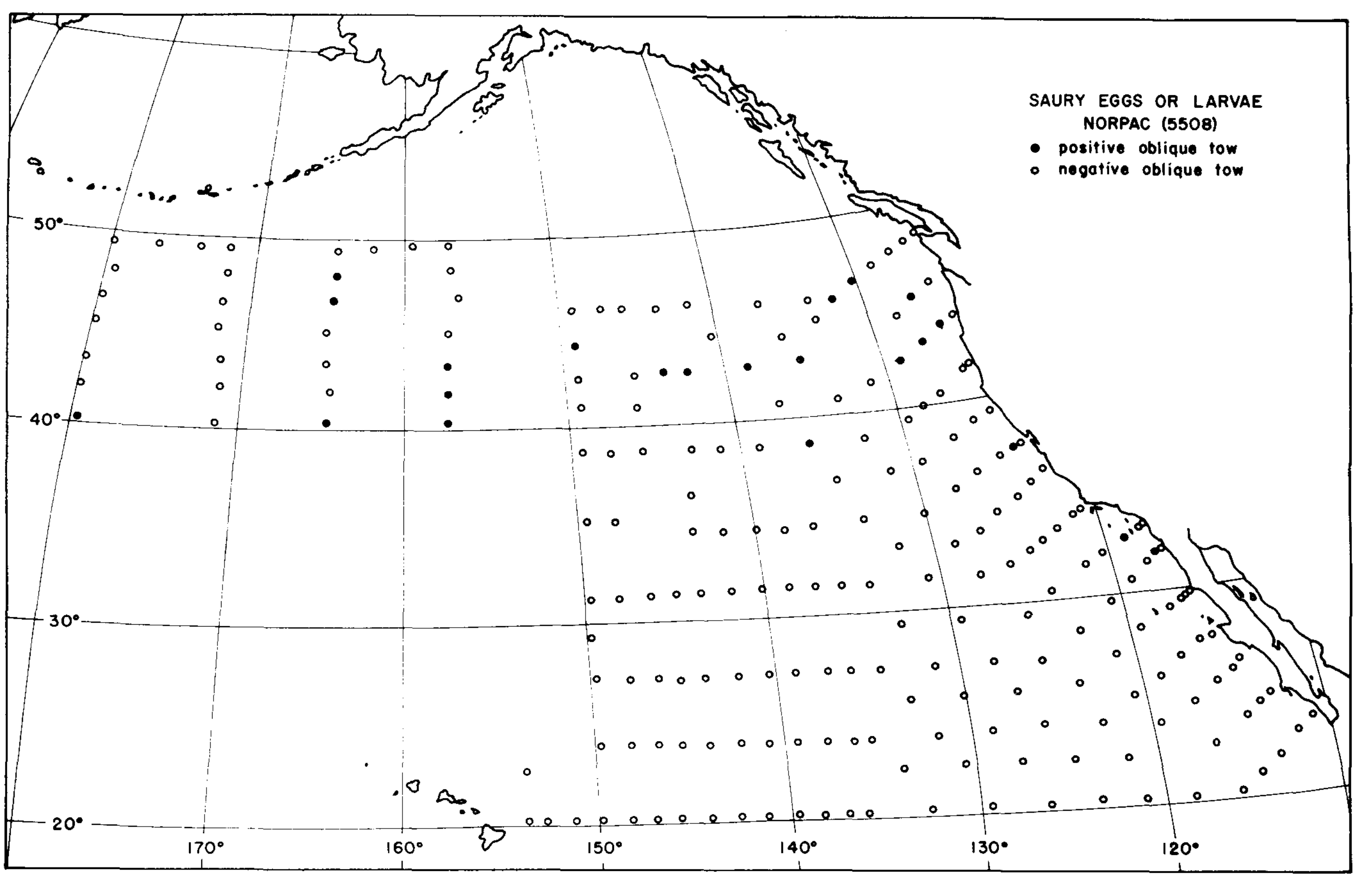


FIGURE 3. The occurrence of saury eggs or larvae in the NORPAC Expedition. August 1955.

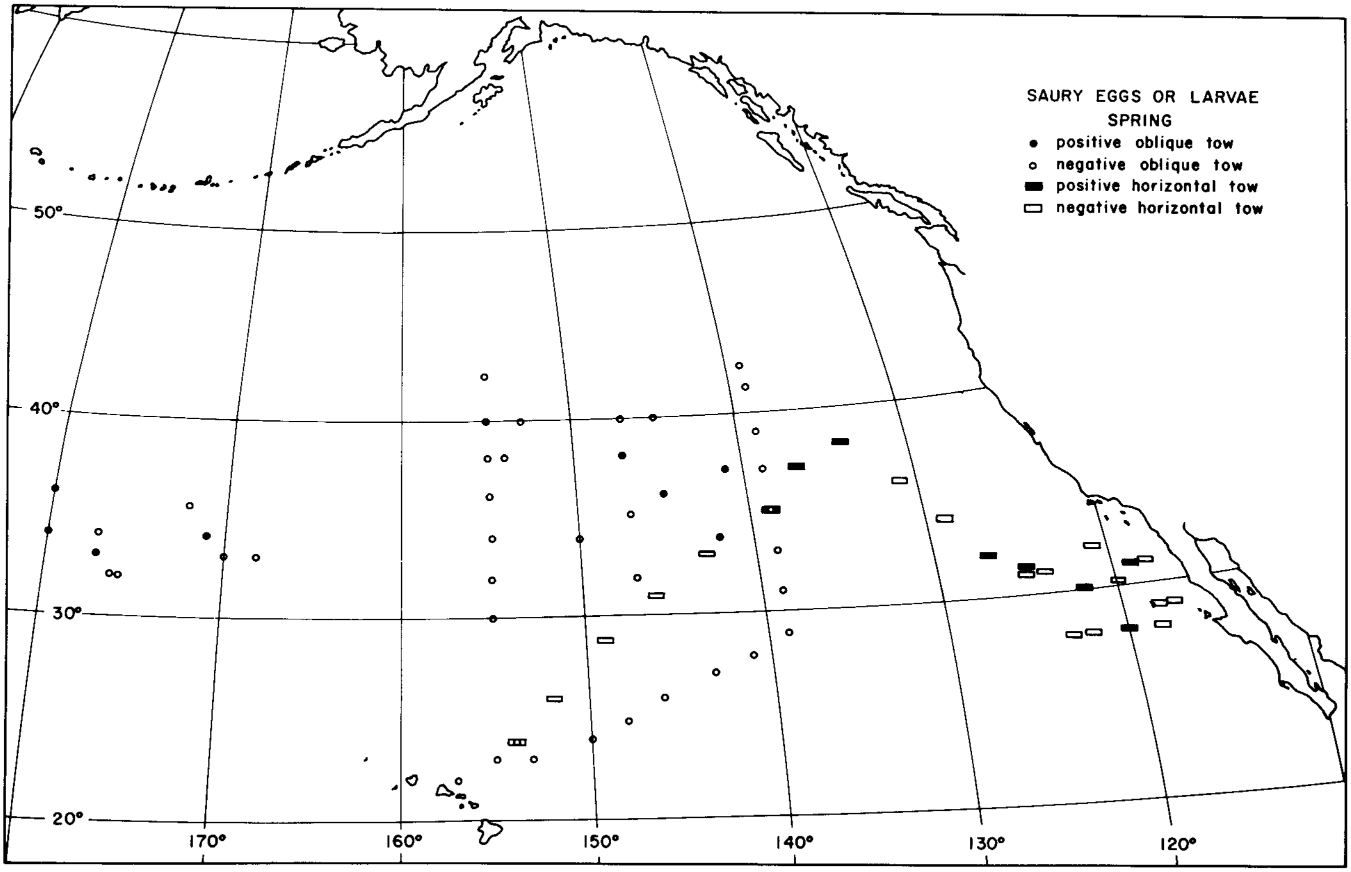
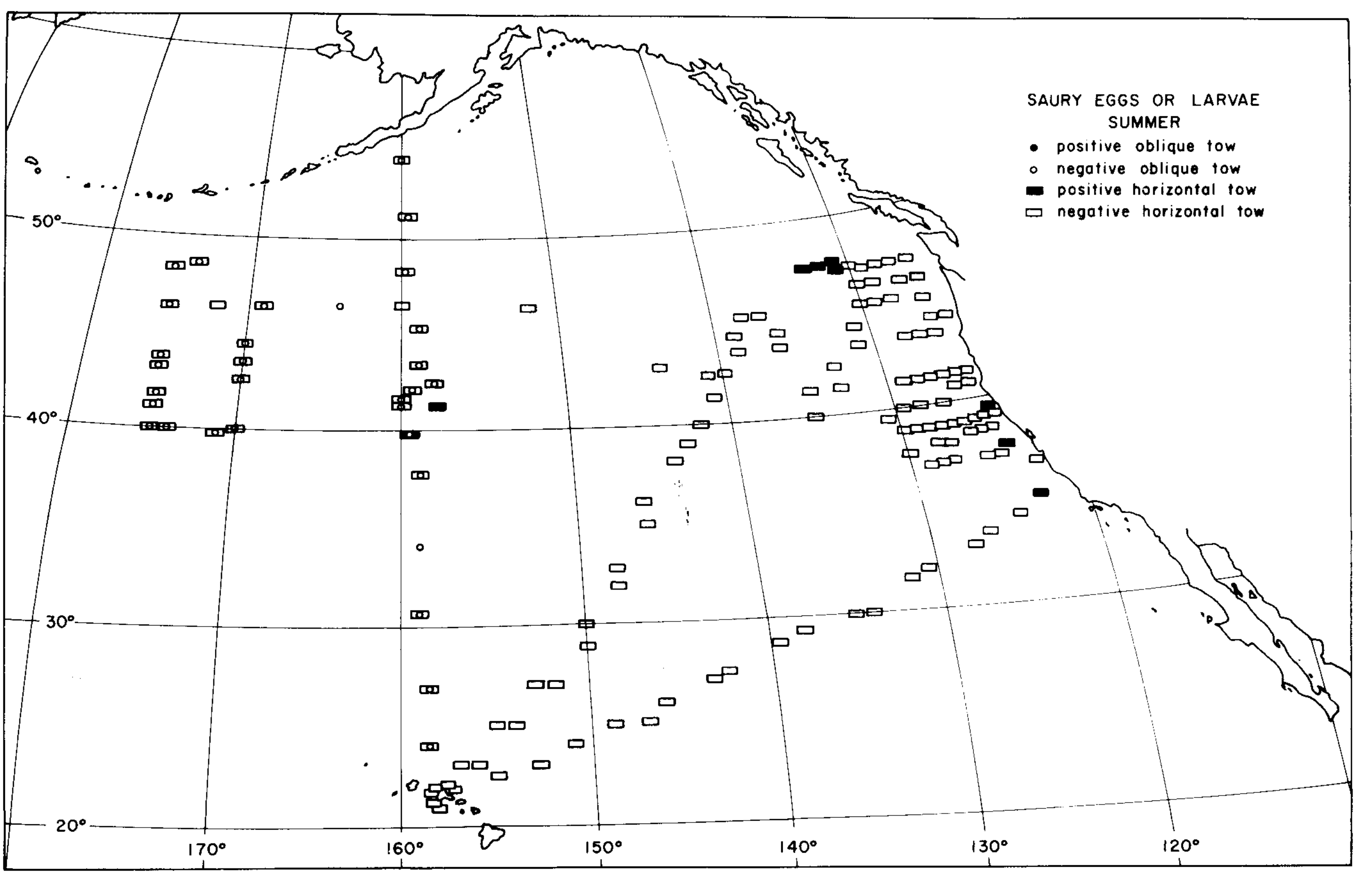
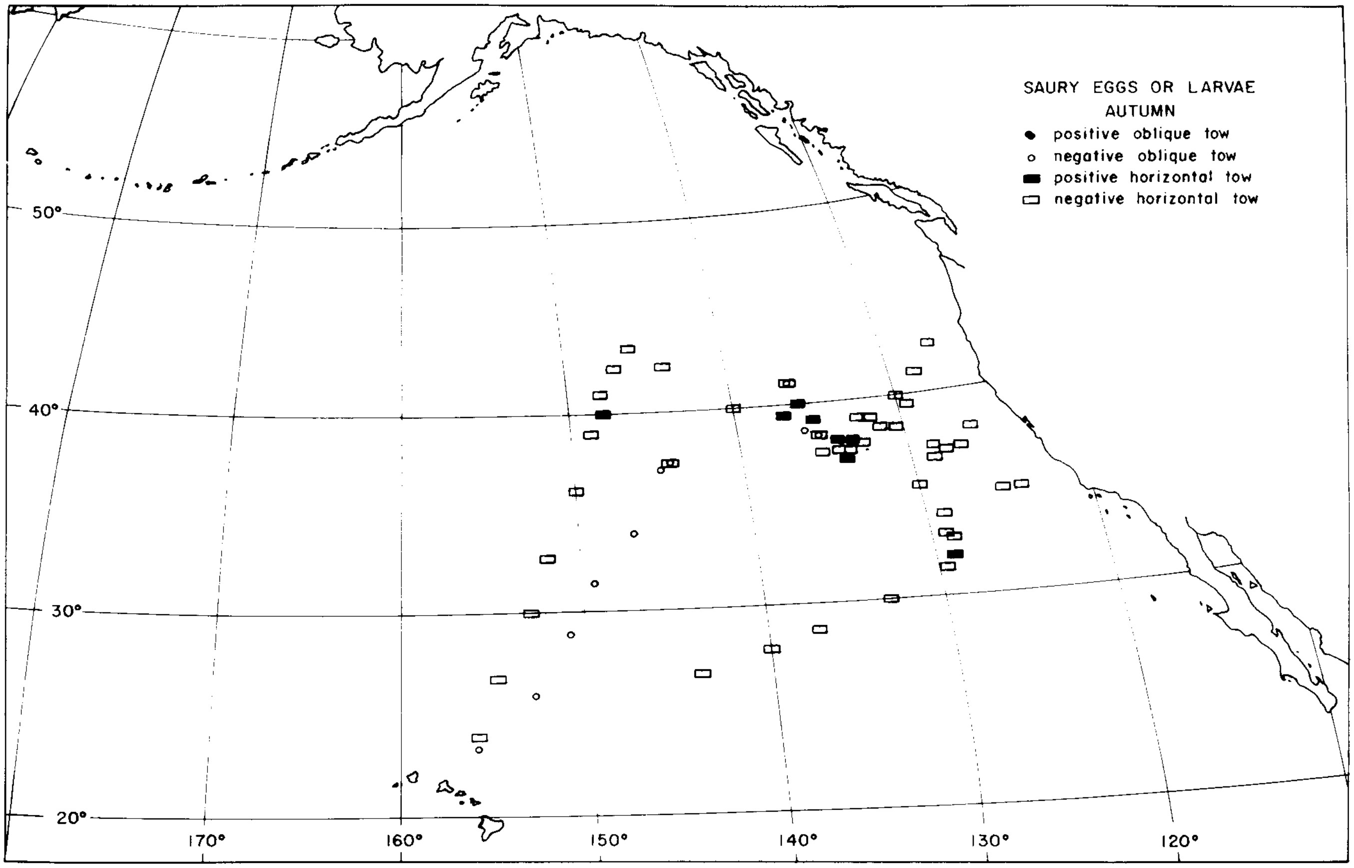


FIGURE 4. The incidence of saury eggs or larvae in samples taken by ships of the Honolulu Biological Laboratory of the Bureau of Commercial Fisheries, arranged by season: spring (a), summer (b), and autumn (c).





the same survey area. We find that the quantities and statistical treatment of them do little more than indicate trends and it is likely that summaries of that kind will be neither stable nor linear parametrically. Even if the quantities were both stable and the trends linear, the conditions of a commercial fishery are so different (Inoue, 1969) that the quantities derived from oceanographic night-light stations would not be applicable. Nevertheless, the seasons and positions at which the observations were made (Appendix II) may furnish information useful for exploratory fishing. Also, the importance of size in the commercial market makes it useful to separate some observations by size. Observations will be discussed by area, season, and seasonal changes in area.

Area

In this subsection we will separately discuss the north-south and the onshore-offshore distributions. Nearshore observations have been summarized by Eberhardt (1954) and the sea surveys of the California Department of Fish and Game have continued. These data reports are published and references to the series may be found in Heimann (1969).

The incidence of saury observations decreased strongly from north to south. Northern California appears strongly favorable for searching purposes and the area from the Mexican border to San Francisco are nearly identical. The incidence of sightings is slight below Guadalupe Island.

Observations within 40 miles of the coast appear to be somewhat less frequent than those in a band 40–120 miles offshore. This appears to be true of all sizes of saury. The large and medium sized saury are, if anything, somewhat nearer the coastline than the very smallest group.

Season

A summary of 3,485 night-light observations is presented in Table 10. It is interesting to note that the maximum likelihood of saury observations occurs in November which coincides with the height of the fishery in the western temperate Pacific. The minimum probability of night-light observations coincides with the maximum probability of sampling eggs.

The maximum likelihood of saury observations occurs at a time when the standing crop of zooplankton is lowest. The minimum likelihood of observation cooccurs with a period of zooplankton standing crop increase (see Lasker, 1970, page 279).

Even though these seasonal extremes coincide, the saury observation distribution is as ubiquitous as the spawning distribution, thus correlation with simple environmental parameters is difficult.

In one sample of 1,310 observations taken in 1954–55 saury were observed at 64% of the stations. The temperature range was from 9° to 26° C and the range of temperature with saury observations was from 10° to 22° C with a rather even maximum for all sizes of saury in temperature ranges from 13° to 17° C.

Saury observations seasonal maxima appear superficially to coincide with a period of rapid temperature change. One can see from monthly surface temperature isotherm graphs (Eber *et al.*, 1968) that the period from September to December is characterized by a vast southward movement of the 16° isotherm. An extreme example is furnished by September–December 1957 when the 16° isotherm coastal intercept moves from north of Pt. Arena in September to Pt. Vicente in December.

Summary—Availability

It appears likely that some saury will be available to any port in California at any season. However, examination of the biological observations shows that we used more information on the size of aggregations and individual sizes of fish in the aggregations to apply to commercial feasibility studies. It seems quite clear that a fishery which depends on attraction to lights would exclude the months March through June. Observations would indicate a maximum offshore 40 miles or more. The northern half of the CalCOFI grid (north of San Diego) is more likely to produce fishable concentrations of saury than the southern half. There is some indication that the area north of San Francisco would be more likely to yield fishable aggregations of saury.

There is some indication that frontal zone development is an important process in the aggregation of saury (Hatanaka, 1956b). Optimum fishing areas and seasons could be determined by spatial and temporal gradients of oceanic features.

DISCUSSION

We think that useful answers to the original questions can be based on the data presented here. What is the range of natural fluctuation in the abundance of Pacific saury in the California Current survey area?

The bimonthly averages of spawning biomass range from 141,700 metric tons in 1959 to 266,500 metric tons in 1953, over an 11-year period from 1951–60 and 1966. Since the Pacific saury spawns outside of the CalCOFI grid area one can expect some of the variability to reflect different proportions of the spawning taking place within the survey area.

What seasons and areas within the California Current area are the most likely for scouting for fishable saury concentrations?

The appropriate season for searching for fishable saury aggregations probably extends from September through December at which time water temperature is falling rapidly and zooplankton is at a minimum. The optimum area of search is north of San Diego to at least Cape Mendocino with an indication that search will be more productive north of San Francisco and offshore 40 miles or more.

TABLE 10

Saury night-light observations, 1952–1958

Month	Obs	Percent +	Percent 0	Percent ×	Percent R	Percent C	Percent A	Percent VA	Percent C+A+VA	Percent A+VA
January	326	33.4	66.6	14.1	8.6	5.5	3.4	1.8	10.7	5.2
February	326	38.0	62.0	10.7	13.5	8.6	3.1	2.1	13.8	5.2
March	317	37.5	62.5	12.6	15.8	6.9	1.6	0.6	9.1	2.2
April	477	24.3	75.7	12.4	8.4	3.1	0.0	0.4	3.5	0.4
May	445	25.8	74.2	8.7	8.1	7.2	1.8	0.0	9.0	1.8
June	364	30.8	69.2	12.1	7.4	7.7	2.2	1.4	11.3	3.6
July	343	37.3	62.7	9.3	8.7	10.6	6.1	2.6	19.3	8.7
August	135	41.5	58.5	15.6	11.1	9.6	3.7	1.5	14.8	5.2
September	131	32.1	67.9	16.8	5.3	5.3	1.5	3.2	10.0	4.7
October	273	27.8	72.2	8.8	4.8	6.6	5.9	1.7	14.2	7.6
November	151	66.9	33.1	27.2	17.2	12.6	6.6	3.3	22.5	9.9
December	197	42.6	57.4	16.8	7.0	13.7	4.6	0.5	18.8	5.1
Total	3485									

Obs = number of night observations recorded.
%+ = percent of night observations with sauries sighted.
%0 = percent of night observations without sighting of sauries.
%× = percent of night observations with sauries present, but not persistent under the lights.
%R = percent of night observations with 1 to 10 sauries persistent under the lights.
%C = percent of night observations with 11 to 100 sauries persistent under the lights.
%A = percent of night observations with 101 to 1,000 sauries persistent under the lights.
%VA = percent of night observations with more than 1,000 sauries persistent under the lights.

REFERENCES

Ahlstrom, Elbert H. 1966. Distribution and abundance of sardine and anchovy larvae in the California Current region off California and Baja California, 1951–64: a summary. *U.S. Fish Wildl. Serv., Spec. Sci. Rept. Fish.* (534) : 71 pp.

Ahlstrom, E. H., and H. D. Casey. 1956. Saury distribution and abundance. Pacific coast, 1950–55. *U.S. Fish Wildl. Serv., Spec. Sci. Rept. Fish.* (190) : 69 pp.

Eber, L. E., J. F. T. Saur, and O. E. Sette. 1968. Monthly mean charts, sea surface temperature north Pacific Ocean, 1947–1962. *U.S. Fish Wildl. Serv., Circ.* (258) : vi + 168 charts.

Eberhardt, Robert L. 1954. Observations of the saury seen near the California coast during 1950–52. *California Fish Game* 40(1) : 39–46.

Hatanaka, M. 1956a. Biological studies on the population of the saury, *Cololabis saira* Brevoort. Part I—Reproduction and Growth. *Tohoku J. Agr. Res.* 6(3) :

——. 1956b. Biological studies on the population of the saury. *Cololabis saira* Brevoort. Part II—Habits and Migrations. *Tohoku J. Agr.* Res. 6(4) :

Heimann, Richard F. G. 1969. California Fish and Game sea survey cruises, 1964. *Calif. Coop. Oceanic Fish. Invest., Data Rept.* (13) : 48 pp.

Inoue, Michael S., and Steven E. Hughes. MS. Detection, extraction, and processing technologies for Pacific saury resources. *Engineering Exp. Sta. Bull. 43, Oregon State Univ.*, Corvallis, Oregon. (In press.)

Lasker, Reuben. 1970. Utilization of zooplankton energy by a Pacific sardine population in the California Current. *Proc. Mar. Food Chain Symp., Denmark*, 1968. (In press.)

Snedecor, G. W., and W. G. Cochran. 1967. Statistical methods. *Iowa State Univ. Press, Ames, Iowa.* 593 pp.

Staff, Scripps Institution of Oceanography. Various dates. Oceanic Observations of the Pacific, Series (1938–1969). Uni. of Calif. Press.

Thrailkill, James R. 1969. Zooplankton volumes off the Pacific coast, 1960. *U.S. Fish Wildl. Serv., Spec. Sci. Rept. Fish.* (581) : 50 pp.

APPENDIX I

Saury Eggs—Numbers by Stations, 1956

Station	Cruise and month												Total
	5601 Jan.	5602 Feb.	5603 Mar.	5604 Apr.	5605 May	5606 June	5607 July	5608 Aug.	5609 Sept.	5610 Oct.	5611 Nov.	5612 Dec.	
40.80	--	--	--	--	0	14	--	--	--	--	--	--	14
.90	--	--	--	--	0	55	--	--	--	--	--	--	55
50.80	--	--	--	--	0	3	--	--	--	--	--	--	3
57.55	--	--	--	--	0	3	--	--	--	--	--	--	3
.65	--	--	--	--	0	7	--	--	--	--	--	--	7
60.57	--	--	--	0	--	3	--	--	--	--	--	--	3
.60	--	--	--	0	12	2	0	--	--	--	--	--	14
.80	--	--	--	0	0	10	0	--	--	--	--	--	10
67.55	--	--	--	0	0	6	0	--	--	--	--	--	6
.65	--	--	--	0	20	2	--	--	--	--	--	--	22
70.52	--	--	--	0	4	0	0	--	--	--	--	--	4
.55	--	--	--	0	0	10	0	--	--	--	--	--	10
.60	--	--	--	0	0	3	0	--	--	--	--	--	3
.90	--	--	--	0	0	4	0	--	--	--	--	--	4
73.70	--	--	--	0	0	10	0	--	--	--	--	--	10
77.60	--	--	--	--	21	0	0	--	--	--	--	--	21
.80	--	--	--	--	24	--	0	--	--	--	--	--	24
80.55	0	0	NS[1]	0	42	0	0	--	--	0	0	0	42
.60	0	0	0	0	12	0	0	--	--	47	0	0	59
.70	0	0	13	0	62	0	0	--	--	0	0	0	75
.80	0	0	7	4	0	0	0	--	--	0	0	0	11
.90	0	0	3	15	0	0	0	--	--	0	0	0	18
82.47	--	0	6	0	5	0	0	--	--	0	0	0	11
83.40	0	NS[1]	0	0	0	0	0	--	--	0	2	--	2
.51	0	0	0	3	64	0	0	--	--	0	0	0	67
.55	--	--	--	3	56	0	0	--	--	0	0	0	59
.60	0	3	0	0	25	0	0	--	--	0	0	0	28
.70	--	--	14	4	0	0	0	--	--	0	0	0	18
87.45	--	--	--	--	3	0	0	--	--	0	0	30	33
.50	0	0	0	3	0	0	0	--	--	0	0	0	3
.55	--	--	--	--	0	0	0	--	--	0	0	16	16
.60	0	6	3	0	2	0	0	--	--	0	0	0	11
.70	--	--	0	7	10	0	0	--	--	--	--	--	17
.75	--	--	--	--	4	--	3	--	--	--	--	--	7
.80	--	--	6	22	0	0	0	--	--	--	--	--	28
.90	--	--	3	6	0	--	0	--	--	--	--	--	9
90.30	0	0	38	0	3	0	0	--	--	0	0	0	41
.37	0	0	0	7	0	0	0	--	--	0	0	0	7
.45	0	0	0	50	0	0	0	--	--	9	0	0	59
.50	--	--	--	--	0	24	0	--	--	0	0	0	24
.55	0	0	0	9	0	0	0	--	--	0	0	0	9
.60	0	0	0	24	31	0	0	--	--	0	0	0	55
.70	0	0	0	7	0	0	0	--	--	0	--	0	7
.80	0	0	0	37	10	0	0	--	--	0	--	0	47
.90	--	--	0	0	32	0	0	--	--	0	--	0	32
93.30	0	0	0	0	33	7	2	--	--	0	0	0	42
.35	--	--	--	--	5	0	0	--	--	0	0	0	5
.40	0	11	3	37	0	0	0	--	--	0	0	0	51
.45	--	--	--	--	0	0	0	--	--	0	3	0	3
.50	0	19	0	16	4	0	0	--	--	0	0	0	39
.55	--	--	--	--	5	0	0	--	--	0	0	0	5
.60	--	3	0	0	0	0	0	--	--	0	0	0	3
.70	--	0	0	20	0	0	0	--	--	--	--	--	20
.75	--	--	--	--	7	0	0	--	--	--	--	--	7
.80	--	--	12	3	0	0	0	--	--	--	--	--	15
.90	--	--	6	0	0	0	0	--	--	--	--	--	6
97.40	0	0	0	11	3	10	0	--	--	0	0	0	24
.50	0	0	0	4	0	0	0	--	--	0	0	0	4
.60	--	3	15	57	13	0	0	--	--	0	0	0	88
.70	--	0	0	8	0	0	0	--	--	--	--	--	8
.80	--	--	3	0	0	0	0	--	--	--	--	--	3
100.33	--	0	0	19	--	0	--	--	--	--	--	--	19
.35	--	--	--	--	0	3	0	--	--	--	--	--	3
.40	0	8	3	0	0	8	0	--	--	--	--	--	19
.50	0	0	6	77	0	0	0	--	--	--	--	--	83
.60	0	3	16	7	6	6	0	--	--	--	--	--	38
.65	--	--	--	--	0	9	0	--	--	--	--	--	9
.70	24	0	22	0	0	--	0	--	--	--	--	--	46
.75	--	--	--	--	9	--	0	--	--	--	--	--	9
.80	0	0	9	0	0	--	0	--	--	--	--	--	9
.90	--	--	15	0	0	--	0	--	--	--	--	--	15
103.40	0	0	0	0	6	0	0	--	--	--	--	--	6
.45	--	--	--	--	3	--	0	--	--	--	--	--	3
.50	0	0	{12, 6}	0	0	--	0	--	--	--	--	--	{12, 6}
.60	0	0	0	7	3	--	0	--	--	--	--	--	10
.70	--	--	{12, 7}	0	0	--	0	--	--	--	--	--	{12, 7}

[1] NS—sample spoiled or spilled.

APPENDIX I—Continued

Saury Eggs—Numbers by Stations, 1956—Continued

Station	Cruise and month												Total
	5601 Jan.	5602 Feb.	5603 Mar.	5604 Apr.	5605 May	5606 June	5607 July	5608 Aug.	5609 Sept.	5610 Oct.	5611 Nov.	5612 Dec.	
.80	--	--	{3, 16}	0	0	--	0	--	--	--	--	--	{3, 16}
.90	--	--	3	0	0	--	0	--	--	--	--	--	3
.95	--	--	--	--	5	--	--	--	--	--	--	--	5
107.35	0	113	0	5	0	0	0	--	--	--	--	--	118
.40	0	3	0	7	0	0	0	--	--	--	--	--	10
.60	6	11	0	0	0	0	0	--	--	--	--	--	17
.80	--	--	0	4	0	0	0	--	--	--	--	--	4
110.33	0	2	0	0	0	32	0	0	0	--	--	--	34
.35	0	11	0	0	0	0	0	0	0	--	--	--	11
.40	3	84	0	0	0	0	0	0	0	--	--	--	87
.50	3	0	0	0	0	0	0	--	--	--	--	--	3
.70	4	9	6	0	0	0	0	--	--	--	--	--	19
.90	--	--	3	0	0	0	0	--	--	--	--	--	3
113.35	4	28	0	0	0	0	0	0	0	--	--	--	32
.40	41	12	0	2	28	0	0	0	0	--	--	--	83
.50	72	6	0	0	0	32	0	--	--	--	--	--	110
.60	25	3	0	0	0	0	0	--	--	--	--	--	28
.70	0	20	0	0	0	0	0	--	--	--	--	--	20
117.26	0	4	0	0	0	0	0	0	0	--	--	--	4
.30	0	0	24	0	0	0	0	0	0	--	--	--	24
.35	0	6	0	0	23	0	0	0	0	--	--	--	29
.40	0	0	0	0	0	7	0	0	0	--	--	--	7
.45	--	--	3	--	0	0	0	--	--	--	--	--	3
.50	10	0	0	20	0	0	0	--	--	--	--	--	30
.55	--	--	14	--	0	0	0	--	--	--	--	--	14
.60	0	0	0	7	0	0	0	--	--	--	--	--	7
118.39	0	0	16	NS[1]	0	0	0	--	--	--	--	--	16
119.33	9	15	0	5	0	0	0	--	--	--	--	--	29
120.25	0	0	0	11	0	0	0	0	0	--	--	--	11
.30	3	0	0	0	0	0	0	0	0	--	--	--	3
.40	0	0	0	2	0	0	0	0	0	--	--	--	2
.45	0	0	0	0	7	0	0	0	0	--	--	--	7
.50	9	0	0	0	0	0	0	--	--	--	--	--	9
.55	6	5	0	2	0	0	0	--	--	--	--	--	13
.60	0	13	0	0	0	0	0	--	--	--	--	--	13
.70	0	0	0	0	3	0	0	--	--	--	--	--	3
123.42	--	0	--	0	10	0	0	0	0	--	--	--	10
127.60	--	--	37	0	0	0	0	--	--	--	--	--	37
130.60	--	0	3	0	0	0	0	--	--	--	--	--	3
133.40	0	0	25	0	0	0	0	--	--	--	--	--	25
.50	--	--	22	--	0	0	0	--	--	--	--	--	22
Total	219	401	415	532	615	270	5	0	0	56	5	46	2,564
Occurrences	14	25	37	37	38	24	2	0	0	2	2	2	183

[1] NS—sample spoiled or spilled.

Saury Eggs—Numbers by Stations, 1957

Station	Cruise and month												Total
	5701 Jan.	5702 Feb.	5703 Mar.	5704 Apr.	5705 May	5706 June	5707 July	5708 Aug.	5709 Sept.	5710 Oct.	5711 Nov.	5712 Dec.	
60.55	--	--	--	--	15	0	0	--	--	--	--	--	15
.60	--	--	--	--	19	0	0	--	--	--	--	--	19
.70	--	--	--	--	9	11	0	--	--	--	--	--	20
.90	--	--	--	--	0	4	--	--	--	--	--	--	4
63.55	--	--	--	--	8	0	0	--	--	--	--	--	8
.60	--	--	--	--	13	0	0	--	--	--	--	--	13
.70	--	--	--	--	18	13	4	--	--	--	--	--	35
.80	--	--	--	--	8	0	0	--	--	--	--	--	8
67.55	--	--	--	--	21	0	0	--	--	--	--	--	21
.60	--	--	--	--	39	0	0	--	--	--	--	--	39
.80	--	--	--	--	4	0	0	--	--	--	--	--	4
70.52	--	--	--	--	7	0	0	--	--	--	--	--	7
.60	--	--	--	--	95	0	0	--	--	--	0	--	95
.90	--	--	--	--	7	0	--	--	--	--	--	--	7
73.60	--	--	--	--	18	0	0	--	--	--	0	--	18
77.55	--	--	--	--	75	0	0	--	--	--	--	--	75
.70	--	--	--	--	0	0	8	--	--	--	--	--	8

APPENDIX I—Continued

Saury Eggs—Numbers by Stations, 1957—Continued

Station	Cruise and month												Total
	5701 Jan.	5702 Feb.	5703 Mar.	5704 Apr.	5705 May	5706 June	5707 July	5708 Aug.	5709 Sept.	5710 Oct.	5711 Nov.	5712 Dec.	
80.51	--	0	0	0	0	25	21	--	--	0	--	0	46
.60	--	0	0	29	12	22	0	--	--	0	0	0	63
.70	--	0	0	26	29	0	0	--	--	0	0	0	55
.80	--	0	0	0	0	0	5	--	--	NS[1]	--	0	5
.90	--	233	0	12	0	6	0	--	--	0	--	0	251
83.51	--	0	--	5	0	0	0	--	--	0	0	--	5
.55	--	--	--	--	7	0	0	--	--	--	0	--	7
.60	--	14	0	82	9	14	0	--	--	0	0	--	119
.70	--	--	0	15	0	0	0	--	--	0	--	--	15
.80	--	--	--	0	9	0	0	--	--	0	--	--	9
87.50	--	0	0	28	0	0	0	--	--	0	0	--	28
.55	--	0	--	--	0	0	11	--	--	0	0	--	11
.60	--	0	0	72	0	0	5	--	--	0	0	--	77
.65	--	--	--	--	3	11	0	--	--	--	--	--	14
.70	--	0	0	136	46	0	0	--	--	0	--	--	182
.75	--	--	--	--	17	0	0	--	--	--	--	--	17
.85	--	--	--	--	3	0	0	--	--	--	--	--	3
.90	--	--	--	0	3	0	0	--	--	0	--	0	3
90.30	--	0	0	0	23	0	0	--	--	0	0	0	23
.37	--	0	0	0	10	0	0	--	--	0	0	0	10
.55	--	0	0	54	0	0	0	--	--	0	0	0	54
.60	--	0	0	3,794	0	0	0	--	--	0	0	0	3,794
.65	--	--	--	--	28	0	0	--	--	--	--	--	28
.70	--	0	0	122	16	3	0	--	--	0	--	0	141
.75	--	--	--	--	3	0	0	--	--	--	--	--	3
.80	--	0	0	0	3	0	0	--	--	0	--	0	3
.85	--	--	--	--	2	0	0	--	--	--	--	--	2
.90	--	0	0	20	30	0	0	--	--	0	--	0	50
93.27	--	0	0	0	9	0	0	--	--	0	0	--	9
.30	--	0	0	0	8	0	0	--	--	0	0	--	8
.35	--	--	--	0	2	6	0	--	--	0	0	--	8
.40	--	0	0	0	3	12	0	--	--	0	0	--	15
.45	--	--	--	0	3	22	0	--	--	--	0	--	25
.50	--	0	0	0	9	0	0	--	--	0	0	--	9
.55	--	--	--	5	6	0	0	--	--	--	0	--	11
.60	--	0	0	0	3	0	0	--	--	0	0	--	3
.70	--	0	0	0	3	0	0	--	--	0	--	--	3
.80	--	--	--	NS[1]	14	0	0	--	--	0	--	--	14
.90	--	--	--	6	0	0	0	--	--	0	--	--	6
97.32	--	0	--	0	10	0	0	--	--	0	0	0	10
97.40	--	0	0	0	16	0	2	--	--	0	0	--	18
.45	--	--	--	6	5	0	0	--	--	--	0	--	11
.50	--	0	0	NS[1]	9	0	0	--	--	0	0	--	9
.60	--	0	--	0	4	0	0	--	--	0	5	--	9
.80	--	--	--	0	4	6	0	--	--	0	--	--	10
.85	--	--	--	--	6	0	0	--	--	--	--	--	6
.90	--	--	--	31	2	0	0	--	--	0	--	--	33
100.33	--	0	0	21	0	0	0	--	--	--	--	--	21
.45	--	--	--	16	0	0	0	--	--	--	--	--	16
.50	--	0	0	9	0	0	0	--	--	0	--	--	9
.55	--	--	--	7	9	0	0	--	--	--	--	--	16
.60	0	0	0	19	0	0	0	--	--	0	--	--	19
.70	--	0	--	2	0	0	--	--	--	0	--	--	2
.90	--	0	--	5	0	0	--	--	--	0	--	--	5
103.35	0	0	0	19	0	0	0	--	--	0	--	--	19
.40	0	0	0	3	0	0	0	--	--	0	--	--	3
.45	--	--	--	18	3	0	0	--	--	--	--	--	21
.50	0	0	0	11	0	0	0	--	--	0	--	0	11
107.60	0	68	NS[1]	0	0	0	0	--	--	0	--	--	68
.70	--	0	0	0	0	6	0	--	--	0	--	--	6
.80	--	--	--	3	0	0	--	--	--	0	--	--	3
110.35	--	0	0	6	0	0	0	0	0	0	--	--	6
.40	0	0	0	7	0	0	0	0	0	0	--	--	7
.45	--	--	--	9	0	0	0	--	--	--	--	--	9
120.30	0	0	0	2	0	0	0	0	0	0	--	--	2
127.70	--	--	--	0	--	--	7	--	--	0	--	--	7
Total	0	315	0	4,600	737	161	63	0	0	0	5	0	5,881
Occurrences	0	3	0	33	53	14	8	0	0	0	1	0	112

[1] NS—sample spoiled or spilled.

APPENDIX I—Continued

Saury Eggs—Numbers by Stations, 1958

Station	Cruise and month												Total
	5801 Jan.	5802 Feb.	5803 Mar.	5804 Apr.	5805 May	5806 June	5807 July	5808 Aug.	5809 Sept.	5810 Oct.	5811 Nov.	5812 Dec.	
43.55	--	--	--	--	--	--	7	--	--	--	--	--	7
47.60	--	--	--	--	--	--	3	--	--	--	--	--	3
50.47	--	--	--	--	--	6	--	--	--	--	--	--	6
.50	--	--	--	--	--	13	--	--	--	--	--	--	13
.70	--	--	--	--	--	--	3	--	--	--	--	--	3
53.55	--	--	--	--	--	13	0	--	--	--	--	--	13
.60	--	--	--	--	--	6	0	--	--	--	--	--	6
57.55	--	--	--	--	--	3	0	--	--	--	--	--	3
60.55	0	--	--	7	3	3	0	--	--	0	--	--	13
.60	--	--	--	0	6	0	0	--	--	0	--	--	6
.65	--	--	--	8	--	--	0	--	--	--	--	--	8
60.70	--	--	--	0	0	3	0	--	--	0	--	--	3
.80	--	--	--	9	8	6	0	--	--	0	--	--	23
.90	--	--	--	10	0	0	0	--	--	0	--	--	10
63.52	0	--	--	0	10	0	0	--	--	0	--	--	10
.55	--	--	--	--	8	NS[1]	0	--	--	0	--	--	8
.60	0	--	--	--	12	12	0	--	--	0	--	--	24
.70	--	--	--	--	19	0	0	--	--	0	--	--	19
.80	--	--	--	--	0	9	0	--	--	0	--	--	9
.90	--	--	--	--	3	3	0	--	--	--	--	--	6
.110	--	--	--	3	--	--	--	--	--	--	--	--	3
67.50	--	--	--	0	3	3	0	--	--	0	--	--	6
.55	0	--	--	3	28	0	0	--	--	0	--	--	31
.60	0	--	--	22	22	12	0	--	--	0	--	--	56
.65	--	--	--	7	--	--	0	--	--	0	--	--	7
.70	--	--	--	0	0	12	0	--	--	0	--	--	12
.80	--	--	--	23	30	0	0	--	--	0	--	--	53
.90	--	--	--	4	32	3	0	--	--	--	--	--	39
70.52	--	--	0	5	18	12	0	--	--	--	--	--	35
.55	--	--	--	0	0	16	0	--	--	0	--	--	16
.60	--	--	0	7	26	12	0	--	--	0	--	--	45
.65	--	--	--	7	--	--	0	--	--	0	--	--	7
.70	0	--	3	7	22	12	0	--	--	0	--	--	44
.75	--	--	--	13	--	--	0	--	--	--	--	--	13
.80	0	--	0	17	17	0	0	--	--	0	--	--	34
.85	--	--	--	20	--	--	0	--	--	--	--	--	20
.90	0	--	0	12	5	3	0	--	--	0	--	--	20
.110	--	--	--	4	--	--	--	--	--	--	--	--	4
73.51	--	--	--	0	5	0	0	--	--	0	--	--	5
.55	0	--	0	19	41	40	0	--	--	0	--	--	100
.60	0	--	--	0	24	17	0	--	--	0	--	--	41
.65	--	--	--	10	--	--	0	--	--	0	--	--	10
.70	--	--	--	25	24	12	0	--	--	0	--	--	61
.75	--	--	--	8	--	--	0	--	--	--	--	--	8
.80	--	--	--	30	12	6	0	--	--	0	--	--	48
.85	--	--	--	6	--	--	--	--	--	--	--	--	6
.90	--	--	0	17	6	0	--	--	--	0	--	--	23
77.50	--	--	--	3	6	0	0	--	--	0	--	--	9
.60	0	--	0	0	32	3	0	--	--	0	--	--	35
.65	--	--	--	5	--	--	8	--	--	--	--	--	13
.70	--	--	--	0	3	6	0	--	--	0	--	--	9
.75	--	--	--	9	--	--	0	--	--	--	--	--	9
.80	--	--	--	6	5	0	0	--	--	0	--	--	11
.90	--	--	0	3	0	0	0	--	--	0	--	--	3
80.55	0	0	0	0	3	0	0	--	--	0	0	0	3
.60	0	0	0	9	4	0	0	--	--	0	0	0	13
.65	--	--	--	16	--	--	0	--	--	--	--	--	16
.70	0	0	0	12	15	0	0	--	--	0	--	0	27
.75	--	--	--	9	--	--	0	--	--	--	--	--	9
.80	0	0	0	0	3	3	0	--	--	0	--	0	6
.85	--	--	--	3	--	--	0	--	--	--	--	--	3
.90	--	5	0	3	12	3	0	--	--	0	--	--	23
.120	--	--	--	8	--	--	--	--	--	--	--	--	8
83.51	0	0	0	21	0	3	0	--	--	0	0	0	24
.55	0	--	0	11	0	44	0	--	--	0	NS[1]	0	55
.60	0	--	0	26	34	20	0	--	--	0	0	0	80
.65	--	--	--	3	72	0	0	--	--	--	--	--	75
.70	0	--	0	7	27	0	0	--	--	0	--	--	34
83.75	--	--	--	4	8	6	0	--	--	--	--	--	18
.80	--	--	0	0	3	3	0	--	--	0	--	--	6
.85	--	--	--	--	3	6	0	--	--	--	--	--	9
.90	--	--	--	--	3	6	0	--	--	0	--	--	9
87.55	0	--	0	0	29	64	0	--	--	0	NS[1]	0	93
.60	0	--	0	0	0	0	3	--	--	0	0	0	3
.65	--	--	--	3	3	0	0	--	--	--	--	--	6
.75	--	--	--	0	3	0	0	--	--	--	--	--	3
.80	0	--	0	3	6	7	0	--	--	0	--	--	16
.85	--	--	--	--	8	0	0	--	--	--	--	--	8
.90	--	--	--	--	12	0	0	--	--	0	--	--	12

[1] NS—sample spoiled or spilled.

APPENDIX I—Continued

Saury Eggs—Numbers by Stations, 1958—Continued

Station	Cruise and month												Total
	5801 Jan.	5802 Feb.	5803 Mar.	5804 Apr.	5805 May	5806 June	5807 July	5808 Aug.	5809 Sept.	5810 Oct.	5811 Nov.	5812 Dec.	
90.37	--	NS[1]	0	0	3	0	0	--	0	0	0	0	3
.45	--	0	0	0	6	18	0	--	0	0	0	0	24
.50	--	0	0	--	8	6	0	--	0	0	0	0	14
.55	--	0	0	35	50	6	0	--	0	0	0	0	91
.60	--	0	0	0	28	0	0	--	0	0	0	0	28
.65	--	--	--	0	18	3	0	--	0	--	--	--	21
.70	--	0	0	0	13	0	NS[1]	--	0	0	0	0	13
.75	--	--	--	2	7	0	0	--	--	--	--	--	9
.80	0	13	0	NS[1]	6	0	0	--	--	0	0	0	19
.85	--	--	--	4	3	0	0	--	--	--	--	--	7
.90	0	7	0	6	7	0	0	--	--	0	--	--	20
93.35	--	0	0	12	0	0	0	--	0	0	0	0	12
.45	--	0	0	NS[1]	0	3,377	0	--	0	0	--	--	3,377
.50	0	0	0	0	21	58	0	--	0	0	0	0	79
.55	--	--	--	0	22	3	3	--	0	0	--	--	28
.60	0	0	0	3	0	0	0	--	0	0	0	0	3
.65	--	--	--	0	0	3	0	--	0	--	--	--	3
.70	0	NS[1]	10	3	0	0	0	--	0	0	0	0	13
.80	7	0	0	0	6	0	0	--	--	0	0	0	13
.85	--	--	--	--	6	0	0	--	--	--	--	--	6
.145	--	--	--	3	--	--	--	--	--	--	--	--	3
97.30	0	2	0	0	0	2	0	--	--	0	0	0	4
.32	0	10	0	0	0	--	0	--	--	0	0	0	10
.35	--	--	--	0	0	9	0	--	--	0	0	0	9
.40	0	0	0	3	3	0	0	--	--	0	0	0	6
.45	--	0	0	0	0	3	0	--	--	0	--	--	3
.55	--	--	--	0	6	3	0	--	--	0	--	--	9
.65	--	--	--	6	0	0	0	--	--	--	--	--	6
.70	0	0	0	3	3	0	0	--	--	0	--	--	6
.75	--	--	--	10	0	0	0	--	--	--	--	--	10
.80	0	6	0	0	2	0	0	--	--	0	--	--	8
100.40	0	0	0	0	0	17	0	--	--	0	0	0	17
.55	--	--	--	0	0	3	0	--	--	0	--	--	3
.60	0	0	0	9	3	0	0	--	--	--	0	0	12
.65	--	--	--	51	0	0	0	--	--	--	--	--	51
.70	0	0	0	6	0	0	0	--	--	0	--	--	6
.75	--	--	--	3	0	0	0	--	--	--	--	--	3
.85	--	--	--	3	0	0	0	--	--	--	--	--	3
.90	0	3	0	0	0	0	0	--	--	0	--	--	3
103.50	0	0	0	0	0	0	11	--	--	0	--	--	11
107.40	0	3	0	0	0	0	0	--	--	0	--	--	3
.50	0	0	4	0	4	0	0	--	--	0	--	--	8
.85	--	--	--	0	6	--	0	--	--	--	--	--	6
110.45	--	--	0	14	0	6	0	--	--	0	--	--	20
.60	0	0	3	6	0	0	0	--	--	0	--	--	9
113.40	0	0	0	0	0	3	NS[1]	0	0	0	--	--	3
113.55	--	--	--	11	0	0	0	--	--	0	--	--	11
.60	0	0	0	7	0	0	0	--	--	0	--	--	7
117.40	0	0	0	4	0	0	0	0	0	0	--	--	4
120.25	--	0	0	0	0	116	0	0	0	0	--	--	116
123.50	0	0	0	0	0	3	0	--	--	0	--	--	3
Total	7	49	20	671	909	4,050	38	0	0	0	0	0	5,744
Occurrences	1	8	4	68	68	55	7	0	0	0	0	0	211

[1] NS—sample spoiled or spilled.

Saury Eggs—Numbers by Stations, 1959

Station	Cruise and month												Total
	5901 Jan.	5902 Feb.	5903 Mar.	5904 Apr.	5905 May	5906 June	5907 July	5908 Aug.	5909 Sept.	5910 Oct.	5911 Nov.	5912 Dec.	
43.50	--	--	--	--	--	--	--	--	--	5	--	--	5
50.70	--	--	--	--	--	--	--	--	--	3	--	--	3
60.52	3	--	--	--	0	--	0	--	--	0	--	--	3
.60	0	--	--	12	0	--	3	--	--	0	--	--	15
.65	--	--	--	27	0	--	0	--	--	--	--	--	27
.75	--	--	--	--	17	--	0	--	--	--	--	--	17
.80	0	--	--	5	5	--	0	--	--	0	--	--	10
.90	0	--	--	7	3	--	0	--	--	0	--	--	10

APPENDIX I—Continued

Saury Eggs—Numbers by Stations, 1959—Continued

Station	Cruise and month												Total
	5901 Jan.	5902 Feb.	5903 Mar.	5904 Apr.	5905 May	5906 June	5907 July	5908 Aug.	5909 Sept.	5910 Oct.	5911 Nov.	5912 Dec.	
63.55	0	--	--	3	0	--	4	--	--	0	--	--	7
.60	0	--	--	7	0	--	17	--	--	0	--	--	24
.65	--	--	--	--	23	--	0	--	--	--	--	--	23
.70	0	--	--	--	24	--	0	--	--	0	--	--	24
.80	--	--	--	--	6	--	0	--	--	0	--	--	6
.85	--	--	--	--	0	--	7	--	--	--	--	--	7
.90	0	--	--	6	0	--	0	--	--	0	--	--	6
67.50	0	--	--	0	6	--	0	--	--	0	--	--	6
.55	0	--	--	0	0	--	22	--	--	0	--	--	22
.60	0	--	--	0	0	--	3	--	--	0	--	--	3
.70	3	--	--	--	0	--	10	--	--	0	--	--	13
.80	--	--	--	--	6	--	0	--	--	0	--	--	6
70.55	0	--	--	0	9	--	0	--	--	0	--	--	9
.60	0	--	--	15	3	--	0	--	--	0	--	--	18
.70	8	--	--	5	--	--	0	--	--	0	--	--	13
.75	--	--	--	--	8	--	0	--	--	--	--	--	8
.80	0	--	--	5	20	--	0	--	--	0	--	--	25
.85	--	--	--	--	4	--	0	--	--	--	--	--	4
73.51	3	0	--	0	0	--	0	--	--	0	--	--	3
.55	0	0	--	0	8	--	0	--	--	0	--	--	8
.60	3	0	--	3	6	--	0	--	--	0	--	--	12
.65	--	--	--	20	3	--	0	--	--	--	--	--	23
.70	0	0	--	0	27	--	0	--	--	0	--	--	27
.75	--	--	--	--	3	--	0	--	--	--	--	--	3
.80	--	--	--	12	0	--	0	--	--	0	--	--	12
.90	--	--	--	6	18	--	0	--	--	0	--	--	24
77.55	0	0	--	3	--	0	0	0	--	0	0	0	3
.60	0	0	--	3	3	3	0	0	--	0	0	0	9
.65	--	--	--	0	3	7	0	--	--	--	--	--	10
.70	0	0	--	3	0	17	0	--	--	0	0	0	20
.75	--	--	--	--	6	--	9	--	--	--	--	--	15
.80	--	--	--	9	6	0	0	--	--	0	--	--	15
.85	--	--	--	--	14	19	0	--	--	--	--	--	33
.90	--	--	--	3	6	0	0	--	--	0	--	--	9
80.55	0	0	--	0	0	0	0	0	--	3	0	53	56
.60	0	0	--	0	3	0	0	0	--	0	0	0	3
.65	--	--	--	0	5	3	0	NS[1]	--	--	--	--	8
.70	0	0	--	3	14	0	0	0	--	0	0	0	17
.75	--	--	--	0	14	0	11	0	--	--	--	--	25
.80	0	0	--	3	16	7	0	0	--	0	--	--	26
.100	--	--	--	--	9	--	--	--	--	--	--	--	9
.110	--	--	--	--	6	--	--	--	--	--	--	--	6
83.40	0	0	0	0	2	0	0	0	--	2	0	0	4
.51	0	0	NS[1]	3	0	0	0	0	--	0	0	0	3
.55	0	0	--	3	3	3	0	0	--	2	0	0	11
.60	0	0	--	0	3	3	0	0	--	7	0	0	13
.65	--	--	--	0	6	6	0	0	--	--	--	--	12
.70	0	0	--	6	3	0	0	0	--	2	--	--	11
.75	--	--	--	3	3	0	0	NS[1]	--	--	--	--	6
.80	0	0	--	0	7	3	0	9	--	0	--	--	19
.85	--	--	--	0	0	9	0	NS[1]	--	--	--	--	9
.90	0	0	--	6	21	0	0	0	--	0	--	--	27
87.50	0	0	0	0	0	0	0	0	--	0	0	5	5
.55	0	0	--	0	3	0	0	0	--	0	0	0	3
.60	0	0	--	3	3	0	0	0	--	0	0	0	6
.65	--	--	--	0	3	0	6	8	--	--	--	--	17
.70	0	0	--	3	10	3	0	0	--	0	--	--	16
.75	--	--	--	0	0	11	NS[1]	0	--	--	--	--	11
.80	0	0	--	0	0	0	0	3	--	0	--	--	3
.90	0	0	--	0	0	6	0	0	--	0	--	--	6
90.50	0	0	0	0	0	11	NS[1]	0	0	0	0	0	11
.55	0	0	0	0	0	12	0	0	0	0	0	0	12
.60	0	0	0	0	0	2	0	0	0	0	0	0	2
.65	--	--	0	NS[1]	0	20	0	0	0	--	--	--	20
.70	0	0	0	0	0	16	0	0	0	0	0	3	19
.75	--	--	--	0	15	6	0	0	0	--	--	--	21
.90	6	0	0	0	0	--	0	0	0	0	--	0	6
93.50	0	0	0	0	0	3	0	0	0	0	0	0	3
.70	0	NS[1]	0	0	3	0	0	0	0	0	9	0	12
.75	--	--	--	0	0	14	0	0	0	--	--	--	14
.80	0	3	0	0	0	0	0	0	0	0	0	3	6
97.32	0	0	0	0	0	0	0	0	--	3	--	--	3
.35	0	0	0	0	8	0	0	0	--	0	--	--	8
.55	0	0	0	NS[1]	9	6	NS[1]	0	--	0	--	--	15
.65	--	--	--	0	0	0	0	6	--	--	--	--	6
.70	0	0	--	0	3	0	0	0	--	0	--	--	3
.75	--	--	--	0	0	0	3	0	--	--	--	--	3
.85	--	--	--	0	6	0	0	3	--	--	--	--	9
.90	2	0	--	0	0	0	0	0	--	0	--	--	2

[1] NS—sample spoiled or spilled.

APPENDIX I—Continued

Saury Eggs—Numbers by Stations, 1959—Continued

Station	Cruise and month												Total
	5901 Jan.	5902 Feb.	5903 Mar.	5904 Apr.	5905 May	5906 June	5907 July	5908 Aug.	5909 Sept.	5910 Oct.	5911 Nov.	5912 Dec.	
100.35	0	0	0	0	3	0	0	0	--	0	--	--	3
.40	NS[1]	0	0	0	3	0	0	0	--	0	--	--	3
.45	0	0	0	0	3	0	0	0	--	0	--	--	3
.50	0	0	0	0	6	0	0	0	--	0	--	--	6
.70	0	5	--	0	0	0	0	0	--	0	--	--	5
100.90	0	0	--	0	3	0	0	0	--	0	--	--	3
103.40	6	0	0	0	0	0	0	0	--	0	--	--	6
.45	0	0	0	0	59	3	0	0	--	0	--	--	62
.50	0	0	0	0	0	3	0	0	--	0	--	--	3
.60	0	0	3	0	0	0	0	0	--	0	--	--	3
.70	0	0	0	0	0	0	0	3	--	0	--	--	3
.85	--	--	--	0	0	0	0	3	--	--	--	--	3
107.32	0	0	0	0	0	6	0	0	--	0	--	--	6
.40	0	2	0	0	0	0	0	0	--	0	--	--	2
.45	0	2	0	0	0	0	0	0	--	0	--	--	2
.50	0	0	0	0	0	0	5	0	--	6	--	--	11
.70	6	NS[1]	0	0	0	0	0	0	--	0	--	--	6
110.40	0	0	0	0	0	0	3	0	0	0	--	--	3
.45	0	0	0	0	0	6	0	0	--	0	--	--	6
.50	0	3	0	0	0	0	0	0	--	0	--	--	3
113.30	0	0	0	5	0	0	NS[1]	0	0	0	--	--	5
117.40	0	0	36	0	0	0	0	0	0	0	--	--	36
120.60	0	0	0	0	19	0	0	0	--	0	--	--	19
137.30	0	0	0	0	0	0	2	NS[1]	0	0	--	--	2
.45	0	0	0	0	0	0	6	0	--	0	--	--	6
.75	--	--	--	--	--	--	3	--	--	--	--	--	3
Total	40	15	39	192	511	208	114	35	0	33	9	64	1,260
Occurrences	9	5	2	29	57	27	16	7	0	9	1	4	166

[1] NS—sample spoiled or spilled.

Saury Eggs—Numbers by Stations, 1960

Station	Cruise and month												Total
	6001 Jan.	6002 Feb.	6003 Mar.	6004 Apr.	6005 May	6006 June	6007 July	6008 Aug.	6009 Sept.	6010 Oct.	6011 Nov.	6012 Dec.	
40.60	0	--	--	3	--	--	--	--	--	--	--	--	3
47.100	5	--	--	--	--	--	--	--	--	--	--	--	5
50.70	0	--	--	3	--	--	--	--	--	--	--	--	3
.80	0	--	--	7	--	--	--	--	--	--	--	--	7
.90	0	--	--	2	--	--	--	--	--	--	--	--	2
53.60	0	--	--	3	--	--	--	--	--	--	--	--	3
.70	0	--	--	2	--	--	--	--	--	--	--	--	2
60.55	0	--	--	4	--	--	0	--	--	0	--	--	4
.60	0	--	--	4	--	--	0	--	--	0	--	--	4
.80	0	--	--	10	--	--	0	--	--	0	--	--	10
.90	0	--	--	0	--	--	3	--	--	0	--	--	3
.100	0	--	--	--	--	--	0	--	--	6	--	--	6
63.70	0	--	--	6	--	--	--	--	--	--	--	--	6
.80	0	--	--	10	--	--	--	--	--	--	--	--	10
.90	--	--	--	5	--	--	--	--	--	--	--	--	5
67.80	0	--	--	5	--	--	--	--	--	--	--	--	5
70.70	0	--	--	5	--	--	0	--	--	0	--	--	5
.90	0	--	--	5	--	--	0	--	--	0	--	--	5
73.51	0	3	0	0	0	0	--	--	--	0	--	--	3
.53	0	18	--	--	--	--	--	--	--	--	--	--	18
.55	0	26	0	0	0	0	--	--	--	0	--	--	26
.60	0	0	2	2	0	0	--	--	--	0	--	--	4
.70	0	0	3	0	--	--	--	--	--	--	--	--	3
.80	0	--	--	2	--	--	--	--	--	--	--	--	2
77.60	0	11	7	0	--	0	--	--	--	0	--	--	18
.75	--	--	--	12	--	--	--	--	--	--	--	--	12
.90	--	--	--	5	--	--	--	--	--	--	--	--	5
80.57	2	0	--	--	--	--	--	--	--	--	--	--	2
.60	0	0	2	2	--	0	0	--	--	0	--	--	4
.65	--	--	--	10	--	0	0	--	--	0	--	--	10
.75	--	--	--	7	--	0	--	--	--	--	--	--	7
.85	--	--	--	4	--	0	--	--	--	--	--	--	4
.90	2	0	0	3	--	3	0	--	--	0	--	--	8

APPENDIX I—Continued

Saury Eggs—Numbers by Stations, 1960—Continued

Station	Cruise and month												Total
	6001 Jan.	6002 Feb.	6003 Mar.	6004 Apr.	6005 May	6006 June	6007 July	6008 Aug.	6009 Sept.	6010 Oct.	6011 Nov.	6012 Dec.	
82.47	0	0	0	2	0	0	0	--	--	0	--	--	2
83.60	2	0	0	0	0	0	0	--	--	0	--	--	2
.70	0	0	0	97	--	0	0	--	--	--	--	--	97
87.40	53	0	0	0	0	0	0	0	--	0	--	--	53
.45	54	0	0	3	0	0	0	0	--	0	--	--	57
.50	17	0	0	0	0	0	0	0	--	0	--	--	17
.60	0	0	0	4	0	0	0	--	--	0	--	--	4
.75	--	--	--	0	--	3	--	--	--	--	--	--	3
.85	--	--	--	2	--	0	--	--	--	--	--	--	2
.90	0	0	--	2	--	0	--	--	--	--	--	--	2
90.50	0	0	2	0	0	0	--	--	--	--	--	--	2
.60	0	0	0	3	0	0	0	0	--	0	--	--	3
.65	--	--	--	341	0	0	0	--	--	0	--	--	341
.70	0	11	3	57	0	0	0	0	--	0	--	--	71
.80	0	6	0	0	0	0	0	0	--	0	--	--	6
.85	--	--	--	3	0	0	--	--	--	--	--	--	3
.90	0	0	0	7	0	0	0	0	--	0	--	--	7
.95	--	--	--	5	0	0	--	--	--	--	--	--	5
.100	0	0	2	5	0	0	0	--	--	0	--	--	7
93.28	0	0	0	0	0	0	0	31	--	0	--	--	31
.40	0	0	2	0	0	0	0	0	--	0	--	--	2
.45	0	0	3	0	0	0	0	--	--	0	--	--	3
.50	5	0	0	3	0	0	0	0	--	0	--	--	8
.60	14	11	0	0	0	0	0	0	--	0	--	--	25
.70	3	0	5	0	12	0	0	0	--	0	--	--	20
.75	--	--	--	3	0	0	--	--	--	--	--	--	3
.80	0	0	0	7	0	0	0	3	--	0	--	--	10
.85	--	--	--	12	0	0	--	--	--	--	--	--	12
.100	--	2	0	0	0	0	0	0	--	0	--	--	2
97.32	3	0	0	6	0	0	0	0	--	0	--	--	9
.35	2	0	0	0	9	0	0	0	--	0	--	--	11
.40	17	6	2	0	0	0	0	10	--	0	--	--	35
.50	3	0	0	0	6	0	0	--	--	0	--	--	9
.60	3	3	13	0	0	0	0	--	--	--	--	--	19
.70	11	0	3	0	--	0	0	--	--	--	--	--	14
.90	0	3	0	0	--	0	--	--	--	--	--	--	3
100.29	3	0	0	2	--	0	--	0	--	--	--	--	5
.35	0	0	6	0	--	0	0	0	--	0	--	--	6
.50	4	3	0	2	--	0	0	--	--	0	--	--	9
.55	9	3	0	0	--	0	0	--	--	0	--	--	12
.60	3	0	0	0	--	0	0	--	--	0	--	--	3
.70	0	0	0	20	--	0	0	--	--	0	--	--	20
100.75	--	--	--	6	--	0	--	--	--	--	--	--	6
.85	--	--	--	5	--	0	--	--	--	--	--	--	5
.90	0	13	0	0	--	0	0	--	--	0	--	--	13
103.35	0	0	0	$\begin{Bmatrix}6\\3\end{Bmatrix}$	0	--	0	0	0	0	--	--	$\begin{Bmatrix}6\\3\end{Bmatrix}$
.40	0	2	0	3	0	0	0	0	0	0	--	--	5
.45	3	4	0	0	0	0	0	--	--	--	--	--	7
.50	3	4	0	0	0	0	0	--	--	--	--	--	7
.60	3	2	3	0	0	0	0	--	--	--	--	--	8
.80	3	0	3	0	0	0	0	--	--	--	--	--	6
.90	0	--	--	2	--	--	--	--	--	--	--	--	2
107.32	3	0	0	3	0	0	0	0	0	0	--	--	6
.45	24	2	3	0	0	0	0	--	--	--	--	--	29
.50	0	2	0	0	3	0	0	--	--	--	--	--	5
.55	0	0	3	0	0	0	0	--	--	--	--	--	3
.80	0	0	3	0	0	0	0	--	--	--	--	--	3
110.55	3	0	0	0	0	0	0	--	--	0	--	--	3
.60	0	0	3	0	0	3	0	--	--	0	--	--	6
.80	0	0	0	3	0	0	0	--	--	0	--	--	3
113.85	--	--	--	6	--	--	--	--	--	--	--	--	6
117.35	0	0	0	0	0	0	0	6	0	436	--	--	442
.70	0	0	5	0	0	0	0	--	--	--	--	--	5
120.55	0	0	0	3	0	0	0	--	--	0	--	--	3
123.55	0	0	3	0	0	0	0	--	--	--	--	--	3
.60	0	0	3	0	0	0	0	--	--	--	--	--	3
.65	--	--	--	2	--	--	--	--	--	--	--	--	2
127.50	12	0	0	0	0	0	0	--	--	0	--	--	12
.55	33	0	0	0	0	0	0	--	--	--	--	--	33
.70	6	--	--	0	--	--	--	--	--	--	--	--	6
133.55	8	--	--	0	--	--	0	--	--	--	--	--	8
143.40	3	--	--	0	--	--	--	--	--	--	--	--	3
Total	319	135	84	748	30	9	3	50	0	442	--	--	1,820
Occurrences	32	20	23	56	4	3	1	4	0	2	--	--	145

APPENDIX I—Continued

Saury Eggs—Numbers by Stations, 1961–62

Station	Cruise and month, 1961					Cruise and month, 1962				
	6101–02 Jan.-Feb.	6104–05 Apr.-May	6107 July	6110–11 Oct.-Nov.	Total	6201–02 Jan.-Feb.	6203–04 Mar.-Apr.	6207–08 July-Aug.	6210–11 Oct.-Nov.	Total
70.70	0	0	0	0	0	0	2	--	0	2
.90	0	0	0	0	0	0	8	--	0	8
.120	0	3	0	0	3	0	0	--	--	0
.200	0	6	0	3	9	0	3	--	0	3
77.55	0	0	0	0	0	0	11	--	0	11
80.55	3	0	0	0	3	0	0	--	0	0
.65	13	6	0	0	19	0	0	--	0	0
.70	5	3	0	0	8	0	0	0	0	0
.80	0	0	0	0	0	18	0	0	0	18
.100	0	4	0	3	7	0	0	0	0	0
.120	0	4	0	0	4	0	0	0	0	0
.200	17	0	0	0	17	0	0	0	0	0
82.47	0	0	0	5	5	0	0	0	0	0
83.60	0	8	0	0	8	0	0	0	0	0
.65	3	0	0	0	3	0	3	0	0	3
.80	0	3	0	0	3	0	3	0	0	3
87.55	3	0	9	0	12	0	0	0	0	0
.60	0	6	0	0	6	0	0	0	0	0
.65	0	0	0	0	0	0	0	0	2	2
.80	3	0	0	0	3	0	3	0	11	14
.90	--	0	0	0	0	0	0	0	10	10
90.28	0	0	2	0	2	0	0	0	0	0
.37	0	0	20	0	20	0	0	--	0	0
.45	0	0	113	0	113	0	0	--	8	8
.53	0	0	0	0	0	0	0	--	14	14
.60	0	0	0	0	0	2	0	0	0	2
.65	3	0	0	0	3	77	0	--	0	77
.80	0	6	0	0	6	0	0	0	0	0
.90	0	0	0	0	0	0	6	0	0	6
.100	0	25	0	0	25	0	0	0	6	6
.120	0	0	0	0	0	0	6	0	0	6
.140	0	0	0	0	0	0	3	0	0	3
.160	0	2	0	0	2	0	0	0	0	0
93.40	0	0	11	0	11	0	0	0	0	0
.50	3	4	0	0	7	0	0	5	0	5
.55	0	7	0	0	7	0	0	0	0	0
.60	6	3	0	0	9	0	0	0	0	0
.65	0	9	0	0	9	0	0	0	0	0
.70	0	0	0	0	0	0	6	0	0	6
.80	6	10	0	0	16	0	0	0	0	0
.100	6	3	0	0	9	0	0	0	0	0
97.35	0	6	0	0	6	6	0	0	0	6
.45	0	3	0	0	3	0	0	0	0	0
.50	0	3	0	0	3	0	0	0	0	0
.55	NS[1]	9	0	0	9	0	0	3	0	3
.65	0	3	0	0	3	0	9	0	0	9
.90	--	4	0	0	4	0	0	0	0	0
100.45	0	0	0	0	0	0	0	0	41	41
.60	0	10	0	0	10	0	0	0	0	0
.65	0	3	0	0	3	0	3	0	0	3
.70	0	10	0	0	10	3	0	0	0	3
.80	0	4	0	0	4	0	0	0	0	0
.100	3	0	0	0	3	8	0	--	0	8
103.30	0	2	0	0	2	0	0	0	0	0
103.35	0	0	0	0	0	0	12	0	0	12
.40	0	3	0	0	3	0	6	0	0	6
.50	0	3	0	0	3	3	3	0	0	6
.60	0	3	0	0	3	0	3	0	0	3
.70	0	0	0	9	9	0	0	0	0	0
.80	0	11	0	0	11	0	0	0	0	0
.90	--	0	0	8	8	0	--	0	0	0
107.32	0	0	0	0	0	6	0	0	0	6
.35	0	6	0	0	6	0	0	0	0	0
.40	0	3	0	0	3	0	6	0	p	6
.45	0	5	0	0	5	0	6	0	0	6
.50	NS[1]	12	0	0	12	0	3	0	0	3
.55	0	6	0	0	6	0	0	0	0	0
.60	0	12	0	0	12	0	0	0	0	0
.65	3	0	0	0	3	0	0	0	0	0
.70	0	2	0	0	2	0	0	0	0	0
.80	0	0	0	3	3	0	6	0	0	6

[1] NS—sample spoiled or spilled.

APPENDIX I—Continued

Saury Eggs—Numbers by Stations, 1961–62—Continued

Station	Cruise and month, 1961					Cruise and month, 1962				
	6101–02 Jan.–Feb.	6104–05 Apr.–May	6107 July	6110–11 Oct.–Nov.	Total	6201–02 Jan.–Feb.	6203–04 Mar.–Apr.	6207–08 July–Aug.	6210–11 Oct.–Nov.	Total
110.33	0	0	0	35	35	0	--	--	--	0
.45	0	0	0	0	0	0	6	0	0	6
.50	0	7	0	0	7	0	0	0	0	0
.55	0	14	0	0	14	0	0	0	0	0
.60	0	0	0	0	0	0	5	0	0	5
.65	0	3	0	0	3	3	10	0	0	13
.70	0	6	0	0	6	0	0	0	0	0
.80	3	0	0	0	3	0	0	0	0	0
.120	0	10	0	0	10	0	0	--	0	0
113.40	0	3	0	0	3	0	0	0	0	0
.45	0	0	0	0	0	0	3	0	0	3
.65	0	0	0	0	0	0	3	0	0	3
.70	0	8	0	0	8	0	0	0	0	0
117.35	0	3	0	0	3	0	0	0	0	0
.45	0	3	0	0	3	6	0	0	0	6
.50	0	0	0	0	0	0	6	0	0	6
.60	0	0	0	0	0	3	0	0	0	3
.65	3	0	0	0	3	0	0	0	0	0
.70	0	3	0	0	3	0	3	0	0	3
120.55	0	0	0	0	0	2	2	0	0	4
.60	0	0	0	0	0	5	0	0	0	5
.70	0	8	0	0	8	0	0	0	0	0
.120	0	0	0	0	0	0	3	--	0	3
123.55	3	0	0	0	3	0	0	0	0	0
127.40	0	0	0	0	0	0	0	15	0	15
.45	0	13	0	0	13	0	0	0	0	0
.70	--	0	0	0	0	0	3	0	0	3
130.45	0	0	0	0	0	0	3	0	0	3
.80	0	3	0	0	3	0	0	0	0	0
133.45	3	0	0	0	3	0	0	--	0	0
.80	--	3	0	0	3	0	0	--	0	0
Total	89	322	155	66	632	142	158	23	92	415
Occurrences	18	54	5	7	84	13	32	3	7	55

Saury Eggs—Numbers by Stations, 1963–64

Station	Cruise and month, 1963					Cruise and month, 1964				
	6301–02 Jan.–Feb.	6304–05 Apr.–May	6307–08 July–Aug.	6310 Oct.	Total	6401–02 Jan.–Feb.	6404 Apr.	6406–07 June–July	6410 Oct.	Total
60.70	0	5	--	--	5	0	0	12	--	12
.80	0	2	--	--	2	0	0	0	--	0
63.70	--	--	--	--	--	--	3	--	--	3
70.52	--	0	--	--	0	0	3	0	--	3
.70	0	0	--	--	0	3	8	0	--	11
.80	0	3	--	--	3	0	0	6	--	6
.100	0	2	--	--	2	0	--	0	--	0
73.51	--	6	--	--	6	0	0	0	--	0
.53	0	3	--	--	3	0	0	0	--	0
.70	--	--	--	--	--	--	6	--	--	6
77.55	0	3	--	--	3	0	0	0	--	0
.57	0	14	--	--	14	0	3	--	--	3
.80	--	--	--	--	--	--	6	--	--	6
77.[8]70	--	--	--	--	--	0	--	9	--	9
80.66[7]	--	--	--	--	--	149	--	0	--	149
.70	0	9	0	0	9	0	6	--	0	6
.80	8	3	0	0	11	0	0	0	0	0
.90	26	0	0	0	26	0	--	0	0	0
.100	0	6	--	--	6	3	--	0	--	3
.120	0	3	--	--	3	0	--	--	--	0
80.[8]60	--	--	--	--	--	0	--	5	--	5
82.[2]60	--	--	--	--	--	0	--	6	--	6
83.51	0	0	0	0	0	0	0	3	0	3
.65	0	6	0	3	9	0	100	0	0	100
.70	0	3	0	0	3	0	9	0	0	9
.80	0	9	0	0	9	0	0	0	0	0
.95	34	--	--	--	34	--	--	--	--	--
.100	3	--	--	--	3	--	--	--	--	--
.110	23	--	--	--	23	--	--	--	--	--

APPENDIX I—Continued

Saury Eggs—Numbers by Stations, 1963–64

Station	Cruise and month, 1963					Cruise and month, 1964				
	6301–02 Jan.–Feb.	6304–05 Apr.–May	6307–08 July–Aug.	6310 Oct.	Total	6401–02 Jan.–Feb.	6404 Apr.	6406–07 June–July	6410 Oct.	Total
85.53	--	--	--	--	--	--	--	3	--	3
.55	--	--	--	--	--	--	--	15	--	15
.60	--	--	--	--	--	--	--	3	--	3
87.40	0	0	0	0	0	0	6	0	0	6
.45	0	3	0	0	3	0	0	0	0	0
.50	0	0	0	202	202	0	0	0	0	0
.65	0	4	0	0	4	0	0	0	0	0
.70	3	0	0	0	3	0	0	0	0	0
.80	7	3	0	0	10	0	41	0	0	41
.90	3	6	0	0	9	0	0	0	0	0
90.27[5]	--	0	0	0	0	0	0	1	0	1
.45	0	0	0	0	0	0	158	0	0	158
.53	0	0	0	0	0	0	0	8	0	8
.60	0	0	0	0	0	0	6	0	0	6
.65	0	2	0	0	2	0	6	0	0	6
.80	0	0	0	0	0	0	14	0	0	14
.90	0	0	0	0	0	0	3	0	0	3
.100	0	0	--	--	0	0	6	126	0	132
.130	6	--	--	--	6	--	--	--	--	--
.140	23	0	--	--	23	0	--	0	--	0
.180	3	0	--	--	3	0	--	0	--	0
93.26[5]	--	0	0	0	0	0	0	0	1	1
.30	0	0	0	0	0	0	0	0	3	3
.35	0	0	0	0	0	0	0	0	3	3
.65	0	3	0	0	3	0	0	0	0	0
.70	0	0	0	0	0	0	0	3	0	3
.80	0	0	0	0	0	0	6	--	0	6
.90	0	0	--	0	0	0	5	--	0	5
.120	9	--	--	--	9	--	--	--	--	--
96.[8]28[7]	--	1	0	0	1	--	--	0	0	0
97.45	0	3	0	0	3	0	0	0	0	0
.65	0	3	0	0	3	0	3	0	0	3
.70	0	0	0	0	0	0	464	0	0	464
.90	0	0	--	0	0	0	3	--	0	3
100.29	--	0	0	0	0	0	0	0	3	3
.50	0	0	0	0	0	7	0	0	0	7
.60	0	0	0	0	0	0	6	0	0	6
.80	0	0	0	0	0	3	0	0	0	3
.120	0	2	--	--	2	0	--	--	--	0
103.40	0	0	0	0	0	0	0	0	46	46
.50	0	0	0	0	0	0	0	0	12	12
.55	0	3	0	0	3	0	0	0	0	0
.70	3	0	0	0	3	0	3	0	0	3
.80	0	0	0	0	0	3	0	0	0	3
.90	3	0	0	0	3	0	0	0	3	3
107.65	0	0	0	0	0	9	0	0	0	9
.80	6	0	0	0	6	6	0	0	9	15
110.60	3	0	0	0	3	0	0	0	0	0
113.65	6	0	0	0	6	0	0	NS[1]	0	0
.70	3	0	0	0	3	0	0	0	0	0
.80	3	0	0	0	3	0	0	0	0	0
117.24[8]	--	1	0	0	1	0	0	0	0	0
.50	10	0	0	0	10	0	0	0	0	0
.60	0	11	0	0	11	0	0	0	0	0
.65	0	0	0	0	0	0	3	0	0	3
.70	0	18	0	0	18	6	0	0	0	6
120.60	3	0	0	0	3	0	0	0	0	0
.70	3	0	0	0	3	0	0	0	0	0
123.42	0	0	0	0	0	0	0	3	0	3
.80	0	0	64	--	64	0	0	0	--	0
127.80	3	0	0	--	3	0	--	0	--	0
Total	194	140	64	205	603	189	877	203	80	1,349
Occurrences	23	29	1	2	55	9	25	14	8	56

[1] NS—sample spoiled or spilled.

APPENDIX I—Continued

Saury Eggs—Numbers by Stations, 1965

Station	Cruise and month, 1965				
	6501-02 Jan.-Feb.	6504 Apr.	6506-08 June-Aug.	6509 Sept.	Total
60.60	0	--	17	--	17
63.55	0	2	0	--	2
.60	0	0	3	--	3
.70	--	7	--	--	7
67.48	0	1	0	--	1
.55	0	43	3	--	46
.60	0	6	0	--	6
.65	--	35	--	--	35
.70	--	3	--	--	3
.80	--	5	--	--	5
70.53	0	8	0	--	8
.60	0	14	0	--	14
.65	--	8	--	--	8
.70	0	12	0	--	12
.80	0	8	0	--	8
.200	15	--	0	--	15
73.50	0	0	9	--	9
.51	0	8	0	--	8
.60	0	25	8	--	33
.70	--	3	--	--	3
.80	--	5	--	--	5
77.57	0	2	0	--	2
.65	--	15	--	--	15
.70	--	44	--	--	44
.80	--	20	--	--	20
80.65	0	3	0	0	3
.80	0	13	0	0	13
.160	9	--	--	--	9
83.55	0	25	0	0	25
.60	0	9	0	0	9
.65	0	41	0	0	41
.70	0	6	0	0	6
.80	0	23	4	0	27
.90	0	--	3	--	3
87.40	0	0	3	0	3
.45	0	3	0	0	3
.55	0	3	6	0	9
.60	0	2	0	0	2
.65	0	13	0	0	13
.70	0	3	6	0	9
.80	0	24	0	0	24
.100	--	3	--	--	3
90.32	0	3	0	0	3
.70	0	3	0	0	3
.80	0	3	0	0	3
.90	0	3	0	0	3
.100	0	9	0	--	9
93.28	0	3	0	0	3
.30	0	0	0	3	3
.40	0	0	0	3	3
.45	0	3	0	0	3
.55	0	4	0	0	4
.60	0	3	0	0	3
.65	0	9	0	0	9
.70	0	3	0	0	3
.80	0	3	0	0	3
.90	6	0	0	0	6

Station	Cruise and month, 1965				
	6501-02 Jan.-Feb.	6504 Apr.	6506-08 June-Aug.	6509 Sept.	Total
97.45	0	7	0	0	7
.55	0	13	9	0	22
.60	0	0	3	0	3
.65	0	3	0	0	3
.70	0	4	0	0	4
.75	--	9	--	0	9
.80	10	4	6	0	20
.85	--	4	--	--	4
.100	--	4	--	--	4
100.50	0	3	0	0	3
.60	0	3	0	0	3
.70	0	3	0	0	3
.75	--	24	--	--	24
.85	--	3	--	--	3
103.40	0	3	0	0	3
.45	0	3	0	0	3
.55	0	3	0	0	3
.85	--	3	--	--	3
107.32	0	3	0	0	3
.60	0	3	0	0	3
.80	3	0	0	--	3
.90	3	0	0	--	3
110.50	0	3	0	0	3
.75	--	3	--	--	3
.90	0	3	0	--	3
113.40	0	3	0	0	3
.45	0	3	0	0	3
.55	0	0	3	0	3
.65	3	0	0	--	3
.70	3	0	0	--	3
117.65	0	3	3	--	6
.75	--	3	--	--	3
.90	3	0	0	--	3
120.45	78	0	0	0	78
.50	25	0	0	0	25
.55	3	0	0	0	3
.60	9	0	0	0	9
.65	14	0	0	--	14
.70	9	3	0	--	12
.80	3	0	0	--	3
.90	3	--	0	--	3
.120	3	--	0	--	3
123.45	6	0	0	0	6
.60	9	NS[1]	0	0	9
.65	3	0	0	--	3
.70	3	0	0	--	3
127.40	11	0	0	0	11
.65	6	0	0	--	6
130.26	1	0	0	0	1
.70	3	0	0	--	3
Total	244	620	86	6	956
Occurrences	26	74	15	2	117

[1] NS—sample spoiled or spilled.

APPENDIX I—Continued

Saury Eggs—Numbers by Stations, 1966

Station	Cruise and month												Total
	6601 Jan.	6602 Feb.	6603 Mar.	6604 Apr.	6605 May	6606 June	6607 July	6608 Aug.	6609 Sept.	6610 Oct.	6611 Nov.	6612 Dec.	
60.60	0	--	--	3	--	0	22	--	--	0	--	0	25
.70	0	--	--	3	--	0	0	--	--	0	--	0	3
63.60	0	--	--	0	--	0	13	--	--	0	--	0	13
67.60	0	--	--	0	--	3	4	--	--	--	--	0	7
.80	--	--	--	0	--	3	0	--	--	0	--	--	3
70.51	0	--	--	0	--	6	0	--	--	0	--	0	6
.65	0	--	--	3	--	13	--	--	--	--	--	--	16
.70	0	--	--	5	--	6	0	--	--	0	--	0	11
.90	0	--	--	--	--	15	0	--	--	0	--	0	15
73.60	0	--	--	0	--	19	0	--	--	0	--	0	19
.70	--	--	--	6	--	10	0	--	--	0	--	0	16
.80	0	--	--	0	--	3	0	--	--	0	--	--	3
.90	NS[1]	--	--	0	--	3	0	--	--	--	--	--	3
77.51	0	--	--	6	--	3	0	--	--	0	--	0	9
.55	0	--	--	0	--	46	0	--	--	0	--	0	46
.60	0	--	--	5	--	19	0	--	--	0	--	0	24
.65	--	--	--	0	--	27	--	--	--	--	--	--	27
.70	--	--	--	0	--	3	3	--	--	0	--	0	6
.80	0	--	--	6	--	17	0	--	--	0	--	--	23
.90	7	--	--	3	--	0	0	--	--	0	--	--	10
80.55	0	--	--	0	21	0	0	0	0	0	--	0	21
.60	0	0	--	0	0	3	0	0	0	0	--	0	3
.65	0	3	--	0	23	27	25	0	0	0	--	0	78
.80	0	0	--	0	10	6	0	0	0	0	--	0	16
.90	0	0	--	0	3	0	0	0	0	0	--	0	3
83.43	0	0	--	0	3	0	0	0	0	0	--	0	3
.60	3	3	--	0	0	6	0	0	0	0	--	0	12
.65	3	0	--	0	0	6	3	0	0	0	--	0	12
.70	31	26	--	6	3	14	0	0	0	0	--	0	80
.80	0	6	--	0	3	9	0	0	0	0	--	0	18
.90	0	0	--	3	0	0	0	0	0	0	--	--	3
87.33	4	0	--	--	0	3	0	0	0	0	--	0	7
.40	0	0	--	0	0	6	0	0	0	0	--	0	6
.55	9	0	--	0	3	0	0	0	0	0	--	0	12
.60	--	0	--	0	0	12	0	0	0	0	--	0	12
.65	--	0	--	0	16	0	0	0	0	0	--	0	16
.80	--	0	--	0	4	0	0	0	0	0	--	3	7
.90	--	0	--	6	4	0	0	0	0	0	--	--	10
90.32	--	0	--	0	0	7	0	0	0	0	--	0	7
.45	--	0	--	9	13	8	0	0	0	0	--	0	30
.53	--	--	--	3	--	9	0	--	--	0	--	0	12
.60	--	0	--	12	4	6	0	0	0	0	--	0	22
.65	--	6	--	40	0	5	0	0	0	0	--	0	51
.70	--	0	--	24	4	0	0	0	0	NS[1]	--	0	28
.90	--	3	--	0	0	0	0	0	0	0	--	0	3
93.27	0	3	--	--	0	0	0	0	0	0	--	0	3
.30	0	0	--	22	0	0	0	0	0	0	--	0	22
.40	0	0	--	0	3	0	NS[1]	0	0	0	--	0	3
.45	0	0	--	36	3	0	0	0	0	0	--	0	39
.50	0	0	--	10	0	0	0	0	0	0	--	0	10
.55	0	0	--	13	0	22	0	0	0	0	--	0	35
.60	0	0	--	0	0	15	0	0	0	0	--	0	15
.65	0	0	--	0	17	0	0	0	0	0	--	0	17
.70	0	0	--	0	14	3	NS[1]	0	0	--	--	0	17
.80	9	0	--	0	0	0	0	0	0	--	--	0	9
.90	3	0	--	0	0	0	0	--	--	0	--	0	3
97.40	0	0	--	0	2,392	0	0	0	0	0	--	0	2,392
.45	0	0	--	3	0	0	0	0	0	0	0	0	3
97.50	0	3	--	0	6	6	0	0	0	0	--	0	15
.55	0	0	--	0	12	3	0	0	0	0	--	0	15
.65	0	0	--	9	4	6	0	0	0	0	--	0	19
.70	0	0	--	0	4	0	0	0	0	0	--	0	4
100.35	0	0	--	0	6	0	0	0	0	0	0	0	6
.40	0	0	--	0	6	7	0	0	0	0	--	0	13
.45	0	0	--	0	16	6	0	0	0	0	0	0	22
.50	0	0	--	3	0	0	0	0	0	0	--	0	3
.70	0	0	--	0	0	0	4	0	0	0	--	0	4
.80	0	9	--	0	0	0	0	--	--	0	--	0	9
.90	0	--	--	4	0	0	0	--	--	--	--	--	4
103.35	0	0	--	0	0	3	0	0	0	0	0	0	3
.40	0	0	--	0	6	0	0	0	0	0	--	0	6
.45	0	0	--	0	11	7	0	0	0	0	0	0	18
.50	0	0	--	0	6	0	0	0	0	0	--	0	6
.60	0	0	--	0	16	0	0	0	0	0	--	0	16
.70	0	6	--	0	0	0	0	0	0	0	--	0	6

[1] NS—sample spoiled or spilled.

APPENDIX I—Continued

Saury Eggs—Numbers by Stations, 1966—Continued

Station	Cruise and month												Total
	6601 Jan.	6602 Feb.	6603 Mar.	6604 Apr.	6605 May	6606 June	6607 July	6608 Aug.	6609 Sept.	6610 Oct.	6611 Nov.	6612 Dec.	
107.35	0	0	--	0	4	--	0	0	0	0	0	0	4
.40	0	3	--	0	3	--	0	0	0	0	--	0	6
.45	0	3	--	0	0	--	0	0	0	0	0	0	3
110.35	0	0	--	0	14	--	0	0	0	0	0	0	14
.40	0	0	--	0	3	--	0	0	0	0	--	0	3
.65	3	0	--	0	0	--	0	0	0	0	--	0	3
.80	0	0	--	3	0	--	0	--	--	--	--	0	3
113.45	0	0	--	0	3	--	0	0	0	0	--	0	3
.60	6	0	--	0	0	--	0	0	0	0	--	0	6
.80	2	--	--	0	0	--	3	--	--	--	--	0	5
117.50	0	3	--	0	0	--	0	0	0	0	--	0	3
.60	0	0	--	4	0	--	0	0	0	0	--	0	4
.65	0	6	--	0	0	--	0	0	0	0	--	0	6
120.80	3	--	--	0	3	--	0	--	--	--	--	0	6
127.65	3,223	--	--	--	0	--	0	--	--	--	--	--	3,223
.70	59	--	--	--	0	--	0	--	--	--	--	--	59
.80	3	--	--	--	--	--	0	--	--	--	--	--	3
130.40	3	--	--	0	0	--	0	0	--	0	0	0	3
.50	3	--	--	0	0	--	0	0	--	0	0	0	3
133.40	6	--	--	0	0	--	0	0	--	0	0	0	6
.60	6	--	--	0	0	--	0	0	--	0	0	--	6
137.22	2	--	--	0	0	--	0	0	--	0	0	0	2
.35	3	--	--	0	0	--	0	0	--	0	0	0	3
Total	3,391	83	--	250	2,666	401	77	0	0	0	0	3	6,871
Occurrences	21	14	--	27	36	41	8	0	0	0	0	1	148

0 = station occupied—no saury eggs taken.
— = station not occupied.
$\left\{\begin{matrix}1\\1\end{matrix}\right\}$ = indicates more than one occupancy of the same station on a cruise.

APPENDIX II

Visual Observations of Saury Abundance, 1956

Night stations occupied	Cruise and month											
	5601 Jan.	5602 Feb.	5603 Mar.	5604 Apr.	5605 May	5606 June	5607 July	5608 Aug.	5609 Sept.	5610 Oct.	5611 Nov.	5612 Dec.
40.38	--	--	--	--	0	--	--	--	--	--	--	--
.40	--	--	--	--	0	--	--	--	--	--	--	--
.45	--	--	--	--	0	+	--	--	--	--	--	--
.50	--	--	--	--	0	0	--	--	--	--	--	--
.90	--	--	--	--	0	0	--	--	--	--	--	--
43.60	--	--	--	--	--	0	--	--	--	--	--	--
47.50	--	--	--	--	0	--	--	--	--	--	--	--
.55	--	--	--	--	0	--	--	--	--	--	--	--
.60	--	--	--	--	--	0	--	--	--	--	--	--
50.55	--	--	--	--	0	--	--	--	--	--	--	--
.60	--	--	--	--	0	0	--	--	--	--	--	--
.70	--	--	--	--	0	--	--	--	--	--	--	--
53.52	--	--	--	--	--	0	--	--	--	--	--	--
.55	--	--	--	--	--	0	--	--	--	--	--	--
57.51	--	--	--	--	--	0	--	--	--	--	--	--
.55	--	--	--	--	--	0	--	--	--	--	--	--
.65	--	--	--	--	0	--	--	--	--	--	--	--
60.50	--	--	--	--	0	--	--	--	--	--	--	--
.55	--	--	--	0	0	--	0	--	--	--	--	--
.60	--	--	--	0	--	--	--	--	--	--	--	--
.70	--	--	--	0	--	--	+	--	--	--	--	--
.80	--	--	--	--	--	+	0	--	--	--	--	--
.90	--	--	--	--	--	+	--	--	--	--	--	--
63.52	--	--	--	--	--	0	--	--	--	--	--	--
.55	--	--	--	--	--	0	--	--	--	--	--	--
.65	--	--	--	--	+	--	--	--	--	--	--	--
.80	--	--	--	0	--	--	--	--	--	--	--	--
67.50	--	--	--	0	--	0	--	--	--	--	--	--
.55	--	--	--	0	--	0	+	--	--	--	--	--
.60	--	--	--	--	--	--	+	--	--	--	--	--
.65	--	--	--	0	0	--	--	--	--	--	--	--
.70	--	--	--	--	--	--	0	--	--	--	--	--
70.52	--	--	--	0	+	--	--	--	--	--	--	--
.55	--	--	--	0	0	0	--	--	--	--	--	--
.60	--	--	--	0	--	--	--	--	--	--	--	--
.80	--	--	--	0	--	0	0	--	--	--	--	--
.90	--	--	--	0	--	0	0	--	--	--	--	--
73.50	--	--	--	--	0	--	--	--	--	--	--	--
.65	--	--	--	0	--	--	--	--	--	--	--	--
.80	--	--	--	--	--	--	0	--	--	--	--	--
77.55	--	--	--	0	--	--	+	--	--	--	--	--
.60	--	--	--	--	--	--	0	--	--	--	--	--
.70	--	--	--	--	0	--	--	--	--	--	--	--
.80	--	--	--	--	0	--	--	--	--	--	--	--
80.51	--	--	0	--	--	--	--	--	--	--	--	--
.55	--	--	0	--	--	--	--	--	--	--	--	--
.60	--	--	0	--	--	--	--	--	--	--	--	0
.70	+	+	--	--	--	+	0	--	--	0	0	0
.80	+	--	--	+	0	--	0	--	--	0	0	0
.90	--	--	0	--	0	--	--	--	--	--	+	--
82.47	--	--	0	--	--	--	--	--	--	--	+	--
83.40	--	--	--	--	--	--	--	--	--	--	0	--
.43	0	--	--	--	--	--	--	--	--	--	+	--
.51	0	--	0	--	+	+	--	--	--	+	--	--
.55	--	--	--	0	+	--	+	--	--	+	--	+
.60	--	+	0	0	0	--	+	--	--	+	--	0
.70	--	--	--	0	--	--	0	--	--	--	--	--
.80	--	--	0	--	--	+	--	--	--	--	--	--
.90	--	--	0	--	--	+	--	--	--	--	--	--
87.36	--	0	--	0	--	--	--	--	--	--	+	+
.40	--	0	--	0	--	--	--	--	--	--	--	+
.45	--	--	--	--	--	--	+	--	--	+	--	0
.50	--	0	0	--	--	--	+	--	--	+	--	0
.55	--	--	--	--	--	+	--	--	--	+	--	--
.60	0	--	--	--	--	0	--	--	--	0	+	--
.65	--	--	--	--	0	--	--	--	--	--	--	--
.70	--	--	--	--	+	--	--	--	--	--	--	--
.75	--	--	--	--	0	--	--	--	--	--	--	--
.80	--	--	--	--	--	--	+	--	--	--	--	--
.85	--	--	--	--	--	--	0	--	--	--	--	--
.90	--	--	+	0	--	--	0	--	--	--	--	--

-- = no observation made.
+ = saury observed.
0 = no saury observed.

APPENDIX II—Continued

Visual Observations of Saury Abundance, 1956—Continued

Night stations occupied	Cruise and month											
	5601 Jan.	5602 Feb.	5603 Mar.	5604 Apr.	5605 May	5606 June	5607 July	5608 Aug.	5609 Sept.	5610 Oct.	5611 Nov.	5612 Dec.
90.28	--	--	--	--	--	--	0	--	--	0	+	--
.30	--	--	--	--	--	+	0	--	--	+	0	--
.37	0	--	+	--	--	+	--	--	--	+	+	--
.45	0	--	+	0	0	--	--	--	--	0	--	+
.50	--	--	--	--	0	--	--	--	--	--	--	+
.55	--	--	0	0	--	--	--	--	--	--	--	0
.60	--	--	--	--	--	0	+	--	--	--	--	+
.65	--	--	--	--	--	0	+	--	--	--	--	--
.70	--	--	--	--	--	--	+	--	--	+	--	--
.80	--	--	--	--	+	+	--	--	--	+	--	--
.85	--	--	--	--	0	--	--	--	--	--	--	--
.90	--	--	0	+	0	--	--	--	--	0	--	0
.95	--	--	--	--	0	--	--	--	--	--	--	--
93.27	--	--	--	--	--	--	+	--	--	--	--	+
.30	--	--	--	--	0	--	+	--	--	--	--	+
.35	--	--	--	--	--	--	+	--	--	--	--	+
.40	--	+	--	0	+	0	--	--	--	0	+	+
.45	--	--	--	--	--	--	--	--	--	0	0	0
.50	+	+	+	0	--	+	--	--	--	0	+	--
.55	--	--	--	--	--	--	0	--	--	0	0	--
.60	--	--	+	--	--	--	+	--	--	--	+	--
.65	--	--	--	--	--	--	+	--	--	--	--	--
.70	--	--	--	--	0	+	+	--	--	--	--	--
.75	--	--	--	--	--	0	--	--	--	--	--	--
.90	--	--	--	--	--	--	0	--	--	--	--	--
.100	--	--	--	--	0	--	--	--	--	--	--	--
97.30	--	--	0	--	--	--	--	--	--	0	+	--
.32	--	--	+	--	--	--	--	--	--	+	0	--
.40	--	--	+	--	--	+	--	--	--	0	+	+
.45	--	--	--	--	--	--	--	--	--	0	--	0
.50	+	+	--	0	0	+	--	--	--	--	--	0
.55	--	--	--	--	0	--	--	--	--	--	--	0
.60	--	--	--	0	0	--	--	--	--	--	--	0
.65	--	--	--	--	0	--	--	--	--	--	--	--
.70	--	--	+	--	--	--	--	--	--	--	--	--
.90	--	--	+	--	--	--	--	--	--	--	--	--
.95	--	--	--	--	0	--	--	--	--	--	--	--
100.29	--	--	--	--	0	+	--	--	--	--	--	--
.30	--	--	0	--	0	--	+	--	--	--	--	--
.33	--	--	--	0	--	0	--	--	--	--	--	--
.35	--	--	--	--	0	--	+	--	--	--	--	--
.40	+	+	--	0	0	--	--	--	--	--	--	--
.45	--	--	--	--	0	--	--	--	--	--	--	--
.50	+	--	--	--	--	--	--	--	--	--	--	--
.60	--	--	0	--	--	--	0	--	--	--	--	--
.70	--	+	+	--	--	--	0	--	--	--	--	--
.80	--	+	0	0	0	--	--	--	--	--	--	--
.90	--	--	--	0	--	--	--	--	--	--	--	--
103.35	--	+	--	--	--	--	--	--	--	--	--	--
.40	--	+	--	--	--	--	0	--	--	--	--	--
.45	--	--	--	--	--	--	0	--	--	--	--	--
.50	--	--	0	+	0	--	0	--	--	--	--	--
.55	--	--	--	--	0	--	--	--	--	--	--	--
.60	--	--	0	--	0	--	--	--	--	--	--	--
.70	--	--	0	--	--	--	--	--	--	--	--	--
.80	--	--	--	--	--	--	0	--	--	--	--	--
.85	--	--	--	--	0	--	0	--	--	--	--	--
.90	--	--	+	--	0	--	+	--	--	--	--	--
.95	--	--	--	--	0	--	--	--	--	--	--	--
107.32	--	0	--	--	--	--	--	--	--	--	--	--
.40	--	--	--	--	0	--	0	--	--	--	--	--
.45	--	--	--	--	0	--	0	--	--	--	--	--
.50	--	--	--	--	0	--	--	--	--	--	--	--
.55	--	--	--	--	0	0	--	--	--	--	--	--
.60	--	+	--	+	--	0	--	--	--	--	--	--
.70	--	--	+	0	--	--	0	--	--	--	--	--
.85	--	--	--	--	--	0	--	--	--	--	--	--
.90	--	--	--	--	0	+	--	--	--	--	--	--
110.33	--	--	--	0	0	--	--	--	--	--	--	--
.35	--	--	--	+	+	+	+	--	0	--	--	--
.40	--	--	--	--	0	+	--	--	0	--	--	--
.45	--	--	--	--	0	--	--	--	--	--	--	--
.50	--	+	--	--	0	--	--	--	--	--	--	--
.65	--	--	--	--	--	0	--	--	--	--	--	--
.70	--	--	--	+	--	+	+	--	--	--	--	--
.80	--	--	--	+	--	--	0	--	--	--	--	--
.85	--	--	--	--	0	--	--	--	--	--	--	--
.90	--	--	--	--	0	--	--	--	--	--	--	--

APPENDIX II—Continued

Visual Observations of Saury Abundance, 1956—Continued

Night stations occupied	Cruise and month											
	5601 Jan.	5602 Feb.	5603 Mar.	5604 Apr.	5605 May	5606 June	5607 July	5608 Aug.	5609 Sept.	5610 Oct.	5611 Nov.	5612 Dec.
113.30	--	--	--	0	--	--	+	--	--	--	--	--
.35	--	--	--	--	--	--	+	--	--	--	--	--
.40	--	--	--	--	--	--	0	--	--	--	--	--
.45	--	--	+	--	--	+	0	--	--	--	--	--
.50	--	+	--	--	--	+	--	--	--	--	--	--
.60	--	--	--	0	0	--	--	--	--	--	--	--
.65	--	--	--	--	0	--	--	--	--	--	--	--
.70	--	0	--	+	--	--	0	--	--	--	--	--
.80	--	--	--	--	--	+	0	--	--	--	--	--
115.27	--	--	--	--	--	--	--	--	0	--	--	--
.30	--	--	--	--	--	--	--	--	0	--	--	--
.35	--	--	--	--	--	--	--	--	0	--	--	--
.40	--	--	--	--	--	--	--	--	0	--	--	--
117.26	--	--	--	+	--	--	--	--	--	--	--	--
.30	--	--	--	0	--	--	--	--	--	--	--	--
.35	--	--	--	+	--	--	--	--	--	--	--	--
.40	--	0	--	--	--	--	0	--	--	--	--	--
.45	--	--	--	--	--	--	+	--	--	--	--	--
.50	--	--	--	0	0	+	0	--	--	--	--	--
.55	--	--	--	--	0	+	--	--	--	--	--	--
.60	--	--	--	+	0	--	--	--	--	--	--	--
.65	--	--	--	--	0	--	--	--	--	--	--	--
.70	--	0	--	--	0	--	--	--	--	--	--	--
.80	--	--	--	--	--	+	--	--	--	--	--	--
118.25	--	--	--	--	--	--	--	--	+	--	--	--
.30	--	--	--	--	--	--	--	--	+	--	--	--
.39	--	0	--	--	--	--	--	--	--	--	--	--
119.33	--	--	--	--	0	--	+	--	--	--	--	--
120.25	--	--	+	--	0	--	--	--	0	--	--	--
.30	--	--	--	--	0	--	0	--	--	--	--	--
.40	--	--	--	--	--	--	0	--	--	--	--	--
120.45	--	0	--	+	+	--	--	--	--	--	--	--
.50	--	0	--	--	0	--	--	--	--	--	--	--
.55	--	0	--	--	+	--	--	--	--	--	--	--
.70	--	--	--	+	--	0	--	--	--	--	--	--
.80	--	--	--	+	--	0	0	--	--	--	--	--
123.37	--	0	--	0	--	--	+	--	0	--	--	--
.40	--	--	--	0	--	0	--	--	--	--	--	--
.42	--	0	--	+	--	--	--	--	0	--	--	--
.45	--	--	--	--	--	--	--	--	0	--	--	--
.50	--	0	--	0	--	+	--	--	--	--	--	--
.55	--	0	--	--	--	--	--	--	--	--	--	--
.60	--	--	--	--	0	--	--	--	--	--	--	--
127.34	--	--	+	--	0	--	+	--	--	--	--	--
.40	--	--	--	--	+	+	--	--	--	--	--	--
.45	--	--	--	--	+	0	--	--	--	--	--	--
.50	--	--	--	--	0	--	--	--	--	--	--	--
.55	--	0	--	--	--	--	--	--	--	--	--	--
.60	--	--	--	+	--	--	--	--	--	--	--	--
130.30	--	--	--	0	--	--	--	0	--	--	--	--
.35	--	--	--	--	--	--	--	0	0	--	--	--
.40	--	--	--	--	0	--	--	0	0	--	--	--
.45	--	--	--	--	--	--	--	--	0	--	--	--
.50	--	--	--	--	--	+	0	--	--	--	--	--
.60	--	0	--	0	--	+	0	--	--	--	--	--
133.25	--	0	--	0	--	--	--	--	0	--	--	--
.30	--	+	--	+	0	+	0	--	0	--	--	--
.35	--	--	--	--	0	--	--	--	--	--	--	--
.40	--	0	--	--	--	--	0	--	--	--	--	--
.50	--	--	--	--	0	--	--	--	--	--	--	--
137.23	--	0	--	0	--	--	+	--	--	--	--	--
.30	--	--	--	+	--	--	0	0	--	--	--	--
.40	--	--	--	--	--	0	--	--	--	--	--	--
.50	--	--	--	--	0	--	--	--	--	--	--	--
.90	--	--	--	--	0	--	--	--	--	--	--	--
140.30	--	+	--	--	--	--	--	--	--	--	--	--
.35	--	0	--	--	--	--	--	--	--	--	--	--
.40	--	+	--	--	--	--	--	--	--	--	--	--
143.26	--	--	--	0	--	--	--	--	--	--	--	--
.30	--	--	--	0	--	--	--	--	--	--	--	--
.35	--	--	--	0	--	--	--	--	--	--	--	--
.40	--	--	--	0	--	--	--	--	--	--	--	--
.50	--	0	--	--	--	--	--	--	--	--	--	--
.60	--	0	--	--	--	--	--	--	--	--	--	--
147.25	--	0	--	--	--	--	--	--	--	--	--	--
.30	--	0	--	--	--	--	--	--	--	--	--	--
.35	--	0	--	+	--	--	--	--	--	--	--	--
.40	--	--	--	0	--	--	--	--	--	--	--	--

APPENDIX II—Continued

Visual Observations of Saury Abundance, 1956—Continued

Night stations occupied	Cruise and month											
	5601 Jan.	5602 Feb.	5603 Mar.	5604 Apr.	5605 May	5606 June	5607 July	5608 Aug.	5609 Sept.	5610 Oct.	5611 Nov.	5612 Dec.
150.19	--	0	--	0	--	--	--	--	--	--	--	--
.25	--	0	--	--	--	--	--	--	--	--	--	--
.30	--	0	--	--	--	--	--	--	--	--	--	--
153.16	--	0	--	0	--	--	--	--	--	--	--	--
.20	--	--	--	0	--	--	--	--	--	--	--	--
.40	--	0	--	--	--	--	--	--	--	--	--	--
.50	--	0	--	0	--	--	--	--	--	--	--	--
157.20	--	--	--	0	--	--	--	--	--	--	--	--
.30	--	0	--	0	--	--	--	--	--	--	--	--
.40	--	+	--	0	--	--	--	--	--	--	--	--
.60	--	--	--	0	--	--	--	--	--	--	--	--
Total observations	11	50	34	75	91	62	71	4	17	24	19	24

Visual Observations of Saury Abundance, 1957

Night stations occupied	Cruise and month											
	5701 Jan.	5702 Feb.	5703 Mar.	5704 Apr.	5705 May	5706 June	5707 July	5708 Aug.	5709 Sept.	5710 Oct.	5711 Nov.	5712 Dec.
60.60	--	--	--	--	--	--	+	--	--	--	--	--
.70	--	--	--	--	--	--	+	--	--	--	--	--
63.60	--	--	--	--	--	0	--	--	--	--	--	--
.90	--	--	--	--	--	0	--	--	--	--	--	--
67.50	--	--	--	--	--	0	--	--	--	--	--	--
.55	--	--	--	--	--	0	--	--	--	--	--	--
.90	--	--	--	--	--	0	--	--	--	--	--	--
70.60	--	--	--	--	--	--	0	--	--	--	+	--
.70	--	--	--	--	--	--	--	--	--	--	+	--
.80	--	--	--	--	--	0	--	--	--	--	0	--
.90	--	--	--	--	--	0	--	--	--	--	--	--
73.51	--	--	--	--	--	--	--	--	--	--	+	--
.55	--	--	--	--	--	+	0	--	--	--	+	--
.60	--	--	--	--	--	0	--	--	--	--	--	--
.70	--	--	--	--	--	+	--	--	--	--	--	--
77.50	--	--	--	--	--	0	--	--	--	--	--	--
.55	--	--	--	--	--	0	--	--	--	--	--	--
.80	--	--	--	--	--	--	0	--	--	--	--	--
.90	--	--	--	--	--	0	0	--	--	--	--	--
80.47	--	--	--	--	--	--	+	--	--	--	--	--
.51	--	0	--	--	--	--	--	--	--	+	--	--
.55	--	0	--	--	--	+	+	--	--	+	+	+
.60	--	+	--	--	--	0	+	--	--	--	+	0
.70	--	+	+	--	--	--	--	--	--	0	--	--
.80	--	--	--	0	--	--	--	--	--	+	--	--
.90	--	--	--	0	--	--	--	--	--	+	--	+
82.47	--	--	--	--	0	--	--	--	--	0	+	--
83.40	--	0	--	--	0	--	--	--	--	0	--	--
.43	--	0	--	--	0	--	+	--	--	--	0	--
.51	--	--	--	0	--	--	--	--	--	--	0	--
.55	--	--	--	--	--	--	--	--	--	--	0	--
.60	--	+	+	0	--	--	--	--	--	--	--	--
.65	--	--	--	--	--	0	0	--	--	--	--	--
.70	--	--	+	--	--	0	--	--	--	0	--	--
86.46	--	--	--	0	--	--	--	--	--	--	--	--
87.36	--	0	--	--	0	--	--	--	--	--	--	--
.38	--	0	--	--	--	--	--	--	--	--	--	--
.40	--	+	--	--	0	--	--	--	--	--	--	--
.45	--	--	--	--	0	--	+	--	--	0	+	--
.50	--	--	--	0	--	+	+	--	--	0	+	--
.55	--	--	--	--	--	0	--	--	--	+	0	--
.60	--	0	--	--	--	--	--	--	--	--	0	--
.70	--	--	--	--	--	--	0	--	--	--	--	--
.80	--	--	--	--	--	0	0	--	--	+	--	--
.85	--	--	--	--	--	0	0	--	--	--	--	--
.90	--	--	--	0	--	0	--	--	--	0	--	--
90.28	--	--	--	--	--	--	--	--	--	--	0	--
.30	--	--	--	--	--	--	--	--	--	0	+	--
.37	--	--	--	--	--	+	--	--	--	0	--	0
.45	--	--	--	--	--	0	0	--	--	--	+	+
.50	--	--	--	--	--	--	--	--	--	--	--	0
.55	--	0	--	--	--	--	--	--	--	--	--	--

APPENDIX II—Continued

Visual Observations of Saury Abundance, 1957—Continued

Night stations occupied	Cruise and month											
	5701 Jan.	5702 Feb.	5703 Mar.	5704 Apr.	5705 May	5706 June	5707 July	5708 Aug.	5709 Sept.	5710 Oct.	5711 Nov.	5712 Dec.
.60	--	0	--	--	0	--	--	--	--	--	--	--
.65	--	--	--	--	0	--	--	--	--	--	--	--
.70	--	--	--	--	0	--	0	--	--	0	--	0
.75	--	--	--	--	0	--	0	--	--	--	--	--
.80	--	--	--	--	--	0	--	--	--	--	--	+
.85	--	--	--	--	--	0	--	--	--	--	--	--
.90	--	--	--	--	--	0	--	--	--	0	--	--
93.27	--	+	--	--	0	--	--	--	--	--	--	--
.30	--	0	--	--	0	--	--	--	--	--	--	--
.35	--	--	--	0	--	--	--	--	--	0	--	--
.40	--	--	--	0	--	--	+	--	+	0	--	--
.45	--	--	--	0	--	--	+	--	--	--	+	--
.50	--	0	--	--	--	--	--	--	0	--	0	--
.55	--	--	--	--	--	+	--	--	--	--	+	--
.60	--	0	--	--	--	0	--	--	--	--	+	--
.65	--	--	--	--	0	--	--	--	--	--	--	--
.70	--	--	--	--	0	--	0	--	--	0	--	--
.75	--	--	--	--	0	--	0	--	--	--	--	--
.80	--	--	--	0	0	--	--	--	--	0	--	--
97.30	--	--	--	--	--	--	--	--	--	--	0	--
.32	--	--	--	--	--	--	--	--	--	0	+	+
.35	--	--	--	--	--	--	--	--	--	0	--	--
.40	--	+	--	--	--	--	--	--	0	0	+	--
.45	--	--	--	--	--	--	0	--	--	--	0	--
.50	--	+	--	--	--	0	0	--	0	--	+	--
.55	--	--	--	--	--	+	--	--	--	--	--	--
.60	--	--	--	0	0	0	--	--	--	0	--	--
.65	--	--	--	--	0	--	--	--	--	--	--	--
.70	--	--	--	--	0	--	--	--	--	--	--	--
.75	--	--	--	--	0	--	--	--	--	--	--	--
.80	--	--	--	--	--	--	0	--	--	0	--	--
.85	--	--	--	--	--	--	0	--	--	--	--	--
.90	--	--	--	--	--	0	--	--	--	--	--	--
100.29	--	--	--	0	--	--	--	--	--	--	--	--
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.33	--	--	+	0	0	--	+	--	--	--	--	--
.35	--	--	--	--	--	--	--	--	--	0	--	--
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.45	--	--	--	--	--	0	--	--	--	--	--	--
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.55	--	--	--	--	--	+	--	--	--	--	--	--
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.70	--	--	--	0	0	--	--	--	--	--	--	--
.75	--	--	--	--	0	--	0	--	--	--	--	--
.80	--	--	--	--	0	--	--	--	--	0	--	--
.85	--	--	--	--	--	0	--	--	--	--	--	--
.90	--	0	--	--	--	0	--	--	--	--	--	--
103.30	--	0	--	--	0	0	--	--	--	0	--	--
.35	0	0	--	+	--	0	--	--	--	0	--	--
.40	--	0	--	0	0	0	--	--	--	--	--	--
.45	--	--	--	--	--	--	0	--	--	--	--	--
.50	--	0	--	--	--	--	0	--	--	--	--	0
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.60	0	--	--	--	--	--	--	--	--	0	--	--
.70	--	--	--	0	+	+	--	--	--	0	--	--
.75	--	--	--	--	+	0	--	--	--	--	--	--
.80	--	--	--	0	0	0	--	--	--	--	--	--
.85	--	--	--	--	0	--	--	--	--	--	--	--
107.32	0	--	--	--	0	--	--	--	--	--	--	--
.35	0	--	--	--	--	--	--	--	--	--	--	--
.40	0	+	--	--	--	--	--	--	--	--	--	--
.50	--	0	--	--	--	--	+	--	--	0	--	--
.55	--	--	--	--	--	--	0	--	--	--	--	--
.60	--	--	--	--	0	--	0	--	--	0	--	0
.65	--	--	--	--	0	0	--	--	--	--	--	--
.67	--	0	--	--	--	--	--	--	--	--	--	--
107.70	--	--	--	0	--	--	--	--	--	--	--	--
.75	--	--	--	--	--	+	--	--	--	--	--	--
.85	--	--	--	--	--	--	0	--	--	--	--	--
.90	--	--	--	--	--	--	0	--	--	--	--	--
110.33	--	0	--	--	--	0	--	+	--	0	--	--
.35	--	0	--	+	--	0	+	--	--	--	--	--
.40	--	+	--	0	0	--	0	--	--	--	--	--
.45	--	--	--	--	0	--	0	--	--	--	--	--
.50	0	--	--	--	0	--	--	--	--	--	--	--
.60	0	--	--	--	--	--	--	--	--	0	--	--
.65	--	--	--	--	--	--	0	--	--	--	--	--
.70	--	0	--	0	--	--	--	--	--	0	--	0
.80	--	0	--	+	--	0	--	--	--	--	--	--
.85	--	--	--	--	0	0	--	--	--	--	--	--
.90	--	+	--	--	0	--	0	--	--	--	--	--

APPENDIX II—Continued

Visual Observations of Saury Abundance, 1957—Continued

Night stations occupied	Cruise and month											
	5701 Jan.	5702 Feb.	5703 Mar.	5704 Apr.	5705 May	5706 June	5707 July	5708 Aug.	5709 Sept.	5710 Oct.	5711 Nov.	5712 Dec.
113.30	0	--	0	--	--	--	--	0	--	0	--	--
.35	--	--	0	--	0	--	--	0	--	0	--	--
.40	--	--	0	--	0	--	--	--	0	--	--	--
.45	--	--	--	--	0	0	--	--	--	--	--	--
.50	0	--	--	--	0	--	0	--	--	--	--	--
.55	--	--	--	--	--	--	0	--	--	--	--	--
.60	0	--	--	--	--	0	--	--	--	--	--	--
.70	0	0	--	--	--	--	--	--	--	0	--	--
.80	--	--	--	--	--	--	--	--	--	0	--	--
115.27	--	--	--	--	--	--	--	0	--	--	--	--
.40	--	--	--	--	--	--	--	--	0	--	--	--
117.26	0	--	0	0	--	--	--	0	--	0	--	--
.30	0	--	0	0	--	0	--	0	0	0	--	--
.35	--	--	0	--	--	--	--	0	0	--	--	--
.40	0	--	--	--	--	0	+	--	0	0	--	--
.45	--	--	--	--	+	0	0	--	--	--	--	--
.50	0	--	--	--	+	--	--	--	--	0	--	--
.55	--	--	--	--	0	--	--	--	--	--	--	--
.60	--	--	0	+	--	--	--	--	--	--	--	--
.70	--	--	--	+	--	--	--	--	--	--	--	--
.75	--	--	--	--	--	--	0	--	--	--	--	--
.80	--	--	--	--	--	--	0	--	--	--	--	--
.90	--	--	--	--	--	0	--	--	--	--	--	--
118.39	--	--	--	--	--	0	+	--	--	--	--	--
118.5.35	--	--	--	--	--	--	--	--	0	--	--	--
119.33	--	--	--	--	--	--	0	--	--	--	--	--
120.25	0	--	0	0	--	0	--	0	--	0	--	--
.30	0	0	--	0	--	0	--	0	--	--	--	--
.35	--	--	--	--	--	0	0	0	--	--	--	--
.40	--	--	--	--	--	--	0	0	--	--	--	--
.50	--	--	--	+	--	0	--	--	--	--	--	--
.55	--	--	--	--	--	0	--	--	--	--	--	--
.60	0	--	0	--	--	0	--	--	--	0	--	--
.65	--	--	--	--	0	0	--	--	--	--	--	--
.70	0	--	--	--	0	--	0	--	--	0	--	--
.75	--	--	--	--	0	--	0	--	--	--	--	--
.80	--	--	--	--	--	--	0	--	--	0	--	--
123.37	0	--	--	--	0	--	--	--	--	--	--	--
.42	--	--	--	--	0	--	0	--	--	--	--	--
.45	--	--	--	--	--	--	--	--	0	--	--	--
.50	--	--	--	--	--	--	0	--	--	--	--	--
.55	--	--	+	--	--	--	--	--	--	--	--	--
.60	--	0	0	--	--	--	--	--	--	0	--	--
.70	--	--	--	--	--	--	--	--	--	0	--	--
.80	--	--	--	+	--	--	--	--	--	--	--	--
127.20	--	--	--	--	--	--	--	--	--	0	--	--
.34	+	--	0	+	--	--	--	0	--	0	--	--
.37	--	--	--	0	--	--	--	--	--	--	--	--
.40	0	--	0	--	--	--	--	0	0	--	--	--
.42	--	--	--	0	--	--	--	--	--	--	--	--
.45	--	--	0	--	--	0	--	0	0	0	--	--
.50	--	--	0	--	--	--	0	--	--	--	--	--
.55	--	0	--	--	--	--	0	--	--	--	--	--
.60	--	0	--	--	--	0	0	--	--	--	--	--
.70	--	--	--	0	--	--	--	--	--	--	--	--
.80	--	--	--	0	--	--	--	--	--	0	--	--
130.30	--	0	0	--	--	--	0	--	--	0	--	--
.35	--	--	--	--	--	--	0	--	--	0	--	--
.40	--	--	0	--	--	--	0	--	--	0	--	--
.45	--	--	--	0	--	0	0	--	--	--	--	--
.50	0	--	0	0	0	0	--	--	--	--	--	--
.55	--	--	--	0	--	0	--	--	--	--	--	--
.60	0	--	--	--	0	0	--	--	--	--	--	--
.70	--	--	--	--	--	--	0	--	--	--	--	--
.80	--	--	--	--	--	--	0	--	--	0	--	--
133.25	0	0	0	--	0	0	0	0	--	--	--	--
.30	--	--	0	--	--	0	0	0	--	--	--	--
.35	0	--	--	--	--	--	--	--	--	--	--	--
.40	0	--	--	--	--	--	--	--	--	0	--	--
.45	--	--	--	0	--	--	--	--	--	--	--	--
.50	--	--	--	0	--	--	--	--	--	0	--	--
.55	--	--	--	0	--	--	--	--	--	--	--	--
.60	--	--	--	--	--	--	0	--	--	0	--	--
.70	--	--	--	--	--	--	0	--	--	--	--	--

APPENDIX II—Continued

Visual Observations of Saury Abundance, 1957—Continued

Night stations occupied	Cruise and month											
	5701 Jan.	5702 Feb.	5703 Mar.	5704 Apr.	5705 May	5706 June	5707 July	5708 Aug.	5709 Sept.	5710 Oct.	5711 Nov.	5712 Dec.
137.23	--	--	--	0	0	0	0	--	--	0	--	--
.30	--	--	--	0	0	--	0	0	0	0	--	--
.35	--	0	0	--	--	--	--	--	--	0	--	--
.40	--	0	--	--	--	--	--	--	--	--	--	--
.50	--	--	0	--	--	--	0	--	--	0	--	--
.60	--	--	--	--	--	--	0	--	--	0	--	--
.70	--	--	--	0	--	--	--	--	--	0	--	--
.80	--	--	--	0	--	--	--	--	--	--	--	--
140.30	--	--	0	--	--	--	--	--	--	--	--	--
.35	--	--	0	--	--	--	--	--	--	--	--	--
.40	--	0	--	--	--	0	--	--	--	--	--	--
.50	--	0	--	0	--	0	--	--	--	--	--	--
.55	--	--	--	0	--	--	--	--	--	--	--	--
.60	--	--	--	0	--	--	--	--	--	--	--	--
143.26	--	--	0	0	--	--	--	--	--	--	--	--
.30	--	--	0	--	--	--	--	--	--	--	--	--
.35	--	--	0	--	--	--	--	--	--	--	--	--
.40	--	--	0	--	--	--	--	--	--	--	--	--
.50	--	--	--	--	--	0	--	--	--	--	--	--
147.20	--	0	--	0	--	0	--	--	--	--	--	--
.25	--	0	--	0	--	--	--	--	--	--	--	--
.30	--	0	--	0	--	--	--	--	--	--	--	--
.35	--	--	--	0	--	--	--	--	--	--	--	--
.40	--	--	0	0	--	--	--	--	--	--	--	--
.45	--	--	--	0	--	--	--	--	--	--	--	--
.80	--	--	--	0	--	--	--	--	--	--	--	--
150.19	--	+	--	--	--	--	--	--	--	--	--	--
.25	--	0	0	0	--	--	--	--	--	--	--	--
.30	--	--	0	0	--	--	--	--	--	--	--	--
.40	--	--	0	0	--	--	--	--	--	--	--	--
153.16	--	--	--	--	--	--	--	0	--	--	--	--
.20	--	--	--	--	--	--	--	0	--	--	--	--
.30	--	--	--	0	--	--	--	--	--	--	--	--
.35	--	--	--	0	--	--	--	--	--	--	--	--
.40	--	0	--	0	--	0	--	--	--	--	--	--
157.15	--	--	--	0	--	--	--	--	--	--	--	--
.20	--	--	--	0	--	--	--	0	--	--	--	--
.25	--	--	--	0	--	--	--	--	--	--	--	--
.30	--	0	--	0	--	--	--	--	--	--	--	--
.35	--	--	--	0	--	--	--	--	--	--	--	--
.40	--	--	--	0	--	0	--	--	--	--	--	--
Total observations	28	54	36	71	56	79	76	20	14	70	27	13

Visual Observations of Saury Abundance, 1958

Night stations occupied	Cruise and month											
	5801 Jan.	5802 Feb.	5803 Mar.	5804 Apr.	5805 May	5806 June	5807 July	5808 Aug.	5809 Sept.	5810 Oct.	5811 Nov.	5812 Dec.
43.50	--	--	--	0	--	--	--	--	--	--	--	--
.55	--	--	--	0	--	--	--	--	--	--	--	--
60.52	--	--	--	0	--	--	--	--	--	--	--	--
.55	0	--	--	0	--	--	--	--	--	--	--	--
.60	--	--	--	+	--	--	--	--	--	--	--	--
.70	--	--	--	--	+	--	--	--	--	--	--	--
.80	--	--	--	--	0	--	--	--	--	--	--	--
.90	--	--	--	+	--	--	--	--	--	--	--	--
63.50	0	--	--	--	--	--	--	--	--	--	--	--
.52	--	--	--	--	0	--	--	--	--	--	--	--
.55	--	--	--	--	0	--	--	--	--	--	--	--
.60	--	--	--	--	0	--	--	--	--	--	--	--
67.55	--	--	--	0	--	--	--	--	--	--	--	--
.60	--	--	--	0	--	--	--	--	--	--	--	--
.70	--	--	--	--	0	--	--	--	--	--	--	--
.90	--	--	--	0	--	--	--	--	--	--	--	--
.110	--	--	--	0	--	--	--	--	--	--	--	--
70.52	+	--	--	0	--	--	--	--	--	--	--	--
.60	--	--	0	0	0	--	--	--	--	--	--	--
.65	--	--	--	--	0	--	--	--	--	--	--	--
.70	--	--	0	0	0	--	--	--	--	--	--	--
.90	0	--	--	--	--	--	--	--	--	--	--	--

APPENDIX II—Continued

Visual Observations of Saury Abundance, 1958—Continued

Night stations occupied	Cruise and month											
	5801 Jan.	5802 Feb.	5803 Mar.	5804 Apr.	5805 May	5806 June	5807 July	5808 Aug.	5809 Sept.	5810 Oct.	5811 Nov.	5812 Dec.
73.55	--	--	+	--	--	--	--	--	--	--	--	--
.70	--	--	--	--	0	--	--	--	--	--	--	--
.75	--	--	--	0	--	--	--	--	--	--	--	--
.80	--	--	--	0	0	--	--	--	--	--	--	--
.90	--	--	0	--	--	--	--	--	--	--	--	--
77.55	--	--	--	--	0	--	--	--	--	--	--	--
.60	--	--	+	0	+	--	--	--	--	--	--	--
.65	--	--	--	0	--	--	--	--	--	--	--	--
.70	--	--	--	0	--	--	--	--	--	--	--	--
.75	--	--	--	0	--	--	--	--	--	--	--	--
.85	--	--	--	0	--	--	--	--	--	--	--	--
.90	--	--	0	0	--	--	--	--	--	--	--	--
80.51	0	--	--	--	--	--	--	--	--	--	--	--
.55	--	0	+	--	--	--	--	--	--	--	--	--
.60	--	0	0	+	--	--	--	--	--	--	--	--
.65	--	--	--	0	--	--	--	--	--	--	--	--
.70	--	0	0	--	--	--	--	--	--	--	--	--
.80	--	--	--	--	+	--	--	--	--	--	--	--
.90	--	--	--	0	0	--	--	--	--	--	--	--
.120	--	--	--	0	--	--	--	--	--	--	--	--
.130	--	--	--	0	--	--	--	--	--	--	--	--
82.47	0	--	--	--	+	--	--	--	--	--	--	--
83.40	--	0	--	--	--	--	--	--	--	--	--	--
.43	--	0	0	--	+	--	--	--	--	--	--	--
.51	+	0	--	--	--	--	--	--	--	--	--	--
.55	+	--	0	0	--	--	--	--	--	--	--	--
.60	0	--	0	--	--	--	--	--	--	--	--	--
83.65	--	--	--	--	0	--	--	--	--	--	--	--
.70	--	--	--	--	0	--	--	--	--	--	--	--
.80	--	--	--	--	0	--	--	--	--	--	--	--
87.35	--	0	+	--	0	--	--	--	--	--	--	--
.40	0	0	+	--	+	--	--	--	--	--	--	--
.45	+	0	0	0	--	--	--	--	--	--	--	--
.50	--	--	--	0	--	--	--	--	--	--	--	--
.55	+	--	--	--	--	--	--	--	--	--	--	--
.70	--	--	--	--	0	--	--	--	--	--	--	--
.75	--	--	--	--	0	--	--	--	--	--	--	--
.80	--	--	0	0	0	--	--	--	--	--	--	--
90.28	--	0	--	--	0	--	--	--	--	--	--	--
.30	--	0	--	0	0	--	--	--	--	--	--	--
.37	--	0	--	--	0	--	--	--	--	--	--	--
.45	--	--	--	--	0	--	--	--	--	--	--	--
.50	--	--	--	--	0	--	--	--	--	--	--	--
.55	--	0	+	--	--	--	--	--	--	--	--	--
.60	--	+	0	--	--	--	--	--	--	--	--	--
.65	--	--	--	--	0	--	--	--	--	--	--	--
.70	--	0	0	--	0	--	--	--	--	--	--	--
.75	--	--	--	--	0	--	--	--	--	--	--	--
.80	0	--	--	--	--	--	--	--	--	--	--	--
.90	0	--	0	--	--	--	--	--	--	--	--	--
.100	--	--	--	0	--	--	--	--	--	--	--	--
.110	--	--	--	0	--	--	--	--	--	--	--	--
.130	--	--	--	0	--	--	--	--	--	--	--	--
.145	--	--	--	0	--	--	--	--	--	--	--	--
93.30	0	--	--	0	--	--	--	--	--	--	--	--
.35	--	0	--	0	--	--	--	--	--	--	--	--
.40	0	0	--	0	+	--	--	--	--	--	--	--
.45	--	+	0	--	0	--	--	--	--	--	--	--
.50	--	--	0	--	+	--	--	--	--	--	--	--
.60	--	--	0	--	--	--	--	--	--	--	--	--
.70	+	--	--	--	--	--	--	--	--	--	--	--
.80	0	+	0	--	0	--	--	--	--	--	--	--
.85	--	--	--	--	0	--	--	--	--	--	--	--
97.30	--	--	0	--	0	--	--	--	--	--	--	--
.32	--	--	0	0	0	--	--	--	--	--	--	--
.35	--	--	--	0	0	--	--	--	--	--	--	--
.40	--	+	+	0	0	--	--	--	--	--	--	--
.45	--	0	--	0	--	--	--	--	--	--	--	--
.50	0	0	--	--	--	--	--	--	--	--	--	--
.60	0	--	--	--	--	--	--	--	--	--	--	--
.70	--	--	0	0	0	--	--	--	--	--	--	--
.75	--	--	--	0	+	--	--	--	--	--	--	--
.80	--	+	0	+	0	--	--	--	--	--	--	--

APPENDIX II—Continued

Visual Observations of Saury Abundance, 1958—Continued

Night stations occupied	Cruise and month											
	5801 Jan.	5802 Feb.	5803 Mar.	5804 Apr.	5805 May	5806 June	5807 July	5808 Aug.	5809 Sept.	5810 Oct.	5811 Nov.	5812 Dec.
100.29	--	--	--	0	0	--	--	--	--	--	--	--
.30	0	--	0	0	0	--	--	--	--	--	--	--
.32	+	--	+	--	--	--	--	--	--	--	--	--
.35	--	--	--	0	0	--	--	--	--	--	--	--
.40	+	+	--	--	0	--	--	--	--	--	--	--
.50	--	+	--	--	--	--	--	--	--	--	--	--
.60	+	--	+	+	--	--	--	--	--	--	--	--
.70	+	--	0	--	+	--	--	--	--	--	--	--
.75	--	--	--	--	+	--	--	--	--	--	--	--
.80	--	--	--	--	0	--	--	--	--	--	--	--
.90	--	0	--	--	--	--	--	--	--	--	--	--
103.30	--	--	0	--	--	--	--	--	--	--	--	--
.35	+	0	--	--	--	--	--	--	--	--	--	--
.40	+	0	--	--	--	--	--	--	--	--	--	--
.50	+	+	--	0	0	--	--	--	--	--	--	--
.55	--	--	--	0	+	--	--	--	--	--	--	--
.60	--	--	0	+	0	--	--	--	--	--	--	--
.70	--	--	+	--	--	--	--	--	--	--	--	--
.85	--	--	--	--	0	--	--	--	--	--	--	--
.90	--	--	--	+	0	--	--	--	--	--	--	--
107.32	--	--	--	0	--	--	--	--	--	--	--	--
.35	+	--	+	--	--	--	--	--	--	--	--	--
.40	+	+	0	--	--	--	--	--	--	--	--	--
.45	--	--	0	--	--	--	--	--	--	--	--	--
.50	0	+	+	--	--	--	--	--	--	--	--	--
.55	--	--	--	0	--	--	--	--	--	--	--	--
.60	--	--	--	0	0	--	--	--	--	--	--	--
.65	--	--	--	0	0	--	--	--	--	--	--	--
.70	0	--	--	--	--	--	--	--	--	--	--	--
.90	--	--	--	+	0	--	--	--	--	--	--	--
110.45	--	--	--	0	--	--	--	--	--	--	--	--
.50	+	--	+	0	--	--	--	--	--	--	--	--
.55	--	--	--	0	+	--	--	--	--	--	--	--
.60	0	--	+	0	+	--	--	--	--	--	--	--
.65	--	--	--	--	+	--	--	--	--	--	--	--
.70	+	--	--	--	--	--	--	--	--	--	--	--
.75	--	--	--	0	--	--	--	--	--	--	--	--
.80	--	--	--	0	--	--	--	--	--	--	--	--
.85	--	--	--	0	--	--	--	--	--	--	--	--
.90	--	--	--	0	--	--	--	--	--	--	--	--
113.30	0	--	0	+	--	--	--	--	--	--	--	--
.35	0	--	0	--	--	--	--	--	--	--	--	--
.40	0	--	--	--	--	--	--	--	--	--	--	--
.45	--	--	--	--	0	--	--	--	--	--	--	--
.50	--	--	--	--	+	--	--	--	--	--	--	--
.55	--	--	--	--	0	--	--	--	--	--	--	--
.60	--	--	0	+	--	--	--	--	--	--	--	--
.65	--	--	--	0	--	--	--	--	--	--	--	--
.70	0	--	0	0	--	--	--	--	--	--	--	--
113.85	--	--	--	--	0	--	--	--	--	--	--	--
.90	--	--	--	--	0	--	--	--	--	--	--	--
117.26	0	--	+	0	--	--	--	--	--	--	--	--
.30	+	--	0	--	0	--	--	--	--	--	--	--
.35	0	--	--	--	0	--	--	--	--	--	--	--
.40	+	--	--	--	--	--	--	--	--	--	--	--
.55	--	--	--	+	--	--	--	--	--	--	--	--
.60	--	--	+	+	0	--	--	--	--	--	--	--
.65	--	--	--	+	0	--	--	--	--	--	--	--
.70	0	--	0	--	0	--	--	--	--	--	--	--
.75	--	--	--	--	0	--	--	--	--	--	--	--
.90	--	--	--	0	--	--	--	--	--	--	--	--
118.39	0	--	--	--	0	--	--	--	--	--	--	--
119.33	0	--	--	--	--	--	--	--	--	--	--	--
120.30	--	--	--	0	--	--	--	--	--	--	--	--
.35	0	--	--	0	0	--	--	--	--	--	--	--
.40	--	--	--	0	0	--	--	--	--	--	--	--
.45	0	--	0	--	0	--	--	--	--	--	--	--
.50	--	--	+	0	0	--	--	--	--	--	--	--
.55	--	--	--	0	--	--	--	--	--	--	--	--
.60	--	--	0	0	--	--	--	--	--	--	--	--
.70	0	--	--	--	--	--	--	--	--	--	--	--
.80	0	--	--	--	0	--	--	--	--	--	--	--
.85	--	--	--	0	0	--	--	--	--	--	--	--
.90	--	--	--	+	0	--	--	--	--	--	--	--
123.37	0	--	0	0	--	--	--	--	--	--	--	--
.42	0	--	0	--	--	--	--	--	--	--	--	--
.50	--	--	0	--	--	--	--	--	--	--	--	--
.60	--	--	--	--	0	--	--	--	--	--	--	--
.70	0	--	--	0	--	--	--	--	--	--	--	--

APPENDIX II—Continued

Visual Observations of Saury Abundance, 1958—Continued

Night stations occupied	Cruise and month											
	5801 Jan.	5802 Feb.	5803 Mar.	5804 Apr.	5805 May	5806 June	5807 July	5808 Aug.	5809 Sept.	5810 Oct.	5811 Nov.	5812 Dec.
127.34	0	--	0	--	--	--	--	--	--	--	--	--
.40	--	--	0	--	--	--	--	--	--	--	--	--
.45	--	--	0	--	--	--	--	--	--	--	--	--
.50	--	--	--	0	--	--	--	--	--	--	--	--
.55	--	--	--	0	--	--	--	--	--	--	--	--
.60	--	--	--	0	0	--	--	--	--	--	--	--
.70	0	--	--	--	--	--	--	--	--	--	--	--
.80	--	--	--	0	--	--	--	--	--	--	--	--
130.30	0	--	0	--	+	--	--	--	--	--	--	--
.35	--	--	--	--	0	--	--	--	--	--	--	--
.40	--	--	--	--	0	--	--	--	--	--	--	--
.45	--	--	--	0	--	--	--	--	--	--	--	--
.50	--	--	--	0	--	--	--	--	--	--	--	--
.55	--	--	--	0	--	--	--	--	--	--	--	--
.60	0	--	0	--	--	--	--	--	--	--	--	--
133.25	0	--	--	0	0	--	--	--	--	--	--	--
.30	0	--	--	0	--	--	--	--	--	--	--	--
.40	--	--	--	0	--	--	--	--	--	--	--	--
.50	--	--	0	--	0	--	--	--	--	--	--	--
.60	0	--	--	--	--	--	--	--	--	--	--	--
.70	--	--	--	0	--	--	--	--	--	--	--	--
.80	--	--	--	0	--	--	--	--	--	--	--	--
137.23	0	--	--	--	0	--	--	--	--	--	--	--
.30	--	--	0	--	--	--	--	--	--	--	--	--
.35	--	--	--	0	--	--	--	--	--	--	--	--
.40	--	--	0	0	--	--	--	--	--	--	--	--
.45	--	--	--	0	0	--	--	--	--	--	--	--
.50	0	--	--	0	0	--	--	--	--	--	--	--
.60	0	--	--	--	--	--	--	--	--	--	--	--
.80	--	--	--	0	--	--	--	--	--	--	--	--
140.30	0	--	0	--	--	--	--	--	--	--	--	--
.35	0	--	0	--	--	--	--	--	--	--	--	--
.40	0	--	--	--	--	--	--	--	--	--	--	--
143.26	--	--	0	--	--	--	--	--	--	--	--	--
.30	--	--	0	--	--	--	--	--	--	--	--	--
.40	0	--	--	--	--	--	--	--	--	--	--	--
.50	0	--	--	--	--	--	--	--	--	--	--	--
.60	0	--	--	--	--	--	--	--	--	--	--	--
147.20	0	--	0	--	--	--	--	--	--	--	--	--
.25	0	--	0	--	--	--	--	--	--	--	--	--
.30	0	--	0	--	--	--	--	--	--	--	--	--
.40	0	--	--	--	--	--	--	--	--	--	--	--
150.19	0	--	--	--	--	--	--	--	--	--	--	--
153.16	0	--	--	--	--	--	--	--	--	--	--	--
.20	0	--	--	--	--	--	--	--	--	--	--	--
.40	0	--	--	--	--	--	--	--	--	--	--	--
.50	+	--	--	--	--	--	--	--	--	--	--	--
157.10	0	--	--	--	--	--	--	--	--	--	--	--
.20	0	--	--	--	--	--	--	--	--	--	--	--
.50	0	--	--	--	--	--	--	--	--	--	--	--
Total observations	81	31	71	103	91	0	0	0	0	0	0	0

APPENDIX III

Hugh M. Smith, Cruise 29—30-Minute Oblique Tows with Open 1-Meter Net

Station	Lat. N.	Long. W.	Date 1955	Time started (local)	Depth of tow (m.)	Water strained (m.³)	Surface temp. (°C.)	Surface salinity (°/₀₀)	Saury	
									Eggs	Larvae
3	30°00′	155°00′	5/6	0756	158	1,457	19.9	35.17	--	--
5	31°54′	154°49′	5/7	0742	140	2,390	19.2	35.05	--	--
7	33°54′	154°45′	5/8	0722	140	1,674	18.3	34.77	--	--
9	35°52′	154°53′	5/9	0707	124	2,071	15.7	33.99	--	--
11	37°40′	154°53′	5/10	0748	140	1,447	14.9	34.12	--	--
13	38°23′	154°51′	5/11	0715	124	1,851	13.6	33.96	--	--
15	40°08′	155°02′	5/12	0721	120	1,844	11.9	33.74	--	1
16	42°20′	154°47′	5/13	0714	139	1,058	10.1	33.57	--	--
17	40°18′	153°12′	5/14	0813	120	1,345	12.5	33.70	--	--
18	34°37′	149°16′	5/16	0806	112	1,828	17.9	34.33	--	--
19	32°12′	147°17′	5/17	0715	124	2,037	19.1	34.84	--	--
23	35°36′	147°31′	5/19	0712	137	2,415	16.5	33.96	--	--
25	37°53′	147°00′	5/20	0710	110	2,218	15.6	33.93	--	2
27	39°53′	146°40′	5/21	0704	125	1,608	13.8	33.88	--	--
31	39°49′	145°19′	5/23	0814	116	1,803	13.9	33.73	--	--
32	36°29′	144°44′	5/24	0809	131	2,290	16.9	34.04	--	1
33	34°03′	142°09′	5/25	0800	107	2,067	17.2	34.43	--	2
34	37°21′	140°47′	5/26	0803	140	1,968	16.1	33.95	--	1
35	40°38′	139°07′	5/27	0804	138	1,702	13.9	33.35	--	--
36	41°48′	138°57′	5/30	0703	132	1,818	12.2	33.30	--	--
37	39°29′	139°02′	5/31	0712	141	1,229	13.6	33.43	--	--
39	37°18′	139°05′	6/1	0704	135	1,805	15.4	33.67	--	--
41	35°11′	138°54′	6/2	0702	151	1,944	16.2	34.04	--	--
42	33°01′	139°06′	6/3	0656	131	1,975	16.6	34.20	--	--
43	30°58′	139°08′	6/4	0655	131	1,626	17.2	34.70	--	--
44	28°55′	139°13′	6/5	0657	138	1,723	18.2	34.96	--	--
45	28°03′	141°23′	6/6	0658	135	2,254	19.2	35.25	--	--
46	26°53′	143°48′	6/7	0653	142	1,819	20.5	35.32	--	--
47	25°54′	145°47′	6/8	0658	139	2,029	21.0	35.37	--	--
48	25°12′	148°11′	6/9	0652	124	2,022	21.8	35.06	--	--
49	24°20′	150°17′	6/10	0700	145	2,149	21.9	35.03	--	--
50	23°28′	152°34′	6/11	0703	128	1,712	22.3	35.14	--	--
51	22°37′	154°47′	6/12	0655	204	922	29.2	34.59	--	--
52	22°07′	156°13′	6/13	0650	144	2,104	23.1	34.77	--	--

APPENDIX III—Continued

Charles H. Gilbert, Cruise 27—30-Minute Oblique Tows with 1-Meter Net

Station	Lat. N.	Long. W.	Date 1956	Time started (local)	Depth of tow (m.)	Water strained (m.^{3})	Surface temp. (°C.)	Surface salinity (°/oo)	Saury	
									Eggs	Larvae
7	34°22′	179°59′	3/27	1408	142	4,092	16.8	34.74	--	1
9	36°16′	179°58′	3/28	1500	140	4,465	14.6	34.45	--	3
11	34°25′	177°40′	4/2	1230	140	4,299	16.6	34.81	--	--
13	33°11′	176°58′	4/3	1231	140	3,645	16.0	34.56	--	1
15	32°06′	176°24′	4/4	1227	140	3,495	17.6	34.78	--	--
17	32°00′	175°44′	4/5	1228	140	3,449	17.5	34.69	--	--
18	34°21′	173°34′	4/6	1231	140	--	--	--	--	--
19	35°39′	172°37′	4/7	1228	140	3,788	15.5	34.74	--	--
21	34°16′	170°46′	4/9	1236	140	3,994	16.5	34.69	--	1
23	33°12′	170°20′	4/10	1232	140	4,207	17.3	34.61	--	--
26	32°56′	167°57′	4/20	1220	140	3,713	16.5	34.72	--	--
27	36°00′	166°49′	4/22	1223	140	--	--	--	--	--
33	32°17′	163°04′	4/30	0850	140	--	--	--	--	--

John R. Manning, Cruise 32—30-Minute Oblique and Horizontal Tows with 1-Meter Net

Station	Lat. N.	Long. E.	Date 1956	Time started (local)	Depth of tow (m.)	Water strained (m.^{3})	Surface temp. (°C.)	Surface salinity (°/oo)	Saury	
									Eggs	Larvae
9	40°01′	174°58′	7/24	2136	--	1,248	18.0	--	--	--
31	47°01′	175°00′	8/4	2206	--	--	--	--	--	--
35	48°59′	175°00′	8/14	2140	--	905	12.6	--	--	--
37	45°52′	171°51′	8/15	2137	--	1,681	14.9	--	--	--
42	46°28′	166°54′	8/19	2143	--	--	--	--	--	--
44	46°00′	160°16′	8/22	2057	--	994	12.1	32.77	--	--
48	46°05′	157°56′	8/25	2205	--	--	--	--	--	--
51	46°27′	152°15′	8/27	2203	--	1,060	12.4	--	--	--
55	46°32′	147°13′	8/29	2220	--	--	--	--	--	--
59	45°59′	145°02′	8/31	2200	--	--	--	--	--	--
61	44°57′	145°01′	9/1	2205	--	--	--	--	--	--
63	43°58′	144°58′	9/2	2140	--	--	--	--	--	--
64	42°22′	144°51′	9/3	2034	--	994	17.9	--	--	--
73	22°11′	157°25′	9/10	2210	--	2,682	25.2	--	--	--
74	21°36′	157°44′	9/11	0325	60	1,589	25.1	35.07	--	--
75	21°57′	157°44′	9/11	0720	60	1,384	25.1	35.03	--	--
76	22°15′	157°47′	9/11	0937	60	2,131	25.3	34.99	--	--
77	21°25′	158°56′	9/11	2325	60	1,485	26.1	34.78	--	--
78	21°25′	158°32′	9/12	0239	60	1,543	25.4	34.90	--	--
79	21°24′	158°18′	9/12	0504	60	--	--	--	--	--

APPENDIX III—Continued

***Charles H. Gilbert*, Cruise 31—30-Minute Horizontal and Oblique Tows with Open 1-Meter Net**

Station	Lat. N.	Long. W.	Date 1956	Time started (local)	Depth of tow (m.)	Water strained (m.³)	Surface temp. (° C.)	Surface salinity (°/₀₀)	Saury	
									Eggs	Larvae
1	23°25′	156°00′	10/23	1335	0–140	1,194	25.9	34.96	--	--
2	25°58′	153°43′	10/24	1340	0–140	1,481	24.9	35.16	--	--
3	28°42′	151°40′	10/25	1331	0–140	1,356	24.0	35.34	--	--
4	31°33′	149°30′	10/26	1403	0–140	1,260	22.9	35.30	--	--
5	34°16′	147°12′	10/27	1340	0–140	1,502	21.8	35.07	--	--
6	36°50′	144°51′	10/28	1400	0–140	1,781	19.7	34.40	--	--
7	37°22′	144°26′	10/28	1820	0	1,585	19.3	34.29	--	--
8	40°14′	136°15′	11/5	1808	0	1,535	16.6	33.68	--	1
9	38°56′	135°06′	11/7	1412	0–140	1,151	16.8	33.42	--	--
10	38°36′	134°42′	11/8	0838	0	1,161	16.6	33.33	--	--
12	37°48′	134°06′	11/9	0755	0	1,409	16.8	33.10	--	--
13	38°03′	133°26′	11/9	1305	0–140	1,426	16.8	33.10	--	--
14	38°31′	132°46′	11/10	0740	0	1,242	16.5	33.98	--	--
15	38°47′	131°58′	11/10	1400	0–140	1,594	16.7	33.06	--	--
16	39°07′	131°23′	11/11	0825	0	1,329	16.2	32.77	--	--
17	39°33′	130°52′	11/11	1300	0–140	1,123	15.7	32.68	--	--
18	39°59′	130°08′	11/12	0815	0	--	16.1	33.02	--	--
19	40°18′	129°39′	11/12	1300	0–140	1,309	15.9	32.77	--	--
20	37°18′	127°45′	11/15	1300	0–140	1,452	15.8	33.01	--	--
21	37°07′	127°44′	11/16	0855	0	1,338	15.9	33.03	--	--
22	36°43′	127°29′	11/16	1300	0–140	1,330	15.9	33.99	--	--
24	35°16′	124°00′	11/21	1300	0–140	1,199	12.1	33.44	--	--
25	38°00′	126°14′	11/28	1300	0–140	1,114	15.2	33.10	--	--
26	37°02′	129°32′	11/29	1300	0–140	1,357	15.6	32.86	--	--
27	35°26′	129°43′	11/30	1300	0–140	865	16.1	33.10	--	--
28	33°56′	129°39′	12/1	1300	0–140	1,067	16.4	33.24	--	--
29	33°17′	129°34′	12/2	0830	0	1,447	16.5	33.33	--	--
30	32°47′	129°35′	12/2	1300	0–140	1,229	16.6	33.33	--	--
31	32°09′	129°36′	12/3	0800	0	1,494	17.8	34.02	--	2
32	31°36′	129°47′	12/3	1300	0–140	1,474	18.2	34.02	--	--
33	30°02′	133°16′	12/4	1300	0–140	1,479	19.4	34.52	--	--
34	28°51′	137°16′	12/5	1300	0–140	1,348	20.7	35.25	--	--
35	28°10′	140°06′	12/6	1300	0–140	1,295	21.1	35.19	--	--
36	26°50′	143°40′	12/7	1300	0–140	1,541	22.1	35.37	--	--

***John R. Manning*, Cruise 33—30-Minute Horizontal Tow with Open 1-Meter Net**

Station	Lat. N.	Long. W.	Date 1956	Time started (local)	Depth of tow (m.)	Water strained (m.³)	Surface temp. (° C.)	Surface salinity (°/₀₀)	Saury Eggs	Saury Larvae
1	24°15′	156°19′	10/18	2015	0	1,556	25.2	--	--	--
2	27°09′	154°55′	10/19	2000	0	--	24.4	35.26	--	--
3	30°04′	153°15′	10/20	1955	0	1,944	23.2	35.44	--	--
4	32°56′	151°48′	10/21	2002	0	1,147	22.0	34.99	--	--
5	35°52′	150°22′	10/22	2000	0	1,604	20.6	34.85	--	--
6	38°54′	149°00′	10/23	1952	0	1,873	17.9	33.75	--	--
7	40°20′	148°07′	10/24	2025	0	1,366	17.8	33.93	--	4
8	41°02′	147°56′	10/25	2030	0	1,348	15.3	33.37	--	--
9	42°06′	147°15′	10/27	2044	0	1,782	14.4	33.26	--	--
10	42°54′	146°27′	10/28	2034	0	1,280	13.5	32.83	--	--
11	41°51′	127°52′	11/14	2001	0	1,392	13.4	32.21	--	--
12	40°52′	128°30′	11/15	2003	0	1,209	15.6	32.79	--	--
13	39°27′	129°23′	11/16	2003	0	1,585	15.9	--	--	--
14	38°42′	130°35′	11/17	2000	0	1,581	16.1	33.01	--	--
15	38°07′	133°46′	11/18	2045	0	1,989	16.3	33.30	--	1
16	37°10′	133°36′	11/19	1930	0	1,617	17.0	33.68	2	--
17	37°29′	135°08′	11/20	1940	0	--	17.1	33.77	--	--
18	39°13′	135°41′	11/21	1930	0	1,326	16.3	33.51	--	2
19	40°10′	136°04′	11/22	1930	0	1,204	15.8	33.66	--	2
20	41°05′	136°36′	11/23	1930	0	1,247	15.2	33.46	--	--
21	40°08′	140°13′	11/26	1937	0	944	16.4	33.82	--	--
22	42°11′	143°56′	11/30	2015	0	1,435	13.3	32 99	--	--

APPENDIX III—Continued

***Hugh H. Smith*, Cruise 40—30-Minute Horizontal Tow with Open 1-Meter Net**

Station	Lat. N.	Long. W.	Date 1957	Time started (local)	Depth of tow (m.)	Water strained ($m.^3$)	Surface temp. (° C.)	Surface salinity (‰)	Saury	
									Eggs	Larvae
2	22°38′	156°43′	7/2	1330	0	931	24.8	--	--	--
3	23°13′	156°14′	7/2	2146	0	1,058	24.8	--	--	--
5	24°40′	154°47′	7/3	1339	0	1,152	24.4	--	--	--
6	25°15′	154°06′	7/3	2145	0	2,009	24.3	--	--	--
8	26°45′	152°35′	7/4	1319	0	1,238	23.9	35.52	--	--
9	27°25′	151°50′	7/4	2132	0	1,905	24.4	35.39	--	--
11	29°10′	150°32′	7/5	1317	0	1,264	23.4	35.43	--	--
12	30°02′	149°55′	7/5	2124	0	2,117	23.2	--	--	--
14	31°47′	148°30′	7/6	1308	0	1,042	23.1	34.97	--	--
16	32°51′	147°44′	7/6	2205	0	2,182	22.8	34.83	--	--
18	34°46′	146°19′	7/7	1314	0	892	24.1	34.42	--	--
20	35°52′	145°33′	7/7	2204	0	2,477	21.8	34.23	--	--
22	37°53′	144°00′	7/8	1313	0	1,058	19.6	33.75	--	--
23	38°47′	143°20′	7/8	2203	0	2,279	18.9	33.66	--	--
24	40°27′	142°06′	7/9	1300	0	1,125	17.3	33.21	--	--
25	41°02′	141°30′	7/9	2152	0	2,540	16.9	33.19	--	--
26	41°32′	141°00′	7/10	0152	0	1,244	15.7	32.97	--	--
27	42°24′	140°06′	7/10	1301	0	1,262	15.5	32.95	--	--
28	43°09′	139°25′	7/10	2154	0	2,201	15.0	32.86	--	--
29	43°52′	138°44′	7/11	0322	0	1,222	14.3	32.88	--	--
30	44°43′	137°52′	7/11	1256	0	1,362	14.2	32.66	--	--
31	45°24′	137°12′	7/11	2209	0	1,564	13.8	32.66	--	--
32	43°46′	136°24′	7/12	1433	0	773	14.8	32.77	--	--
33	43°02′	136°10′	7/12	2123	0	1,670	15.2	32.77	--	--
34	41°10′	135°20′	7/13	1254	0	1,241	16.8	33.22	--	--
35	40°33′	134°37′	7/13	2324	0	2,205	17.1	33.26	--	--
36	40°43′	133°18′	7/14	1321	0	1,022	16.8	33.04	--	--
37	41°29′	132°46′	7/14	2215	0	1,224	16.5	33.01	--	--
38	43°04′	131°34′	7/15	1346	0	810	16.1	32.83	--	--
39	43°33′	131°09′	7/15	1934	0	1,032	15.8	32.83	--	--
40	43°45′	130°59′	7/15	2215	0	2,105	15.4	32.81	--	--
41	44°49′	130°02′	7/16	1110	0	1,187	14.9	32.68	--	--
42	44°56′	130°00′	7/16	1323	0	939	14.9	32.68	--	--
43	45°12′	129°03′	7/16	2215	0	2,067	15.6	32.38	--	--
44	45°26′	128°06′	7/17	0530	0	998	15.7	31.98	--	--
45	45°41′	127°04′	7/17	1315	0	1,102	16.1	31.74	--	--
46	45°43′	126°48′	7/17	1512	0	1,250	16.2	32.52	--	--
47	45°54′	125°58′	7/17	2215	0	1,832	16.5	31.83	--	--
49	47°01′	126°18′	7/22	1328	0	1,129	16.6	31.15	--	--
50	47°02′	126°35′	7/22	1619	0	926	16.6	31.40	--	--
51	47°02′	126°53′	7/22	1852	0	1,129	16.6	31.65	--	--
52	47°02′	127°08′	7/22	2100	0	1,965	16.1	30.81	--	--
53	47°00′	127°07′	7/23	0513	0	1,181	16.1	31.38	--	--
54	47°00′	127°18′	7/23	0728	0	1,264	16.1	31.38	--	--
55	47°01′	127°48′	7/23	1207	0	1,265	16.2	31.71	--	--
56	47°01′	127°48′	7/23	1350	0	1,015	15.4	32.38	--	--
57	47°00′	129°08′	7/23	2210	0	2,172	15.1	32.18	--	--
58	46°47′	130°22′	7/24	1317	0	1,115	15.1	32.50	--	--
59	46°44′	130°49′	7/24	1715	0	2,393	15.1	32.54	--	--
60	46°45′	131°04′	7/24	2151	0	2,584	15.5	32.48	--	--
61	46°46′	130°49′	7/24	2322	0	2,684	15.0	32.48	2	--
62	46°48′	132°07′	7/25	1324	0	885	14.6	32.52	1	--
63	46°51′	132°46′	7/25	1722	0	778	14.4	32.54	--	--
64	46°55′	133°23′	7/25	2139	0	1,937	14.3	32.54	1	--
67	46°06′	130°04′	7/27	1318	0	1,312	15.3	32.57	--	--
68	46°04′	129°48′	7/27	1525	0	1,290	15.7	32.61	--	--
69	46°01′	128°55′	7/27	2306	0	2,460	15.8	32.52	--	--
70	45°58′	127°29′	7/28	1316	0	1,247	16.4	32.43	--	--
71	45°15′	126°52′	7/28	2150	0	2,353	17.3	31.71	--	--
72	44°20′	125°54′	7/29	1347	0	1,002	18.0	30.28	--	--
73	44°00′	125°07′	7/29	2133	0	2,562	16.0	30.62	--	--
74	43°18′	126°00′	7/30	1319	0	1,375	16.9	31.94	--	--
75	42°56′	126°59′	7/30	2236	0	1,592	17.8	32.07	--	--
76	42°47′	127°15′	7/31	0617	0	1,180	17.6	32.28	--	--
77	42°36′	127°53′	7/31	1126	0	1,385	17.5	32.14	--	--
81	41°32′	131°05′	8/1	2205	0	--	--	--	--	--
82	41°26′	129°26′	8/2	1318	0	1,131	17.4	32.93	--	--
83	41°23′	129°02′	8/2	1623	0	1,286	17.7	32.84	--	--
84	41°18′	128°25′	8/2	2141	0	1,462	17.1	32.86	--	--
85	41°04′	126°56′	8/3	1432	0	1,044	15.3	32.60	--	--
87	40°58′	126°01′	8/3	2142	0	1,233	15.7	32.12	--	--
88	40°48′	125°00′	8/4	1050	0	718	12.3	33.04	--	--
89	40°40′	125°19′	8/4	1317	0	664	12.6	32.90	--	--
90	40°36′	125°30′	8/4	1456	0	979	13.5	32.84	--	--
91	40°34′	125°36′	8/4	1603	0	948	15.8	34.07	--	--
92	40°26′	126°16′	8/4	2117	0	1,105	15.4	32.64	--	--
94	40°12′	127°23′	8/5	1313	0	1,053	16.9	32.68	--	--
95	40°04′	128°20′	8/5	2134	0	997	17.1	32.74	--	--
97	39°45′	129°29′	8/6	1320	0	1,126	17.5	32.87	--	--
98	39°32′	130°42′	8/6	2132	0	1,090	18.0	32.98	--	--
100	39°17′	129°45′	8/7	1321	0	1,224	17.8	33.00	--	--

APPENDIX III—Continued

***Hugh M. Smith*, Cruise 40—30-Minute Horizontal Tow with Open 1-Meter Net—Continued**

Station	Lat. N.	Long. W.	Date 1957	Time started (local)	Depth of tow (m.)	Water strained (m.³)	Surface temp. (° C.)	Surface salinity (°/₀₀)	Saury	
									Eggs	Larvae
101	39°08′	128°40′	8/7	2130	0	1,310	17.7	32.92	--	--
102	39°02′	128°21′	8/8	0538	0	1,234	17.5	32.95	--	--
103	38°59′	127°56′	8/8	0946	0	1,186	17.6	32.96	--	--
104	39°00′	127°33′	8/8	1543	0	1,369	17.8	32.99	--	--
105	39°02′	127°01′	8/8	2208	0	1,258	16.2	32.86	--	--
106	39°10′	125°37′	8/9	1342	0	1,179	17.2	32.88	--	--
107	39°09′	125°26′	8/9	1508	0	--	17.1	32.89	--	--
108	39°00′	124°35′	8/9	2013	0	1,328	14.4	32.81	--	--
109	38°57′	124°24′	8/9	2123	0	762	13.4	33.17	20	--
111	38°43′	124°46′	8/10	0850	0	996	14.2	33.38	--	--
112	38°37′	125°01′	8/10	1126	0	785	14.2	33.30	--	--
113	38°31′	125°31′	8/10	1646	0	940	17.0	32.85	--	--
114	38°26′	126°00′	8/10	1928	0	952	17.1	32.86	--	--
116	38°10′	127°26′	8/11	0949	0	1,326	17.7	32.95	--	--
117	38°02′	127°51′	8/11	1400	0	1,232	17.7	33.04	--	--
118	37°53′	128°34′	8/11	1954	0	1,447	17.7	32.94	--	--
119	37°28′	130°12′	8/12	0614	0	1,402	18.5	33.06	--	--
120	37°19′	129°20′	8/12	1315	0	1,202	18.7	33.19	--	--
121	37°16′	129°08′	8/12	1524	0	1,191	17.9	33.10	--	--
122	37°11′	128°46′	8/12	1807	0	1,035	17.9	33.04	--	--
123	37°09′	128°34′	8/12	2112	0	1,128	17.9	33.10	--	--
124	37°02′	128°13′	8/13	0722	0	1,024	17.9	33.03	--	--
125	37°01′	127°30′	8/13	1310	0	1,342	17.5	32.95	--	--
127	37°00′	125°26′	8/14	1316	0	1,145	17.3	32.94	--	--
128	37°06′	125°04′	8/14	1725	0	1,247	16.3	32.97	--	--
130	37°26′	123°52′	8/15	0212	0	--	14.1	33.58	7	--
132	36°43′	122°24′	8/26	2146	0	1,277	15.2	33.40	--	--
134	35°14′	123°13′	8/27	1313	0	1,070	15.6	33.55	4	--
135	34°29′	124°17′	8/27	2132	0	894	17.2	33.31	--	--
137	33°36′	126°30′	8/28	1315	0	1,111	18.9	33.37	--	--
138	33°08′	127°47′	8/28	2010	0	2,266	19.1	33.22	--	--
140	32°10′	130°28′	8/29	1304	0	1,232	21.1	34.04	--	--
141	31°43′	131°44′	8/29	2059	0	2,458	21.7	34.09	--	--
143	30°44′	134°20′	8/30	1310	0	1,210	21.4	34.31	--	--
144	30°14′	135°33′	8/30	2100	0	1,975	21.9	34.25	--	--
146	29°12′	138°23′	8/31	1306	0	1,007	23.1	35.35	--	--
147	28°44′	139°36′	8/31	2055	0	2,147	22.9	35.42	--	--
149	27°43′	142°13′	9/1	1311	0	1,137	23.6	35.41	--	--
150	27°16′	143°27′	9/1	2058	0	2,255	23.4	35.32	--	--
152	26°09′	146°01′	9/2	1305	0	1,138	24.1	35.26	--	--
153	25°41′	147°10′	9/2	2054	0	2,232	23.5	35.30	--	--
155	24°38′	149°40′	9/3	1306	0	983	24.1	35.39	--	--
156	24°07′	150°51′	9/3	2056	0	2,002	24.5	35.25	--	--
158	23°04′	153°24′	9/4	1308	0	904	24.9	35.19	--	--
159	22°32′	154°39′	9/4	2056	0	2,051	24.8	35.17	--	--

***Hugh M. Smith*, Cruise 46—30-Minute Horizontal and Oblique Tows with 1-Meter Net**

Station	Lat. N.	Long. W.	Date 1958	Time started (local)	Depth of tow (m.)	Water strained (m.³)	Surface temp. (°C.)	Surface salinity (°/₀₀)	Saury	
									Eggs	Larvae
4	23°56′	158°28′	7/22	2127	142	1,623	25.4	--	--	--
4	23°56′	158°28′	7/22	2201	0	1,106	25.4	--	--	--
7	27°08′	158°38′	7/23	2150	130	1,951	23.9	--	--	--
10	30°36′	158°56′	7/24	2119	137	1,940	--	--	--	--
10	30°36′	158°56′	7/24	2201	0	1,229	24.2	--	--	--
13	34°03′	158°54′	7/25	2104	144	1,400	--	--	--	--
16	37°25′	159°09′	7/26	2145	141	1,847	--	--	--	--
16	37°25′	159°09′	7/26	2220	0	1,134	--	--	--	--
19	39°41′	159°24′	7/27	2158	140	1,892	14.8	--	--	--
19	39°41′	159°24′	7/27	2240	0	1,129	14.8	--	1	--
22	40°49′	159°38′	7/28	2145	150	1,327	17.5	--	--	--
22	40°49′	159°38′	7/28	2220	0	1,553	17.5	--	--	--
26	41°20′	159°56′	7/29	2141	109	2,403	16.3	--	--	--
26	41°20′	159°56′	7/29	2222	0	903	16.3	--	--	--
29	41°46′	159°24′	7/30	2051	142	1,708	14.8	--	--	--
29	41°46′	159°24′	7/30	2127	0	1,176	14.8	--	--	--
33	41°09′	158°24′	7/31	2040	123	1,598	16.3	--	1	--
33	41°09′	158°24′	7/31	2113	0	1,421	16.3	--	1	--
37	42°19′	158°22′	8/1	2045	140	1,345	--	--	--	--
37	42°19′	158°22′	8/1	2118	0	1,065	--	--	--	--
40	43°10′	158°47′	8/2	2052	140	1,746	13.7	--	--	--
40	43°10′	158°47′	8/2	2136	0	1,197	13.7	--	--	--
43	45°02′	159°23′	8/4	2120	143	1,770	--	--	--	--

APPENDIX III—Continued

Hugh M. Smith, Cruise 46—30-Minute Horizontal and Oblique Tows with 1-Meter Net—Continued

Station	Lat. N.	Long. W.	Date 1958	Time started (local)	Depth of tow (m.)	Water strained (m.³)	Surface temp. (°C.)	Surface salinity (°/₀₀)	Saury	
									Eggs	Larvae
43	45°02′	159°23′	8/4	2155	0	1,089	--	--	--	--
46	48°06′	159°42′	8/5	2330	141	1,671	9.7	--	--	--
46	48°06′	159°42′	8/6	0006	0	1,158	9.7	--	--	--
48	50°56′	159°49′	8/6	2128	142	1,840	--	--	--	--
48	50°56′	159°49′	8/6	2207	0	1,382	--	--	--	--
50	54°00′	159°56′	8/7	2043	140	1,039	--	--	--	--
50	54°00′	159°56′	8/7	2112	0	1,121	--	--	--	--
53	48°03′	174°45′	8/12	0113	140	1,005	10.9	--	--	--
53	48°03′	174°45′	8/12	0144	0	893	10.9	--	--	--
56	46°12′	174°56′	8/12	2139	137	--	--	--	--	--
56	46°12′	174°56′	8/12	2220	0	1,572	--	--	--	--
60	45°12′	174°53′	8/13	2124	114	911	--	--	--	--
63	43°29′	174°48′	8/15	1926	145	1,098	--	--	--	--
63	43°29′	174°48′	8/15	2050	0	--	--	--	--	--
64	43°22′	174°43′	8/16	1835	142	1,644	14.9	--	--	--
67	42°48′	175°08′	8/17	1900	142	1,731	16.1	--	--	--
68	42°46′	175°08′	8/18	1920	0	--	--	--	--	--
69	41°35′	175°08′	8/19	2108	0	--	16.4	--	--	--
69	41°35′	175°08′	8/19	2143	143	1,078	16.4	--	--	--
71	41°35′	175°02′	8/22	1220	0	--	--	--	--	--
75	41°33′	175°01′	8/22	1839	137	2,267	16.5	--	--	--
79	40°29′	175°11′	8/23	1826	143	1,216	17.8	--	--	--
79	40°29′	175°11′	8/23	1852	0	1,385	17.8	--	--	--
85	39°50′	170°52′	8/25	2208	112	1,430	18.7	--	--	--
85	39°50′	170°52′	8/25	2242	0	1,775	18.7	--	--	--
88	40°15′	170°16′	8/26	1825	141	1,591	--	--	--	--
88	40°15′	170°16′	8/26	2159	0	1,257	--	--	--	--
90	42°21′	170°12′	8/28	2135	140	1,484	--	--	--	--
90	42°21′	170°12′	8/28	2210	0	1,265	--	--	--	--
91	42°50′	169°57′	8/29	2236	156	1,495	--	--	--	--
91	42°50′	169°57′	8/29	2314	0	1,569	--	--	--	--
94	43°57′	169°30′	8/30	1809	173	1,441	--	--	--	--
94	43°57′	169°30′	8/30	1841	0	1,314	--	--	--	--
96	45°46′	168°46′	8/31	1918	141	1,613	12.6	--	--	--
96	45°46′	168°46′	8/31	2023	0	1,308	12.6	--	--	--
98	46°34′	164°44′	9/1	1759	140	914	--	--	--	--

Hugh M. Smith, Cruise 52—30-Minute Horizontal Tows with 1-Meter Net

Station	Lat. N.	Long. E.	Date 1959	Time started (local)	Depth of tow (m.)	Water strained (m.³)	Surface temp. (°C.)	Surface salinity (°/₀₀)	Saury	
									Eggs	Larvae
2	23°51′	154°40′	4/29	2015	--	1,252	22.8	35.00	--	--
4	26°12′	151°48′	4/30	2005	--	1,380	22.3	34.97	--	--
6	28°40′	148°48′	5/1	2005	--	1,393	20.0	35.11	--	--
8	31°06′	145°41′	5/2	2037	--	1,500	18.3	34.61	--	--
10	33°16′	142°50′	5/3	2032	--	1,579	17.1	34.12	--	--
14	35°53′	139°14′	5/5	2030	--	1,535	16.0	33.75	13	--
16	37°12′	137°31′	5/6	2030	--	1,594	16.1	33.57	5	--
20	37°47′	133°46′	5/8	2030	--	1,478	14.6	33.16	5	--
23	35°38′	131°05′	5/10	2005	--	1,506	15.4	33.22	--	--
25	33°45′	128°45′	5/11	2031	--	1,478	15.7	33.20	--	--
27	32°04′	127°24′	5/17	2030	--	1,607	16.4	33.40	5	--
29	30°48′	124°52′	5/18	2030	--	1,111	16.6	33.59	--	--
31	28°28′	123°04′	5/21	2027	--	1,671	17.6	33.96	--	--
39	27°33′	118°23′	5/25	2000	--	1,405	17.8	33.81	--	--
41	30°56′	117°47′	5/26	2000	--	1,342	16.1	33.60	--	--
48	32°07′	121°19′	6/1	2031	--	1,157	15.7	33.40	--	--
50	31°08′	124°22′	6/2	2032	--	1,274	16.5	33.60	--	--
52	31°28′	124°56′	6/3	2030	--	1,422	16.3	--	5	--
56	30°12′	122°08′	6/5	2030	--	1,227	16.8	33.56	13	--
58	29°51′	120°27′	6/6	2030	--	1,264	16.3	33.47	--	--
61	29°10′	117°53′	6/8	2030	--	1,019	17.9	33.85	--	--
67	28°37′	118°07′	6/11	2003	--	1,533	18.1	33.87	--	--
69	28°04′	120°08′	6/12	2028	--	1,548	18.8	34.10	1	--
73	28°24′	121°39′	6/14	2030	--	1,302	18.0	34.09	--	--
75	29°55′	120°20′	6/15	2035	--	1,161	16.7	33.55	--	--
78	31°21′	119°14′	6/17	2030	--	1,098	16.3	33.82	22	--

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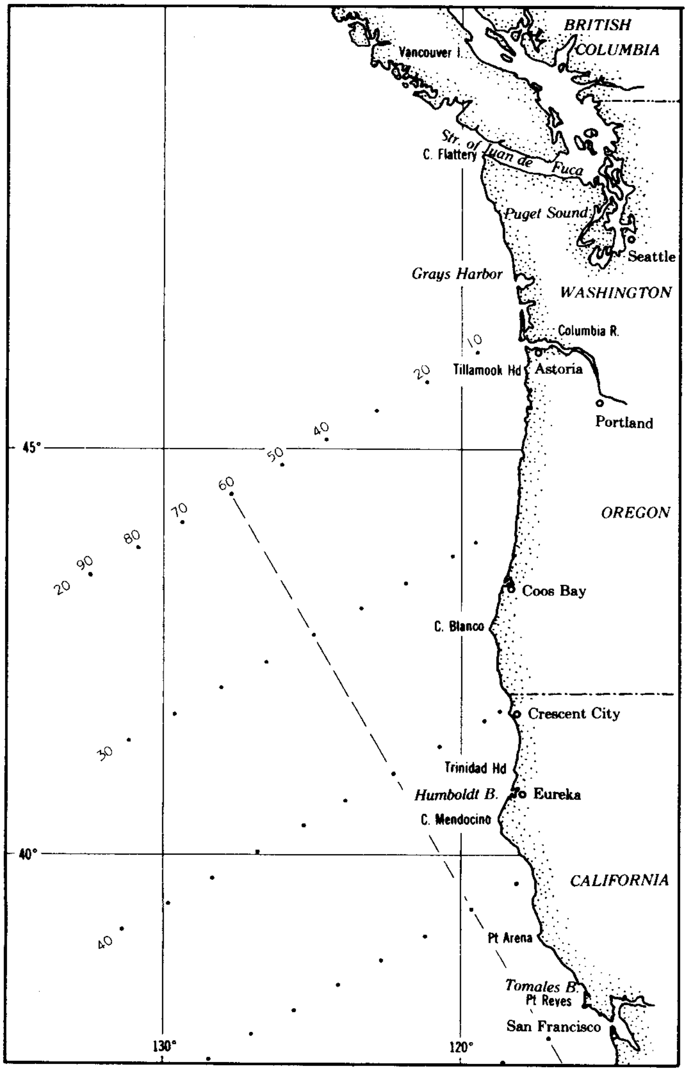

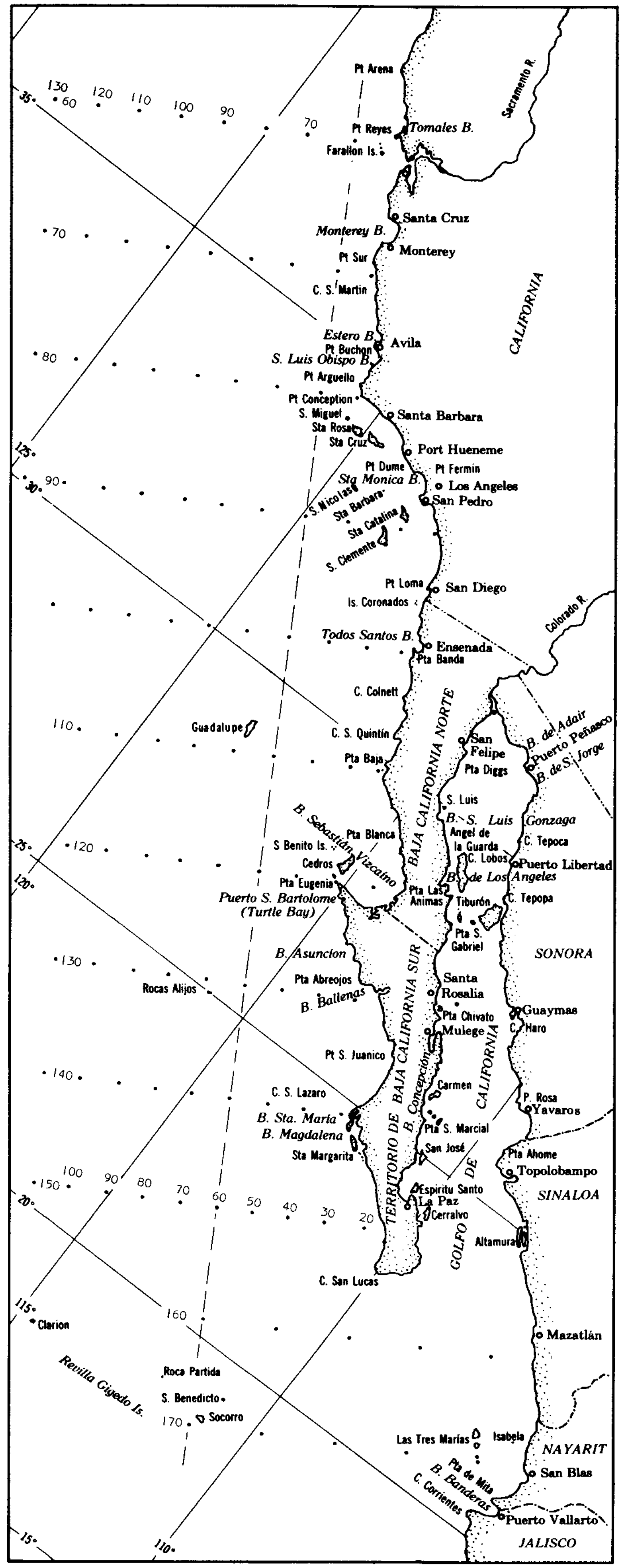

These maps are designed to show essential details of the area most intensively studied by the California Cooperative Oceanic Fisheries Investigations. This is approximately the same area as is shown in red on the front cover. Geographical place names are those most commonly used in the various publications emerging from the research. The cardinal station lines extending southwestward from the coast are shown. They are 120 miles apart. Additional lines are utilized as needed and can be as closely spaced as 12 miles apart and still have individual numbers. The stations along the lines are numbered with respect to the station 60 line, the numbers increasing to the west and decreasing to the east. Most of them are 40 miles apart, and are numbered in groups of 10. This permits adding stations as close as 4 miles apart as needed. An example of the usual identification is 120.65. This station is on line 120, 20 nautical miles southwest of station 60.

The projection of the front cover is Lambert's Azimuthal Equal Area Projection. The detail maps are a Mercator projection. Art work by George Mattson, National Marine Fisheries Service.

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