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Fish Bulletin 139. Utilization of Kelp-Bed Resources in Southern California

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FISH BULLETIN 139
Utilization of Kelp-Bed Resources in Southern California

Compiled and Edited by
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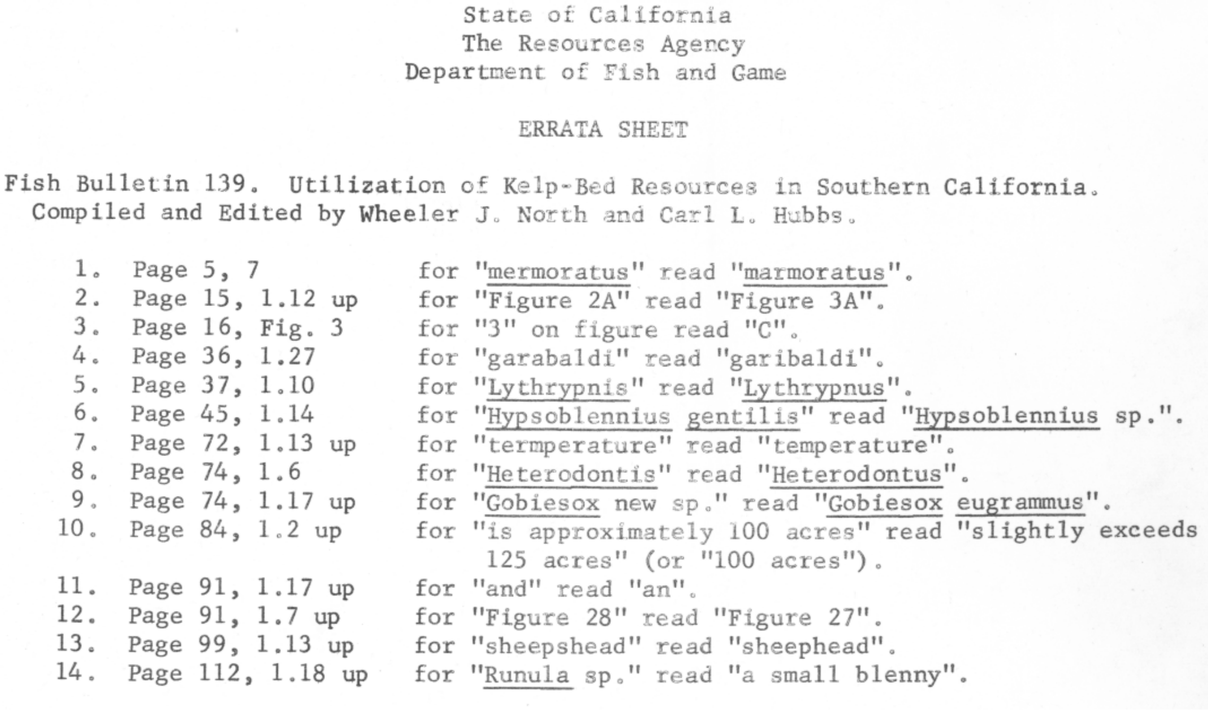
and
CARL L. HUBBS
Scripps Institution of Oceanography
1968

ABSTRACT: This bulletin is one of three large publications summarizing kelp investigations at the University of California's Institute of Marine Resources. The general objective of the bulletin is to assess the impact of man's past, present, and future activities on the kelp-bed environment. Possibilities for future improvement are examined in the opening chapters which describe the life history of the giant-kelp plant and show how this knowledge can be used for culturing and transplanting. Ecology of kelp-bed fishes is treated in detail as a background for evaluating influences of human activities. The distributions and ranges of physical parameters important to fishes are outlined with emphasis on temperature, wave action, visibility, and topography. Diets, behavior, preferred habitats, abundances, and life histories of kelp fishes are described, showing the ecological roles played by kelp as a food source, shelter, attractant, and vehicle for making phytoplankton productivity more available to associated fauna. It was found, however, that kelp was not a habitat requirement for most fishes, nor did it increase species diversity significantly. There was evidence that it may contribute to greater standing crops of fishes but bottom topography was considered a more important attractant. It was estimated that kelp harvesting removed an annual maximum of about 10 percent of the food supplies available for fishes. This was not considered serious because generally there appear to be ample food reserves in kelp beds.

Statistical correlations were sought between harvest returns and sportfish catches and catches per unit of effort. Neither statewide totals nor selected situations representing southern, northern, and island environments yielded any relation. Analyses were broken down to the more important groups or species of sportfishes and the only relation observed was a negative correlation between California barracuda catches and harvest yields. Since barracuda are pelagic the relation was considered to be indirect, resulting from interactions with ocean temperature. Fishing was better in beds harvested more frequently. Fishing in deteriorating beds was analyzed. Generally emphasis shifted to new groups of sportfish when more conventional fisheries declined. Statistical treatment was extended to comparisons of adjacent kelp beds that had been subjected to quite different intensities of harvesting. Harvest yield was not affected by harvesting intensity for the 11-year period examined. Kelp was sampled as it came aboard a harvesting vessel and about one third of the motile canopy fauna was removed from the habitat. The attached fauna, however, was entirely removed. Physiological studies indicated that cutting did not influence photosynthesis in adjacent kelp tissues of the cut frond. Growth of young fronds was, in some cases, retarded for periods up to a month but in other cases growth was stimulated. The complex interplay of environmental variables probably determined the character of any changes in growth rate. The interplay was described by a mathematical model and five cutting experiments were undertaken to test model predictions. Results were considered satisfactory.

It was generally concluded that giant kelp encourages development of a rich associated fauna. No adverse influence of harvesting could be found among the statistics or field observations for the periods studied. The need for intelligent management is stressed to ensure that optimum utilization of the kelp resources will continue.



State of California
The Resources Agency
Department of Fish and Game

ERRATA SHEET

Fish Bulletin 139. Utilization of Kelp-Bed Resources in Southern California. Compiled and Edited by Wheeler J. North and Carl L. Hubbs.

1.	Page 5, 7	for "*mermoratus*" read "*marmoratus*".
2.	Page 15, 1.12 up	for "Figure 2A" read "Figure 3A".
3.	Page 16, Fig. 3	for "3" on figure read "C".
4.	Page 36, 1.27	for "garabaldi" read "garibaldi".
5.	Page 37, 1.10	for "*Lythrypnis*" read "*Lythrypnus*".
6.	Page 45, 1.14	for "*Hypsoblennius gentilis*" read "*Hypsoblennius* sp.".
7.	Page 72, 1.13 up	for "termperature" read "temperature".
8.	Page 74, 1.6	for "*Heterodontis*" read "*Heterodontus*".
9.	Page 74, 1.17 up	for "*Gobiesox* new sp." read "*Gobiesox eugrammus*".
10.	Page 84, 1.2 up	for "is approximately 100 acres" read "slightly exceeds 125 acres" (or "100 acres").
11.	Page 91, 1.17 up	for "and" read "an".
12.	Page 91, 1.7 up	for "Figure 28" read "Figure 27".
13.	Page 99, 1.13 up	for "sheepshead" read "sheephead".
14.	Page 112, 1.18 up	for "*Runula* sp." read "a small blenny".

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1. 1. FOREWORD

WHEELER J. NORTH
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This bulletin assesses the impact of man on the kelp environment in southern California. The effects that kelp harvesting may have on kelp plants and on the fishlife of the beds receive primary emphasis; secondarily, potential and present methods for improving and expanding our kelp resources are described. In preparing their various chapters, the six authors drew upon all information available to them but the bulletin stresses their hitherto unpublished researches.

1.1. PERSPECTIVE

To help the reader distinguish the old from the new, and to enable him to appreciate our present state of understanding, the state of knowledge of the kelp environment as it existed about 10 years ago will be briefly summarized. By 1955 the life cycle of Macrocystis was known in detail but little information was available on ecological factors affecting the microscopic states of the cycle. Systematics of the genus were somewhat confused, although its anatomy and developmental morphology had been studied rather carefully. Knowledge of physiology was limited to a few photosynthesis and translocation studies, and to growth measurements. Contributions to the ecology of kelp beds had been made by workers in different locations but the subject was so complex that the surface had scarcely been scratched. Accordingly broad assumptions were necessary to apply available knowledge to practical problems of resource management.

There was general concern in California because important kelp areas were dwindling. Some feared that the regression, noted in a few areas, was true of all the kelp beds and that little if any kelp would remain unless conservation policies were changed drastically. The causes of deterioration were largely a matter of speculation, but beliefs were strong with blame for the losses directed principally toward pollution and kelp harvesting. Pertinent factual information was scarce and sometimes appeared to be conflicting. Those with experience in kelp resources were often reluctant to discuss the problems for fear of intensifying controversies. Immediate action was urged in certain quarters and legislation proposed to the State Assembly would have restricted harvesting severely or eliminated it altogether.

The effects of harvesting on fish resources was perhaps the most intense of the controversies centering on kelp beds. It was obvious that kelp tissues support food chains that must involve fishes. Many assumed that removal of a portion of the standing kelp crop by man represented equivalent losses in fish food and also feared that the cutting of stipes during harvesting might be injurious to the plant. If such injuries affected organic productivity significantly, further losses in fish food might be expected.

While these considerations justified concern, other possibilities existed and required study. Harvesting, for example, might not damage the beds; conceivably it might be beneficial. Canopy removal would certainly enhance penetration of submarine daylight and this could aid photosynthesis in previously shaded portions of the plant, encourage juvenile kelp, and illuminate other bottom vegetation. Also, the decrease in bulk might lessen the ability of storms and rough water to tear loose kelp plants or large portions of plants. Likewise very little was known concerning the preferred food of most kelp fishes and invertebrates. Some might not be at all dependent on kelp, others might be dependent but not be influenced by harvesting. Perhaps those species utilized by man would fall in these categories.

The Legislature and the Department of Fish and Game considered it unwise to formulate policies in the face of so much controversy and uncertainty. Accordingly, a State Kelp Study Committee was formed to advise the California Fish and Game Commission. It was composed of experts and of those having commercial and recreational interests in kelp resources. The Committee concluded that much fundamental biological knowledge was needed before proper decisions could be made and recommended that a large-scale research program on kelp be undertaken. In a memorandum, to the Commission, dated 18 August 1955, the Committee listed the following eight fields as deserving further study:

1. The relation of pollution to the kelp beds.
2. Effects on kelp and on fish of various methods of harvesting, such as rotation of cutting, leaving sections uncut for longer periods, strip harvesting, etc.
3. Practicability of expanding the present beds through culturing methods (the possibility of growing strains of kelp of increased economic value is involved).
4. Bearing of kelp beds (and of kelp harvesting, if any) on beach erosion, beach litter, etc.
5. The economics of kelp, involving fishery values, beach litter, beach protection, etc.
6. Changes in the extent of kelp beds, including especially the disappearance of some beds (study to involve historical and ecological approaches, recharting of the beds, analysis of the factors involved, etc.).
7. Natural causes of kelp bed deterioration, including storms, sand movements, water turbidity, high temperatures, diseases of kelp, smothering of kelp fronds by encrusting growths and predation on young kelp by sea urchins, abalones, and other herbivorous animals.
8. Factors responsible for the healthy growth of individual kelp plants and kelp beds.

1.2. THE INSTITUTE OF MARINE RESOURCES KELP PROGRAM AND ITS PUBLICATIONS

The recommendations of the Kelp Study Committee won general approval. The Department of Fish and Game budgeted funds over a 5-year period to support the Kelp Investigations Program which began operations in the summer of 1956 at the Institute of Marine Resources (IMR). Research was concentrated on items 3, 6, and 7, above, and on the general problem of the effect of harvesting on kelp and on fish-life. A year later additional support was furnished by the State Water Quality Control Board for an investigation of the first item on the Committee's list. This study, The Effects of Discharged Wastes on Kelp, began in the fall of 1957.

As these investigations progressed, new and important problems were perceived and a grant was obtained from the National Science Foundation for pursuing one broad phase that was of particular importance to the Kelp Investigations Program. This new study was "An Investigation of Food Chain Intermediates in Kelp Beds." The three separately-funded studies were collectively known as the IMR Kelp Program. The Program lasted from 1956 to 1963 and supported 12 principal investigators in the field of taxonomy, ecology, botany, zoology, fisheries biology, microbiology, physiology, and biochemistry.

The present volume arose from discussions during a meeting of the Kelp Study Committee near the end of the phase of kelp investigations sponsored by the Department of Fish and Game. Representatives of the Department emphasized the need for a publication highlighting the research supported by the Fish and Game grant which would be of interest to the general public. Publication in a Fish Bulletin was suggested because this series of the Department of Fish and Game is commonly used for presenting information both to scientists and laymen. Many potential readers would not have easy access to technical journals with more limited distribution.

The findings from the study supported by the State Water Quality Control Board were reported separately (1964). Since this was the first of the volumes to be published, a great deal of background information on kelp beds was included that has not been repeated here.

Some of the studies of the IMR Kelp Program continued in a program called the "Kelp Habitat Improvement Project," supported by grants from the Kelco Company of San Diego, California. Two annual reports have been issued by the Project and may be of interest to readers of this bulletin. Likewise Fish Bulletin 124, describing the studies of the Ocean Fish Habitat Development Project (Carlisle, Turner, and Ebert, 1964) reports observations and experiments in the kelp-bed environment.

Editing and typing of the final manuscript was made possible by funding from the California Institute of Technology.[1]

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[1] A third and final major publication of the IMR Kelp Program, ‘The Biology California Kelp Beds’ will be published by J. Cramer, Germany.

1.3. SUMMARY OF THE KELP POLLUTION PUBLICATIONS

1.3.1. An Investigation of the Effects of Discharged Wastes on Kelp

This volume was first reproduced in a limited edition by the University of California, Institute of Marine Resources as IMR Ref. 63–6. In 1964 the State Water Quality Control Board published it as Publication No. 26. It is available from this agency (Room 316, 1227 O Street, Sacramento, California) for $2.50.

The text comprises three sections: Background Information, Investigations, and Conclusions. A short introduction describes the appearance of the nearshore zone, emphasizing kelp beds, and briefly lists kelp bed resources and the natural factors causing kelp deterioration.

The major portion of Background Information is devoted to a history of three formerly important kelp areas where wastes are currently discharged (Pt. Loma, Palos Verdes, Santa Barbara) and of a control area (La Jolla). Changes in area occupied by the beds are compared to the relative annual harvests and the volumes of wastes discharged nearby. A steady decline in kelp was found for Pt. Loma and Palos Verdes, terminating in virtually complete disappearance and subsequent cessation of significant harvesting. A small localized loss of kelp at Santa Barbara was complicated by construction and operation of a harbor, but kelp remained in the approximate vicinity of the sewer outfall. In general, kelp closest to the outfall was the first to disappear and the regression spread from this center. This pattern is the principal evidence that suggests a relationship between waste discharge and kelp disappearance.

Eight pages are devoted to kelp-bed ecology (readers unfamiliar with the subject would profit by reviewing these pages as useful background for this bulletin) and the section closes with a summary of possible harmful effects waste disposal might have on kelp.

The section "Investigations of Causes of Kelp Regression" is divided into seven parts (surveys, toxicity, grazing, turbidity, sedimentation, phytoplankton, microbiology) corresponding to the studies that were conducted. Toxic substances, sedimentation, excessive phytoplankton blooms, and pathogenic microorganisms were considered unlikely causes of kelp damage except in the immediate vicinity of a discharge. Indirect evidence that turbidity might be affecting plant growth adversely near the bottom was cited, but the financial limitation of the project precluded an extensive and conclusive investigation. The surveys revealed high densities of grazers, particularly sea urchins, at Pt. Loma and Palos Verdes. When sea urchins were cleared from experimental plots, vegetation, including kelp, returned in a few weeks. Few urchins were found on the sedimentary bottom at the Santa Barbara outfall because most urchins prefer a rocky substrate. The causes of dense and persistent urchin populations at Pt. Loma and Palos Verdes remain unknown, but an investigation studying possible nutritional relationships between sewage disposal and sea urchins is currently underway.

The final section summarizes the above findings, followed by an index to the progress reports issued by the IMR Kelp Program, arranged according to subject.

1.4. KELP-BED RESOURCES

The term "kelp bed" designates the nearshore areas where certain large brown seaweeds, the floating kelps, achieve sufficient density to be conspicuous to the casual observer. Kelp beds are found along the entire California coast and extend several hundred miles south into Baja California. They usually develop best where there is some protection from heavy wave surge. In southern California the gently sloping continental shelves, protective offshore islands, and upwelling processes provide optimal conditions for large kelp beds.

Giant kelp, Macrocystis, is extensively utilized in southern California. The harvest is processed to varying degrees, yielding several commodities. These include human and animal food additives, fertilizer, and alginic acid, a polysaccharide incorporated into many products. Formerly kelp was an important source of potash and a commercial process was developed for synthesizing acetone from the tissues.

At their greatest extent, the kelp beds of southern California were reckoned at about 100 mi^2 (approximately 260 km^2) but presently they are only one-half to three-fourths as large. Currently, the annual Macrocystis harvest is over 100,000 wet tons. Dried kelp sells for $90 to $125 per ton. The major portion of the California kelp harvest is processed for algin (a colloid in the cell walls). Prices for algin have ranged from 5 cents to more than 1 dollar per pound, value varying with the quality or grade. Scheffer (1943) stated that production of algin in 1941 in the United States was about 2 million pounds, worth approximately $1,500,000. Although two companies produced algin in America at that time the major part came from California (Tseng 1945). In 1941 the total California kelp harvest was 56,000 wet tons. California kelp also finds use in food additives and fertilizer. Formerly it served as a source for iodine, potash, and acetone but these uses have been discontinued. Technical and historical information on the kelp industry was given by Tseng (1945, 1947), Chapman (1950), and Scofield (1959).

The fishes of the beds are the primary animal resource. There is commercial fishing for such species as white seabass, black sea bass, sculpin, lobster, and abalone, but sportfishing, which is extremely popular, probably accounts for most of the fishes removed by man (*cf.* Davies, Chapter 10, this bulletin).

The nearshore marine resources for the San Diego region were evaluated in 1958 (San Diego Marine Consultants, 1959) as an aid in locating the San Diego outfall (Table 1) . The estimated annual yield of kelp bed resources for the Pt. Loma and La Jolla areas amounted to $780,000.

1.5. OBJECTIVES

The primary purpose of this bulletin is to further the conservation and intelligent use of the kelp resources by clarifying the processes that affect abundance of the fauna and flora. Particular emphasis has been given to the biology of fishes and to the effects of harvesting, for fishing and harvesting constitute the major uses of the kelp resources and appear to be of greatest public concern.

Conservation policies, however, intelligent, cannot preserve these resources indefinitely in the face of mounting demands from an ever-increasing population. We must learn to augment the bounties of nature by artificial means. A substantial effort has been put into such research. It is described in the third chapter to give the reader a concept of the potentialities for "ocean farming." Numerous controversies have existed as to proper management of the beds. It is hoped that this bulletin will unify opinion and direct the energies of all concerned toward a useful, positive approach: that of increasing the kelp resources to meet the needs of the future.

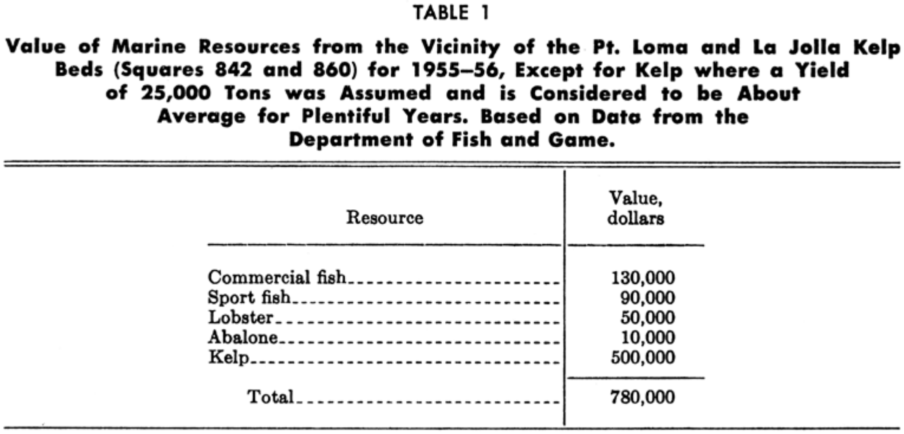

TABLE 1

Value of Marine Resources from the Vicinity of the Pt. Loma and La Jolla Kelp Beds (Squares 842 and 860) for 1955–56, Except for Kelp where a Yield of 25,000 Tons was Assumed and is Considered to be About Average for Plentiful Years. Based on Data from the Department of Fish and Game.

Resource	Value, dollars
Commercial fish	130,000
Sport fish	90,000
Lobster	50,000
Abalone	10,000
Kelp	500,000
Total	780,000

TABLE 1

Value of Marine Resources from the Vicinity of the Pt. Loma and La Jolla Kelp Beds (Squares 842 and 860) for 1955–56, Except for Kelp where a Yield of 25,000 Tons was Assumed and is Considered to be About Average for Plentiful Years. Based on Data from the Department of Fish and Game.

The kelp investigations sponsored by the Department of Fish and Game terminated in 1961 with submission of a final report by the University of California. However, several investigators of the Program and other researchers have continued to study kelp and associated organisms. We have included pertinent material from these newer studies wherever possible. In consequence this is more than a final report. It is an appraisal, as complete and up-to-date as possible, of man's impact on the kelp resources and what can be done to improve them.

2. 2. THE LIFE HISTORY OF MACROCYSTIS IN THE SEA

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and
FRANCIS T. HAXO
Scripps Institution of Oceanography
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The giant kelp, Macrocystis, as observed in the common nearshore kelp beds of California waters, represents only one stage of a very complicated life cycle. This cycle involves two distinct plants. There is an alternation of generations between an inconspicuous, microscopic, gamete-producing (gametophyte) stage, and the large spore-producing plant or sporophyte (Figure 1) familiar to nearly anyone who has visited the seashore. The environmental factors influencing this reproductive cycle and controlling the time required for its completion fundamentally affect almost every aspect of the biology of giant kelp and the organisms that associate with it. Studies on aspects of the

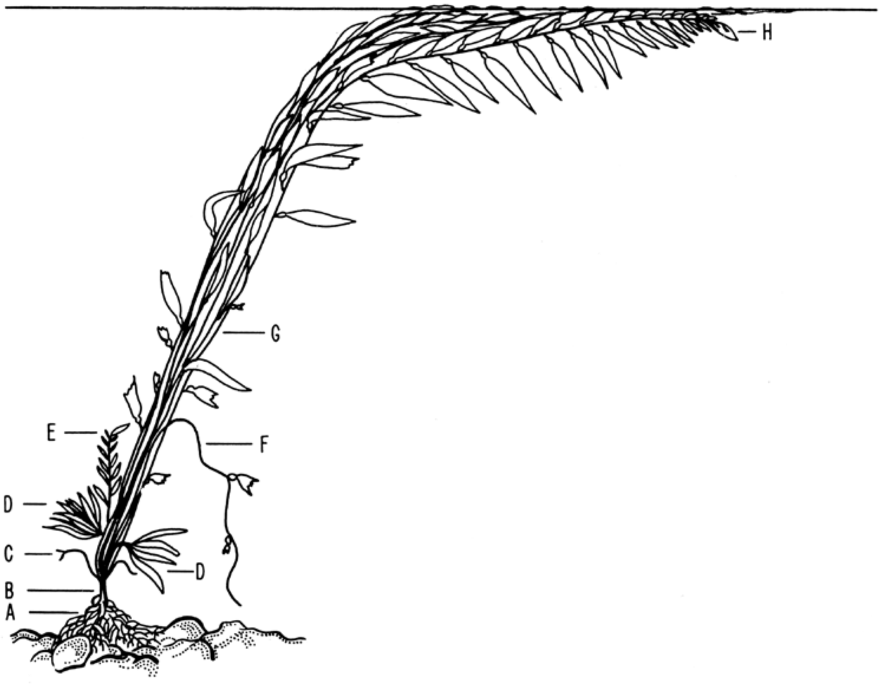

FIGURE 1. Diagram of a mature plant of the giant kelp, *Macrocystis pyrifera*, one to two years old, standing in 20 to 30 feet of water. A, holdfast; B, primary stipe; C, stub of an old frond; D, sporophyll clusters; E, juvenile frond; F, senile frond; G, stipe bundle; H, apical blade of mature frond, giving rise to additional blades.

FIGURE 1. ***Diagram of a mature plant of the giant kelp, Macrocystis pyrifera, one to two years old, standing in 20 to 30 feet of water. A, holdfast; B, primary stipe; C, stub of an old frond; D, sporophyll clusters; E, juvenile frond; F, senile frond; G, stipe bundle; H, apical blade of mature frond, giving rise to additional blades.***

ecology of the Macrocystis reproductive cycle include those of Brandt (1923), Moore (1943), Scagel (1948), Neushul and Haxo (1963), and Neushul (1963).

There are two distinct species of Macrocystis in southern California with characteristic differences in their mode of reproduction. M. angustifolia reproduces vegetatively as well as sexually, whereas M. pyrifera apparently depends entirely on the completion of the sexual cycle for the production of new individuals. This difference has caused considerable confusion in the past. Until recently little was known of the rates of vegetative reproduction, because most investigations concentrated on the sexual cycle.

The basic sexual cycle of Macrocystis as it occurs in laboratory dish culture, is well known (Delf and Levyns, 1926; Papenfuss, 1942), and the stages encountered are essentially the same as those produced by other members of the Laminariales (Figure 2). The morphology of the microscopic gametophyte of Macrocystis is at present indistinguishable from that of other kelp. Kelp gametophytes are not commonly

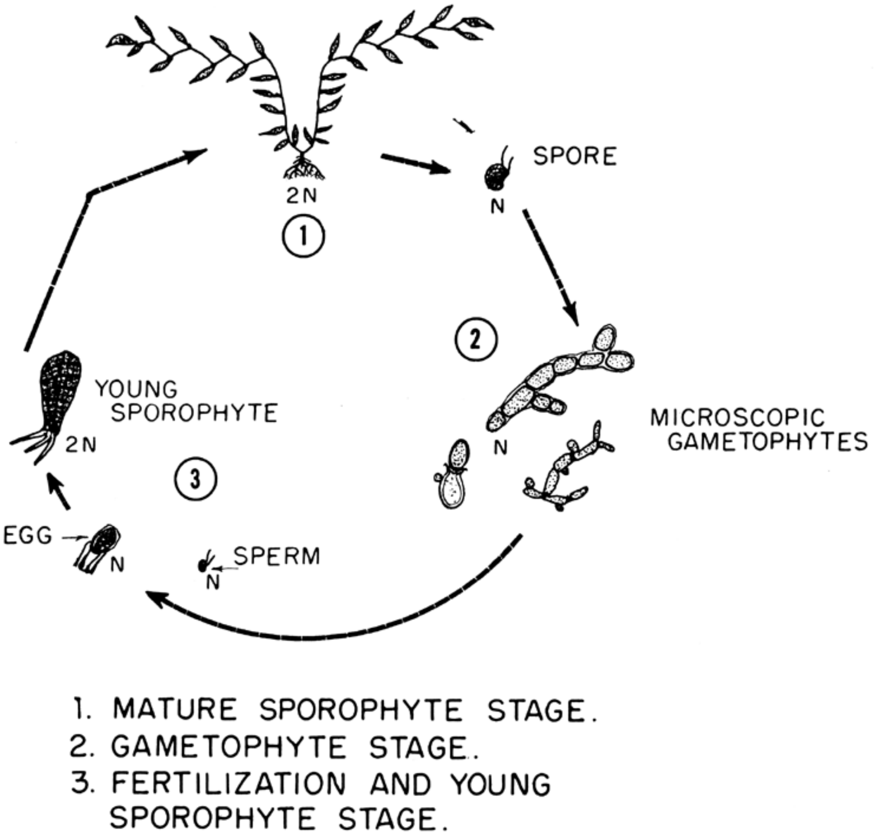

FIGURE 2. ***The life history of Macrocystis.***

observed in the sea. Thus the bulk of our knowledge of these stages has been derived from laboratory dish cultures. It should be emphasized that the natural environmental factors influencing these more inconspicuous stages in the life history are just as important as the more obvious ones influencing the macroscopic plant. The gametophytes as well as the spores and sporophytes of the related Japanese kelp, Undaria, can be distributed by water currents (Saito, 1962). The extension of such studies to Macrocystis in the ocean would be of obvious importance.

Suto, as discussed in Saito (1962), discovered in 1951 that large numbers of Undaria gametophytes could be grown in laboratory tanks, and their identity could be confirmed by the subsequent production of the characteristic sporophytes. The same technique has been used for Macrocystis culture by Neushul and Haxo (1963), whose results have been confirmed recently by North (personal communication). Tank-grown gametophytes differ morphologically somewhat from those grown under more restricted conditions in dishes, and it seems reasonable to assume that these resemble more closely those gametophytes occurring in the sea. Gametophytes of Macrocystis have not as yet been observed in nature.

The gametophytic phases of the Macrocystis life-cycle are completed in tanks in less than 1 month, whereas growth and maturation of the large sporophytic plant consumes considerably more time. Information on the time required for this phase of the life cycle has been obtained in several ways. These include photographic growth records at intervals of young plants transplanted from beneath kelp canopies to rafts anchored at known depths in the sea (Figure 3a); experimentation with young sporophytes held at different light levels in the laboratory; and observations in the sea on the development of a newly arising population. By observing young sporophytes in the laboratory, the influence of light on growth and the optimum growth rate can be clearly demonstrated. of greatest interest here perhaps are the *in situ* observations made on a developing population of plants tagged at a stage similar to the smallest size shown in Figure 2a and followed to maturity. Their growth rates were similar to those of plants grown in the laboratory.

On the basis of all these findings, the minimum time needed for the completion of the life history of Macrocystis in the sea is estimated to be from 12 to 14 months. Confirming evidence has been obtained in the Kelp Habitat Improvement Project (North, personal communication). It is believed, however, that reproduction at this rate is probably the exception rather than the rule in most areas. Many factors, including reduced light intensity due to shading by other plants and grazing pressure, adversely affect the rate with which this cycle can be completed in the sea.

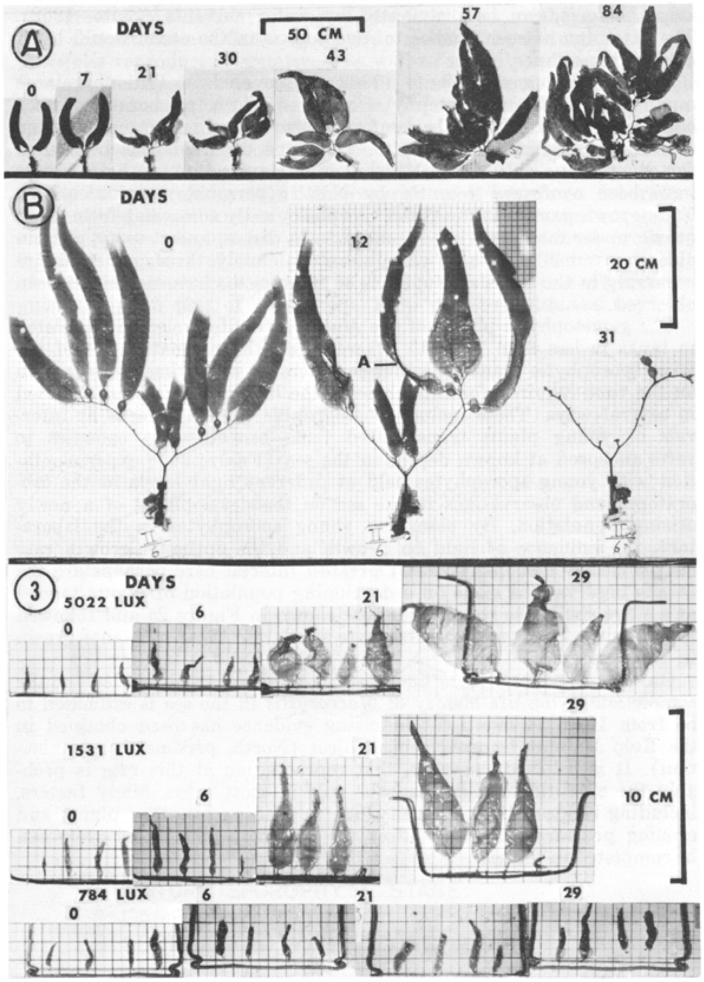

FIGURE 3. **Development of young sporophytes of *Macrocystis*.**

a. Photographic record of the growth of a young plant grown at a depth of 50 feet in the sea.

b. Damage to an outplanted individual due to grazing and (A) amphipod attack.

c. Photographic record of laboratory growth under controlled conditions of light and temperature (15° C. or 59° F.).

FIGURE 3. ***Development of young sporophytes of Macrocystis.***

3. 3. A NOTE ON THE POSSIBILITIES OF LARGE SCALE CULTIVATION OF MACROCYSTIS

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and
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3.1. INTRODUCTION

The problems involved in large-scale cultivation of the giant kelp, Macrocystis, make such schemes appear visionary and impractical at first sight. Lack of familiarity with marine plants and with their actual and potential uses adds to the misgivings of many people when cultivation of marine algae is mentioned. Giant kelp, however, has proven its economic value for several decades. The products made directly from the harvested kelp and its *in situ* contributions as food and shelter to fishes and invertebrates have established importance to consumers, the harvesting industry, and sportsfishermen. Obviously more extensive and "managed" kelp beds would be desirable, if they could be produced.

The technical difficulties in cultivating seaweeds are not insurmountable (Ogata, 1961; Kurogi, 1961, 1963; Hasegawa, 1962; Saito, 1962; Tseng, 1959). Macrocystis has been successfully cultured in the laboratories of many workers and numerous transplants have been conducted in the sea. Although failures have been encountered, the general requirements are understood and it seems to be more a question of avoiding known pitfalls than of bad luck because of unknown factors. An outstanding problem is posed by economic considerations. Cultivation of seaweeds in oriental countries has been possible because of cheap labor. Labor costs for harvesting operations in California have been lowered through the development of efficient mechanical methods for gathering the crop. At present a breakthrough is needed in the area of achieving large-scale cultivation by rapid and inexpensive methods. Large-scale cultivation, when developed, will doubtless depend on the reproductive potential of the mature plants, methods of culturing gametophytic stages, and transplanting techniques for various phases of the life cycle.

3.2. REPRODUCTIVE POTENTIAL

A factor of outstanding importance for cultivating giant kelp is the tremendous reproductive potential, which is large even in the marine environment where many organisms commonly produce thousands to millions of offspring each year. It is realistic to estimate that an average plant is capable of liberating trillions of spores annually. It is difficult to comprehend the significance of such a large number and a hypothetical example will serve to put this reproductive potential into perspective. Suppose all the beds of giant kelp along California and Baja California were to perish, leaving only one plant of average size as the survivor. Suppose also that all the spores liberated by the lone plant were completely successful in giving rise to gametophytes, which in turn yielded half as many sporophytes, spread evenly over the entire area formerly colonized by kelp. The resulting beds would then be about a million times more dense than they are at present. Obviously many microscopic and juvenile plants must be lost in nature. If ways could be devised to preserve a small fraction of those lost, much denser stands of kelp might be effected.

Realization of the full reproductive potential is not necessarily an idle dream. Occasionally examples are seen in nature when factors apparently change increasing survival chances of gametophytes and juvenile sporophytes. One such instance occurred when the wreck of an oil tanker, the Tampico, apparently caused the destruction of virtually all grazing animals along several hundred feet of shoreline in Baja California and also reduced wave surge substantially in the lee of the hull. Approximately 100,000 Macrocystis plants developed in the protected lee within about 3 months, where only four individuals had existed previously. More recently, conditions favorable to giant kelp appeared at the southern end of Point Loma. Possible causes may have been reduction of grazing urchins by lime treatments and/or a change in the method of sewage disposal in the area. Prior to the changed conditions a small strip of giant kelp existed, about 100 feet wide by 2000 feet long. Within a year the coverage had expanded to a width of 1000 to 2000 feet and a length of some 3 miles. The sudden success of kelp was reflected in the harvesting statistics for the area: a 25-fold increase occurred during this period.

3.3. KELP CULTURE AND TRANSPLANTATION

Spores of the giant kelp are easily obtained by holding a few of the fruiting blades or sporophylls from a mature plant (Figure 4) in a cool, moist, dark container for several hours and then placing them in an illuminated dish or small aquarium. Broad spore-bearing blades should be selected since these usually have well-developed sori. Frequently, they also have a frayed, whitish appearance at the terminal end. The spores are oblong or pyriform and swim rapidly by means of two flagella. Spores attach to a wide variety of substrates and develop recognizable gametophyte stages within a few days. Continuous illumination is apparently not harmful and hastens completion of the cycle. Temperatures in excess of 60° F should be avoided and seawater or other culture media should be filtered to remove diatoms and protozoans. Embryonic sporophytes appear after 13 to 14 days. The development of tiny bladelets, just visible to the naked eye, requires 4 to 6 weeks. Additional life-cycle details are discussed by Neushul and Haxo (Chapter 2, this bulletin), who cite pertinent literature.

The transplantation of entire large plants is accomplished over a short distance by towing dislodged individuals at speeds of not more than 3 knots. This avoids loss of fronds and damage that occurs when

FIGURE 4. Photograph of a kelp transplant at Imperial Beach, California, showing the basal part with the fruiting blades or sporophylls clustered at the top of the holdfast.

FIGURE 4. ***Photograph of a kelp transplant at Imperial Beach, California, showing the basal part with the fruiting blades or sporophylls clustered at the top of the holdfast.***

the heavy plants are lifted in and out of the water. Plants that are carried for long distances on deck or in containers should be spread sufficiently to prevent them from being crushed by their own weight. Plants should be covered immediately to prevent solarization injury and should be splashed or sprayed with cold seawater frequently to prevent evaporation damage.

Frequently, the transplantation of plants is successful but grazers overwhelm them in the new environment. Benthic grazers such as sea urchins can be avoided by buoying the holdfast a foot or more above the anchorage (Figure 5). When benthic grazers are absent the holdfast may be tied directly to a rock or other substrate feature (Figure 6). An isolated plant often attracts fish, which may graze upon and destroy the upper portions (Figure 7). Turner *et al.* (personal communication), by surrounding large transplants with protective nets of hardware cloth, have successfully maintained giant kelp for about half a year in an area of heavy fish grazing.

Isolated or semi-isolated plants may also fall victims to severe encrusting by sessile invertebrates. The weight of the animals tends to sink the fronds to depths where the floats are crushed. Encrusting animals also attract carnivorous fishes, which damage the kelp tissue while they feed on these organisms.

Prospective transplants should be gathered from about the same depth as that of the location where they will be anchored. If the transplants are anchored deeper, the pneumatocysts may be imploded; if they are anchored at too shallow depths, growth is apparently disrupted (North, 1964). Holdfasts may be cut or pried loose from the bottom without harming the transplant, provided the primary stipe is not injured. When securing the plant to its anchorage, ropes or lines should not touch the primary stipe or basal dichotomies. The crevices formed by such impingement seem to favor infections or grazing which eventually

FIGURE 5. A kelp transplant with the holdfast attached to a buoy to hold the plant off the bottom and prevent attack by benthic grazers.

FIGURE 5. ***A kelp transplant with the holdfast attached to a buoy to hold the plant off the bottom and prevent attack by benthic grazers.***

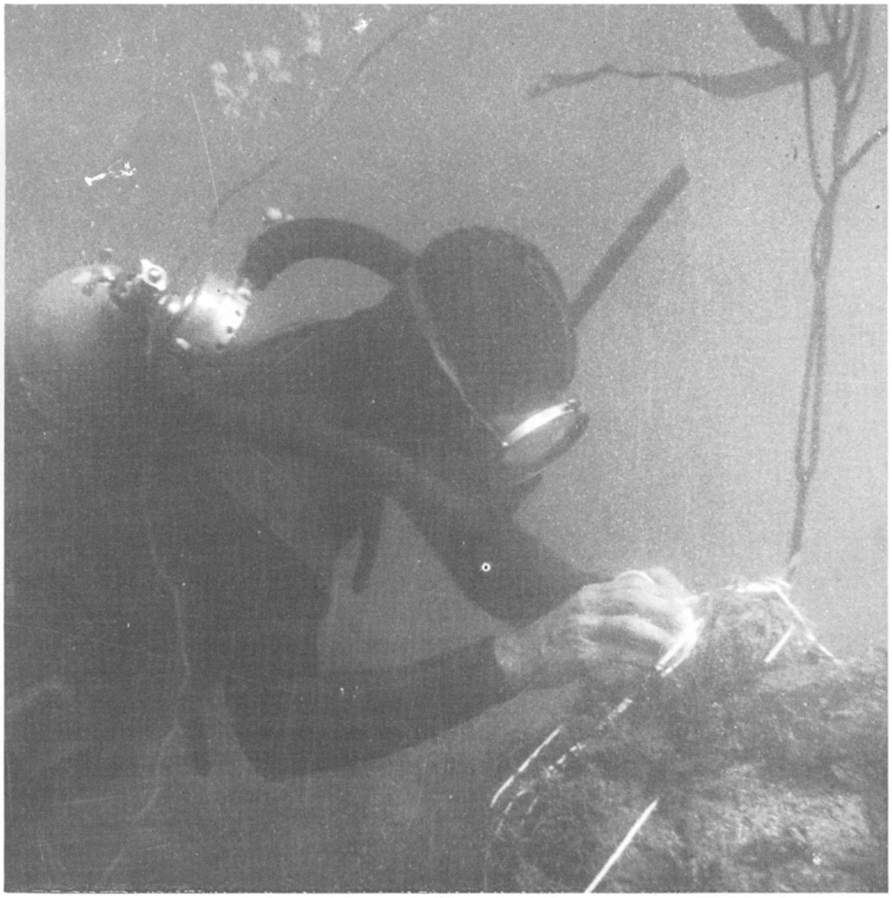

FIGURE 6. A kelp transplant being tied to a rock in an area where grazing by benthic animals was negligible.

FIGURE 6. ***A kelp transplant being tied to a rock in an area where grazing by benthic animals was negligible.***

severs the stipe. It is best to thread the line several times through existing gaps or holes in the holdfast and thus attach the plant loosely but securely to its anchorage (Figure 8).

3.3.1. Examples of Transplants

The authors know of no permanent beds of kelp produced by transplantation. This may seem discouraging, but it should be emphasized that when average lifetimes have been determined for kelp plants growing naturally in the areas where transplants are introduced, the new plant usually remains as long as the naturally occurring individual and can exceed the average life-span, because of special protection from grazing. Persistence of transplants for 1 to 2 years is about the maximum that has been achieved. During this period normal growth of fronds and haptera has been recorded and loss usually results from failure of the mooring or the anchorage. Even nylon line suffers deterioration when submerged deeply for a year and tends to part rather easily.

Neushul (1959) raised young transplanted sporophytes on rafts anchored at various depths at the edge of the Scripps submarine canyon. Juveniles that had been cultured by Neushul in the laboratory showed considerable growth after being transplanted into San Diego Bay to tests for effects of pollution (North, 1957), but the effects of grazing were severe. A similar study involved the transplant of juvenile plants gathered off Point Loma to the Palos Verdes region (Calif. Water Quality Control Bd. 1964). The experiment was abandoned when the plants became so large they completely filled the cages used to protect them from grazers. During the period 1959 to 1961 many plants were transplanted from Turtle Bay, Baja California, to La Jolla by one of us (WJN) to demonstrate the practicability of such operations. The longest survival of these transplants was about 1 year. Mature Point Loma plants have been transplanted in attempts to "seed" rocks off Imperial Beach. Many other transplants have also been undertaken with varying degrees of success. Transplanting a mature

FIGURE 7. A young kelp plant with all the blades removed by some pelagic grazer, probably fish. Isolated transplants and individuals located near the edges of beds often suffer this type of damage.

FIGURE 7. ***A young kelp plant with all the blades removed by some pelagic grazer, probably fish. Isolated transplants and individuals located near the edges of beds often suffer this type of damage.***

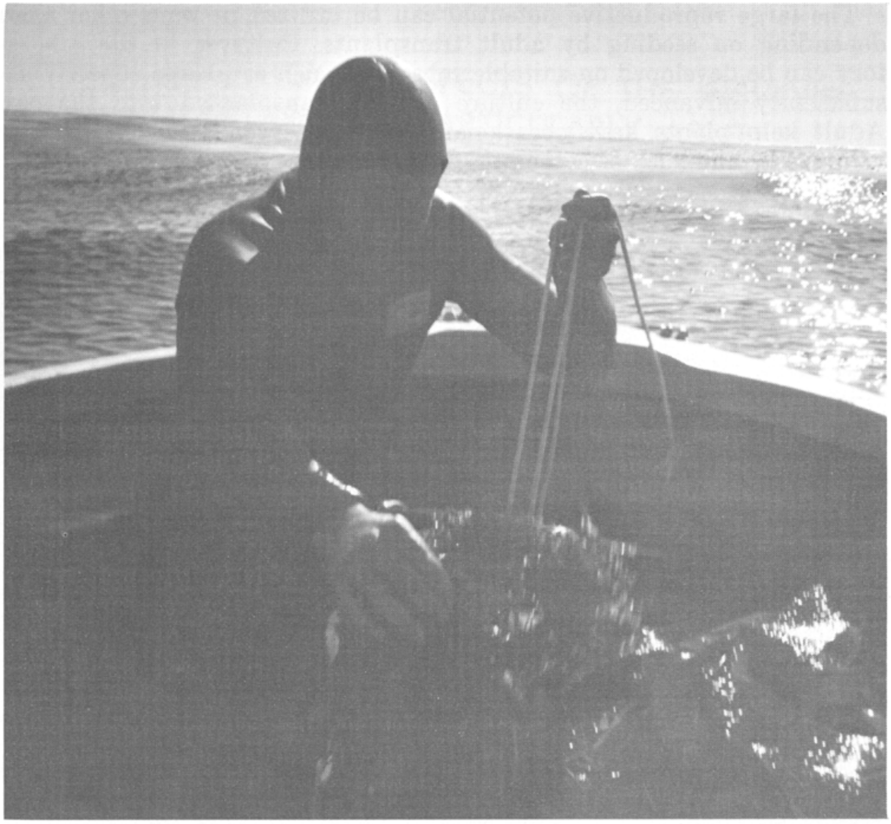

FIGURE 8. Photograph of a kelp plant undergoing transplantation, showing how ¼ inch nylon line was threaded through the holdfast to assist in anchoring the specimen.

FIGURE 8. ***Photograph of a kelp plant undergoing transplantation, showing how ¼ inch nylon line was threaded through the holdfast to assist in anchoring the specimen.***

giant kelp is a major task requiring careful planning and considerable physical effort. This constitutes a handicap to large-scale transplanting projects.

3.4. FUTURE RESEARCH

As indicated above, the problems of large-scale cultivation revolve largely around reduction of labor costs. Easy, inexpensive, and reliable methods are needed for establishing large colonies of young kelp plants over areas of several acres on the sea floor. Once substantial plots of kelp become established it appears likely that they will expand by natural colonization, assuming there are no complications from excessive grazing. Single isolated transplants may not seed a sufficiently large area to permit permanent colonization of offspring. North (Calif. Univ. IMR, 1963) introduced a transplant into a barren area at Imperial Beach and found offspring as far as 5 meters (16 ft.) away from the parent. The concentration of juveniles varied inversely as the cube of the distance from the adult transplant. The number of transplants necessary to colonize a large area of say, an acre, with their offspring is as yet unknown, as is the number of plants necessary to survive in areas of various grazing pressures.

The large reproductive potential can be utilized in ways other than depending on seeding by adult transplants. Cultures in the laboratory can be developed on suitable substrates such as plastic rope. When sufficiently advanced, the culture can be transplanted into the sea. Adult kelp plants have occasionally been observed attached to rope (Figure 9) and such a method might be an efficient way to start a large colony. The sporophylls themselves might be transported instead of the entire plant, although a preliminary experiment along these lines was unsuccessful (Calif. Univ. IMR, 1963). Large slabs of substrate might be placed in an established kelp bed long enough to acquire a thick crop of juveniles and then be transported to the desired area.

FIGURE 9. Photograph of a kelp plant that had developed on a 1-inch nylon transect line at Point Loma.

FIGURE 9. ***Photograph of a kelp plant that had developed on a 1-inch nylon transect line at Point Loma.***

In summary, large-scale cultivation of giant kelp could be usefully undertaken immediately if economic problems could be solved. Basic experimentation indicates there are no large technical difficulties and for the present the major limitation apparently resides in our own ingenuity.

4. 4. SOME PHYSICAL ASPECTS OF THE INSHORE ENVIRONMENT, PARTICULARLY AS IT AFFECTS KELP-BED FISHES

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4.1. INTRODUCTION

The kelp beds of southern California are named for the dominant algal species, Macrocystis pyrifera, which comprises all but a very small fraction of the floral standing crop in alongshore areas. Not only is a rich fish fauna associated with the kelp beds, but kelp itself has economic value, particularly for alginic acid and food additives. From 1950 to 1960 many dense beds of kelp seriously declined along the coast of southern California and Baja California. The thinning or occasional outright disappearance, was presumed to cause losses of the resident sportfishes, alarming sportfishing, conservation, and commercial interests. This alarm resulted in several successive research programs at the Scripps Institution of Oceanography, La Jolla, to expand general knowledge of kelp beds and their ecology. A 5½-year study by the late Conrad Limbaugh surveyed the biology of kelp beds and their fauna (Limbaugh, 1955). In July 1956, the Institute of Marine Resources of the University of California undertook a 5-year study of the biology of kelp and the associated fishes and invertebrates. This study, known henceforth as the Kelp Program, utilized specialists in botany, bacteriology, fisheries biology, ichthyology, biochemistry, and invertebrate zoology. Although administered and supported in part by the University of California, San Diego, basic support was derived from the California Department of Fish and Game.

4.2. ACKNOWLEDGMENTS

Editing and helpful criticism were furnished by Carl L. Hubbs and Wheeler J. North. The late Conrad Limbaugh, an excellent SCUBA diver and biologist gave SCUBA instruction, and furnished invaluable counsel on the biology of kelp beds and their fauna. Diving technicians of the Kelp Program, particularly Jean Kauanui, James R. Stewart, and Earle G. Cunnison, also played an essential role in the research. The manuscript was typed by Lois I. Rushing.

4.3. THE KELP ENVIRONMENT

The kelp[1] plant (Figure 10) grows from an anchoring structure, the holdfast, which is usually attached to a rocky substrate. The plant extends to the surface, where the buoyant fronds may spread horizontally for 20 feet or more. These floating fronds form a canopy, which, like the upper foliage of terrestrial plants, shades the regions below.

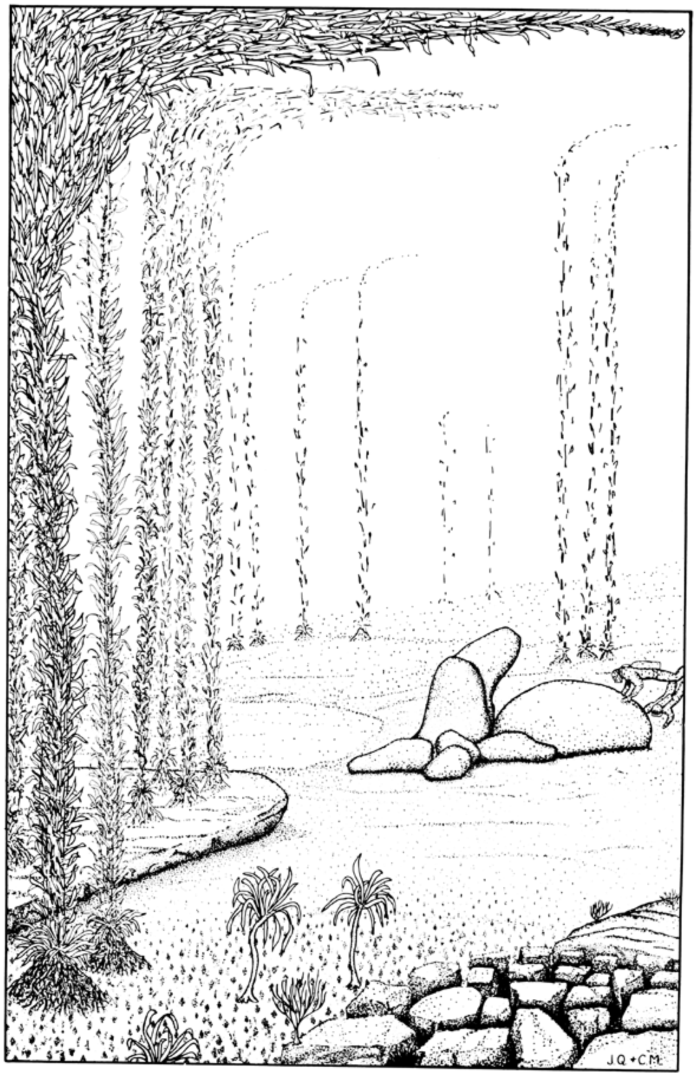

FIGURE 10. Drawing of a representative kelp bed of the San Diego region. The rock formations depicted are fragmented rock (right foreground), pavement rock (center), a ledge (left center), and boulders (right background). Plants include columns of kelp *(Macrocystis pyrifera)*, the 2–4-foot *Pterygophora californica* (or the similar *Eisenia arborea)* and a short (2–4 inches) tufted coralline algae that clothes the pavement rock (center). A 1-foot gorgonian is represented on the fragmented rock (right foreground). Two divers are included for scale (right background). No fish are represented. A sand patch, common in some areas, is shown in the left background, behind the ledge.

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Although kelp usually occurs on rocks it also attaches to ropes, cables, pier pilings, and metal objects. In a protected environment, such as the Santa Barbara region, it may occur on a sand bottom. Relatively calm conditions exist here because a westerly trending coastline and a chain of offshore islands damp the prevailing west and northwest swells.

Kelp beds typically extend from quite shallow water (*ca.* 20 feet) to 80 feet or more. At the shallow limit giant kelp intergrades with and is replaced by feather boa kelp, Egregia laevigata; at the deeper margin it typically is replaced by bull kelp, Pelagophycus porra, after a zone of intergradation. Whether one or more species of *Macrocystis* occur in southern California is uncertain. Some specialists classify the kelp north of Palos Verdes, near Los Angeles, as M. angustifolia. Any species differences have slight or negligible effects on the environment of fishes.

Under water, kelp beds typically resemble forests with nearly complete canopies (Figure 10). Tangled columns arise from conical holdfasts which are topped with clumps of sporophylls. Holdfast size generally increases with age. Although the holdfast is perennial, maximum life of the stipes is usually 6 months, possibly extending to 8 or 9 months under the best growing conditions (*cf.* North, 1961). Usual diameter of kelp holdfasts near La Jolla is between 10 inches and 2 feet. Holdfasts contain characteristic aggregations of invertebrates (Ghelardi, 1960) as well as fishes (discussed in succeeding sections). Kelp-bed substrates will be divided into three categories, representing subjective estimates of their physical relief. "Low relief" includes sand, silt, or pavement rock bottom or combinations thereof. These are regions with few macroscopic holes for fish or invertebrate refuge. "High relief" refers to bottoms with large exposed rock surface per unit area. Examples are boulder piles, cobbles, boulder-cobble flooring with a high interstitial volume, and solid rock terrains with numerous crevices, cliffs, projecting shelves, ledges, or rotten or honeycombed rock. "Moderate relief" applies to intermediate conditions such as pavement-rock areas with isolated rock piles, depicted in Figure 10, or rocky areas with a slightly broken substrate.

4.4. TEMPERATURE

In shallow inshore waters the temperature structure generally grades from well-developed vertical stratification during summer and fall to nearly isothermal conditions in winter and spring. Surface temperatures are normally coldest from January to March but minimum temperatures at 100 feet normally occur in May and June (Figure 11). This lag in the cooling of deeper waters was suggested by Leipper (1955) and was verified by diving observations during the Kelp Program. Maximum temperature stratification occurs between June, the month of lowest temperatures at 100 feet, and August, the month of maximum surface temperatures. Such a temperature sequence characterizes regions of upwelling (Sverdrup, Johnson, and Fleming, 1942). Cooler water is brought near the surface from February through June by strong northwest winds that are frequent along the coast of the Californias at this time of year (a wind-induced ocean

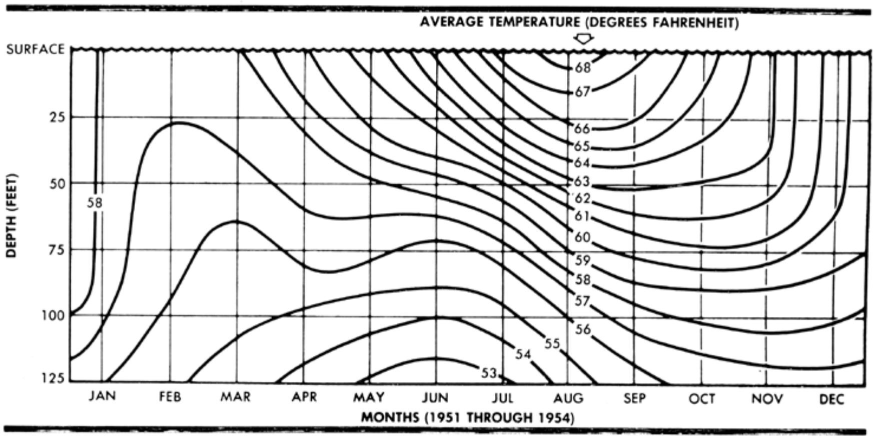

FIGURE 11. Average water temperature off La Jolla (MLR Sta. 93, 30 nautical miles offshore) during 1951–1954. The bottom water (100-feet) was coldest in June and the surface was warmest in August, with an intervening period of highest stratification. Upper part of column was nearly isothermal from November through January (Diagram furnished by Mrs. Margaret K. Robinson, Division of Marine Resources, Scripps Institution of Oceanography).

FIGURE 11. ***Average water temperature off La Jolla (MLR Sta. 93, 30 nautical miles offshore) during 1951–1954. The bottom water (100-feet) was coldest in June and the surface was warmest in August, with an intervening period of highest stratification. Upper part of column was nearly isothermal from November through January (Diagram furnished by Mrs. Margaret K. Robinson, Division of Marine Resources, Scripps Institution of Oceanography).***

current moves at 45° to the right of the wind direction). Highest geostrophic wind velocities occur in June for coastal regions and in July for offshore regions (Eber and Sette, 1959). Leipper (1955) postulates that inshore isotherms rise during spring because cold upwelled water originating near Point Conception moves southward. Additional local upwelling at various points south of Point Conception is implied by Sverdrup, Johnson, and Fleming (1942). Narrow bands of cold water occur along the coast of Baja California south of projecting points or headlands, due to local upwelling (Leipper, *l.c.*). This phenomenon has been well documented by temperature records collected for more than a decade by Prof. Carl L. Hubbs of the Scripps Institution of Oceanography (unpublished).

Although inshore waters display well-developed temperature stratification during summer and early fall, temperature stability is poor during these seasons insofar as the biota is concerned. Tidal excursion (up to 6 feet in the San Diego region) may subject attached inshore animals to daily fluctuations of several degrees Fahrenheit. Much greater temperature fluctuations have been measured at fixed points during this season of temperature stratification and are attributable to at least two causes: (i) internal waves moving toward shore beneath the ocean surface and (ii) short-term local upwelling from sporadic offshore or northerly winds.

LaFond (1959) demonstrated that nearly all longitudinal surface slicks off Mission Beach, San Diego, are associated with internal waves. Beneath and slightly behind each slick the isotherms plunged bottom-ward (Figure 12). Although no data were presented on the frequency of such slicks from day to day, they are of nearly daily occurrence during the summer and fall months (La Fond, *l.c.*). Average shoreward speed was 0.31 knots, with a frequency of one to nine waves per hour. An analysis of the depth distribution of the isotherms in LaFond's figures showed that the greatest temperature fluctuations encountered

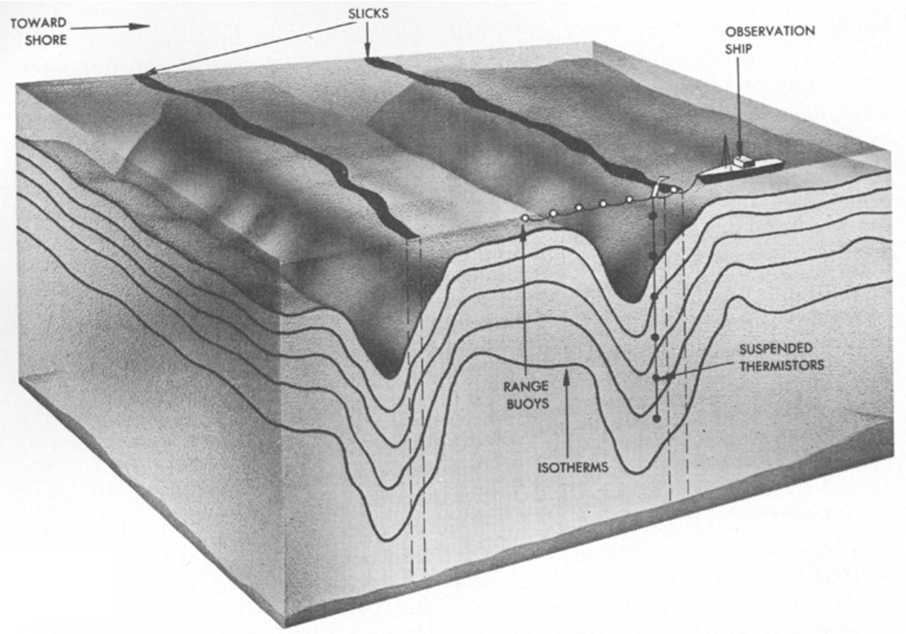

FIGURE 12. Three-dimensional representation of internal waves in the inshore waters off Mission Beach, San Diego. (From LaFond, 1959.)

*FIGURE 12. **Three-dimensional representation of internal waves in the inshore waters off Mission Beach, San Diego. (From LaFond, 1959.)***

by a fixed biota occur well below the surface (Figure 13). This region of temperature fluctuations descends at least to 30 feet, the greatest depth measured by LaFond, and undoubtedly penetrates much deeper. For example, during measurements on 12 June 1958, the maximum fluctuations of 11.4° F. occurred at 20 feet, during seven

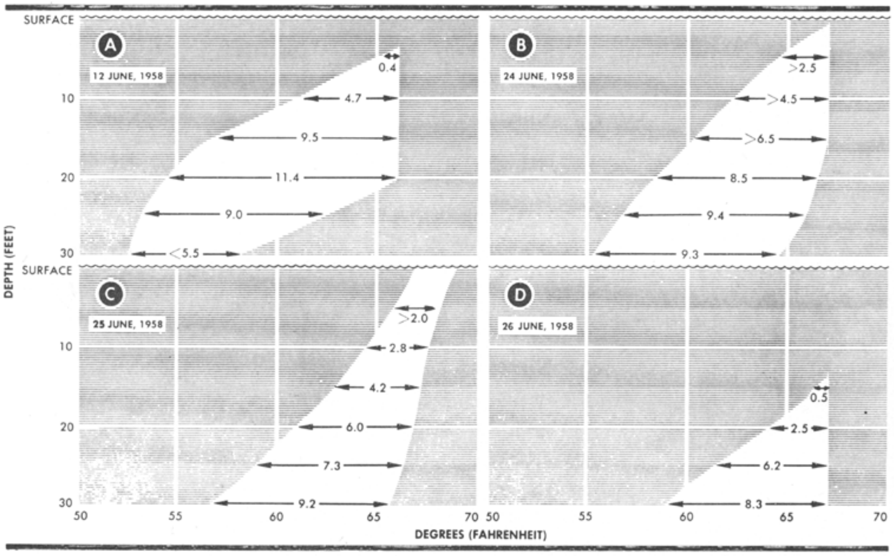

FIGURE 13. Examples of hypothetical temperature excursions with depth for kelp beds of the San Diego region in June. (Calculated from LaFond, 1959.)

*FIGURE 13. **Examples of hypothetical temperature excursions with depth for kelp beds of the San Diego region in June. (Calculated from LaFond, 1959.)***

slicks, in contrast to a 4-degree difference at 5 feet and 5.5 degrees at 30 feet(Figure 13A). On 24 June the region of maximum temperature change (9.4 degrees) was near 25 feet and the eurythermal zone obviously extended much deeper, with 14 slicks occurring in 4 hours and 45 minutes (Figure 13B). On June 25 the eurythermal zone extended to the surface; however, the maximum temperature oscillation (9.2° F.) was probably below the deepest measurement (Figure 13C). Similarly, on 26 June the eurythermal zone apparently reached its greatest dispersion (8.3° F.) at depths greater than the maximum surveyed, and the surface 14 feet were isothermal (Figure 13D).

Temperature elevations occasionally develop in normally cold, upwelling areas south of projecting headlands, down to considerable depths. Westerly winds maintain the upwelling process during summer but occasional storms accompanied by strong southerly or southwesterly winds could theoretically "pile up" warm surface waters to depths of 100 feet or more in these normally cold regions. Although this mechanism has not actually been witnessed, it offers a reasonable explanation for sudden disappearances of kelp from the southwest side of Punta Banda, Baja California, during the fall of 1957 and again in 1959. A surprising scarcity of fishes was also found in the area in June, 1960. High standing crops had been measured previously by wall-net collections and underwater transects (described in following chapters).

4.5. WAVE ACTION

One of the striking features of kelp-bed environments on open coasts is the reversing horizontal water movement or "surge" caused by heavy swells. It is normally present from the surf zone to depths of 30 feet or more. Frequently it extends to 60 feet, with estimated horizontal transits of 6 to 10 feet by suspended bottom materials. Occasionally divers experience slight surge at 100 feet, particularly during times of long-period swell.

Such water motion appears to have profound effects upon the biology of the rocky-shore environment. Particles of shell and sand may be lifted 5 to 10 feet off the bottom at 60 feet by the turbulence and kelp plants are subjected to strong lateral forces. Divers may need to cling to bottom objects to accomplish work, and fishes must swim rapidly in alternate directions to remain within a small area. Turbulence sweeping irregular bottom features appears to create important feeding regions for fishes. Schools of Chromis punctipinnis typically feed about or above prominences on the bottom. At least during spring, kelp bass and sheephead are more abundant near bottom features of high relief.

4.6. VISIBILITY

The importance of visibility for food getting and protection in fishes is easily judged on *a priori* grounds, and observations offer convincing evidence that water clarity is extremely important in the lives of the majority of the fish species. Clarity of rocky-shore environments is subject to considerable daily, weekly, and seasonal variations. Likewise a single area may sometimes vary considerably from hour to hour and frequently differs between surface and bottom. Usually, however, visibility remains fairly constant for periods of weeks or more.

Three factors regulate visibility importantly: (i) bottom disturbance due to surge, (ii) plankton blooms, and (iii) water-exchange. Wave action may cause considerable turbulence near the bottom down to 60 feet, particularly during long-period swell. At such times, bottom visibilities are typically reduced to 10 feet or less. Intense turbidity may occur only in the lower 6 to 10 feet of the water column, particularly during times of long-period swells in calm weather. Concentrations of fishes normally occur near the bottom, but under these conditions the turbid layer may be nearly devoid of fish (even when allowance is made for the restricted visibility). If kelp is present, fishes such as the kelp bass and kelp rockfish under such conditions are much more abundant in the upper, clearer waters.

High plankton density frequently causes poor visibility in inshore waters at La Jolla, especially during the summer months. Although dense plankton layers are usually no more than 10 to 15 feet deep, they occasionally extend down 100 feet or more, allowing only 4- to 5-foot visibility. An example was noted by the writer during a dive on 25 July 1960 near the Scripps Institution of Oceanography with the diving officer James R. Stewart: “"The first dive was made at approximately 1 PM in the Scripps Submarine Canyon. Patches of red tide (Gonyaulax polyhedra) were visible at the surface, however, we expected that the turbid zone would not extend more than 10–15 feet below the surface, or 30 feet at most. However, as we went down the anchor line (which went straight down because the small anchor had slipped off the canyon wall) we noticed no clearing of the water. Visibility decreased and the illumination rapidly dimmed. Finally at approximately 115 foot depth Jimmy stopped and signaled that we might as well go up again. I agreed as I could barely see him (he was at a distance of approximately 2 feet)—it was like diving into a pot of ink."”

Usually the lower boundary of a surface turbid layer is characterized by a dramatic improvement in visibility and a sudden temperature drop. It is possible that the exceptional deep concentration of plankton noted above resulted from diving by chance in the surface-convergent part of an internal wave. As noted previously, the surface layer may extend to considerable depths at such times.

Inshore waters occasionally become very clear off La Jolla and San Diego. The bottom may be visible from the surface to depths of 30 feet or more. If ocean temperatures drop simultaneously, upwelling may have caused the clear water. If there is no considerable drop in temperature, a mass of clear oceanic water may have been carried into the shallow water zone.

Poor underwater visibility is not necessarily associated with the stormy half of the year and its periods of rough water. Two years of diving observations around San Diego disclosed that visibilities on and near the bottom averaged better during the rough-water season than for the calm half of the year (Figure 14). Good visibility (25–30 feet) was recorded several times within a day or two after the passage of a storm front and the strong northwest winds and rough water associated with the second half. It is not known if suspended materials settled rapidly, or if turbid water was replaced by oceanic or upwelled water.

Routine observations during the relatively calm summer and fall seasons indicated that visibility is usually better for surface and mid-water regions than near the bottom (Figure 14). This is not true in summer when heavy plankton blooms cause very poor visibility near the surface. More uniform visibility throughout the water column during winter and spring may result from storms, long-period swells, and weak stratification. Clear oceanic water lies close to the coast near San Diego. Good visibilities characterize the Coronado Islands, Baja California only 8 nautical miles off the coast (Figure 14).

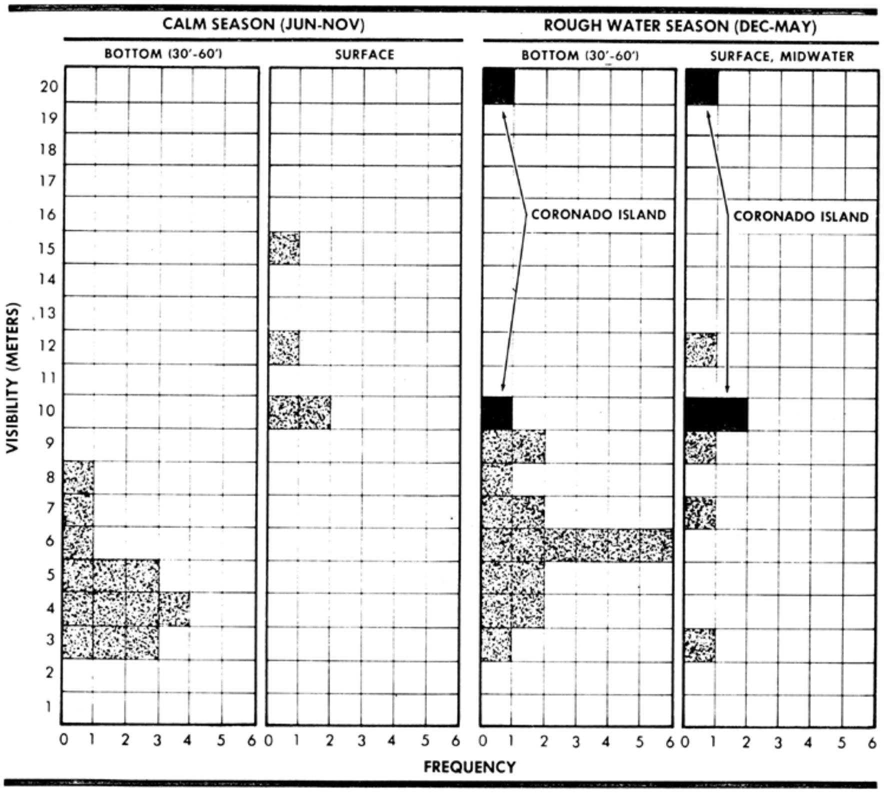

FIGURE 14. Frequency of visibility distances that were encountered underwater during a year of dives in the San Diego region. Shaded areas represent inshore waters; and the solid areas offshore waters near the Coronados Islands, Baja California, Mexico.

FIGURE 14. ***Frequency of visibility distances that were encountered underwater during a year of dives in the San Diego region. Shaded areas represent inshore waters; and the solid areas offshore waters near the Coronados Islands, Baja California, Mexico.***

4.7. DISCUSSION

These important physical factors of the kelp-bed environment are presented as background for succeeding chapters on the kelp-bed fishes. Undoubtedly they play a very important role in the biology of the kelp beds and their fauna, but detailed studies of amplitudes and effects were beyond the resources of the Kelp Program.

In general terms, two rocky-bottom habitats are apparent to the SCUBA diver in the San Diego region. A shallow subtidal zone is delimited from the deep habitat approximately by the 100-foot depth contour. The shallow region is subject to surge and currents, to considerable daily and seasonal temperature fluctuations, and, in some localities, to moving sediments and poor visibilities. In the San Diego region, this zone has a reasonably well-defined demersal fish fauna which may be called the rocky-inshore fauna. The zone and fauna correspond loosely to the inner sublittoral zone and fauna of Hedgpeth (1957). The lower depth boundary varies with local conditions of wave exposure, substrate character, and water clarity. The dominant fishes usually range throughout the zone and considerably deeper, apparently disregarding bottom composition and temperature. These species, which include the kelp bass, California sheephead, and kelp perch, usually show no clear-cut bathymetric distributions relative to strong thermoclines in shallow water. This apparent disregard for temperature contrasts indicates that these fishes are probably adapted to a thermally unstable environment and are relatively unaffected by such changes. Numerous causes of temperature differences in the inshore region are identifiable. Differences may be associated with coastal configuration and wind direction: Because the prevailing winds of southern California and Baja California are from the northwest, warm water tends to accumulate on the north side of headlands and cold water upwells on the south side. Reversals occur during prolonged southerly gales that sometimes accompany storms. Internal waves caused significant short-term temperature fluctuations in the inshore zone. The fauna apparently tolerates these changes rather than moving considerable vertical or horizontal distances to maintain an isothermal environment. Temperatures of the upper and lower regions of the inshore zone also vary seasonally, but in nearly opposite directions: Surface layers are usually warmest between mid-summer and mid-fall and coldest in winter, whereas at 100 feet temperatures are usually lowest at the beginning of summer and highest in fall.

Although its effects have not been assessed, surge influences the inshore environment profoundly, and is undoubtedly important to fishes. Water clarity is also very important and seems to regulate the volume of water available for foraging by many species (a point discussed more fully in succeeding chapters).

Below the inshore zone physical conditions appear to be much more stable. The shallow-water fauna diminishes and cold-water species appear. The effects of physical factors outlined above decrease. Fleshy algae become scarce, presumably due to the low levels of illumination. Cover for demersal fish species is limited to isolated areas of rock, in places abundantly covered with attached gorgonians. A more northern fish fauna appears here. The bathymetric range of this fauna actually extends into the intertidal where upwelling is nearly continuous, and extends shoreward considerably during temporary shallow incursions of colder water.

4.8. SUMMARY

1. General physical aspects of southern California kelp beds influence the fishes importantly.

2. Kelp beds of southern California and the Pacific coast of Baja California normally occur on rock. Some beds of the Santa Barbara region, however, grow on sand and mud.

3. Surface and bottom water temperatures differ most during summer, particularly in July, when the surface water is nearly at its highest temperature and the bottom water is nearly at its lowest.

4. Large fluctuations in water temperature, with a period of less than 1 hour, are believed to occur in kelp beds at mid-depths during summer and early fall months. Fluctuations of 11° F. apparently are not extreme, and some temperature fluctuations penetrate at least to the depth of 60 feet.

5. Temperature fluctuations with periods greater than 1 hour but less than seasonal, are attributed to local currents, upwelling, and incursions of oceanic water.

6. Wave action in the San Diego region extends to depths of 60 feet, occasionally deeper, and is important to many organisms.

7. Observed seasonal differences in underwater visibility may be attributed to several causes.

8. The lower boundary of the inshore environment in the San Diego region is approximately 100 feet deep. Shallower depths are characterized by high levels of illumination, fleshy algae, a distinctive fish fauna, warmer temperatures than the deeper layers, marked temperature fluctuations during the summer and fall, heavy and frequent surge, and, generally, by poor visibility near the bottom.

5. 5. FISH FAUNA OF THE ROCKY INSHORE ZONE

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5.1. INTRODUCTION

This chapter on kelp-bed fishes and their biology concerns the composition of the fish fauna, the geographic and bathymetric ranges, and the faunal ecology; and involves a discussion of the fish community. The standing crop of fish, the food, biology, and sport fishery of the kelp bass, and the food of other common fishes of the kelp beds, are treated in some detail in succeeding chapters.

Three years of data were obtained principally while using SCUBA (self-contained underwater breathing apparatus). Notes were compiled immediately after dives and observations were recorded within 1 day. Quantitative information, discussed in Chapter 6, was based on belt-transect surveys and wall-net collections. Species lists were compiled from observations made specifically for purposes of faunal survey and include information from 71 dives.

5.2. THE ROCKY-INSHORE FAUNA

Although the number of species of demersal fishes inhabiting the southern California rocky sublittoral probably exceeds 150, approximately only one-third this number was noted in the rocky inshore zone during the 3 years of the study. The list of observed, "common" species (Table 2) excludes strictly intertidal forms, numerous common but cryptic species, small forms of uncertain specific identity, and species normally limited to depths below 130 feet. The listed fauna forms the bulk of the standing crop of fish in the rocky areas that were surveyed. Common names generally conform with "Common and Scientific Names of Fishes from the United States and Canada," Bailey *et al.* (1960). Localities of observations and collections are shown in Chapter 7 (Figure 23).

Species most frequently encountered in the rocky areas and kelp beds during the surveys were kelp bass and sheephead. Kelp bass were seen on nearly every dive. A few species were seen frequently, but more than half were seen on less than 10 percent of the dives.

Species frequency plotted against number of species occurring at various frequencies suggests a hyperbolic function (Figure 15), which superficially resembles the relationship between these variables in many terrestrial situations (*cf.* Preston, 1948). In contrast to the terrestrial situations, however, the underwater data represent only sighting a species and do not indicate the number of individuals seen. Because some species school, the relationship between species commonness and faunal diversity would have to be altered considerably if number of individuals, or species abundance, were graphed. If all small species

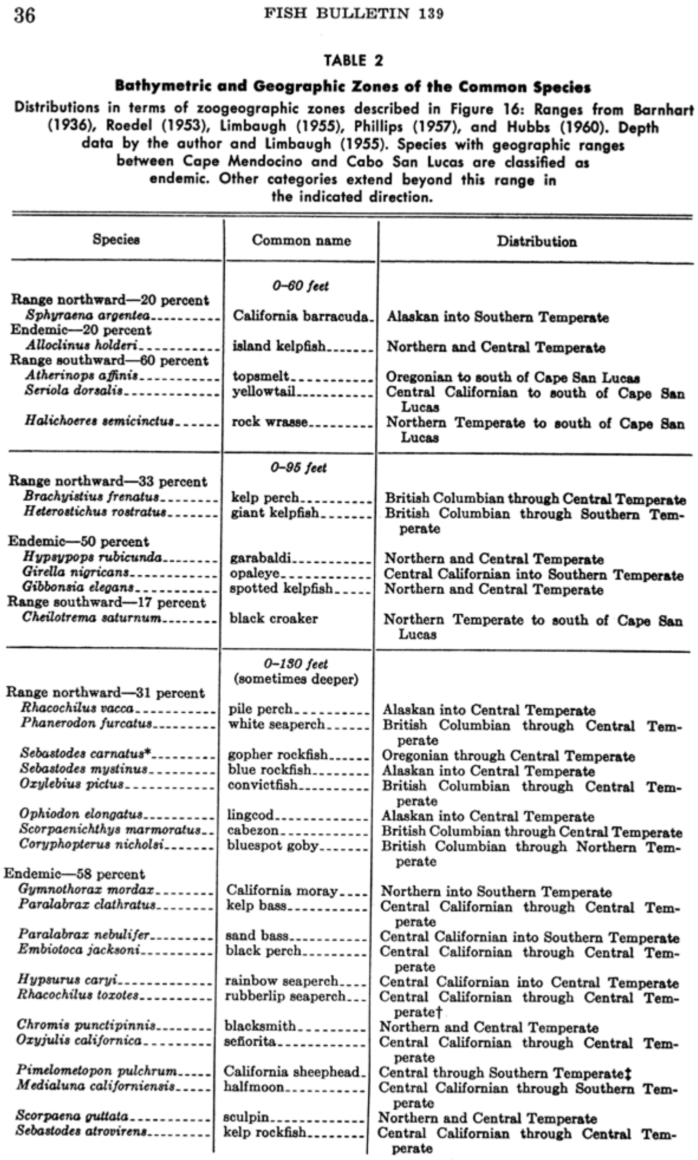


TABLE 2

Bathymetric and Geographic Zones of the Common Species

Distributions in terms of zoogeographic zones described in Figure 16: Ranges from Barnhart (1936), Roedel (1953), Limbaugh (1955), Phillips (1957), and Hubbs (1960). Depth data by the author and Limbaugh (1955). Species with geographic ranges between Cape Mendocino and Cabo San Lucas are classified as endemic. Other categories extend beyond this range in the indicated direction.

Species	Common name	Distribution
	0–60 feet	
Range northward—20 percent		
Sphyraena argentea	California barracuda	Alaskan into Southern Temperate
Endemic—20 percent		
Alloclinus holderi	island kelpfish	Northern and Central Temperate
Range southward—60 percent		
Atherinops affinis	topsmelt	Oregonian to south of Cape San Lucas
Seriola dorsalis	yellowtail	Central Californian to south of Cape San Lucas
Halichoeres semicinctus	rock wrasse	Northern Temperate to south of Cape San Lucas
	0–95 feet	
Range northward—33 percent		
Brachyistius frenatus	kelp perch	British Columbian through Central Temperate
Heterostichus rostratus	giant kelpfish	British Columbian through Southern Temperate
Endemic—50 percent		
Hypsypops rubicunda	garabaldi	Northern and Central Temperate
Girella nigricans	opaleye	Central Californian into Southern Temperate
Gibbonsia elegans	spotted kelpfish	Northern and Central Temperate
Range southward—17 percent		
Cheilotrema saturnum	black croaker	Northern Temperate to south of Cape San Lucas
	0–130 feet (sometimes deeper)	
Range northward—31 percent		
Rhacochilus vacca	pile perch	Alaskan into Central Temperate
Phanerodon furcatus	white seaperch	British Columbian through Central Temperate
*Sebastodes carnatus**	gopher rockfish	Oregonian through Central Temperate
Sebastodes mystinus	blue rockfish	Alaskan into Central Temperate
Oxylebius pictus	convictfish	British Columbian through Central Temperate
Ophiodon elongatus	lingcod	Alaskan into Central Temperate
Scorpaenichthys marmoratus	cabezon	British Columbian through Central Temperate
Coryphopterus nicholsi	bluespot goby	British Columbian through Northern Temperate
Endemic—58 percent		
Gymnothorax mordax	California moray	Northern into Southern Temperate
Paralabrax clathratus	kelp bass	Central Californian through Central Temperate
Paralabrax nebulifer	sand bass	Central Californian into Southern Temperate
Embiotoca jacksoni	black perch	Central Californian through Central Temperate
Hypsurus caryi	rainbow seaperch	Central Californian into Central Temperate
Rhacochilus toxotes	rubberlip seaperch	Central Californian through Central Temperate†
Chromis punctipinnis	blacksmith	Northern and Central Temperate
Oxyjulis californica	señorita	Central Californian through Central Temperate
Pimelometopon pulchrum	California sheephead	Central through Southern Temperate‡
Medialuna californiensis	halfmoon	Central Californian through Southern Temperate
Scorpaena guttata	sculpin	Northern and Central Temperate
Sebastodes atrovirens	kelp rockfish	Central Californian through Central Temperate

TABLE 2

Bathymetric and Geographic Zones of the Common Species

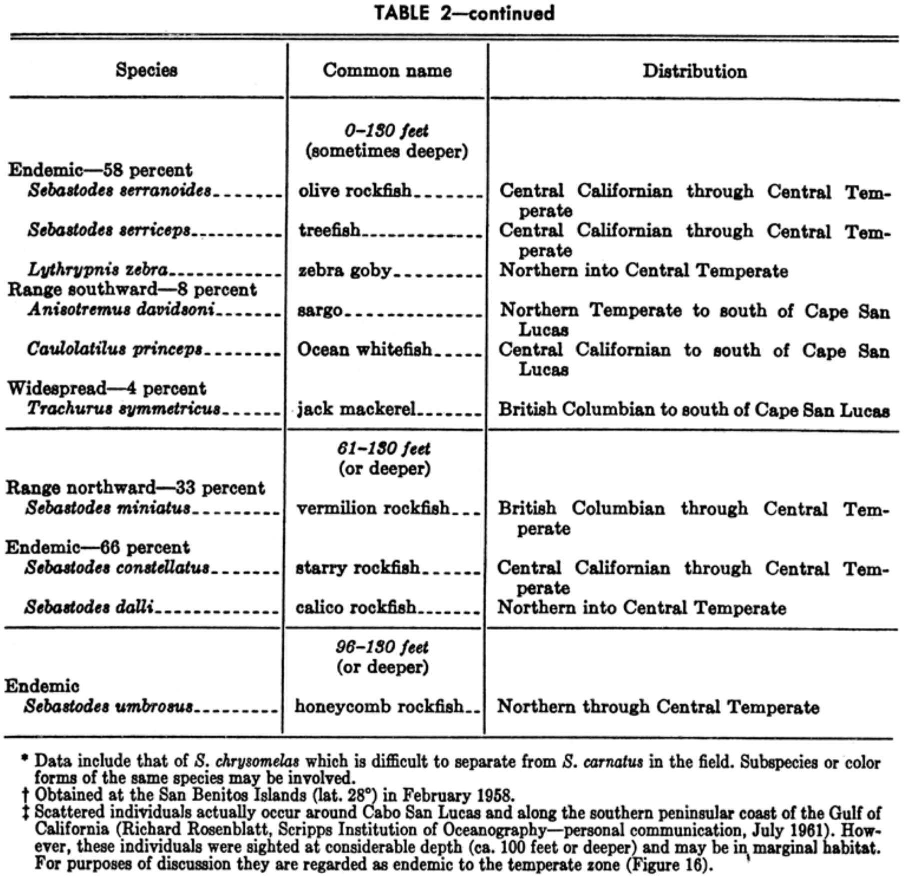


TABLE 2—continued

Species	Common name	Distribution
	0–130 feet (sometimes deeper)	
Endemic—58 percent		
Sebastodes serranoides	olive rockfish	Central Californian through Central Temperate
Sebastodes serriceps	treefish	Central Californian through Central Temperate
Lythrypnis zebra	zebra goby	Northern into Central Temperate
Range southward—8 percent		
Anisotremus davidsoni	sargo	Northern Temperate to south of Cape San Lucas
Caulolatilus princeps	Ocean whitefish	Central Californian to south of Cape San Lucas
Widespread—4 percent		
Trachurus symmetricus	jack mackerel	British Columbian to south of Cape San Lucas
	61–130 feet (or deeper)	
Range northward—33 percent		
Sebastodes miniatus	vermilion rockfish	British Columbian through Central Temperate
Endemic—66 percent		
Sebastodes constellatus	starry rockfish	Central Californian through Central Temperate
Sebastodes dalli	calico rockfish	Northern into Central Temperate
	96–130 feet (or deeper)	
Endemic		
Sebastodes umbrosus	honeycomb rockfish	Northern through Central Temperate

* Data include that of *S. chrysomelas* which is difficult to separate from *S. carnatus* in the field. Subspecies or color forms of the same species may be involved.

† Obtained at the San Benitos Islands (lat. 28°) in February 1958.

‡ Scattered individuals actually occur around Cabo San Lucas and along the southern peninsular coast of the Gulf of California (Richard Rosenblatt, Scripps Institution of Oceanography—personal communication, July 1961). However, these individuals were sighted at considerable depth (ca. 100 feet or deeper) and may be in marginal habitat. For purposes of discussion they are regarded as endemic to the temperate zone (Figure 16).

TABLE 2

Bathymetric and Geographic Zones of the Common Species

were considered, these undoubtedly would be the most frequently encountered, in accordance with the size-frequency pyramid of numbers within the fish community, discussed below.

Graphical analysis reveals several marked latitudinal attenuations in the distribution of the San Diego rocky-inshore fauna compared with neighboring regions (Figure 16). Northward, nearly one-third of the recorded species ranges terminate at Point Conception (approximately 34° N) and two-thirds at Cape Mendocino (approximately 40° N). After a further drop of approximately 22 percent only three species enter the Alaskan zone. Depletion southward is much more abrupt and a boundary south of Punta Eugenia (near 27° N) limits nearly one-half of the species. Five species (13 percent) extend farther south, beyond Cabo San Lucas.

If the geographic ranges of the San Diego species are analyzed in terms of the zonal subdivisions of Figure 16, two distinct frequency groups are apparent (Figure 17). The larger has a mode at four zonal subdivisions, with an apparent range of from two to six. This group

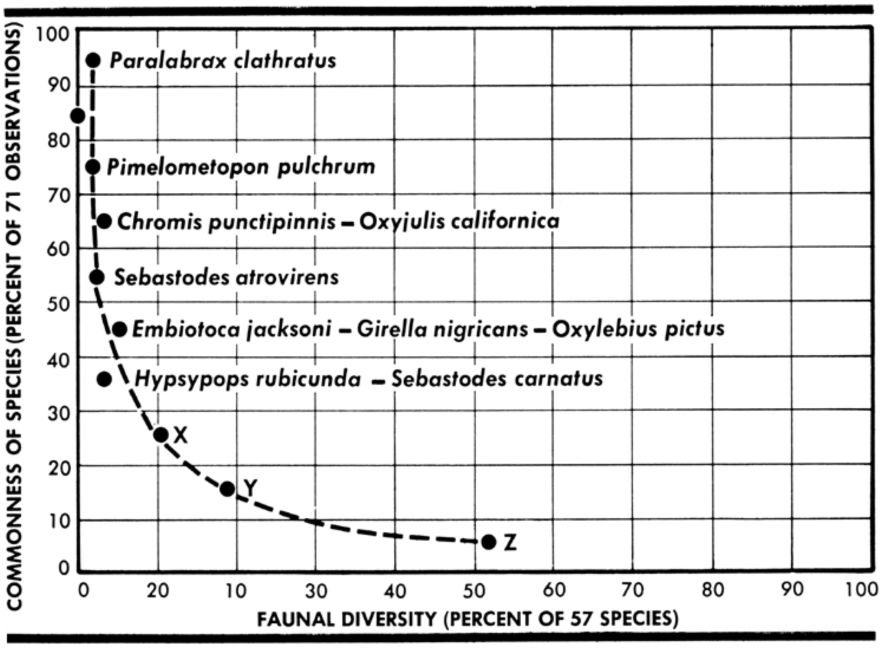


FIGURE 15. Relative frequency of common rocky-inshore fish species, based on visual sighting. Ordinate: percent of dives that a species was noted, midpoints of 10-percent frequency classes plotted. Abscissa: number of species, as a percent, that occurred within each decile of frequency. Category X includes *Rhacochilus vacca, Medialuna californiensis, Scorpaena guttata, Sebastodes serranoides, Sebastodes serriceps, Coryphopterus nicholsi;* Y includes *Paralabrax nebulifer, Atherinops affinis, Caulolatilus princeps, Brachyistius frenatus, Hypsurus caryi, Rhacochilus toxotes, Halichoeres semicinctus, Sebastodes dalli, S. mystinus, Scorpaenichthys marmoratus, Heterostichus rostratus;* Z includes 30 species.

FIGURE 15. ***Relative frequency of common rocky-inshore fish species, based on visual sighting. Ordinate: percent of dives that a species was noted, midpoints of 10-percent frequency classes plotted. Abscissa: number of species, as a percent, that occurred within each decile of frequency. Category X includes Rhacochilus vacca, Medialuna californiensis, Scorpaena guttata, Sebastodes serranoides, Sebastodes serriceps, Coryphopterus nicholsi; Y includes Paralabrax nebulifer, Atherinops affinis, Caulolatilus princeps, Brachyistius frenatus, Hypsurus caryi, Rhacochilus toxotes, Halichoeres semicinctus, Sebastodes dalli, S. mystinus, Scorpaenichthys marmoratus, Heterostichus rostratus; Z includes 30 species.***

is composed principally of endemic species infrequent in collections north of Point Conception. The smaller group includes wide-ranging species recorded for seven or more zones. Fishes ranging into tropical waters include topsmelt and jack mackerel, and the following 11 species range into boreal waters: California barracuda, kelp perch, pile perch, white seaperch, vermilion rockfish, blue rockfish, painted greenling, lingcod, cabezon, giant kelpfish, and bluespot goby.

Although the evidence is far from conclusive, sight records for the San Diego region indicate that the tropical-ranging topsmelt and yellowtail are restricted to the upper 60 feet of the water column (Table 2). The jack mackerel was also noted only in this surface zone, although Limbaugh (1955) recorded it deeper. Restriction of tropical species to surface waters would be expected on *a priori* grounds and is evident when the faunal composition is compared for four depth zones between the surface and 130 feet (Table 3) . Occurrence of the few southern species decreases with depth.

Northern and endemic species contribute nearly equally to all depth zones. Endemic species exhibit wide bathymetric ranges with at least two-thirds noted from the surface to 130 feet (Table 4) . Kelp bass, California sheephead, and blacksmith belong to this eurybathic group

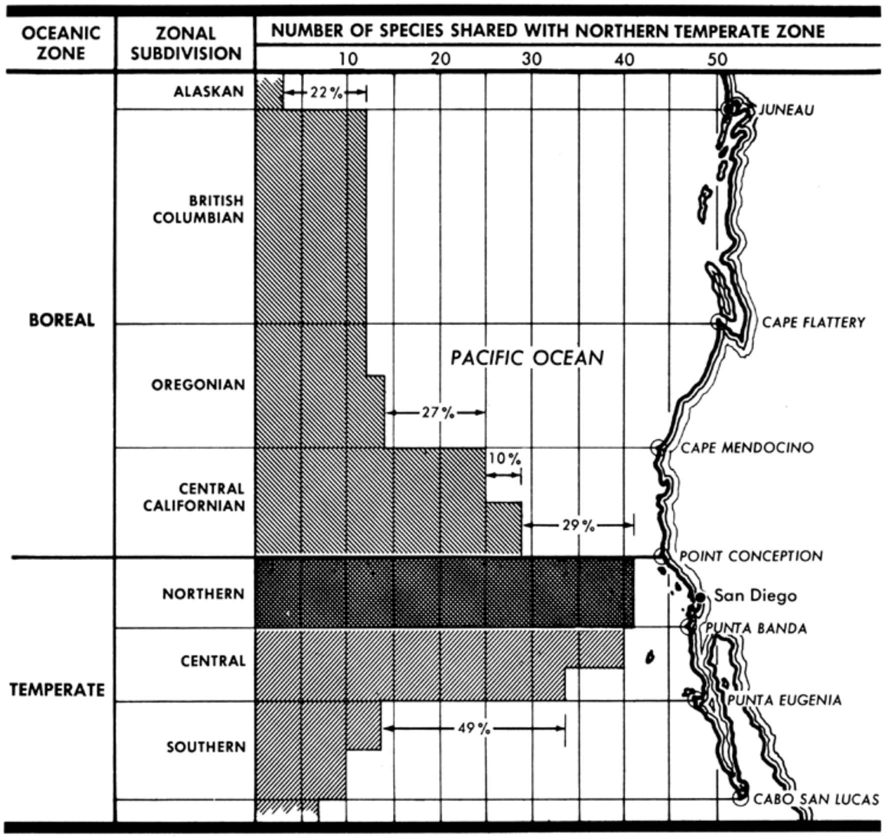


FIGURE 16. Decline in affinity with the San Diego fauna as a function of distances. Boreal and temperate zones after Hedgpeth (1957), with Point Conception taken as the boundary. The zonal subdivisions are mainly for discussion purposes and may or may not be of zoogeographic importance.

FIGURE 16. ***Decline in affinity with the San Diego fauna as a function of distances. Boreal and temperate zones after Hedgpeth (1957), with Point Conception taken as the boundary. The zonal subdivisions are mainly for discussion purposes and may or may not be of zoogeographic importance.***

and comprise the bulk of the visible standing fish crop in nearly all kelp-bed areas.

Kelp perch and giant kelpfish, presumably cold-tolerant species because they range into the boreal zone, were noted principally in the shallow, generally warmer portions of the water column. While they could probably reside at greater depths, they are limited bathymetrically in the La Jolla regions because their favored habitat lies in shallow waters. Both species utilize kelp for cover and feed on food organisms associated with the fronds and stipes. Both species seem to be much the most numerous in beds of giant kelp. The California barracuda occasionally ranges into the boreal zone, but sightings off San Diego have been restricted to surface waters (Table 2). Possibly its normal feeding region is in surface waters but at other times it ranges into deeper, colder waters, explaining the occurrence in the boreal zone. More likely, however, the boreal records merely represent expatriate populations carried into northern areas by rare intrusions of warm southern waters. If so, the surface sightings would represent a true

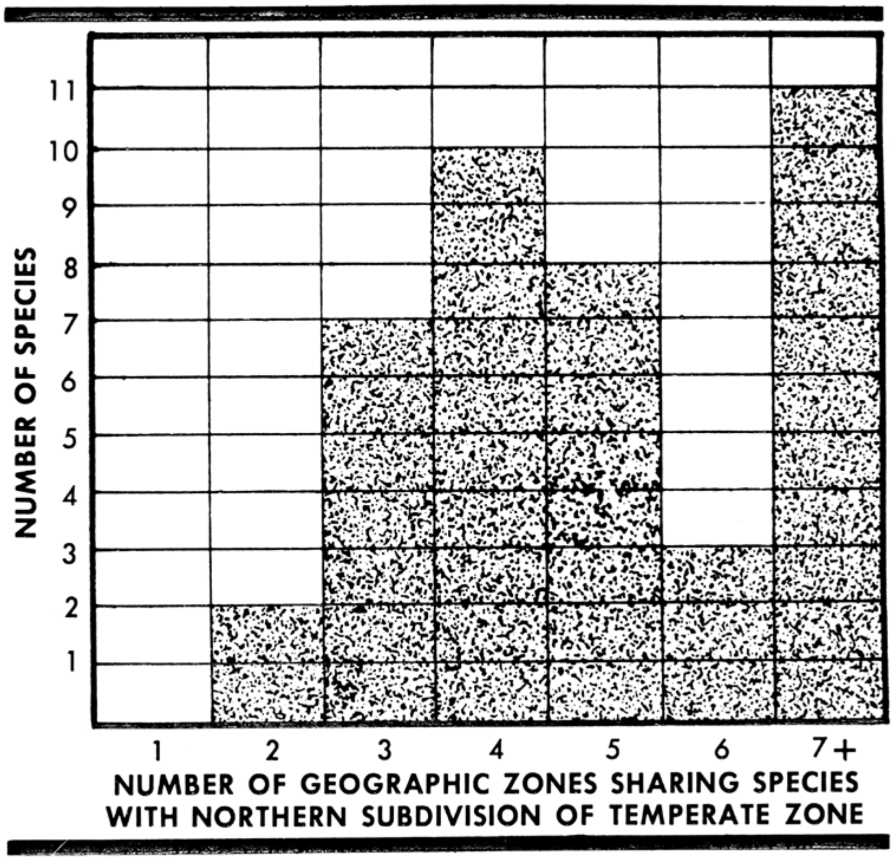


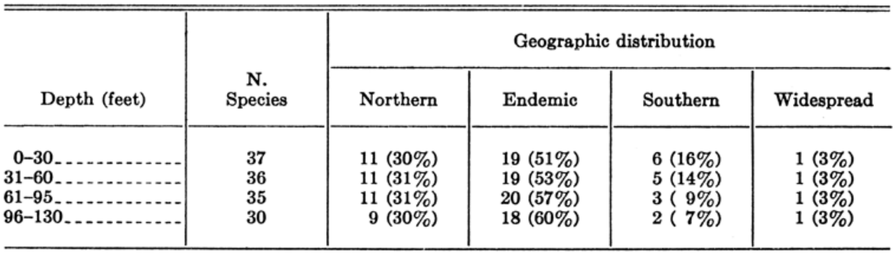
FIGURE 17. Number of geographic zones (as shown in Figure 16) showing the listed common species of the Northern Subdivision of the Temperate Zone. Data from the literature and personal notes of the author.

FIGURE 17. ***Number of geographic zones (as shown in Figure 16) showing the listed common species of the Northern Subdivision of the Temperate Zone. Data from the literature and personal notes of the author.***

TABLE 3

Geographic Distribution of the Rocky-Inshore Fishes Encountered at Four Levels of the 0–130 Foot Zone

Percentages and number of species calculated from data of Table 2.



Depth (feet)	N. Species	Geographic distribution			
		Northern	Endemic	Southern	Widespread
0–30	37	11 (30%)	19 (51%)	6 (16%)	1 (3%)
31–60	36	11 (31%)	19 (53%)	5 (14%)	1 (3%)
61–95	35	11 (31%)	20 (57%)	3 (9%)	1 (3%)
96–130	30	9 (30%)	18 (60%)	2 (7%)	1 (3%)

TABLE 3

Geographic Distribution of the Rocky-Inshore Fishes Encountered at Four Levels of the 0–130 Foot Zone

preference for warm water. of the remaining eight wide-ranging species that penetrate boreal waters, white seaperch, pile perch, vermilion rockfish, blue rockfish, lingcod, painted greenling, cabezon, and bluespot goby, all except the vermilion rockfish (a deeper-water species) have correspondingly wide bathymetric ranges.

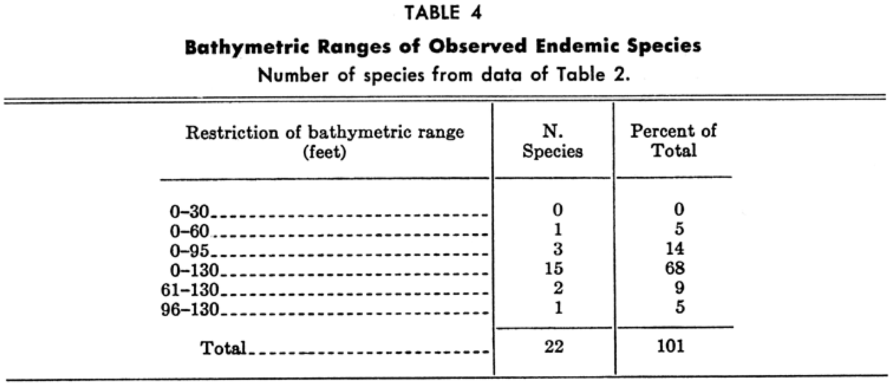


TABLE 4

Bathymetric Ranges of Observed Endemic Species

Number of species from data of Table 2.

Restriction of bathymetric range (feet)	N. Species	Percent of Total
0–30	0	0
0–60	1	5
0–95	3	14
0–130	15	68
61–130	2	9
96–130	1	5
Total	22	101

TABLE 4

Bathymetric Ranges of Observed Endemic Species

Temperature decline northward provides a ready explanation for the prominent attrition of the San Diego fauna north of Point Conception. Presumed temperature effects on faunal distribution are well documented (Hubbs, 1948; Ekman, 1953; Radovich, 1961). Approximate values in degrees Fahrenheit for average sea-surface temperatures for the warmest (September) and coldest (February) months along the coast (U.S. Fish and Wildlife Service, 1962; Robinson, 1957) are as follows: Punta Eugenia, Mexico (approximately 28° N), 73.5 and 59.0; Monterey, California, 59.0 and 52.0; at 45° N in Oregon, 60.0 and 49.0; and Cape Flattery, 55.0 and 45.0. During the warmest month, therefore, the average surface temperatures drop nearly 14° between Punta Eugenia and Monterey (approximately 170 miles NW of Point Conception), none between Monterey and the 45th parallel in Oregon, and approximately 5 degrees between the 45th parallel and Cape Flattery. During the coldest period, the decrease northward is more uniform (7.0, 3.0, and 4.0). Cape Flattery temperatures at their warmest are below those of Punta Eugenia at their coldest.

Winter breakdown in temperature stratification creates nearly uniform conditions down to 100 feet, adding to the significance of surface measurements (Figures 11 and 18). Rocky inshore fishes thus are exposed to a definite and quite even gradient in minimum temperatures, decreasing northward between Punta Eugenia and Cape Flattery. The reverse is not true during summer. Strong stratification makes surface measurements poor indicators of environmental temperatures for all but the shallowest and least vagile species. The reason for the abrupt attrition of the San Diego fauna south of Punta Eugenia (Figure 16) is less obvious, but temperature is undoubtedly involved. Reid (1960) showed a distinct increase in oceanic temperatures (as well as an extremely shallow oxygen minimum) south of Punta Eugenia during all seasons. Macrocystis becomes scarce despite continuation of rocky habitat to the southward, and there is a general increase in warm-temperate and tropical fish species. Fish distribution along the western coast of Baja California was discussed by Hubbs (1960).

5.3. GENERAL ECOLOGY

Faunal diversity seems related both to bottom relief and to depth. Numbers of species sighted showed negligible depth-effect in low or

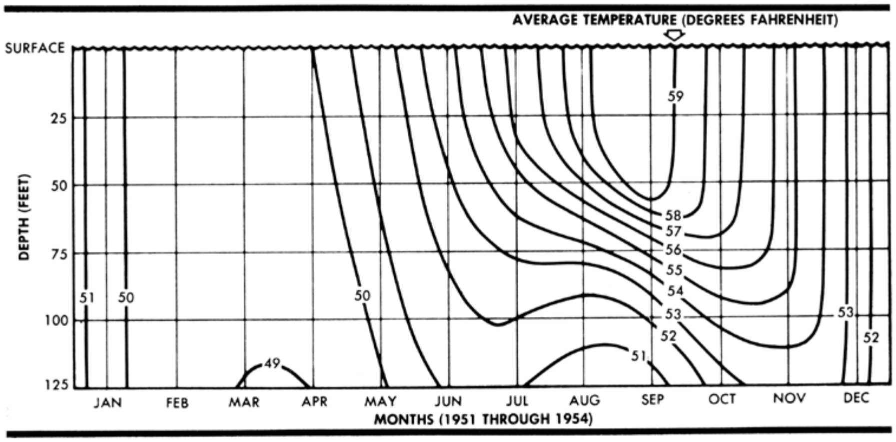


FIGURE 18. Average water temperatures off Cape Mendocino during 1941–1952 (from Robinson, 1957).

FIGURE 18. ***Average water temperatures off Cape Mendocino during 1941–1952 (from Robinson, 1957).***

moderate-relief habitats, but a considerable effect in high relief regions (Table 5) . Rocky areas at moderate depth appeared to attract fishes from both the shallower and deeper zones. Some mail-cheeked fishes, such as treefish, calico rockfish, honeycomb rockfish, and lingcod, and several embiotocids, normally became common about rocky habitats of moderate or low relief only at depths greater than 60 feet. Species common in shallow waters also were frequent in deeper habitats of high relief, swelling the species lists for these situations. Some shallow-water regions may be exceptionally rich however, and several lists for high-relief regions at 30-foot depths in La Jolla Bay exceeded 20 species.

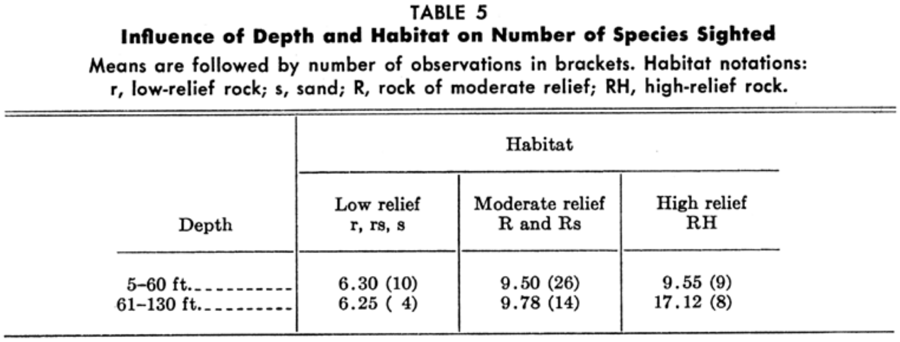


TABLE 5

Influence of Depth and Habitat on Number of Species Sighted

Means are followed by number of observations in brackets. Habitat notations: r, low-relief rock; s, sand; R, rock of moderate relief; RH, high-relief rock.

Depth	Habitat		
	Low relief r, rs, s	Moderate relief R and Rs	High relief RH
5–60 ft.	6.30 (10)	9.50 (26)	9.55 (9)
61–130 ft.	6.25 (4)	9.78 (14)	17.12 (8)

TABLE 5

Influence of Depth and Habitat on Number of Species Sighted

Although no fish species associated with the southern California kelp beds seemed completely dependent on the kelp for survival, the presence of kelp probably enables higher fish production and also a higher standing crop. Not only does kelp contribute nutritionally, but it also augments tremendously attachment surfaces available for prey organisms, particularly filtering and predaceous small invertebrates. The augmented numbers of these key-industry animals multiply the resources for converting plankton into larger food units for the resident fishes. Invertebrate populations exceeded 100,000 per square meter on some kelp fronds (Clendenning and Wing, n.d.). Sessile invertebrates include bryozoans (Membranipora serrilamella, Bugula neritina) , a sea anemone (Epiactis sp.), and several species of Caprellidae. More motile invertebrates include at least several species each of flatworms, mysids, ostracods, copepods, isopods, gammarid amphipods, shrimp, and gastropods. The kelp bed with its fish and invertebrate predators resembles a giant filter that constantly removes plankton from the impinging coastal water. An extremely wide size-range of prey is included, and the "filtered" items include fish up to several feet in length (prey of large carnivores such as black sea bass, Stereolepis gigas, and sea lions).

Substrate character seems of primary importance to the rocky inshore fishes, while presence or absence of kelp is secondary. Kelp-bed substrates with high physical relief generally support a richer fish fauna than those of low relief. Similarly, kelp beds of low substrate relief seem to support more fishes than those with flat or sandy bottoms. Both blacksmith and California sheephead, for example, are common in rocky areas about San Diego, whether or not Macrocystis is present, but are absent from the region of Gaviota (west of Santa Barbara) in dense kelp beds that have a sandy substrate. Standingcrop estimates for the Gaviota beds are much lower than estimates for bottoms of moderate relief in the San Diego region, despite heavier fishing pressure about San Diego (see Chapter 6).

Kelp improves the habitability of an area for fishes by furnishing orientation points or land marks throughout the water column. This is especially important for zones above visual range of the bottom. As discussed in Chapter 4, underwater visibility is highly variable in southern California but objects usually are not visible beyond 20 feet. Demersal fishes seem reluctant to move beyond visual range of their habitat and the reference points furnished by kelp probably encourage them to extend their zones of feeding upward. The kelp columns act as guideposts to the bottom and special refuge areas. The kelp columns may be an orientation aid for the upper members of blacksmith schools, sometimes distributed vertically. Schools of this species are commonly encountered in the vicinity of rocky prominences and in the vicinity of kelp beds. Another method might orient the upper members if each fish would stay within a given distance of the lower neighbors and the lowest fish were to orient on bottom features. By this mechanism a school could remain "anchored" in space and extend off the bottom in waters of poor visibility. Limits of visibility may also explain the "floor" or layer of fishes (kelp bass, ocean whitefish, olive rockfish) frequently encountered by a descending SCUBA diver. At approximately this level the ocean bottom is first discernible.

The wide size range and variety of prey organisms complicate fish classification by food criteria. Understanding of trophic organization and niches available to the fauna, however, requires such a classification and I have attempted this by summarizing the food data discussed in Chapter 8 (Table 6) . The so-called "herbivorous" and omnivorous fish present special problems because available data indicate that much

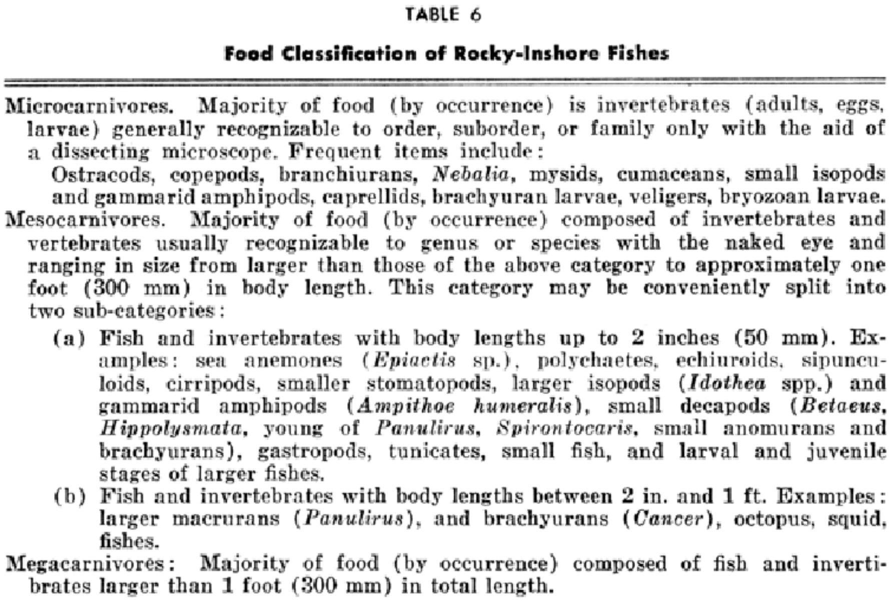


TABLE 6

Food Classification of Rocky-Inshore Fishes

Microcarnivores. Majority of food (by occurrence) is invertebrates (adults, eggs, larvae) generally recognizable to order, suborder, or family only with the aid of a dissecting microscope. Frequent items include:

Ostracods, copepods, branchiurans, *Nebalia*, mysids, cumaceans, small isopods and gammarid amphipods, caprellids, brachyuran larvae, veligers, bryozoan larvae.

Mesocarnivores. Majority of food (by occurrence) composed of invertebrates and vertebrates usually recognizable to genus or species with the naked eye and ranging in size from larger than those of the above category to approximately one foot (300 mm) in body length. This category may be conveniently split into two sub-categories:

(a) Fish and invertebrates with body lengths up to 2 inches (50 mm). Examples: sea anemones (*Epiactis* sp.), polychaetes, echiuroids, sipunculoids, cirripods, smaller stomatopods, larger isopods (*Idothea* spp.) and gammarid amphipods (*Ampithoe humeralis*), small decapods (*Betaeus, Hippolysmata*, young of *Panulirus, Spirontocaris*, small anomurans and brachyurans), gastropods, tunicates, small fish, and larval and juvenile stages of larger fishes.

(b) Fish and invertebrates with body lengths between 2 in. and 1 ft. Examples: larger macrurans (*Panulirus*), and brachyurans (*Cancer*), octopus, squid, fishes.

Megacarnivores: Majority of food (by occurrence) composed of fish and invertibrates larger than 1 foot (300 mm) in total length.

TABLE 6

Food Classification of Rocky-Inshore Fishes

if not all of their nutrition is gained from small invertebrates ingested with the bulky algae. For this reason, opaleye, zebraperch, and half-moon are classified as microcarnivores although their diets are superficially composed of macroscopic items. Fishes in general are not specialized as to species of prey, but feed within the broad categories of Table 6, over relatively large size-ranges available in the habitat.

There is a spectrum of dependence on rocks or kelp as refuge sites that can be classified according to habitat and feeding (Table 7 and Figure 19). Species normally found in or closely associated with cover utilize Zone I; they usually lack gas bladders and generally are rather specialized in form or size. The young of certain relatively large species, such as the kelp bass and California sheephead, also utilize Zone I. These young swim very close to cover and have gas bladders, in contrast to the permanent occupants. They normally "hover" near the substrate, seeming to contact it only infrequently. Their attitude at night is not documented but perhaps they seek contact with a substrate during darkness. Specialized Zone I fishes include the eel-like representatives (moray, eel-blennies), numerous mail-cheeked fishes (Cottoidei), and representatives of the Clinidae, Gobiesocidae, and Syngnathidae. Many smaller representatives not only roam the bottom but the kelp columns and canopy as well. Larger species, such as sculpin and cabezon, usually are restricted to the bottom, which is traversed in "hops" and glides. Once a 2-foot cabezon was seen at least 15 feet off the bottom in a kelp plant (this behavior probably was due to avoidance of exceptionally turbid bottom water). Zone I species, though generally small, contribute substantially to the biomass of fishes in kelp beds. A wide range of food size is utilized although animals of small size are probably the chief food resource.

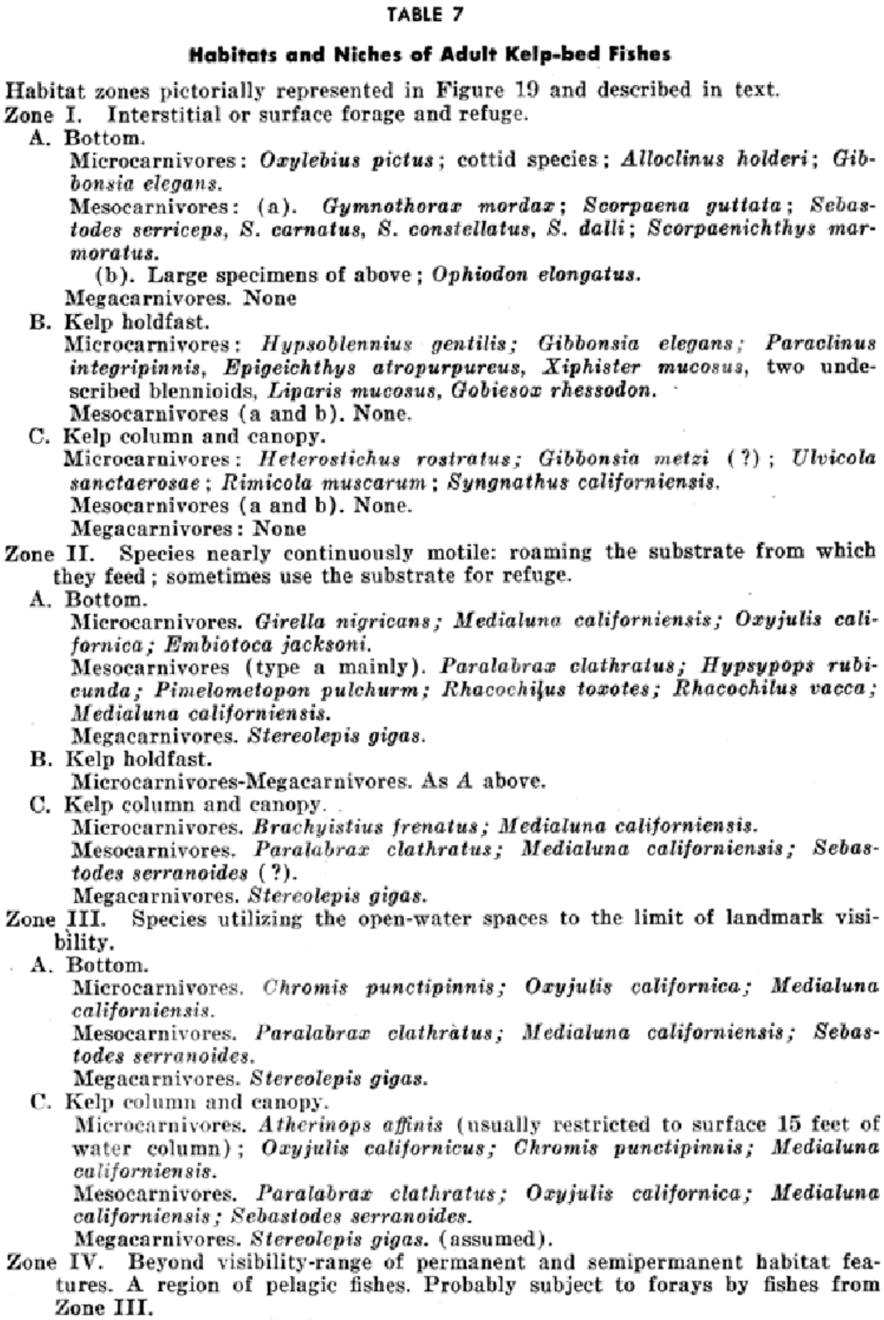


TABLE 7

Habitats and Niches of Adult Kelp-bed Fishes

Habitat zones pictorially represented in Figure 19 and described in text.

Zone I. Interstitial or surface forage and refuge.
- A. Bottom.
  - Microcarnivores: *Oxylebius pictus*; cottid species; *Alloclinus holderi*; *Gibbonsia elegans.*
  - Mesocarnivores: (a). *Gymnothorax mordax*; *Scorpaena guttata*; *Sebastodes serriceps, S. carnatus, S. constellatus, S. dalli*; *Scorpaenichthys marmoratus.*
    - (b). Large specimens of above; *Ophiodon elongatus.*
  - Megacarnivores. None
- B. Kelp holdfast.
  - Microcarnivores: *Hypsoblennius gentilis; Gibbonsia elegans; Paraclinus integripinnis, Epigeichthys atropurpureus, Xiphister mucosus,* two undescribed blennioids, *Liparis mucosus, Gobiesox rhessodon.*
  - Mesocarnivores (a and b). None.
- C. Kelp column and canopy.
  - Microcarnivores: *Heterostichus rostratus; Gibbonsia metzi* (?); *Ulvicola sanctaerosae*; *Rimicola muscarum*; *Syngnathus californiensis.*
  - Mesocarnivores (a and b). None.
  - Megacarnivores: None

Zone II. Species nearly continuously motile: roaming the substrate from which they feed; sometimes use the substrate for refuge.
- A. Bottom.
  - Microcarnivores. *Girella nigricans; Medialuna californiensis; Oxyjulis californica; Embiotoca jacksoni.*
  - Mesocarnivores (type a mainly). *Paralabrax clathratus; Hypsypops rubicunda; Pimelometopon pulchurm; Rhacochilus toxotes; Rhacochilus vacca; Medialuna californiensis.*
  - Megacarnivores. *Stereolepis gigas.*
- B. Kelp holdfast.
  - Microcarnivores-Megacarnivores. As *A* above.
- C. Kelp column and canopy.
  - Microcarnivores. *Brachyistius frenatus; Medialuna californiensis.*
  - Mesocarnivores. *Paralabrax clathratus; Medialuna californiensis; Sebastodes serranoides* (?).
  - Megacarnivores. *Stereolepis gigas.*

Zone III. Species utilizing the open-water spaces to the limit of landmark visibility.
- A. Bottom.
  - Microcarnivores. *Chromis punctipinnis; Oxyjulis californica; Medialuna californiensis.*
  - Mesocarnivores. *Paralabrax clathratus; Medialuna californiensis; Sebastodes serranoides.*
  - Megacarnivores. *Stereolepis gigas.*
- C. Kelp column and canopy.
  - Microcarnivores. *Atherinops affinis* (usually restricted to surface 15 feet of water column); *Oxyjulis californicus; Chromis punctipinnis; Medialuna californiensis.*
  - Mesocarnivores. *Paralabrax clathratus; Oxyjulis californica; Medialuna californiensis; Sebastodes serranoides.*
  - Megacarnivores. *Stereolepis gigas.* (assumed).

Zone IV. Beyond visibility-range of permanent and semipermanent habitat features. A region of pelagic fishes. Probably subject to forays by fishes from Zone III.

TABLE 7

Habitats and Niches of Adult Kelp-bed Fishes

The numerous rockfishes of the Zone I habitat include the gopher rockfish, treefish, and, infrequently, grass rockfish (a shallow-water inhabitant). Deeper-water representatives include the starry and honeycomb rockfishes. All are closely associated with high-relief rocky substrate, and all but the honeycomb rockfish frequently utilize crevices and caves. Smaller rock-loving species of other taxonomic groups include

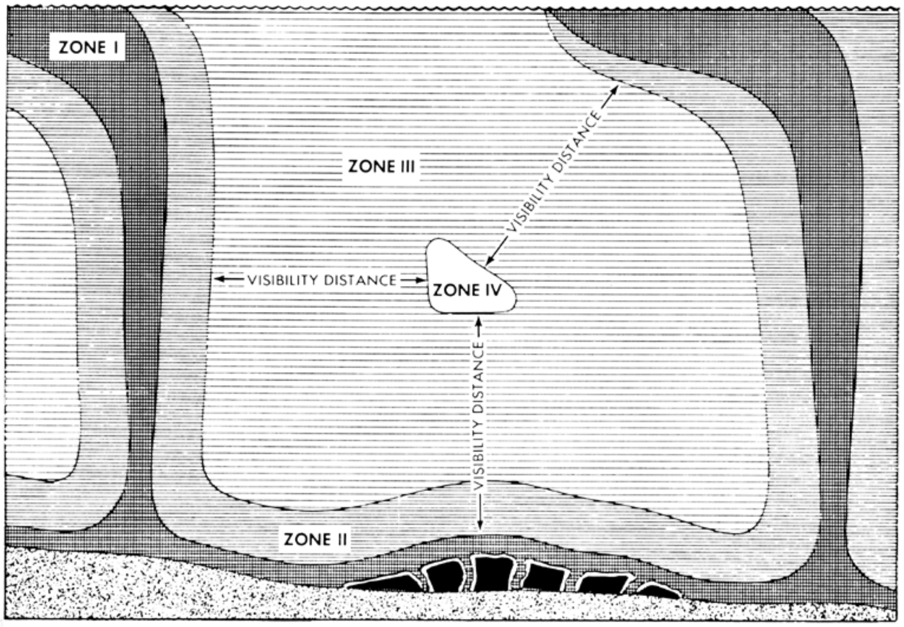


FIGURE 19. Subdivisions of the kelp-bed habitat for fishes. Zones described in Table 7 and text.

FIGURE 19. ***Subdivisions of the kelp-bed habitat for fishes. Zones described in Table 7 and text.***

the painted greenling, several species of cottids, and, rarely in the San Diego vicinity, island kelpfish. In coastal regions the moray eel was noted at depths shallower than 30 feet.

Zone I species closely associated with flabellate and coralline red algae of the bottom include the spotted kelpfish, and cottid species (not identified in the field). These cryptically colored species are difficult to see and identify. Those utilizing the interlocking haptera of the kelp holdfast include the slimy snailfish, reef finspot, reef blenny, black prickleback, two undescribed elongate blennioids, and the California clingfish. Because of their cryptic habits, these species also were rarely noted in the field. The tangled kelp stipes and fronds in the kelp columns and canopy are utilized by another group of small and cryptically colored fishes; the kelp pipefish, striped kelpfish, giant kelpfish (despite its name the majority are less than 1 foot long), kelp gunnel, and kelp clingfish. The giant kelpfish is more frequently noted despite its cryptic coloration, kelp-blade shape, and concealing behavior.

The Zone II fishes (Table 7) possess gas bladders, have a more generalized form, and usually swim actively at various distances above the bottom during daylight hours. Black perch associate with flabellate or coralline red algae in the kelp beds (the common name is misleading, because individuls are nearly always reddish when associated with this common habitat). They become infrequent as the substrate becomes bare, although they have been noted down to 130 feet in the La Jolla region. Adult pile perch, rubberlip perch, and sargo are larger, usually swim farther off the bottom than the black perch, are schooling, and are more vagile. They are common about moderate- to high-relief bottoms to depths exceeding 100 feet. Other Zone II species include señorita, and the three characteristic kelp-bed species, California sheephead, kelp bass, and kelp perch. In the presence of kelp, kelp bass of all sizes usually are distributed throughout the water column, both above and below any thermocline. Individuals probably associate with particular bottom formations and clusters of kelp plants. California sheephead seem more reluctant to rise beyond sight of the bottom, even when kelp is present. Kelp perch are nearly always in close proximity to kelp columns or canopy, and the large loose schools typically are distributed from the surface nearly to the bottom, and through any thermocline. Although kelp perch nearly always associate closely with kelp when it is present, individuals may be abundant where Macrocystis is absent. A good example was the underwater boulder slopes of Guadalupe Island, Mexico, where a closely related species associates with large clumps of Eisenia and Sargassum. Señoritas nearly always occur in loose schools and commonly associate with larger laminarian algae, such as Pterygophora, Eisenia or Macrocystis. An individual señorita is sometimes "mobbed" by adults of other species (frequently blacksmith or halfmoon), presumably to induce the señorita to pick their external parasites (*cf.* Limbaugh, 1955). Schools of large adult opaleyes roam the kelp-bed floors and sometimes the canopy. They seem most abundant at the inside margin of the beds or further inshore. Lone opaleyes were occasionally seen near the bottom.

Zone III (Table 7) varies with underwater visibility, and exists because even the more active demersal fishes seem reluctant to swim beyond visibility range of environmental landmarks. For example, kelp bass may readily be "chummed" to the surface even if no kelp is present, provided the water is very clear. They rarely behave in such fashion in similar regions when the water is turbid except when large kelps (Macrocystis pyrifera, Pelagophycus porra) extend upward through the water column. Other environmental landmarks may be rock pinnacles, pier pilings, cables and anchored ships or barges. Occasionally kelp bass associate with drifting kelp. Zone III harbors many individuals but is poor in species compared to other zones. All food sizes are utilized, from the microscopic (by topsmelt and blacksmith) upward. Topsmelts inhabit the surface waters and are not common deeper than fifteen feet. They are frequently seen feeding in the lee of isolated kelp plants when there is a surface current. Blacksmiths normally utilize the water column below the topsmelt zone, down to the bottom. Both species are common about open spaces in the beds.

Zone IV, which lies beyond visibility ranges of permanent and semi-permanent habitat features is a region of pelagic fishes, but probably subject to forays from Zone III.

It seems unlikely that kelp-bed fishes display a species diversity relationship to kelp height and diversity as demonstrated between birds and foliage by MacArthur and MacArthur (1961). As noted previously, tall laminarian algae merely represent a vertical extension of the bottom algal zone as far as the fish fauna is concerned (see above). It is doubtful if the surface canopy extension is responsible for any noticeable increase in species diversity. Although some neritic species (those that wander the surface waters in the manner of pelagic fishes, but are generally limited to the regions over the continental shelves) do congregate about the columns and canopy of large kelps, these species do not appear to have any special adaptations to kelp and probably find some attraction in any large objects or shore features, floating or fixed, organic or inorganic. Common kelp-bed species such as kelp bass and sheephead, and even close associates such as kelpfish and kelp perch, may also occur abundantly where giant kelp is absent (Guadalupe Island, Mexico). Although suggestive of terrestrial foliage types at first glance, the kelp-bed habitat actually corresponds in very few ways to the relationship between herbs, bushes, and trees described by MacArthur and MacArthur (1961). Fish species lists are nearly the same for regions that roughly correspond to a forest and to an herbaceous boulder-strewn field in the terrestrial environment. With other factors equal, the prime ecological requirements for a diverse subtidal fauna appear to be broken or highly irregular rock covered by a rich algal carpet. Although an algal carpet up to a foot in depth is reasonably analogous to a terrestrial herbaceous layer, the presence of analogues of shrubs (Eisenia, Pterygophora, Cystoseria, Sargassum) or trees (Macrocystis, Pelagophycus) seems to have no observable effect on the list of fish species. Close consideration reveals that the relationship between fishes and the surrounding flora is quite different than for the terrestrial analogues: (a) a large portion of the fishes have gas bladders and have few "perching" needs during daylight hours, (b) species without gas bladders that use the Macrocystis columns and canopies are normally also present on the bottom, and (c) few, if any, of the fish species appear to be dependent on the shrub and tree analogues for reproductive activities such as courtship and nest building.

5.4. THE FISH COMMUNITY

An animal community may be defined as an assemblage of populations living in a prescribed area or physical habitat. In addition to the individual population components, it will have functional unity and characteristic trophic structures and energy flow. Taxonomic unity, in that there is a probability that certain species will occur together, is also a characteristic. A community need not be completely isolated from other communities, and overlap and interdependence is the rule. Further, the community need not contain all the elements of the trophic pyramid. One definable segment of the ecosystem can be considered.

The rocky inshore fishes of these studies fit the community concept quite well. Their physical habitat is the rocky shallow subtidal region with its rich variety of algae and invertebrates. Under conditions yet to be fully understood, the rocks will support the large laminarian alga, Macrocystis pyrifera, in some areas. Regions where giant kelp was present were studied most intensively.

As noted previously, holdfasts and columns of Macrocystis are generally utilized by the fauna as if these features were vertical extensions of the bottom rock and algal habitat. Despite broader utilization of the habitat by individual species, characteristic animal groupings occur in identifiable subdivisions such as the interstices of broken rock, among the dense short algae growing on the rocks, in the tangled passageways between the haptera of the conical kelp holdfasts, among the loose clusters of stipes and blades in the kelp columns and canopy, and in the regions of surrounding waterspace.

The rocky-inshore community overlaps two other prominent communities, the neritic and the demersal-sandy. Some of the species captured in our quantitative collections were attributed to these three different communities (Tables [8] , [9]) but may actually represent ecotonal situations. The data, however, are insufficient to establish this point.

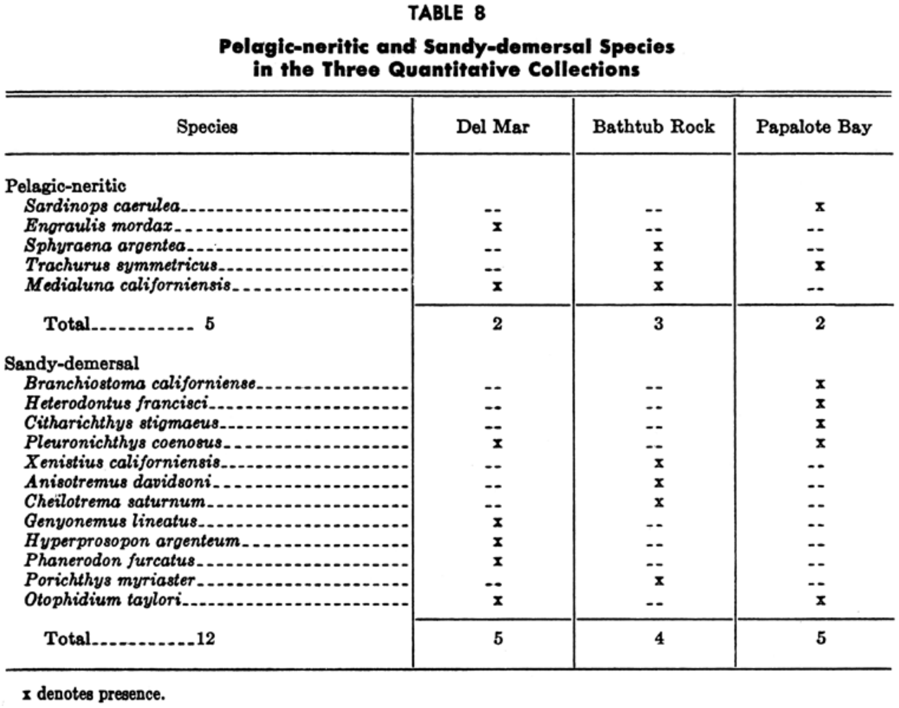


TABLE 8

Pelagic-neritic and Sandy-demersal Species in the Three Quantitative Collections

Species	Del Mar	Bathtub Rock	Papalote Bay
Pelagic-neritic			
Sardinops caerulea	--	--	x
Engraulis mordax	x	--	--
Sphyraena argentea	--	x	--
Trachurus symmetricus	--	x	x
Medialuna californiensis	x	x	--
Total 5	2	3	2
Sandy-demersal			
Branchiostoma californiense	--	--	x
Heterodontus francisci	--	--	x
Citharichthys stigmaeus	--	--	x
Pleuronichthys coenosus	x	--	x
Xenistius californiensis	--	x	--
Anisotremus davidsoni	--	x	--
Cheilotrema saturnum	--	x	--
Genyonemus lineatus	x	--	--
Hyperprosopon argenteum	x	--	--
Phanerodon furcatus	x	--	--
Porichthys myriaster	--	x	--
Otophidium taylori	x	--	x
Total 12	5	4	5

x denotes presence.

TABLE 8

Pelagic-neritic and Sandy-demersal Species in the Three Quantitative Collections

Quantitative collection sites were chosen as preponderating in rocks and Macrocystis but the species lists were not expected to represent only this habitat. Inclusion of some sand habitat was unavoidable and neritic species would also be expected. Obviously our defined fish community represents only an arbitrary part of the ecosystem. Another part is the large invertebrate community ranging from individuals of roughly the same size as fishes to the innumerable smaller invertebrates. These are not included in Tables 8 and 9 but are in the fish food analyses of Chapter 8. Higher sections of the trophic pyramid occupied by the black sea bass and the marine mammals are also missing from the tables.

A classical Eltonian pyramid of numbers was obtained in the collections and represents a supra-population characteristic (Figure 20). Fish weight was utilized as an index to fish "size" in constructing the pyramid because this measurement is more closely correlated to the mass of variably shaped organisms than length. For ease of analysis, lengths only were taken on the specimens. Weights were later reconstructed from weight-length regressions calculated for this purpose.

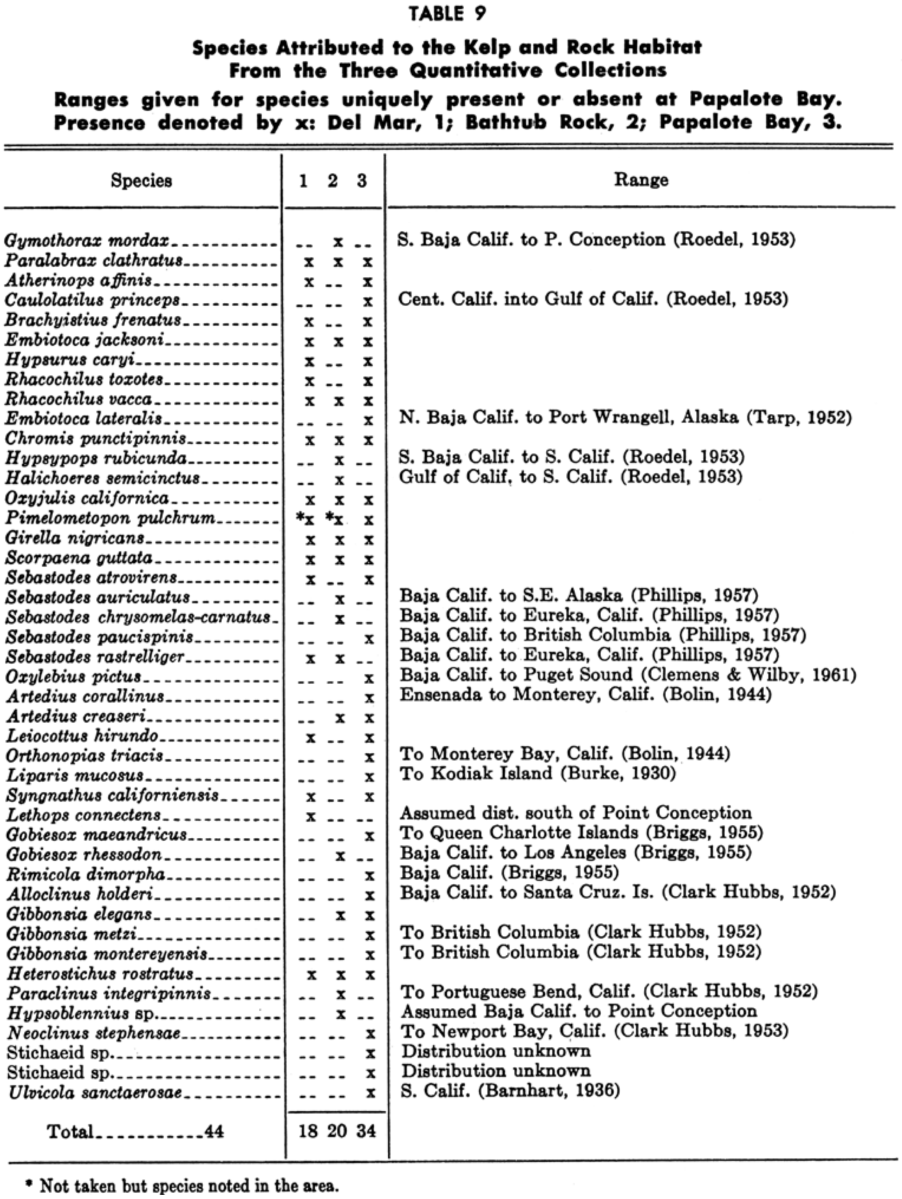


TABLE 9

Species Attributed to the Kelp and Rock Habitat
From the Three Quantitative Collections

Ranges given for species uniquely present or absent at Papalote Bay.
Presence denoted by x: Del Mar, 1; Bathtub Rock, 2; Papalote Bay, 3.

Species	1	2	3	Range
Gymothorax mordax	--	x	--	S. Baja Calif. to P. Conception (Roedel, 1953)
Paralabrax clathratus	x	x	x	
Atherinops affinis	x	--	x	
Caulolatilus princeps	--	--	x	Cent. Calif. into Gulf of Calif. (Roedel, 1953)
Brachyistius frenatus	x	--	x	
Embiotoca jacksoni	x	x	x	
Hypsurus caryi	x	--	x	
Rhacochilus toxotes	x	--	x	
Rhacochilus vacca	x	x	x	
Embiotoca lateralis	--	--	x	N. Baja Calif. to Port Wrangell, Alaska (Tarp, 1952)
Chromis punctipinnis	x	x	x	
Hypsypops rubicunda	--	x	--	S. Baja Calif. to S. Calif. (Roedel, 1953)
Halichoeres semicinctus	--	x	--	Gulf of Calif. to S. Calif. (Roedel, 1953)
Oxyjulis californica	x	x	x	
Pimelometopon pulchrum	*x	*x	x	
Girella nigricans	x	x	x	
Scorpaena guttata	x	x	x	
Sebastodes atrovirens	x	--	x	
Sebastodes auriculatus	--	x	--	Baja Calif. to S.E. Alaska (Phillips, 1957)
Sebastodes chrysomelas-carnatus	--	x	--	Baja Calif. to Eureka, Calif. (Phillips, 1957)
Sebastodes paucispinis	--	--	x	Baja Calif. to British Columbia (Phillips, 1957)
Sebastodes rastrelliger	x	x	--	Baja Calif. to Eureka, Calif. (Phillips, 1957)
Oxylebius pictus	--	--	x	Baja Calif. to Puget Sound (Clemens & Wilby, 1961)
Artedius corallinus	--	--	x	Ensenada to Monterey, Calif. (Bolin, 1944)
Artedius creaseri	--	x	x	
Leiocottus hirundo	x	--	x	
Orthonopias triacis	--	--	x	To Monterey Bay, Calif. (Bolin, 1944)
Liparis mucosus	--	--	x	To Kodiak Island (Burke, 1930)
Syngnathus californiensis	x	--	x	
Lethops connectens	x	--	--	Assumed dist. south of Point Conception
Gobiesox maeandricus	--	--	x	To Queen Charlotte Islands (Briggs, 1955)
Gobiesox rhessodon	--	x	--	Baja Calif. to Los Angeles (Briggs, 1955)
Rimicola dimorpha	--	--	x	Baja Calif. (Briggs, 1955)
Alloclinus holderi	--	--	x	Baja Calif. to Santa Cruz. Is. (Clark Hubbs, 1952)
Gibbonsia elegans	--	x	x	
Gibbonsia metzi	--	--	x	To British Columbia (Clark Hubbs, 1952)
Gibbonsia montereyensis	--	--	x	To British Columbia (Clark Hubbs, 1952)
Heterostichus rostratus	x	x	x	
Paraclinus integripinnis	--	x	--	To Portuguese Bend, Calif. (Clark Hubbs, 1952)
Hypsoblennius sp.	--	x	--	Assumed Baja Calif. to Point Conception
Neoclinus stephensae	--	--	x	To Newport Bay, Calif. (Clark Hubbs, 1953)
Stichaeid sp.	--	--	x	Distribution unknown
Stichaeid sp.	--	--	x	Distribution unknown
Ulvicola sanctaerosae	--	--	x	S. Calif. (Barnhart, 1936)
Total 44	18	20	34	

* Not taken but species noted in the area.

TABLE 9

Species Attributed to the Kelp and Rock Habitat From the Three Quantitative Collections Ranges given for species uniquely present or absent at Papalote Bay. Presence denoted by x: Del Mar, 1; Bathtub Rock, 2; Papalote Bay, 3.

Formulae are presented in the Appendix of Chapter 6. For each of the collections, similar regressions were obtained when logarithms of the frequencies of individuals per 100-gram size class were plotted against logarithms of the size-class midpoints. The regression slopes approximate minus two in each collection and spread of the data about the regression line seems reasonably similar, as do also the locations of the Y-intercepts. The few highly divergent datum points do not invalidate the regressions. In the Bathtub Rock collection (Figure

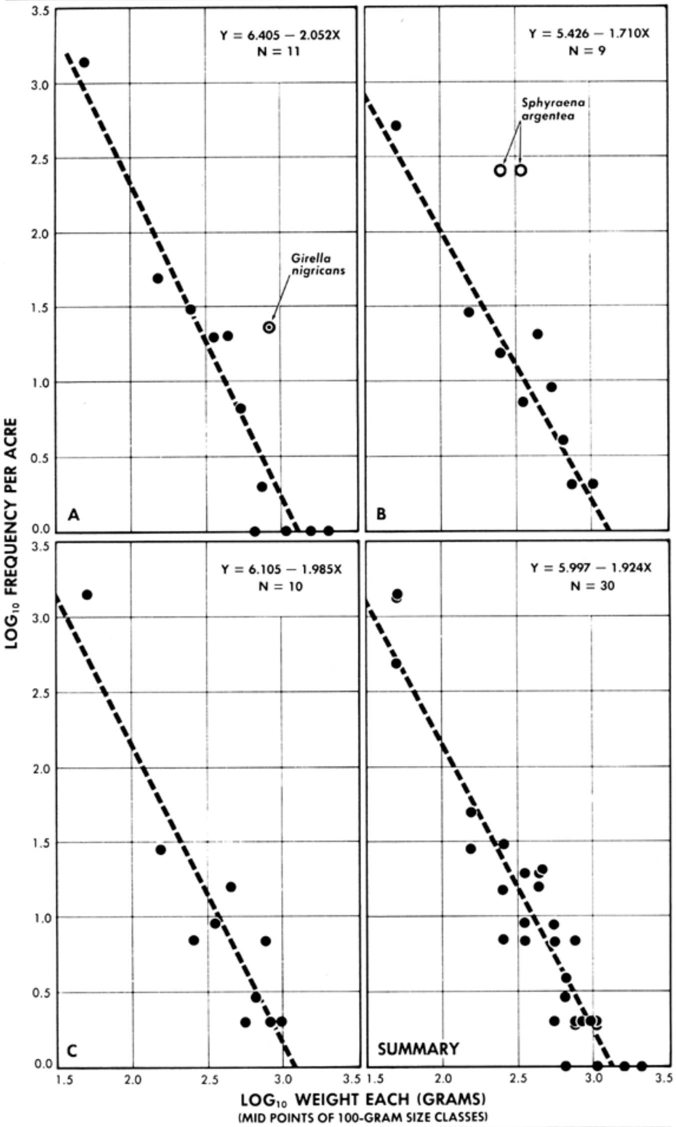


FIGURE 20. Weight frequency regressions for kelp-bed fishes in three quantitative collections.

FIGURE 20. ***Weight frequency regressions for kelp-bed fishes in three quantitative collections.***

20B) the exceptional point was principally due to a large school of California barracuda that was unavoidably encircled by the net. This species is neritic and occurs only incidentally in the kelp beds. A second exceptional datum point principally resulted from a large school of opaleyes taken in the Del Mar collection (Figure 20A). Although this opaleye frequency seems too high, judging from transect estimates of the species, the opaleye may normally be somewhat above the number predicted by the regressions for the kelp-bed collections. Despite its size, the opaleye is probably a microcarnivore (see Chapter 8). Because it utilizes unusually small prey size, the fish feeds at a lower trophic level than its similar-sized associates (kelp bass, sheephead) and may thus have a potential for greater population density.

Effect of fishing activity on the fish community could be analyzed by means of the weight-frequency regressions. An area unfished for a long period might be expected to show a flatter slope in the regression plot than the areas sampled in the Kelp Program studies. The large carnivorous fishes should be more abundant and, possibly, their prey less abundant, than in the fished areas. Also of interest would be the changes in weight-frequency regression for fishes of an isolated kelp bed that had been destroyed by storms when kelp and fishes were being reconstituted.

An energy flow leading from smaller to larger organisms is well documented by food studies on the species (Chapter 8). However, invertebrates contribute directly and substantially at all trophic levels of the fish community. This underscores the incompleteness of the present study from the synecological viewpoint. The wide variety of food items consumed by most fish species is noteworthy. Such catholic tastes probably lend a strong stabilizing influence to the community (MacArthur, 1955).

The degree of taxonomic unity between the three quantitative collections is shown by a comparison of the species lists (Table 10) . From the list of all species taken, 25 (57 percent) occur once, 10 (23 percent) were represented twice, and 9 (20 percent) were taken in all three collections. Nearly one-half of the species (19, or 43 percent) were represented in more than one collection. Papalote Bay, richest in species, shared nearly one-half of its species with Del Mar and approximately one-third with Bathtub Rock. Taxonomic similarities between the three sites can be evaluated more objectively if species occurrence (absent, shared by pairs of sites, present in all three sites) is compared with expected frequency based on the size of the collections and the complete species list (Table 11) . If there were considerable differences in species composition between the three sites, then the frequency of unique species would be greater than that expected by chance and the frequency of shared species less. Thus the theoretical probability of occurrence of 1 of the 44 species in a collection totalling 22 species would be 0.50, and the probability of sharing 1 species between two collections of 22 species each would be 0.50 times 0.50 or 0.25. A table of actual and expected frequencies was constructed using these principles (Table 11). All differences from theoretical frequencies are well below significance. This lack of significance argues that the occurrences of unique and shared species at and between the three sites approximately

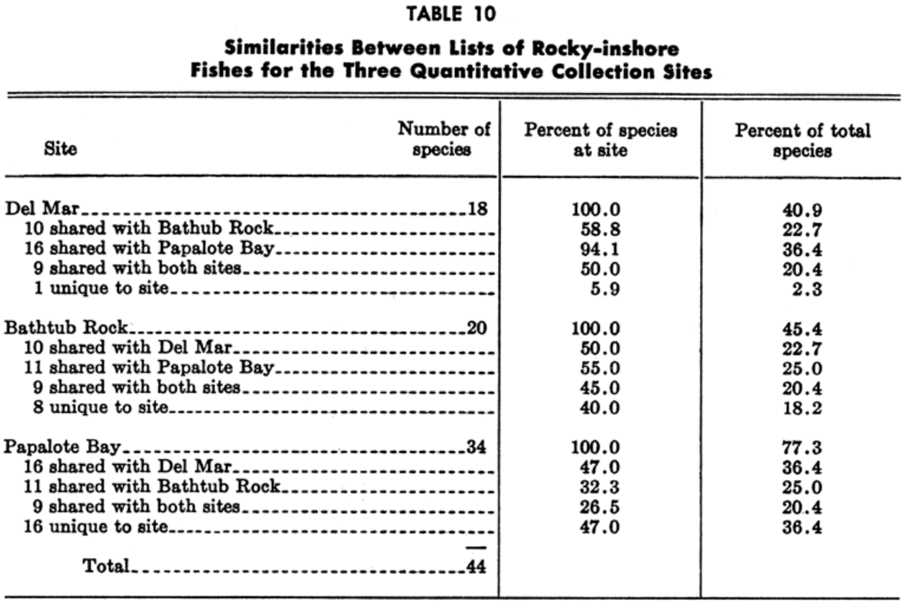


TABLE 10

Similarities Between Lists of Rocky-inshore Fishes for the Three Quantitative Collection Sites

Site	Number of species	Percent of species at site	Percent of total species
Del Mar	18	100.0	40.9
10 shared with Bathub Rock		58.8	22.7
16 shared with Papalote Bay		94.1	36.4
9 shared with both sites		50.0	20.4
1 unique to site		5.9	2.3
Bathtub Rock	20	100.0	45.4
10 shared with Del Mar		50.0	22.7
11 shared with Papalote Bay		55.0	25.0
9 shared with both sites		45.0	20.4
8 unique to site		40.0	18.2
Papalote Bay	34	100.0	77.3
16 shared with Del Mar		47.0	36.4
11 shared with Bathtub Rock		32.3	25.0
9 shared with both sites		26.5	20.4
16 unique to site		47.0	36.4
Total	44		

TABLE 10

Similarities Between Lists of Rocky-inshore Fishes for the Three Quantitative Collection Sites

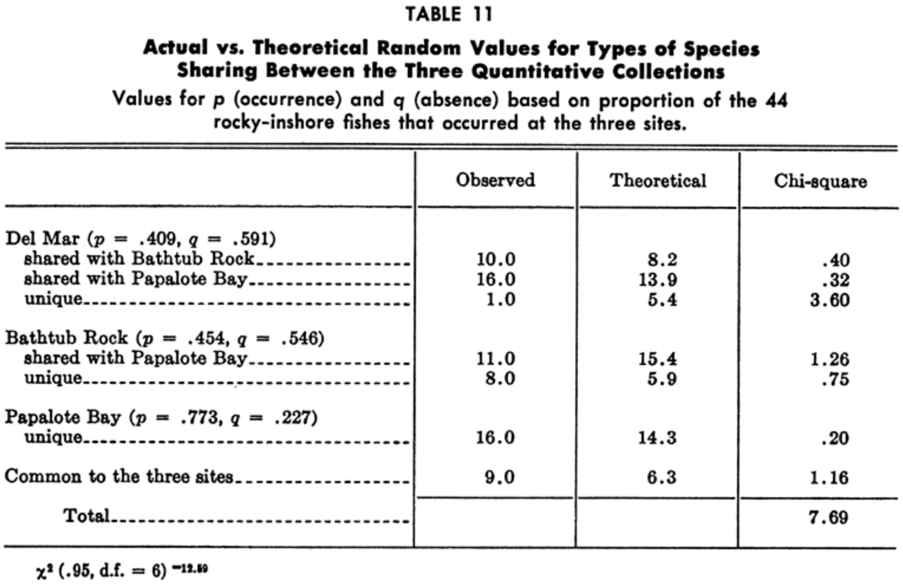


TABLE 11

Actual vs. Theoretical Random Values for Types of Species Sharing Between the Three Quantitative Collections

Values for p (occurrence) and q (absence) based on proportion of the 44 rocky-inshore fishes that occurred at the three sites.

	Observed	Theoretical	Chi-square
Del Mar (p = .409, q = .591)			
shared with Bathtub Rock	10.0	8.2	.40
shared with Papalote Bay	16.0	13.9	.32
unique	1.0	5.4	3.60
Bathtub Rock (p = .454, q = .546)			
shared with Papalote Bay	11.0	15.4	1.26
unique	8.0	5.9	.75
Papalote Bay (p = .773, q = .227)			
unique	16.0	14.3	.20
Common to the three sites	9.0	6.3	1.16
Total			7.69

χ^2 (.95, d.f. = 6) $^{=12.59}$

TABLE 11

Actual vs. Theoretical Random Values for Types of Species Sharing Between the Three Quantitative Collections

matched expectations if one removed three samples of the size of the collections from a population with species distributed at random. The factors that influenced the size of species lists from the three collections are not definitely established. The area treated in the Del Mar collection is estimated at 1.31 acres, and the area represented by the Bathtub Rock and by the Papalote collections was 0.55 acre. The Del Mar collection was poorest in species despite the fact that it covered the greatest area. In all three collections fish pickup by SCUBA divers was thorough and judged adequate. Each site displayed some sandy habitat in the form of patches or meandering channels among the rocks, but the proportions of the two habitat types were not measured. Rocks were preponderant at all three sites and differences in amount of sandy habitat were not considered significant. The three sites, however, did show two types of coastal conditions. The Del Mar and Bathtub Rock sites are surrounded by areas of sandy beach with heavy surf. Both have relatively soft-rocky substrate and are located near poorly compacted, eroding sea cliffs. Both sites are near a slough and are undoubtedly subject to occasional alongshore currents, silting, and burial in sand. The Papalote Bay site, in contrast, is located in a bay on the southwest shore of an extensive rocky headland (Punta Banda). Sandy beaches are minor features and upwelling is intense (Hubbs, 1960); hence the water is highly productive and of low silt content. Although sand was present in the vicinity of the site, it did not dominate the rocky bay bottom. The igneous rock of Punta Banda headland is definitely much more resistant to erosion than the substrate of the Del Mar and Bathtub Rock sites. It is concluded that differences between the three sites in number of species is principally due to proximity to shifting sand and silt, durability of the rocky substrate, and exposure to upwelled water.

Lack of significant dissimilarities between the species list of the Papalote Bay site on the one hand, and the Del Mar and Bathtub Rock sites on the other, is of considerable interest. The southern side of Punta Banda is a known region of summer upwelling and has long been suspected of harboring a northern element in its fish fauna (*cf.* Hubbs, 1960). Common coastal conditions of temperature and exposure to upwelling are much more closely approximated by the Del Mar and Bathtub Rock sites. If the Papalote Bay site contains a fauna with greater cold-water affinities, it should have northern species that are absent at average sites along the coastline and also should lack some "warm-water" species present at the average sites. This appears to be true although the differences are not great enough to test as significant at the 95-percent confidence level if random occurrence of the species is assumed (Table 12) . However, the "northern" bias of the Papalote Bay faunal list coupled with the earlier observations of Hubbs (1960) to the same effect may be taken as strong evidence that Papalote Bay harbored a distinct northern faunal element in contrast to the other two collection sites.

5.5. SUMMARY

1. Kelp bass, California sheephead, and blacksmith were the most frequently encountered species in kelp beds of the San Diego region.
2. Data on species frequency (visual notes on presence or absence) approximate a hyperbolic curve. More than one-half of the "common" species in the rocky-inshore habitat were noted during less than seven percent of the dives. Probably the relationship would change if cryptic species could be accurately recorded.
3. Apparent faunal breaks at Point Conception, Cape Mendocino, Punta Eugenia, and Cape San Lucas, limit the geographic distribution of common San Diego fishes. Nearly one-half of the listed species are absent south of Punta Eugenia.
4. As expected, species extending into tropical regions were noted, with some exceptions, principally in surface waters near San Diego, and species with northern, cold-water, distributions were usually present at all depths to 130 feet.
5. Numerical and species abundance of fish during dives were generally positively correlated with degree of bottom relief, and were also influenced by depth. The

fauna usually was richest in high-relief habitats deeper than 60 feet, but a rich fauna was also observed about shallow, rocky, regions in La Jolla Bay.

6. Kelp augments food supplies of the rocky-inshore fishes by increasing the food for herbivorous invertebrates and by enlarging the habitat for surface-associated organisms. Macrocystis also encourages some demersal species to forage throughout the entire water column.
7. Underwater visibility regulates foraging activities of fishes and kelp furnishes points of reference to fish beyond visual range of the bottom.
8. The kelp-bed habitat is divisible into four ecological categories with associated fish.
9. Diversity of fish species does not seem to be affected materially by presence or absence of Macrocystis.
10. Ecological data on the rocky-inshore fishes satisfies the community concept. A definite physical habitat is occupied and the species aggregate shows a well-defined energy flow, an Eltonian Pyramid of numbers, and taxonomic unity from site to site.
11. The species list for Papalote Bay, on the southern side of Punta Banda, Baja California, was not significantly different by two criteria from two collections made near Scripps Institution of Oceanography. The Papalote Bay collection did show a marked bias toward having more "northern" species and fewer "southern" species, however, and this evidence coupled with similar earlier observations of Carl Hubbs may be taken as a conclusive indication of the presence of a distinct northern faunal element.

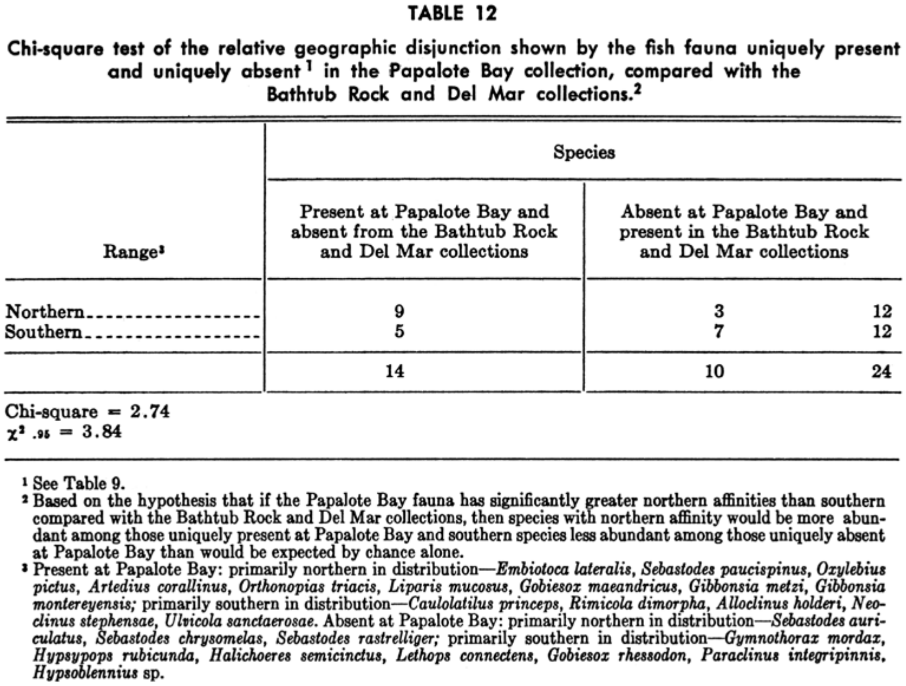


TABLE 12

Chi-square test of the relative geographic disjunction shown by the fish fauna uniquely present and uniquely absent[1] in the Papalote Bay collection, compared with the Bathtub Rock and Del Mar collections.[2]

Range[3]	Species		
	Present at Papalote Bay and absent from the Bathtub Rock and Del Mar collections	Absent at Papalote Bay and present in the Bathtub Rock and Del Mar collections	
Northern	9	3	12
Southern	5	7	12
	14	10	24

Chi-square = 2.74

$\chi^2_{.95} = 3.84$

---

[1] See Table 9.

[2] Based on the hypothesis that if the Papalote Bay fauna has significantly greater northern affinities than southern compared with the Bathtub Rock and Del Mar collections, then species with northern affinity would be more abundant among those uniquely present at Papalote Bay and southern species less abundant among those uniquely absent at Papalote Bay than would be expected by chance alone.

[3] Present at Papalote Bay: primarily northern in distribution—*Embiotoca lateralis, Sebastodes paucispinus, Oxylebius pictus, Artedius corallinus, Orthonopias triacis, Liparis mucosus, Gobiesox maeandricus, Gibbonsia metzi, Gibbonsia montereyensis;* primarily southern in distribution—*Caulolatilus princeps, Rimicola dimorpha, Alloclinus holderi, Neoclinus stephensae, Ulvicola sanctaerosae.* Absent at Papalote Bay: primarily northern in distribution—*Sebastodes auriculatus, Sebastodes chrysomelas, Sebastodes rastrelliger;* primarily southern in distribution—*Gymnothorax mordax, Hypsypops rubicunda, Halichoeres semicinctus, Lethops connectens, Gobiesox rhessodon, Paraclinus integripinnis, Hypsoblennius* sp.

TABLE 12

Chi-square test of the relative geographic disjunction shown by the fish fauna uniquely present and uniquely absent[1] in the Papalote Bay collection, compared with the Bathtub Rock and Del Mar collections.[2]

6. 6. ESTIMATES OF THE POPULATIONS AND THE STANDING CROP OF FISHES

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6.1. INTRODUCTION

This third chapter in a series of five on the fishes of the kelp beds of southern California, describes methods used for evaluating fish density and standing crop and presents research findings. The two preceding chapters are concerned with the general ecology of the rocky-inshore fish fauna and with the community relationships of the fauna. The subsequent two cover the biology of the kelp bass, an important sport fish of the kelp beds, and the foods of the kelp-bed fishes.

There is a growing literature on the standing crop of fishes in a variety of habitats; lakes, coral reefs, and select regions of the continental shelf. Other than methods, however, little of the information published to date is directly applicable to the region studied by the Kelp Program, namely the rocky-inshore kelp-bed habitat of southern California and Baja California. Such information is a prerequisite to correct evaluation of the inshore fish resources of the region and was a major goal of the program. Two different methods were employed for estimating numbers and weight of the fish populations. A net 558 feet long, henceforth called a wall net, was designed and constructed to enclose completely approximately one-half acre of a selected region of a kelp bed. The area was then treated with an ichthyocide and the fish were recovered by SCUBA divers with hand nets. In the other method, the fish were counted along a transect line laid on the ocean bottom. Although the two methods were first used to check each other, it was found that neither gave all the information desired. Instead of duplicating faunal measurements the two methods were more nearly complementary.

The wall-net and transect studies required the services of numerous personnel and assistance from members of the Kelp Program and other scientific and technical personnel at Scripps is gratefully acknowledged. Special thanks are due to Mrs. Jean Kauanui, my able diving partner, for her assistance with the transects.

6.2. METHODS

6.2.1. The Belt Transect

At first, use of the wall-net technique was envisioned as an absolute and reliable means of measuring the fish standing crop within a known delimited area. The first "quantitative" collection, however (made while the net was under construction), demonstrated that problems of staging such a complex operation would rule out this type of collection in all but special circumstances. Consequently, a more flexible measurement method was sought. The transect method was chosen because it required only two divers and used a minimum of equipment.

Variations of the transect method are well known to terrestrial ecologists and have been used with SCUBA for marine studies by Brock (1954) and Bardach (1959). Both used two lines to delineate areas of coral reef for surveys of fish populations. Kelp beds, however, apparently differ markedly in underwater visibility from coral reefs, because plants obstruct the view and the water frequently is more turbid. In addition, laying two parallel lines through a kelp bed is difficult. For this reason a single-line method was adopted. A single-line method is as accurate as the two-line method in a typical kelp bed and is considerably easier to use. Accurate comparisons between the two methods are not possible at present, because neither Brock nor Bardach gave statistical parameters for their data.

In the Kelp Program surveys, a line 100 or 120 meters long was ordinarily laid in a straight course over the ocean bottom and fishes seen within a predetermined distance from the line were counted. One diver tallied fishes on a white Formica slate and the other operated the reel of line (Figure 21). Fish tallies and habitat notes were made in pencil on the slate (the writing could be removed with household cleanser after transcription). The slate had a compass and glass thermometer attached to the upper plywood portion and the Formica was permanently ruled into columns and rows with a sharp lathe tool.

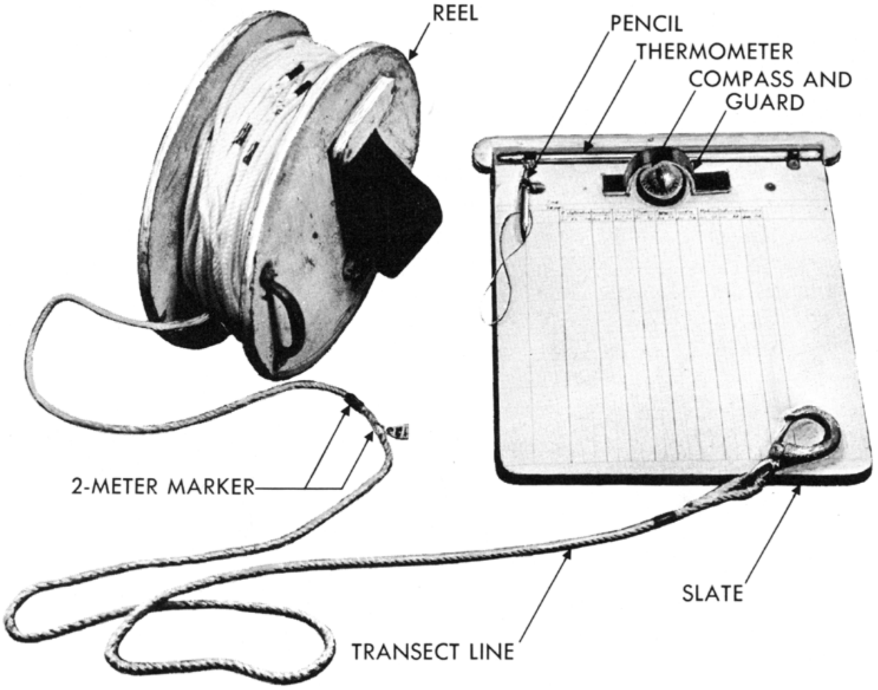

FIGURE 21. Line, reel, and slate used for the belt-transect fish surveys. See text for explanatory notes.

FIGURE 21. ***Line, reel, and slate used for the belt-transect fish surveys. See text for explanatory notes.***

Visibility of the grooves was improved by marking them with a pencil. A spherical underwater compass was important for underwater navigation, and was easily read, tilted at nearly any angle. Both compass and thermometer were recessed and protected by suitable guards. In a typical operation a skiff was anchored in a predetermined location and two divers descended to the anchor. The end of the line was clipped to the anchor and the leading diver with the slate followed a predetermined compass course over the bottom, or along a depth contour when the bottom sloped sharply. Fish within visibility distance were counted by the lead diver except on the rare occasions of very clear water, when counts were restricted to an estimated 10 meters on each side of the lead diver. When kelp was dense the band width was narrowed to a path that the lead diver could adequately inspect. Fish were counted in the forward hemisphere only and duplication was avoided as far as possible. On the "out" transect (swimming away from the anchor) the lead diver would occasionally glance back and evaluate the amount of line remaining on the reel. After completing the out transect visibility was measured by sighting along the bottom, down the transect line, and counting the number of black 2-meter markers visible along the white nylon line. This distance was normally less than 10 meters. Transect band width was estimated thereby, with considerable accuracy, because it was found that near the limits of visibility objects disappeared rapidly. When juvenile fish or adults of small or cryptically marked species were surveyed, the total band width was limited to approximately 1-meter, since this was the maximum path that could be scrutinized efficiently as the divers moved over the bottom. Differential visibility of adults was not considered an important source of bias for the species stressed in the belt transect surveys (kelp bass, sheephead, blacksmith, and opaleye). Precautions during surveys and the wide tolerances in density estimates necessitated by the nature of the statistical distributions (discussed below) make any such bias negligible. During the return or "in" portion of the transect a procedure similar to the out portion was followed except that the lead diver swam along the line while the second diver rewound it. Swimming rates were standardized as fully as possible. In relatively deep kelp beds, a second transect was made through the kelp canopy near the surface. Approximately 50 belt-transect surveys were made during 1959 and 1960, usually in habitats with rocky substrate and at depths of 30 to 90 feet. Habitats with and without kelp were included. The surveys were as widespread geographically as possible, and also included a series of 17 at a single locality.

The majority of transects were 100 meters long. Loss of the 100-meter line prompted construction of a 120-meter line, considered slightly superior because of the additional length. The area sampled was easily varied by changing the length of line, with maximum feasible length limited by air supply and depth of survey. A standard 71-cubic-foot SCUBA tank filled to 1,800 p.s.i. was sufficient to make a 120-meter transect at 80 feet, which was judged an adequate maximum depth for the surveys.

The possibility of eliminating the transect line by converting time and swimming rate into distance was investigated and records were kept of swimming rates along the transect line during the surveys

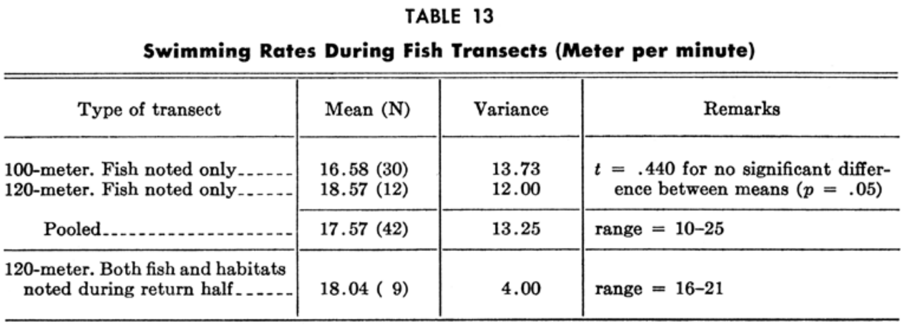

TABLE 13

Swimming Rates During Fish Transects (Meter per minute)

Type of transect	Mean (N)	Variance	Remarks
100-meter. Fish noted only	16.58 (30)	13.73	t = .440 for no significant difference between means (p = .05)
120-meter. Fish noted only	18.57 (12)	12.00	
Pooled	17.57 (42)	13.25	range = 10–25
120-meter. Both fish and habitats noted during return half	18.04 (9)	4.00	range = 16–21

TABLE 13

Swimming Rates During Fish Transects (Meter per minute)

(Table 13) . Rates when fish only were noted, averaged 17.6 meters per minute with a range from 10–25. The earlier 100-meter surveys were not significantly different from the later 120-meter studies. Transects wherein both fish and habitat were recorded, showed approximately the same average but variability was considerably less. For transects in which fish only were counted, approximately the middle 90 percent of the theoretical distribution lies between the rates of 12.8 and 22.3 meters per minute. This represents a 27 percent variation of the mean, on either side of the mean. Such variation would be included in resultant estimates of population density. Combined with other sources of variability, surveys based on swimming rate and time would not be very accurate, but are probably suitable for pilot projects or gross density measurements.

6.2.2. The Wall Net

Preliminary plans for the net were developed by David H. Davies, fisheries biologist, formerly on the program. The net was designed to surround completely part of a kelp bed and extend from the surface to the bottom. Divers would kill fishes with an ichthyocide within the walled-off area and gather the specimens in hand nets.

The completed net utilized ¾-inch (stretched-measurement) synthetic netting and measured 40 x 558 feet. It enclosed approximately 0.55 acres, the area varying with overlap at the ends and the degree to which the set approximated a circle. Cost of the net and ancillary equipment was approximately $2,500 in 1959 (Appendix A gives a breakdown of components and cost).

After the set, Pro-noxfish[1] solution was pumped through a hose to a pipe applicator held by a diver (Figure 22). The ichthyocide and seawater were mixed and delivered by a gasoline-driven centrifugal pump. Concentrated Pro-noxfish solution was drawn into the pump through plastic tubing attached to a regulating valve on the intake pipe. The apparatus drained a 25-gallon drum of poison and mixed it with sea water in 3 to 5 minutes. Usually the poison was spread at the ocean bottom first and the intermediate layers were treated subsequently. This sequence killed fish near the bottom to prevent feeding on dead and dying invertebrates settling from the kelp canopy above. (In one operation the canopy was inadvertently poisoned first; food analyses for fishes in this collection may be untrustworthy.) Small fish were gathered in hand nets and large ones in burlap sacks.

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[1] A commercial product of S. B. Penick and Co. composed of rotenone and other cubé extractives (7.5%), Sulfoxide (2.5%), and inert (hydrocarbon) ingredients (90%).

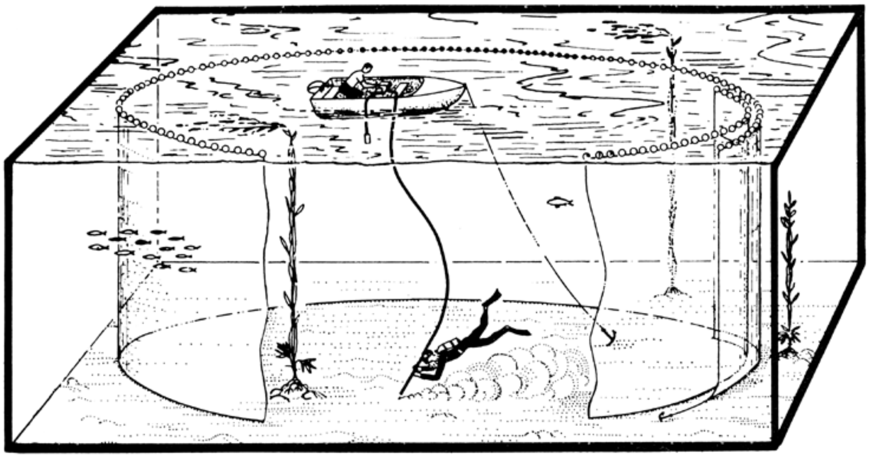


FIGURE 22. **Diagram of wall net, skiff, and diver as used in the quantitative collections. The SCUBA diver is applying a mixture of ichthyocide and seawater, pumped through a hose from the skiff.**

FIGURE 22. ***Diagram of wall net, skiff, and diver as used in the quantitative collections. The SCUBA diver is applying a mixture of ichthyocide and seawater, pumped through a hose from the skiff.***

of three attempted wall-net collections, only one was completely successful. With experience, higher efficiencies might be obtained, but the equipment must be kept in perfect order, oceanic conditions must be watched carefully, and many divers and ancillary personnel should be available. Under ideal conditions a collection at 30-foot depth could be completed in one-half day, and would utilize approximately 15 gallons of concentrated poison, six divers, and 18, 71-cubic-foot-SCUBA bottles of air (filled to 1,800 p.s.i.). Ideal conditions are rare, however, and it is recommended that additional poison, divers, and air tanks be available.

Numerous difficulties were encountered by the Kelp Program in operations with the net. On one occasion a plastic valve between the plastic tubing from the Pro-noxfish can and the intake pipe of the pump became blocked because the solution dissolved part of the valve. Once a mild current carried the poison solution out of the enclosure before the fish were affected. On two occasions the net ends were not closed completely because the circle laid was too large (the pull of the discharging net tended to straighten the course of the laying boat). On all three sets the lower portion of the net became fouled on the bottom and extensive repairs were necessary afterward (several divers should be on the bottom to disengage the net from obstacles as it is being lifted). Two of the sets yielded usable data.

The first sets by anyone using this technique should be supervised by an experienced person such as a purse-seine fisherman, and a 20-foot or larger power-driven craft should be used to lay the net. After the set, the cork line should be stabilized at three or more points by external anchored buoys to prevent the top of the net from drifting or closing. After the poison application, pickup should be delayed until a maximum kill of fish is obtained.

Increasing the depth of wall-net collections would be severely limited by complications arising in nearly every aspect of the operation. For example, an increase from 30 to 60 feet would involve the following problems. Duration of air supply in the SCUBA tanks would be reduced nearly one-third and either more tanks or the same tanks filled to higher pressures would be necessary. Allowable bottom time at 30 feet is nearly unlimited but divers would be limited to approximately 1 hour at 60 feet unless a decompression schedule were followed. Temperatures at the principal region of effort probably would be considerably lower due to the increased depth, reducing bottom time and efficiency for the divers and decreasing ichthyocide efficiency (during June average bottom temperatures in the La Jolla region would be 61° F at 30 feet, 57° at 60 feet; during August, 66° and 61° F respectively). More than twice the amount of ichthyocide would be required to treat the increased water column because more poison would drift out of the net. A larger pump would be necessary to treat quickly all parts of the water column. Additional stabilizing lines probably would be necessary at the midwater regions because the extended net column could buckle in a slight current, constituting a serious hazard to divers within.

Perhaps the most formidable of the complications from increasing depth of fishing would be vertical stabilization of the column and efficient poison coverage. A slight current would seriously handicap any application unless all regions were treated nearly simultaneously (dynamite, followed by many divers discharging poison from plastic bags into the entire water column simultaneously might be effective). With equipment and techniques similar to those actually used, optimal depth for the set in marine situations is probably 35 feet or shallower.

A major disadvantage with the procedure is an unavoidable spread of poison to surrounding areas, especially when currents develop. Even slight currents will carry the chemicals in a lethal cloud for considerable distances. Although many fishes undoubtedly are able to escape, numerous small species are killed as well as fish strongly associated with eggs or territories. Invertebrates are also severely affected.

6.3. ESTIMATION OF THE STANDING CROP OF FISHES

6.3.1. Belt-Transect Surveys

Forty-six transect surveys were made in southern California and Baja California. Principal study areas were Gaviota, the San Diego localities of La Jolla, Bird Rock, and Point Loma, and the Mexican localities of Coronado Islands, Punta Banda, Guadalupe Island, and Turtle Bay (Figure 23). Depth of survey varied from 30 to 90 feet with the modal frequency near 55 feet. The belt transect method is evaluated below chiefly in terms of the results for kelp bass, sheephead, and blacksmith, because adults of these species were frequently encountered, easily seen, and formed a large proportion of the standing crop. For each species, the first data to be discussed will be those from the La Jolla transect site where 17 transects were made in the same area during February-May 1960. Data were examined to determine (i) whether an important differential bias occurred between the data gathered on the "out" vs. the "in" halves of each transect; (ii) whether important changes occurred in the density estimates between the first and second halves of the series, and (iii) to place confidence limits on the estimates for each species. Other data bearing on accuracy

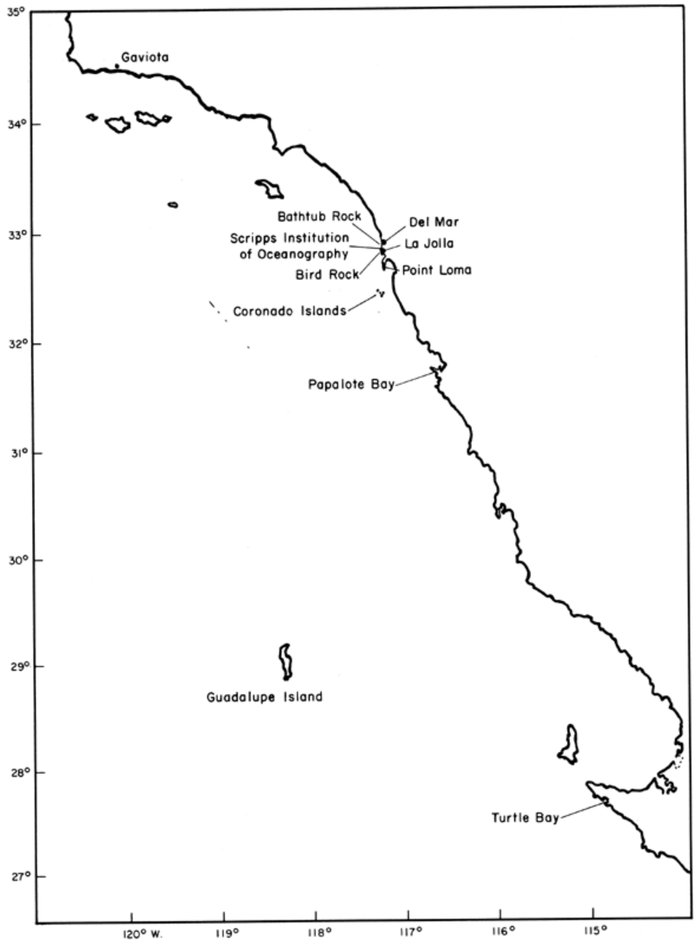


FIGURE 23. Map of coast of southern California and Baja California, showing localities of wall-net collections and belt-transect surveys.

FIGURE 23. ***Map of coast of southern California and Baja California, showing localities of wall-net collections and belt-transect surveys.***

of the counts will also be discussed, followed by interpretation of the density data with respect to locality and the presence or absence of kelp. All tests utilized 95-percent confidence limits. In most species the variance obtained was very large relative to the mean, so data were transformed by the $\log_{10}(N + 1)$ transformation, discussed by Barnes (1952). In these cases comparison of means and tests of significance were performed on the transformed data, and confidence limits were set on the transformed data before reconversion to arithmetical values. During reconversion the mean was adjusted as recommended by Barnes by adding 1.15 times the variance prior to the back transformation. Since the variance for the larger aggregation is smaller, grand averages after transformation back will usually have lower values than the average for any of their subgroups. This irregularity is of little consequence because of large variability in the raw data.

Repetitive data for La Jolla kelp bass were unimodal but decidedly skewed. The variance was brought into a much more favorable relationship to the mean by the $\log_{10}(N + 1)$ transformation (Table 14) . Although counts were made of kelp bass on all 17 transects, only the first 15 were used because the last 2 may not have been representative—a sportfishing boat anchored within the survey area during these transects and the fish appeared abnormally grouped.

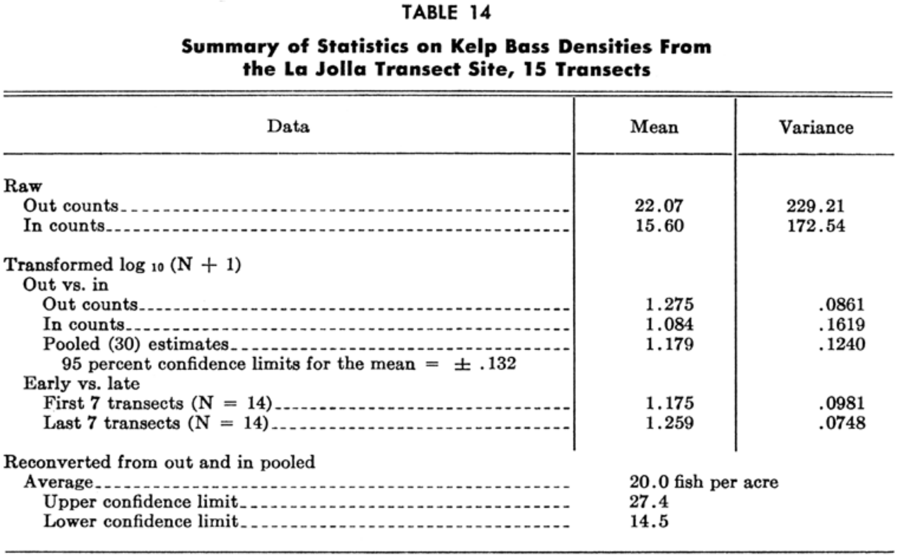


TABLE 14

Summary of Statistics on Kelp Bass Densities From the La Jolla Transect Site, 15 Transects

Data	Mean	Variance
Raw		
Out counts	22.07	229.21
In counts	15.60	172.54
Transformed log 10 (N + 1)		
Out vs. in		
Out counts	1.275	.0861
In counts	1.084	.1619
Pooled (30) estimates	1.179	.1240
95 percent confidence limits for the mean = ± .132		
Early vs. late		
First 7 transects (N = 14)	1.175	.0981
Last 7 transects (N = 14)	1.259	.0748
Reconverted from out and in pooled		
Average	20.0 fish per acre	
Upper confidence limit	27.4	
Lower confidence limit	14.5	

TABLE 14

Summary of Statistics on Kelp Bass Densities From the La Jolla Transect Site, 15 Transects

Differential bias between the out and in halves of the transects was investigated for kelp bass by a *t*-test of the transformed data. The variances tested as homogeneous. The value for *t*(1.486) did not lie in the rejection region, indicating that the means for the pooled data for out and in halves of the transects were not significantly different. The two halves of each transect, therefore, should represent independent estimates of the population. No time trend of significance was apparent through the series, as judged by a *t*-test comparison of density estimates for the first and last halves of the series ($t = .756$; rejection region, $t < -2.16$ or > 2.16, Table 14). The 30 estimates of kelp bass density in the La Jolla transect site (out and in data for the 15 transects) were, therefore, considered independent. The transformed data have a coefficient of variation of 30 percent. The reconverted data have a mean of 20.0 fish per acre with 95 percent confidence limits at 14.5 and 27.4.

No significant correlation was found between the out and in counts in the La Jolla transect site estimates (Spearman rank correlation coefficient was 0.227 for the raw data, well below the 95 percent confidence limit of 0.440). Yet the count pairs were significantly correlated when transects from all localities were compared (Spearman rank correlation coefficient of 0.685, well above the 95 percent confidence limit of 0.351). Thus variation within the La Jolla transect site was relatively slight compared with variation between sites and it may be concluded that differences found between sites were significant. Because of significant correlation between out and in counts for between-site comparisons, the two transect halves for each site were pooled for further calculations.

Classification according to two degrees of kelp density and two degrees of fishing intensity revealed significant differences only where fishing intensity varied and kelp was light or absent ($t = 3.77$; rejection region $t < -2.08$ or > 2.08, Table 15). Presence or absence of kelp, therefore, had little to do with density of kelp bass when fishing pressure

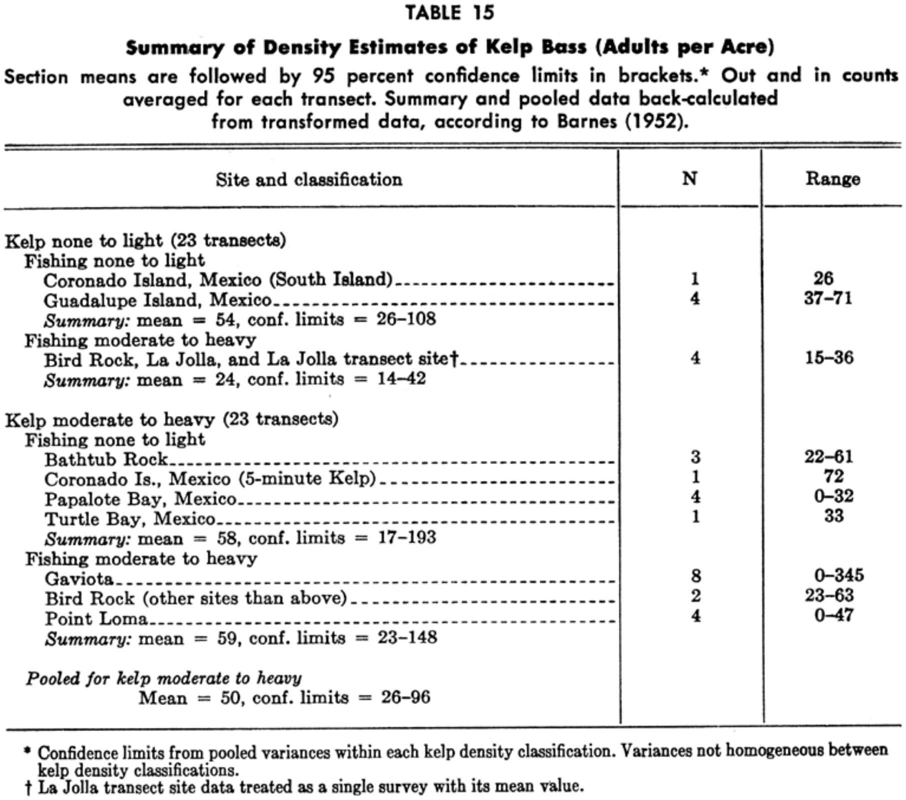


TABLE 15

Summary of Density Estimates of Kelp Bass (Adults per Acre)

Section means are followed by 95 percent confidence limits in brackets.* Out and in counts averaged for each transect. Summary and pooled data back-calculated from transformed data, according to Barnes (1952).

Site and classification	N	Range
Kelp none to light (23 transects)		
Fishing none to light		
Coronado Island, Mexico (South Island)	1	26
Guadalupe Island, Mexico	4	37–71
Summary: mean = 54, conf. limits = 26–108		
Fishing moderate to heavy		
Bird Rock, La Jolla, and La Jolla transect site†	4	15–36
Summary: mean = 24, conf. limits = 14–42		
Kelp moderate to heavy (23 transects)		
Fishing none to light		
Bathtub Rock	3	22–61
Coronado Is., Mexico (5-minute Kelp)	1	72
Papalote Bay, Mexico	4	0–32
Turtle Bay, Mexico	1	33
Summary: mean = 58, conf. limits = 17–193		
Fishing moderate to heavy		
Gaviota	8	0–345
Bird Rock (other sites than above)	2	23–63
Point Loma	4	0–47
Summary: mean = 59, conf. limits = 23–148		
Pooled for kelp moderate to heavy		
Mean = 50, conf. limits = 26–96		

* Confidence limits from pooled variances within each kelp density classification. Variances not homogeneous between kelp density classifications.

† La Jolla transect site data treated as a single survey with its mean value.

TABLE 15

Summary of Density Estimates of Kelp Bass (Adults per Acre)

was light or absent. Absence of kelp or thin stands and moderate to heavy fishing pressure were associated with low kelp-bass densities. A complete explanation of this relationship cannot be given at present because too little is known about behavior of the species. It does appear that regions of kelp are preferred by the species and individuals from bare areas will move into kelp regions (which are preferred sportfishing sites) as density at the kelp sites is lowered by fishing. The species can do well where the giant kelp is absent, however, as is attested by the high values for Guadalupe Island (Table 15).

The untransformed data on sheephead from the La Jolla transect site had a distribution approximately normal and a variance much smaller than for the kelp bass (Table 16). The data accordingly were not transformed for analysis. Variances were quite similar for various aspects of the La Jolla transect data (Table 16). Differences between means for the out and in portions of the transect series showed no significance (*t* = 1.44; rejection region, *t* -2.04 or 2.04) and the out and in portions were presumed not differentially biased to a significant degree. No significant indications of a time trend appeared, comparing the means of the first eight and the last eight transects (*t* = 1.82; rejection region, *t* -2.04 or 2.04). The out and in estimates for the La Jolla transect site were, therefore, regarded as independent estimates of the same population throughout the transect series. Further evidence of independence is shown by the low correlation between out and in halves of the paired estimates for the La Jolla transect series (*r* = 0.189; confidence limits at ± 0.482). All values were, therefore, pooled for calculation of mean density and confidence limits for the mean (Table 16). The coefficient of variation was 53 percent.

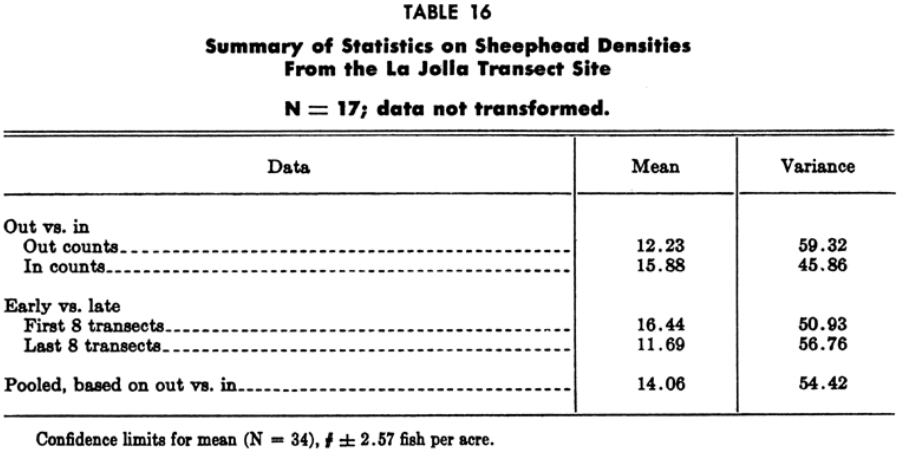


TABLE 16

Summary of Statistics on Sheephead Densities From the La Jolla Transect Site

N = 17; data not transformed.

Data	Mean	Variance
Out vs. in		
Out counts	12.23	59.32
In counts	15.88	45.86
Early vs. late		
First 8 transects	16.44	50.93
Last 8 transects	11.69	56.76
Pooled, based on out vs. in	14.06	54.42

Confidence limits for mean (N = 34), $\bar{y} \pm 2.57$ fish per acre.

TABLE 16

Summary of Statistics on Sheephead Densities From the La Jolla Transect Site N = 17; data not transformed.

Similar to kelp bass, out and in estimates within pairs were correlated significantly when all sites were compared (*r* = 0.598; confidence limits at ± 0.468). Between-site variation, therefore, is considerable and significant in comparison to within-site variation. Because of the correlation between paired out and in counts when different sites were compared, the values for out and in were pooled for further comparisons.

The data show no discernible differences when areas of heavy and light fishing were compared, probably because sheephead are taken infrequently in the sportfish catch relative to other species. Density estimates for regions classified by kelp density showed a slightly higher average for moderate-dense kelp but the values are of questionable significance (Table 17). The large variance for regions with moderate to heavy kelp was chiefly due to single transects made at Papalote Bay and Turtle Bay, where other diving operations immediately preceded the fish census. Probably the disturbance caused an influx of fish into the transect area prior to the census. An overall value of 14 adults per acre (as for the La Jolla transect site) might be a more reasonable

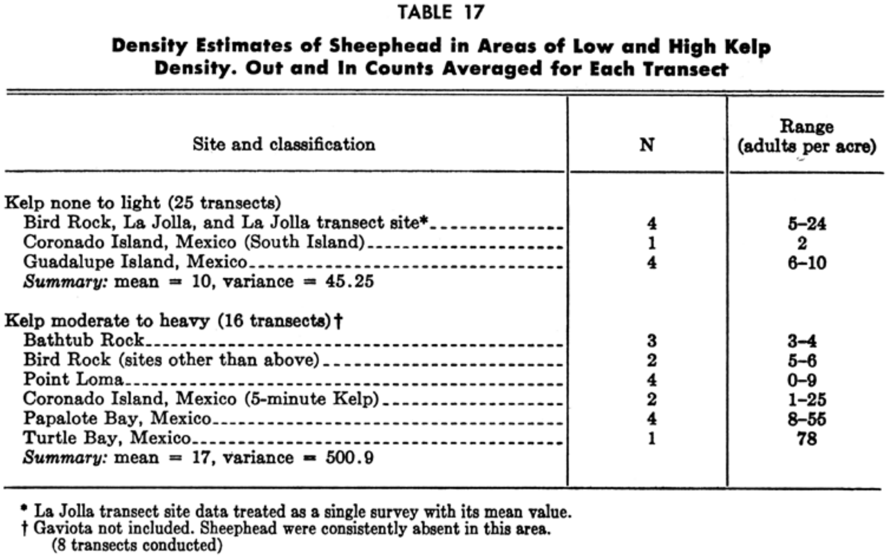


TABLE 17

Density Estimates of Sheephead in Areas of Low and High Kelp Density. Out and In Counts Averaged for Each Transect

Site and classification	N	Range (adults per acre)
Kelp none to light (25 transects)		
Bird Rock, La Jolla, and La Jolla transect site*	4	5–24
Coronado Island, Mexico (South Island)	1	2
Guadalupe Island, Mexico	4	6–10
Summary: mean = 10, variance = 45.25		
Kelp moderate to heavy (16 transects)†		
Bathtub Rock	3	3–4
Bird Rock (sites other than above)	2	5–6
Point Loma	4	0–9
Coronado Island, Mexico (5-minute Kelp)	2	1–25
Papalote Bay, Mexico	4	8–55
Turtle Bay, Mexico	1	78
Summary: mean = 17, variance = 500.9		

* La Jolla transect site data treated as a single survey with its mean value.
† Gaviota not included. Sheephead were consistently absent in this area. (8 transects conducted)

TABLE 17

Density Estimates of Sheephead in Areas of Low and High Kelp Density. Out and In Counts Averaged for Each Transect

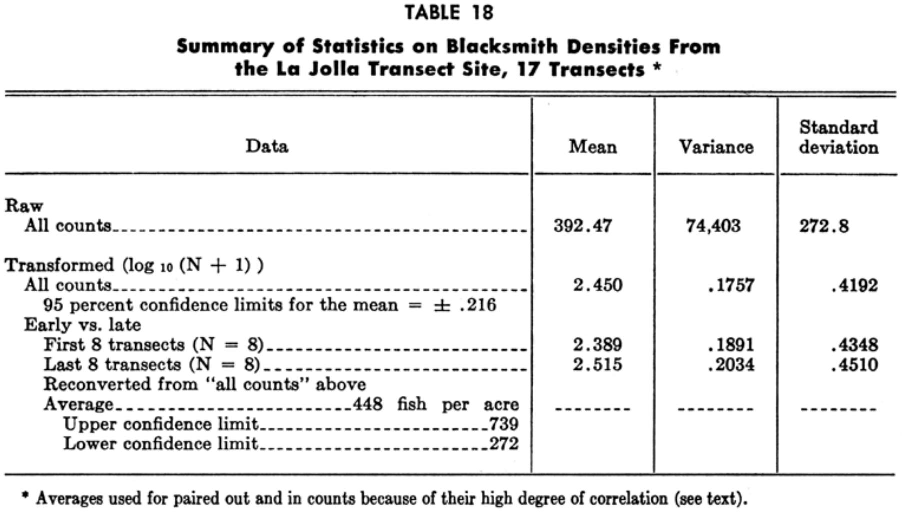


TABLE 18

Summary of Statistics on Blacksmith Densities From the La Jolla Transect Site, 17 Transects *

Data	Mean	Variance	Standard deviation
Raw			
All counts	392.47	74,403	272.8
Transformed ($\log_{10}(N + 1)$)			
All counts	2.450	.1757	.4192
95 percent confidence limits for the mean = ± .216			
Early vs. late			
First 8 transects (N = 8)	2.389	.1891	.4348
Last 8 transects (N = 8)	2.515	.2034	.4510
Reconverted from "all counts" above			
Average 448 fish per acre	--------	--------	--------
Upper confidence limit 739			
Lower confidence limit 272			

* Averages used for paired out and in counts because of their high degree of correlation (see text).

TABLE 18

Summary of Statistics on Blacksmith Densities From the La Jolla Transect Site, 17 Transects*

figure for the areas investigated. The data are too variable to warrant further numerical comparisons.

The data on blacksmith, Chromis punctipinnis, from the La Jolla transect site showed a high variance in relation to the mean, and the two statistics were brought into a more useful relationship by the $\log_{10}(N + 1)$ transformation (Table 18) . Clumped distribution was the rule for this species and large schools typically occur about or above rocky underwater prominences. Out and in portions of transects cover the same terrain and the schools are relatively stationary. Hence it would be expected that the paired out and in estimates of density would show a regression coefficient near 1.0 and a high degree of correlation. These relations held for the La Jolla transect site counts (slope, raw counts, = 0.887, r = 0.788; r significant when greater than 0.515). Because of correlation between out and in counts within pairs, they were averaged for each transect before the data were transformed for further consideration.

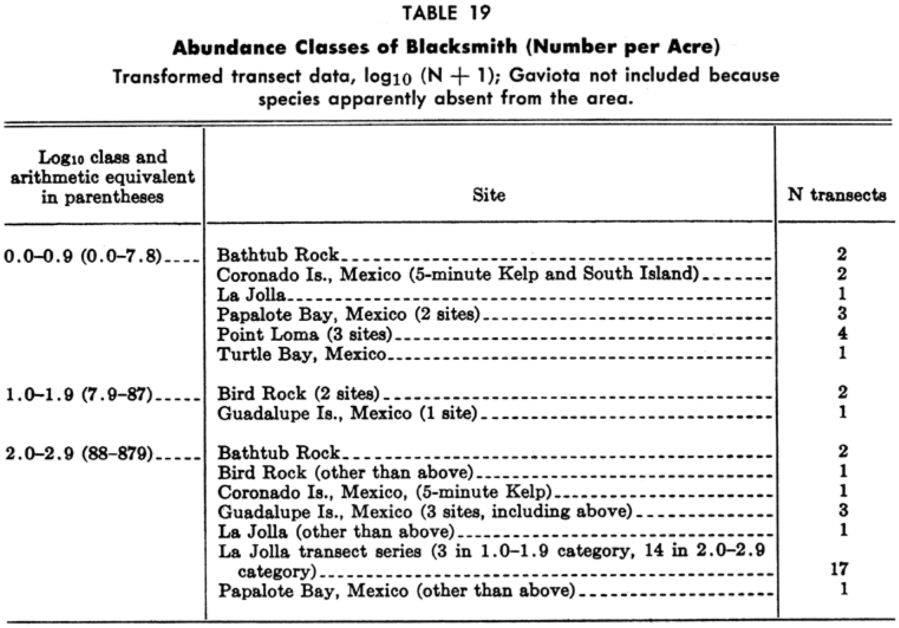


TABLE 19

Abundance Classes of Blacksmith (Number per Acre)

Transformed transect data, $\log_{10}$ (N + 1); Gaviota not included because species apparently absent from the area.

$\log_{10}$ class and arithmetic equivalent in parentheses	Site	N transects
0.0–0.9 (0.0–7.8)	Bathtub Rock	2
	Coronado Is., Mexico (5-minute Kelp and South Island)	2
	La Jolla	1
	Papalote Bay, Mexico (2 sites)	3
	Point Loma (3 sites)	4
	Turtle Bay, Mexico	1
1.0–1.9 (7.9–87)	Bird Rock (2 sites)	2
	Guadalupe Is., Mexico (1 site)	1
2.0–2.9 (88–879)	Bathtub Rock	2
	Bird Rock (other than above)	1
	Coronado Is., Mexico, (5-minute Kelp)	1
	Guadalupe Is., Mexico (3 sites, including above)	3
	La Jolla (other than above)	1
	La Jolla transect series (3 in 1.0–1.9 category, 14 in 2.0–2.9 category)	17
	Papalote Bay, Mexico (other than above)	1

TABLE 19

Abundance Classes of Blacksmith (Number per Acre)

Chromis densities averaged considerably higher for the last eight transects at the La Jolla transect site than the first (560 fish per acre vs. 403), but the difference was not significant in the transofrmed data (t = -.601; rejection region = t -2.14 or 2.14). There may be a biological justification for an increase, because Limbaugh (1955) and Turner and Ebert (1962) both noted that this fish breeds in June. It is possible that aggregation increases progressively prior to this time. The transformed data shows a smaller coefficient of variation (16 percent) than for either the kelp bass or sheephead.

Between-site variation, as well as between-transect variation, was considerable in some areas (Table 19) . Principal reasons appear to be the schooling habit of blacksmith and chance inclusion of one or more schools in the transect belts. Rocky-bottom relief appears important to the species. Blacksmith were not encountered during eight transects and associated dives in kelp on a sand bottom at Gaviota. Counts were low at all Point Loma sites. A single transect at Turtle Bay, Mexico, also yielded a low count, although rock of low to moderate relief was present. Considerable densities of blacksmiths were encountered in at least some of the transects at all other sites. Undoubtedly other ecological factors, such as water temperature and turbidity, exposure to food-bearing currents, turbulence, and density of demersal algae and invertebrates, play a definitive role in determining the density of this species. Presence of blacksmiths in moderate to very heavy density along the boulder-strewn underwater slopes of Guadalupe Island (Table 19) demonstrates that giant kelp is not a prerequisite for abundance of this species. Cumulative data on densities indicated a disproportionate number of low estimates in beds of moderate to heavy kelp density and a disproportionate number of high estimates in areas where kelp was light or absent (Table 20) .

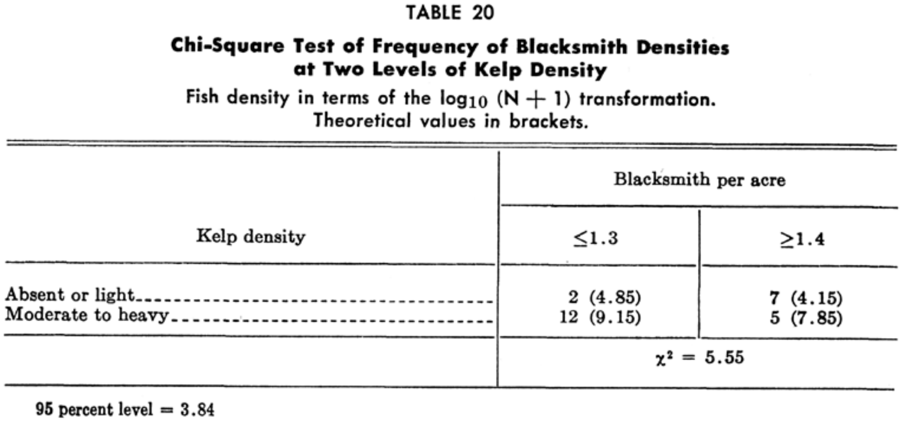


TABLE 20

Chi-Square Test of Frequency of Blacksmith Densities at Two Levels of Kelp Density

Fish density in terms of the $\log_{10}(N + 1)$ transformation. Theoretical values in brackets.

Kelp density	Blacksmith per acre	
	≤ 1.3	≥ 1.4
Absent or light	2 (4.85)	7 (4.15)
Moderate to heavy	12 (9.15)	5 (7.85)
	$\chi^2 = 5.55$	

95 percent level = 3.84

TABLE 20

Chi-Square Test of Frequency of Blacksmith Densities at Two Levels of Kelp Density

Density estimates of these and other fish species encountered at various sites during the transect studies are summarized in Table 21.

6.3.2. Evaluation of the Belt-Transect Estimates

Detailed consideration of the belt-transect data has disclosed numerous possible sources of inaccuracy and bias. The foregoing conclusions regarding population densities must be regarded as tentative until further intensive work is conducted on the various species. One important complication is behavior of fish in respect to divers. Whether a fish ignores, swims toward or swims away from a diver will depend not only upon species response patterns but also on learned behavior prior to the survey. Where repeat surveys are made in the same area, the learning will also include a gradual conditioning to the presence of divers. So, theoretically at least, a true replicate experiment might be impossible for a species that reacts to divers. Other plausible factors of unknown importance that could condition fish behavior include degree of sportfishing in the area, amount of predation (seals, sea lions, large fish), diver activities (abalone hunters probably make food available

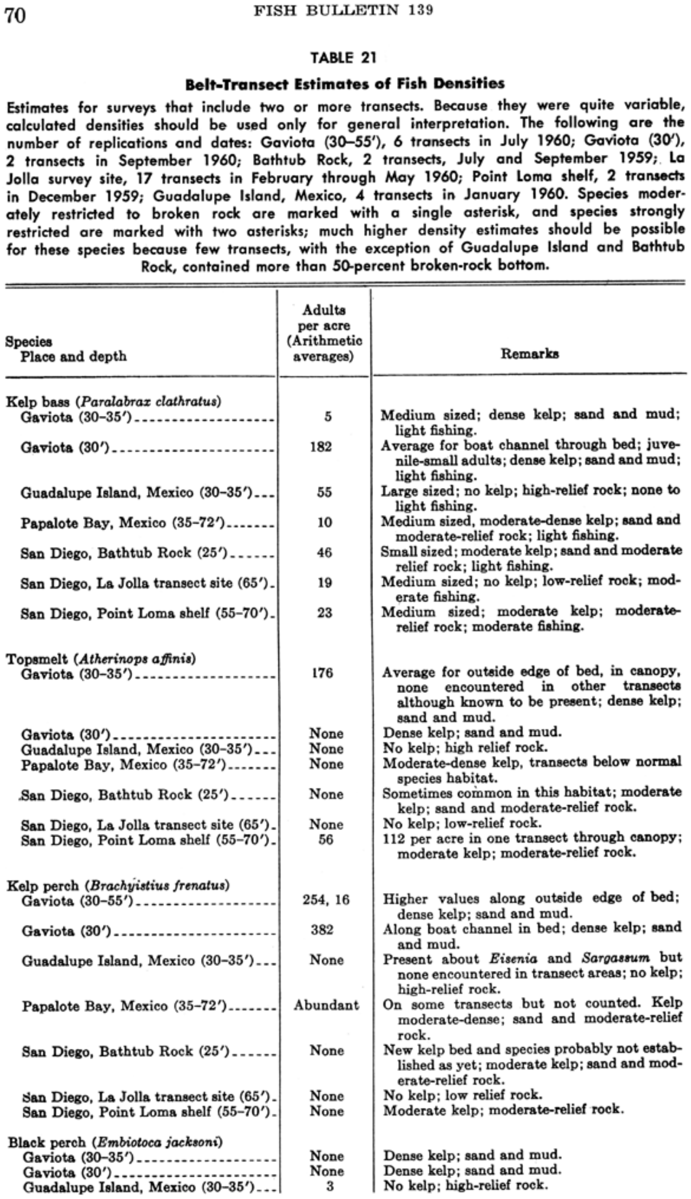


TABLE 21

Belt-Transect Estimates of Fish Densities

Estimates for surveys that include two or more transects. Because they were quite variable, calculated densities should be used only for general interpretation. The following are the number of replications and dates: Gaviota (30–55′), 6 transects in July 1960; Gaviota (30′), 2 transects in September 1960; Bathtub Rock, 2 transects, July and September 1959; La Jolla survey site, 17 transects in February through May 1960; Point Loma shelf, 2 transects in December 1959; Guadalupe Island, Mexico, 4 transects in January 1960. Species moderately restricted to broken rock are marked with a single asterisk, and species strongly restricted are marked with two asterisks; much higher density estimates should be possible for these species because few transects, with the exception of Guadalupe Island and Bathtub Rock, contained more than 50-percent broken-rock bottom.

Species Place and depth	Adults per acre (Arithmetic averages)	Remarks
Kelp bass (*Paralabrax clathratus*)		
Gaviota (30–35′)	5	Medium sized; dense kelp; sand and mud; light fishing.
Gaviota (30′)	182	Average for boat channel through bed; juvenile-small adults; dense kelp; sand and mud; light fishing.
Guadalupe Island, Mexico (30–35′)	55	Large sized; no kelp; high-relief rock; none to light fishing.
Papalote Bay, Mexico (35–72′)	10	Medium sized, moderate-dense kelp; sand and moderate-relief rock; light fishing.
San Diego, Bathtub Rock (25′)	46	Small sized; moderate kelp; sand and moderate relief rock; light fishing.
San Diego, La Jolla transect site (65′)	19	Medium sized; no kelp; low-relief rock; moderate fishing.
San Diego, Point Loma shelf (55–70′)	23	Medium sized; moderate kelp; moderate-relief rock; moderate fishing.
Topsmelt (*Atherinops affinis*)		
Gaviota (30–35′)	176	Average for outside edge of bed, in canopy, none encountered in other transects although known to be present; dense kelp; sand and mud.
Gaviota (30′)	None	Dense kelp; sand and mud.
Guadalupe Island, Mexico (30–35′)	None	No kelp; high relief rock.
Papalote Bay, Mexico (35–72′)	None	Moderate-dense kelp, transects below normal species habitat.
San Diego, Bathtub Rock (25′)	None	Sometimes common in this habitat; moderate kelp; sand and moderate-relief rock.
San Diego, La Jolla transect site (65′)	None	No kelp; low-relief rock.
San Diego, Point Loma shelf (55–70′)	56	112 per acre in one transect through canopy; moderate kelp; moderate-relief rock.
Kelp perch (*Brachyistius frenatus*)		
Gaviota (30–55′)	254, 16	Higher values along outside edge of bed; dense kelp; sand and mud.
Gaviota (30′)	382	Along boat channel in bed; dense kelp; sand and mud.
Guadalupe Island, Mexico (30–35′)	None	Present about *Eisenia* and *Sargassum* but none encountered in transect areas; no kelp; high-relief rock.
Papalote Bay, Mexico (35–72′)	Abundant	On some transects but not counted. Kelp moderate-dense; sand and moderate-relief rock.
San Diego, Bathtub Rock (25′)	None	New kelp bed and species probably not established as yet; moderate kelp; sand and moderate-relief rock.
San Diego, La Jolla transect site (65′)	None	No kelp; low relief rock.
San Diego, Point Loma shelf (55–70′)	None	Moderate kelp; moderate-relief rock.
Black perch (*Embiotoca jacksoni*)		
Gaviota (30–35′)	None	Dense kelp; sand and mud.
Gaviota (30′)	None	Dense kelp; sand and mud.
Guadalupe Island, Mexico (30–35′)	3	No kelp; high-relief rock.

TABLE 21

Belt-Transect Estimates of Fish Densities

TABLE 21—Continued

Species Place and depth	Adults per acre (Arithmetic averages)	Remarks
Black perch (continued)		
Papalote Bay, Mexico (35–72′)	Present	None encountered on transects. Kelp moderate-dense; sand and moderate-relief rock.
San Diego, Bathtub Rock (25′)	3	Moderate kelp; sand and moderate-relief rock.
San Diego, La Jolla transect site (65′)	None	No kelp; low-relief rock.
San Diego, Point Loma shelf (55–70′)	7	Moderate kelp; moderate-relief rock.
Blacksmith (*Chromis punctipinnis*)*		
Gaviota (30–55′)	None	Dense kelp; sand and mud.
Gaviota (30′)	None	Dense kelp; sand and mud.
Guadalupe Island, Mexico (30–35′)	349	No kelp; high-relief rock.
Papalote Bay, Mexico (35–72′)	71	Kelp moderate-dense; sand and moderate-relief rock.
San Diego, Bathtub Rock (25′)	133	Moderate kelp; sand and moderate-relief rock.
San Diego, La Jolla transect site (65′)	57–935	Counts increased during spring; no kelp; low-relief rock.
San Diego, Point Loma shelf (55–70′)	1	Moderate kelp; moderate-relief rock.
Garibaldi (*Hypsypops rubicunda*)**		
Gaviota (30–55′)	None	Dense kelp; sand and mud.
Gaviota (30′)	None	Dense kelp; sand and mud.
Guadalupe Island, Mexico (30–35′)	13	No kelp; high-relief rock.
Papalote Bay, Mexico (35–72′)	1	Kelp moderate-dense; sand and moderate-relief rock.
San Diego, Bathtub Rock (25′)	16	Moderate kelp; sand and moderate-relief rock.
San Diego, La Jolla transect site (65′)	1	No kelp; low-relief rock.
San Diego, Point Loma shelf (55–70′)	None	Moderate kelp; moderate-relief rock.
Señorita (*Oxyjulis californica*)		
Gaviota (30–55′)	None	Dense kelp; sand and mud.
Gaviota (30′)	None	Dense kelp; sand and mud.
Guadalupe Island, Mexico (30–35′)	92	No kelp; high-relief rock.
Papalote Bay, Mexico (35–72′)	463	Kelp moderate-dense; sand and moderate-relief rock.
San Diego, Bathtub Rock (25′)	72	Moderate kelp; sand and moderate-relief rock.
San Diego, La Jolla transect site (65′)	9	No kelp; low-relief rock.
San Diego, Point Loma shelf (55–70′)	42	Moderate kelp; moderate-relief rock.
California sheephead (*Pimelometopon pulchrum*)		
Gaviota (30–55′)	None	Dense kelp; sand and mud; light fishing.
Gaviota (30′)	None	Dense kelp; sand and mud; light fishing.
Guadalupe Island, Mexico (30–35′)	10	No kelp; high-relief rock.
Papalote Bay, Mexico (35–72′)	26	Kelp moderate-dense; sand and moderate-relief rock.
San Diego, Bathtub Rock (25′)	3	Moderate kelp; sand and moderate-relief rock; light fishing.
San Diego, La Jolla transect site (65′)	14	No kelp; low-relief rock; moderate fishing.
San Diego, Point Loma shelf (55–70′)	11	Moderate-kelp; moderate-relief rock; moderate fishing.
Opaleye (*Girella nigricans*)		
Gaviota (30–55′)	None	Dense kelp; sand and mud.
Gaviota (30′)	None	Dense kelp; sand and mud.
Guadalupe Island, Mexico (30–35′)	8	No kelp; high-relief rock.
Papalote Bay, Mexico (35–72′)	39	Kelp moderate-dense; sand and moderate-relief rock.
San Diego, Bathtub Rock (25′)	56	Moderate kelp; sand and moderate-relief rock.
San Diego, La Jolla transect site (65′)	trace	No kelp; low-relief rock.
San Diego, Point Loma shelf (55–70′)	8	Moderate kelp; moderate-relief rock.
Halfmoon (*Medialuna californiensis*)		
Gaviota (30–55′)	None	Dense kelp; sand and mud.
Gaviota (30′)	None	Dense kelp; sand and mud.
Guadalupe Island, Mexico (30–35′)	5	No kelp; high-relief rock.

TABLE 21
Belt-Transect Estimates of Fish Densities

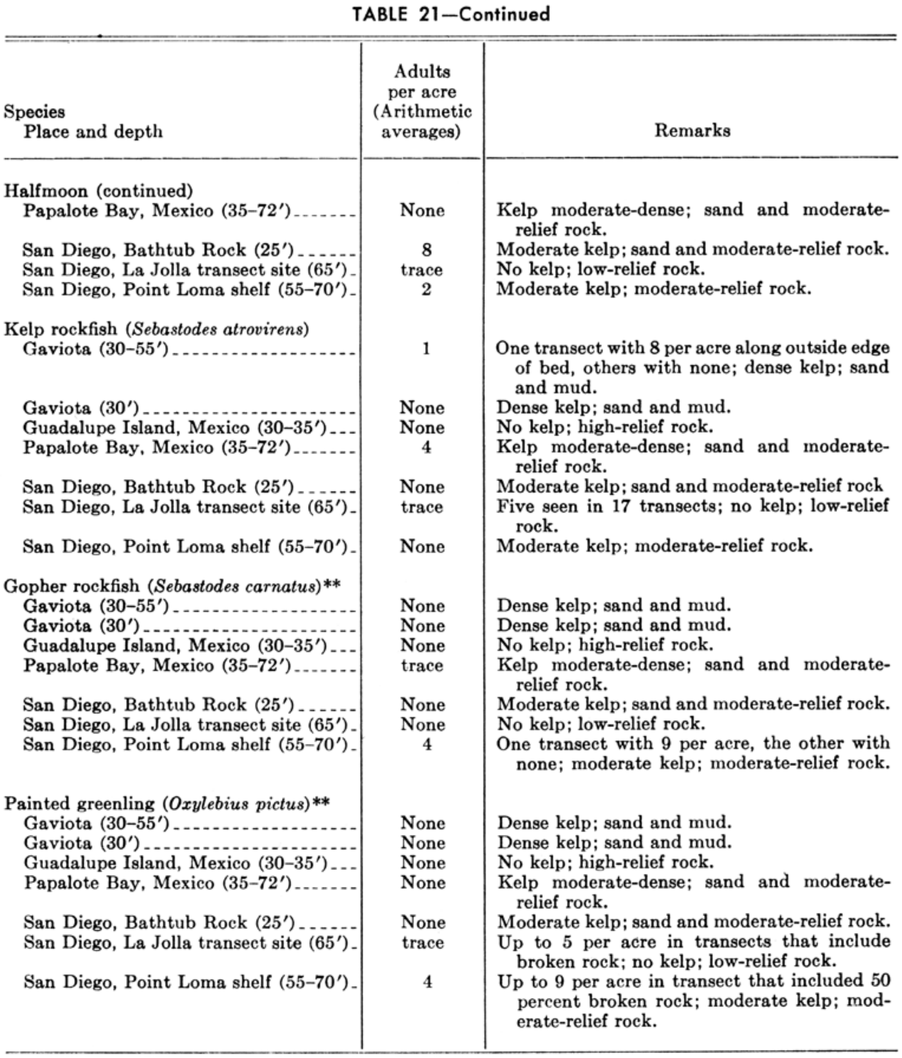


TABLE 21—Continued

Species Place and depth	Adults per acre (Arithmetic averages)	Remarks
Halfmoon (continued)		
Papalote Bay, Mexico (35–72′)	None	Kelp moderate-dense; sand and moderate-relief rock.
San Diego, Bathtub Rock (25′)	8	Moderate kelp; sand and moderate-relief rock.
San Diego, La Jolla transect site (65′)	trace	No kelp; low-relief rock.
San Diego, Point Loma shelf (55–70′)	2	Moderate kelp; moderate-relief rock.
Kelp rockfish (*Sebastodes atrovirens*)		
Gaviota (30–55′)	1	One transect with 8 per acre along outside edge of bed, others with none; dense kelp; sand and mud.
Gaviota (30′)	None	Dense kelp; sand and mud.
Guadalupe Island, Mexico (30–35′)	None	No kelp; high-relief rock.
Papalote Bay, Mexico (35–72′)	4	Kelp moderate-dense; sand and moderate-relief rock.
San Diego, Bathtub Rock (25′)	None	Moderate kelp; sand and moderate-relief rock
San Diego, La Jolla transect site (65′)	trace	Five seen in 17 transects; no kelp; low-relief rock.
San Diego, Point Loma shelf (55–70′)	None	Moderate kelp; moderate-relief rock.
Gopher rockfish (*Sebastodes carnatus*)**		
Gaviota (30–55′)	None	Dense kelp; sand and mud.
Gaviota (30′)	None	Dense kelp; sand and mud.
Guadalupe Island, Mexico (30–35′)	None	No kelp; high-relief rock.
Papalote Bay, Mexico (35–72′)	trace	Kelp moderate-dense; sand and moderate-relief rock.
San Diego, Bathtub Rock (25′)	None	Moderate kelp; sand and moderate-relief rock.
San Diego, La Jolla transect site (65′)	None	No kelp; low-relief rock.
San Diego, Point Loma shelf (55–70′)	4	One transect with 9 per acre, the other with none; moderate kelp; moderate-relief rock.
Painted greenling (*Oxylebius pictus*)**		
Gaviota (30–55′)	None	Dense kelp; sand and mud.
Gaviota (30′)	None	Dense kelp; sand and mud.
Guadalupe Island, Mexico (30–35′)	None	No kelp; high-relief rock.
Papalote Bay, Mexico (35–72′)	None	Kelp moderate-dense; sand and moderate-relief rock.
San Diego, Bathtub Rock (25′)	None	Moderate kelp; sand and moderate-relief rock.
San Diego, La Jolla transect site (65′)	trace	Up to 5 per acre in transects that include broken rock; no kelp; low-relief rock.
San Diego, Point Loma shelf (55–70′)	4	Up to 9 per acre in transect that included 50 percent broken rock; moderate kelp; moderate-relief rock.

TABLE 21

Belt-Transect Estimates of Fish Densities

to fish and thereby attract them; spear-fishermen probably induce wariness), hunger, breeding condition, water turbidity, water termperature, and the degree to which individuals of a species monitor the activities of their neighbors. Inspection of the data discloses numerous unexplained fluctuations in the raw data. Out counts of kelp bass from the La Jolla transect site, for example, average approximately 41 percent larger than the in counts (Table 14) and in the sheephead data the early transects were larger than the late transects by a similar percentage (Table 16). Early blacksmith counts were approximately 38 percent lower than later ones (see text). These differences do not test as significant, but even if they do, would not have altered the conclusions materially. For more sensitive measurements, great care will have to be taken in planning and execution. Ninety-five percent confidence limits for mean counts ([X]) of kelp bass, sheephead, and blacksmith at the La Jolla transect site lie well within the region defined by X/2 and 2X. This is considered reasonable accuracy and adequate for the relatively gross comparisons drawn.

6.3.3. Quantitative Collections

All specimens were measured after preservation for estimating fish biomass. Lengths were converted to weights by means of weight-length regressions prepared from museum specimens and freshly collected material. Deducing fresh weights from measurements on preserved fish introduced only negligible errors.

of the four quantitative collections attempted, three were regarded as successful. The net was not completely closed on the fourth, unsuccessful collection, and an alongshore current carried poison out of the enclosed area before it could affect fish. The discussion will pertain only to the first three collections (two with the wall net, one with ichthyocide and explosives).

The first study was made during June 1958, prior to completion of the wall net. The site chosen was a section of kelp projecting from an offshore bed south of Del Mar, approximately 5 nautical miles north of the Scripps Institution of Oceanography (Figure 23). David H. Davies planned and supervised the operation; 16 SCUBA divers were utilized. Average depth was 35 feet and the area measured approximately 190 x 300 feet (1.31 acres). Both dynamite and Pro-noxfish were used. Twenty-four species of fish were obtained (Table 22) .

The second collection was run on July 29, 1959 off Bathtub Rock, an area of young kelp on rocky substrate approximately 3 nautical miles north of the Scripps Institution of Oceanography (Figure 23). The collection utilized Pro-noxfish within the newly constructed wall net. Substrate at the second site was dominated by undercut boulders set in sand. Young Macrocystis sporophytes abounded and reached heights of 10 to 12 feet but formed no surface canopy since the depth averaged 25 feet. SCUBA observations from previous years (W. J. North, Conrad Limbaugh, and others, personal communication) indicated the kelp in this bed was regularly removed by winter and spring storms which buried the rocks in sand. Such environmental instability probably explains the nearly complete absence of abalones and sea urchins in the area. Twenty-six fish species were taken from the 0.54 acre that was enclosed (Table 22).

The third collection was on August 10, 1959, in a rocky bay on the south side of Punta Banda, a volcanic peninsula south of Ensenada, Baja California (Figure 23). The net was laid around a section of kelp projecting seaward from an alongshore bed. Kelp plants rose 35 feet from a bottom of flat boulders, cobbles, and sand and terminated in a dense surface canopy. In contrast to Bathtub Rock, there were numerous abalones (mainly red (Haliotis rufescens) , but also some pink (H. corrugata) , white (H. sorenseni) , and one black (H. cracherodii) according to Conrad Limbaugh). Many sea cucumbers (Stichopus spp.) and giant sea urchins (Strongylocentrotus franciscanus) were also noted. The net enclosed approximately 0.57 acre. A gap of 5 to 7 feet at the ends allowed numerous larger fish to escape (kelp bass, sheephead, and opaleye). Thirty-nine fish species were obtained (Table 22).

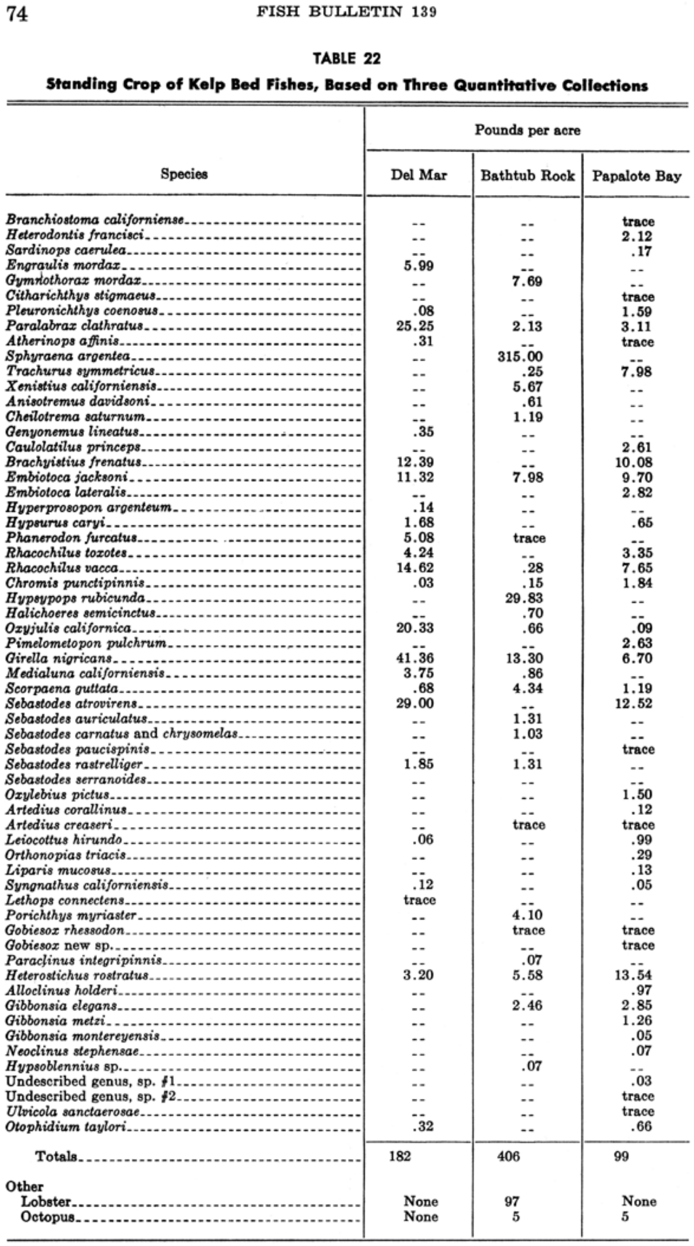


TABLE 22

Standing Crop of Kelp Bed Fishes, Based on Three Quantitative Collections

Species	Pounds per acre		
	Del Mar	Bathtub Rock	Papalote Bay
Branchiostoma californiense	--	--	trace
Heterodontis francisci	--	--	2.12
Sardinops caerulea	--	--	.17
Engraulis mordax	5.99	--	--
Gymnothorax mordax	--	7.69	--
Citharichthys stigmaeus	--	--	trace
Pleuronichthys coenosus	.08	--	1.59
Paralabrax clathratus	25.25	2.13	3.11
Atherinops affinis	.31	--	trace
Sphyraena argentea	--	315.00	--
Trachurus symmetricus	--	.25	7.98
Xenistius californiensis	--	5.67	--
Anisotremus davidsoni	--	.61	--
Cheilotrema saturnum	--	1.19	--
Genyonemus lineatus	.35	--	--
Caulolatilus princeps	--	--	2.61
Brachyistius frenatus	12.39	--	10.08
Embiotoca jacksoni	11.32	7.98	9.70
Embiotoca lateralis	--	--	2.82
Hyperprosopon argenteum	.14	--	--
Hypsurus caryi	1.68	--	.65
Phanerodon furcatus	5.08	trace	--
Rhacochilus toxotes	4.24	--	3.35
Rhacochilus vacca	14.62	.28	7.65
Chromis punctipinnis	.03	.15	1.84
Hypsypops rubicunda	--	29.83	--
Halichoeres semicinctus	--	.70	--
Oxyjulis californica	20.33	.66	.09
Pimelometopon pulchrum	--	--	2.63
Girella nigricans	41.36	13.30	6.70
Medialuna californiensis	3.75	.86	--
Scorpaena guttata	.68	4.34	1.19
Sebastodes atrovirens	29.00	--	12.52
Sebastodes auriculatus	--	1.31	--
Sebastodes carnatus and *chrysomelas*	--	1.03	--
Sebastodes paucispinis	--	--	trace
Sebastodes rastrelliger	1.85	1.31	--
Sebastodes serranoides	--	--	--
Oxylebius pictus	--	--	1.50
Artedius corallinus	--	--	.12
Artedius creaseri	--	trace	trace
Leiocottus hirundo	.06	--	.99
Orthonopias triacis	--	--	.29
Liparis mucosus	--	--	.13
Syngnathus californiensis	.12	--	.05
Lethops connectens	trace	--	--
Porichthys myriaster	--	4.10	--
Gobiesox rhessodon	--	trace	trace
Gobiesox new sp.	--	--	trace
Paraclinus integripinnis	--	.07	--
Heterostichus rostratus	3.20	5.58	13.54
Alloclinus holderi	--	--	.97
Gibbonsia elegans	--	2.46	2.85
Gibbonsia metzi	--	--	1.26
Gibbonsia montereyensis	--	--	.05
Neoclinus stephensae	--	--	.07
Hypsoblennius sp.	--	.07	--
Undescribed genus, sp. #1	--	--	.03
Undescribed genus, sp. #2	--	--	trace
Ulvicola sanctaerosae	--	--	trace
Otophidium taylori	.32	--	.66
Totals	182	406	99
Other			
Lobster	None	97	None
Octopus	None	5	5

TABLE 22

Standing Crop of Kelp Bed Fishes, Based on Three Quantitative Collections

6.3.4. Combined Estimates

A serious limitation on the use of the belt transect for biomass estimation lies in the error inherent in conversion of estimates of fish size to fish weight. It is reasonable to expect at least 20 percent average diver error in fish-length estimates. Since the normal relationship of weight to length is approximately cubic (Appendix B) any error is magnified when lengths are converted to weights. Overestimation of length is commonest, since the faceplate magnifies objects by approximately 25 percent.

The most reliable estimate available of average size for kelp bass in the San Diego area is the length-weight data that were obtained from concurrent studies in the sportfishery (See Chapter 7). Although undoubtedly somewhat biased, the sportfishery average of 953 grams or approximately 2.1 pounds per adult fish seems reasonable, judging from other experience with the species.

Calculations for average size of sheephead are more tenuous than for kelp bass because length and weight frequency distributions from the sportfishery were severely biased toward large fish. The quantitative collections did not yield enough sheephead to give a reliable estimate. As a result, the average weight of adults in the study regions was arbitrarily considered 2.5 pounds, a value that seems reasonable but possibly may be somewhat low, because individuals weigh up to 30 lbs. (Roedel, 1953).

Chance encounters with schools of adult opaleyes caused great variation in wall-net and belt-transect estimates; hence these data were also analyzed for average densities (Table 23) . Highest densities occurred in the shallower section of the rocky-inshore region, although both single individuals and schools were found to depths of 65 feet and more. Higher densities were correlated with Macrocystis but direct causal

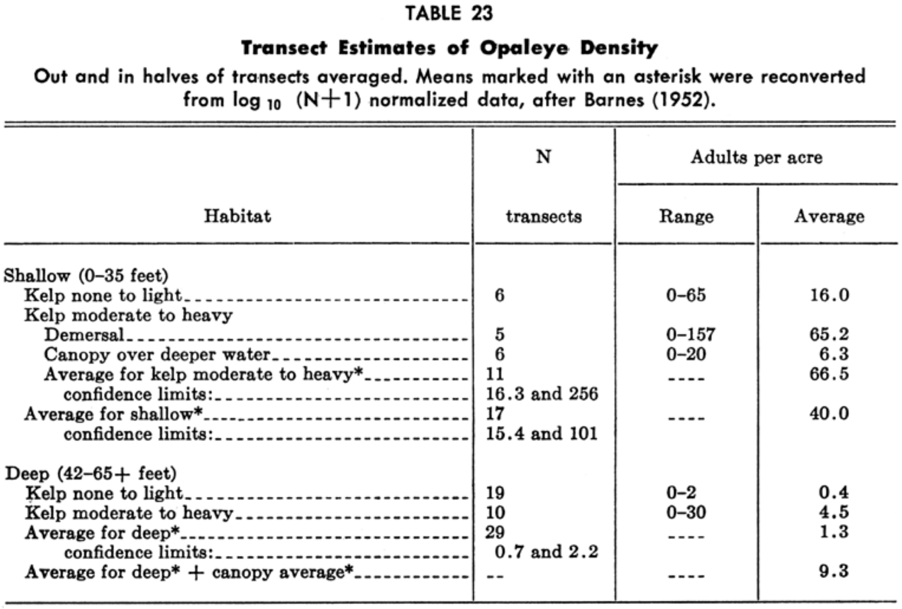


TABLE 23

Transect Estimates of Opaleye Density

Out and in halves of transects averaged. Means marked with an asterisk were reconverted from log 10 (N+1) normalized data, after Barnes (1952).

Habitat	N transects	Adults per acre Range	Adults per acre Average
Shallow (0–35 feet)			
Kelp none to light	6	0–65	16.0
Kelp moderate to heavy			
Demersal	5	0–157	65.2
Canopy over deeper water	6	0–20	6.3
Average for kelp moderate to heavy*	11	----	66.5
confidence limits:	16.3 and 256		
Average for shallow*	17	----	40.0
confidence limits:	15.4 and 101		
Deep (42–65+ feet)			
Kelp none to light	19	0–2	0.4
Kelp moderate to heavy	10	0–30	4.5
Average for deep*	29	----	1.3
confidence limits:	0.7 and 2.2		
Average for deep* + canopy average*	--	----	9.3

TABLE 23

Transect Estimates of Opaleye Density

factors were not established. Increases with depth and with kelp association may both be related to a third factor. Although opaleyes frequently consume large amounts of Macrocystis when available, they also feed heavily on moss-like red algae of the shallow inshore zone. An average weight of 1.8 pounds was computed from the Del Mar collection, in which opaleye were fairly well represented.

The first set of the net indicated that kelp bass, sheephead, and opaleye would be underestimated by the quantitative collection method. Large fish noted within the enclosure at the beginning of the poison operation did not materialize in the pickup and could not be located in the immediate area. In all three collections density values for large species are well below transect estimates in the same area and also below subjective impressions of density estimated from other dives at the sites. For these reasons the standing crop estimates from the quantitative collections were revised upward. Transect values for density were multiplied by the factors discussed above for average weight of adults of the three species (Table 24) . Averages for estimates of resident fish for the three collections varied from 296 to 335 pounds per acre and averaged 313 pounds per acre for animal standing crop of some localities (Table 22). Addition of all other inverterbrates could multiply the sum manyfold.

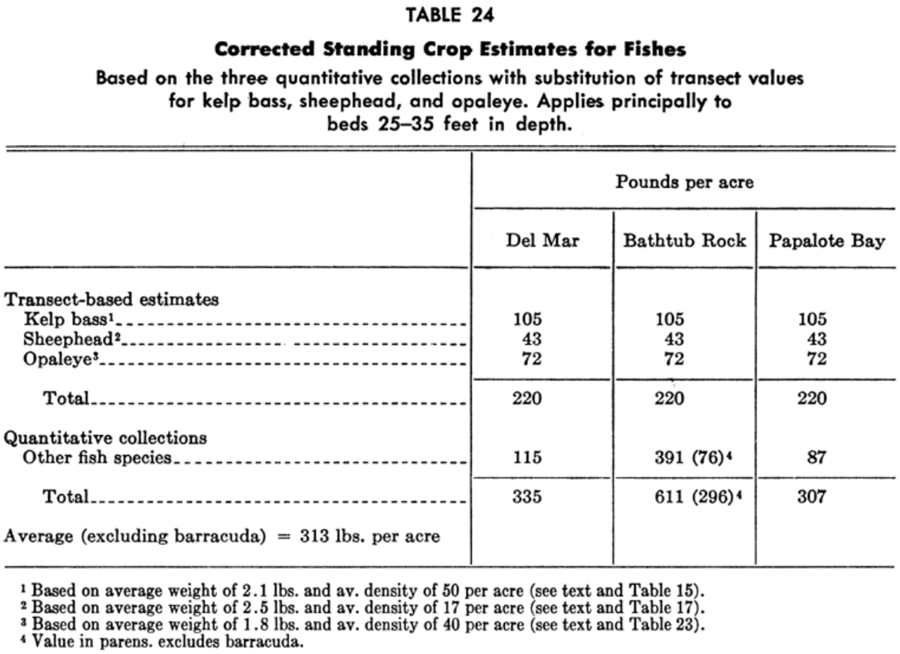


TABLE 24

Corrected Standing Crop Estimates for Fishes

Based on the three quantitative collections with substitution of transect values for kelp bass, sheephead, and opaleye. Applies principally to beds 25–35 feet in depth.

	Pounds per acre		
	Del Mar	Bathtub Rock	Papalote Bay
Transect-based estimates			
Kelp bass[1]	105	105	105
Sheephead[2]	43	43	43
Opaleye[3]	72	72	72
Total	220	220	220
Quantitative collections			
Other fish species	115	391 (76)[4]	87
Total	335	611 (296)[4]	307
Average (excluding barracuda) = 313 lbs. per acre			

[1] Based on average weight of 2.1 lbs. and av. density of 50 per acre (see text and Table 15).
[2] Based on average weight of 2.5 lbs. and av. density of 17 per acre (see text and Table 17).
[3] Based on average weight of 1.8 lbs. and av. density of 40 per acre (see text and Table 23).
[4] Value in parens. excludes barracuda.

TABLE 24

Corrected Standing Crop Estimates for Fishes

A comparison of these estimates with literature values for lakes and coral reefs demonstrated that the kelp bed estimates were close to the median values for the other habitats (Table 25) . The present kelp-bed estimates, of course, apply only to resident species that spend their adult lives in association with restricted geographic regions of the rocky-inshore habitat. They do not include neritic species such as anchovy, sardine, barracuda, jack mackerel, bonito and yellowtail.

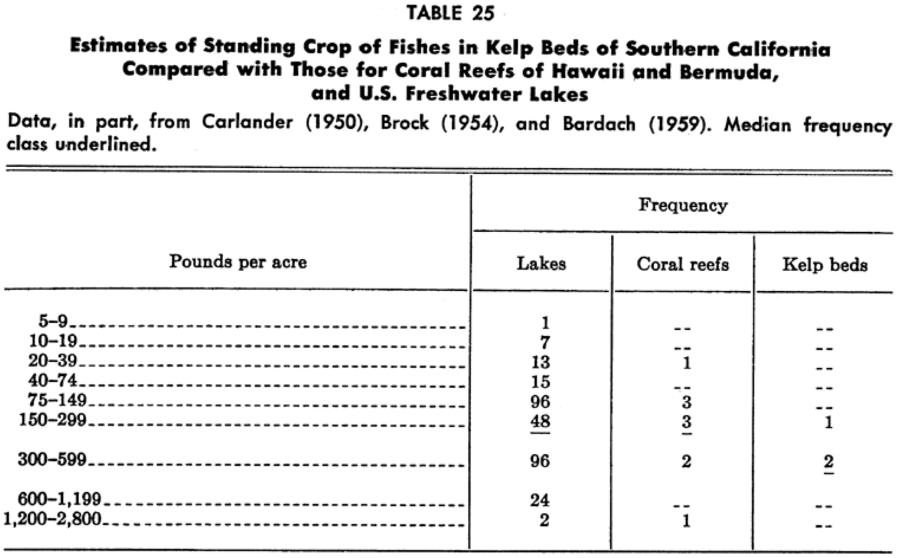


TABLE 25

Estimates of Standing Crop of Fishes in Kelp Beds of Southern California Compared with Those for Coral Reefs of Hawaii and Bermuda, and U.S. Freshwater Lakes

Data, in part, from Carlander (1950), Brock (1954), and Bardach (1959). Median frequency class underlined.

Pounds per acre	Frequency		
	Lakes	Coral reefs	Kelp beds
5–9	1	--	--
10–19	7	--	--
20–39	13	1	--
40–74	15	--	--
75–149	96	3	--
150–299	48	3	1
300–599	96	2	2
600–1,199	24	--	--
1,200–2,800	2	1	--

TABLE 25

Estimates of Standing Crop of Fishes in Kelp Beds of Southern California Compared with Those for Coral Reefs of Hawaii and Bermuda, and U.S. Freshwater Lakes

Chance sampling of some of these species could increase our standing crop figures by several times.

Nearly all species of the kelp bed biocoenose usually decline with attrition of Macrocystis. The causal chain of this collapse is not obvious. The short algæ normally harbor numerous small Crustacea that are important food items (as discussed in Chapter 8); their disappearance means the loss of an important food source for the fishes. During the 1950's the author saw profound changes over much of the rocky inshore region of the Palos Verdes peninsula, near Los Angeles. Heavy kelp-bed areas, rich in fishes and short algae, are now barren rock. Many of these barren areas now display very small standing crops of resident fishes and invertebrates.

7. SUMMARY

1. Techniques for estimating fish densities included a 558-foot enclosure net and SCUBA surveys of adults along a belt transect.

2. The enclosure-net (wall net) and belt-transect methods were nearly complementary. The net gave the best data on small and cryptic fishes; the transect the best data on large, more motile fishes.

3. Fifteen repeat transects in the same area (La Jolla transect site) over a 3-month period showed no significant differences for kelp bass between the out and in halves of transects or between transects performed in the first and last halves of the series. Populations averaged 20.0 fish per acre with 95 percent confidence limits at 14.5 and 27.4.

4. Although the 15 repeat transects for kelp bass at one site showed no correlation between counts on out and in halves of the transects, there was a high correlation between halves when different sites were compared; i.e., within-site variation was slight in comparison with between-site variation.

5. Population densities of kelp bass were not significantly different between areas of zero to light kelp density and those supporting moderate

to heavy kelp density, except where fishing pressure was high. Regions of low kelp density and high fishing pressure had few fish.

6. The giant kelp, Macrocystis, is not necessary for the maintenance of dense kelp-bass populations composed of large fish.

7. Although not necessary for the maintenance of kelp bass, indirect evidence suggested that the species prefers some stands of Macrocystis to regions where Macrocystis is absent.

8. For sheephead as well as for kelp bass, counts for the repeat transect site were not significantly different between the out and in halves of transects or between the first and last halves of the series. Populations averaged 14 fish per acre with 95 percent confidence limits at 12 and 17.

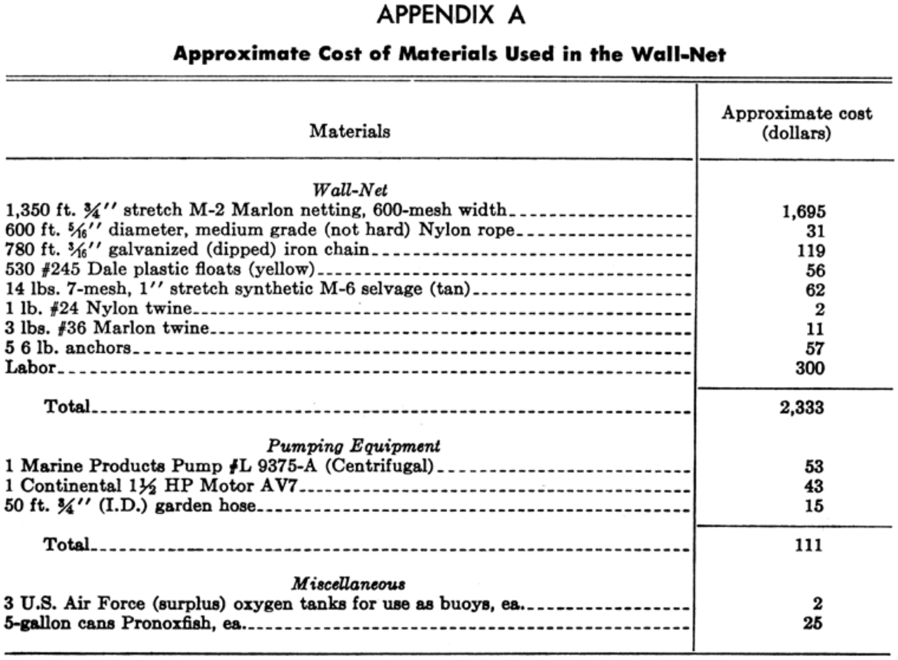
9. For sheephead as well as for kelp bass, within-site correlation between out and in halves of transects was negligible in comparison with correlation when sites were contrasted; i.e., within-site variation was slight compared to between-site variation.

10. The sheephead data show no important differences in respect to effects of kelp density or fishing pressure.

11. Data on blacksmith from the area of repeat transects show high correlation between counts obtained on the in and out halves of transects. This was expected, because the fish are schooling and schools are usually restricted to regions of rocky prominences or broken bottom.

12. In the repeat transect area, blacksmith densities averaged 448 fish per acre, with 95 percent confidence limits at 272 and 739. No significant shift in counts was noted during the 3-month period of survey.

13. Presence of giant kelp is not a habitat requirement for populations of blacksmith. Some data suggest that dense kelp may actually exclude this species.



APPENDIX A

Approximate Cost of Materials Used in the Wall-Net

Materials	Approximate cost (dollars)
Wall-Net	
1,350 ft. 3/4'' stretch M-2 Marlon netting, 600-mesh width	1,695
600 ft. 5/16'' diameter, medium grade (not hard) Nylon rope	31
780 ft. 3/16'' galvanized (dipped) iron chain	119
530 #245 Dale plastic floats (yellow)	56
14 lbs. 7-mesh, 1'' stretch synthetic M-6 selvage (tan)	62
1 lb. #24 Nylon twine	2
3 lbs. #36 Marlon twine	11
5 6 lb. anchors	57
Labor	300
Total	2,333
Pumping Equipment	
1 Marine Products Pump #L 9375-A (Centrifugal)	53
1 Continental 1 1/2 HP Motor AV7	43
50 ft. 3/4'' (I.D.) garden hose	15
Total	111
Miscellaneous	
3 U.S. Air Force (surplus) oxygen tanks for use as buoys, ea.	2
5-gallon cans Pronoxfish, ea.	25

APPENDIX A
Approximate Cost of Materials Used in the Wall-Net

14. Ninety-five percent confidence intervals for mean counts [X] of kelp bass, sheephead, and blacksmith in repeat transects at the La Jolla transect site were well within the limits of [X]/2 and 2[X]. This relatively narrow range of variability justified the relatively gross comparisons based on the belt-transect surveys.

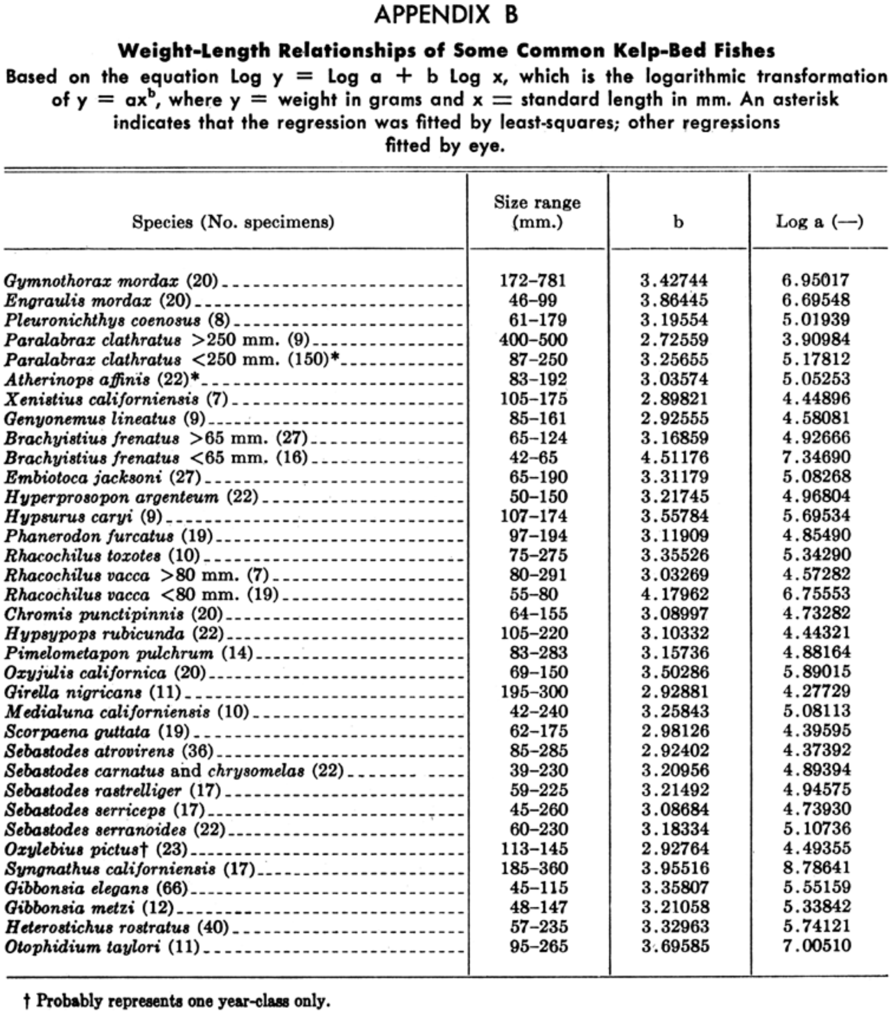
15. Opaleye occurred in greater densities in water shallower than 35 feet and in regions of moderate to heavy Macrocystis as compared with regions where Macrocystis was absent or sparse.

16. Fish biomass in the kelp beds was estimated from three quantitative collections, supplemented by data from approximately 50 belt transects.

17. Three standing crop estimates of resident kelp-bed fishes amounted to 335, 296, and 307 pounds per acre, with 313 as the mean.

18. Incorporating invertebrate biomasses or chance inclusion of schooling pelagic-neritic fish species would multiply values for resident fishes manyfold.

19. Standing crop estimates of resident fishes in kelp beds are close to median values from the literature for lakes and coral reefs.



APPENDIX B

Weight-Length Relationships of Some Common Kelp-Bed Fishes

Based on the equation Log y = Log a + b Log x, which is the logarithmic transformation of $y = ax^b$, where y = weight in grams and x = standard length in mm. An asterisk indicates that the regression was fitted by least-squares; other regressions fitted by eye.

Species (No. specimens)	Size range (mm.)	b	Log a (—)
Gymnothorax mordax (20)	172–781	3.42744	6.95017
Engraulis mordax (20)	46–99	3.86445	6.69548
Pleuronichthys coenosus (8)	61–179	3.19554	5.01939
Paralabrax clathratus >250 mm. (9)	400–500	2.72559	3.90984
Paralabrax clathratus <250 mm. (150)*	87–250	3.25655	5.17812
Atherinops affinis (22)*	83–192	3.03574	5.05253
Xenistius californiensis (7)	105–175	2.89821	4.44896
Genyonemus lineatus (9)	85–161	2.92555	4.58081
Brachyistius frenatus >65 mm. (27)	65–124	3.16859	4.92666
Brachyistius frenatus <65 mm. (16)	42–65	4.51176	7.34690
Embiotoca jacksoni (27)	65–190	3.31179	5.08268
Hyperprosopon argenteum (22)	50–150	3.21745	4.96804
Hypsurus caryi (9)	107–174	3.55784	5.69534
Phanerodon furcatus (19)	97–194	3.11909	4.85490
Rhacochilus toxotes (10)	75–275	3.35526	5.34290
Rhacochilus vacca >80 mm. (7)	80–291	3.03269	4.57282
Rhacochilus vacca <80 mm. (19)	55–80	4.17962	6.75553
Chromis punctipinnis (20)	64–155	3.08997	4.73282
Hypsypops rubicunda (22)	105–220	3.10332	4.44321
Pimelometapon pulchrum (14)	83–283	3.15736	4.88164
Oxyjulis californica (20)	69–150	3.50286	5.89015
Girella nigricans (11)	195–300	2.92881	4.27729
Medialuna californiensis (10)	42–240	3.25843	5.08113
Scorpaena guttata (19)	62–175	2.98126	4.39595
Sebastodes atrovirens (36)	85–285	2.92402	4.37392
Sebastodes carnatus and *chrysomelas* (22)	39–230	3.20956	4.89394
Sebastodes rastrelliger (17)	59–225	3.21492	4.94575
Sebastodes serriceps (17)	45–260	3.08684	4.73930
Sebastodes serranoides (22)	60–230	3.18334	5.10736
Oxylebius pictus† (23)	113–145	2.92764	4.49355
Syngnathus californiensis (17)	185–360	3.95516	8.78641
Gibbonsia elegans (66)	45–115	3.35807	5.55159
Gibbonsia metzi (12)	48–147	3.21058	5.33842
Heterostichus rostratus (40)	57–235	3.32963	5.74121
Otophidium taylori (11)	95–265	3.69585	7.00510

† Probably represents one year-class only.

APPENDIX B
Weight-Length Relationships of Some Common Kelp-Bed Fishes

8. 7. OBSERVATIONS ON THE FOOD AND BIOLOGY OF THE KELP BASS, PARALABRAX CLATHRATUS WITH NOTES ON ITS SPORTFISHERY AT SAN DIEGO, CALIFORNIA

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8.1. INTRODUCTION

The kelp bass is widespread and abundant in southern California, and is highly valued by sportfishermen and skindivers. Although usually not preferred to albacore, yellowtail, or barracuda (Collyer and Young, 1953, personal observations), the species is an important staple to the sportfishery because it is abundant, delectable, a good fighter, and available throughout the year. Kelp beds are increasingly used by recreational and commercial interests. The decline of many beds in extent and density during 1957–58 aroused interest in management of the beds and associated fishes. This concern stimulated considerable research on the kelp bass, including a preliminary study by Collyer and Young (1953), life-history notes by Limbaugh (1955), a study of the sportfishery statistics by Davies (1958), and a study of the kelp bass and its fishery by Young (1963). The present work complements that of Young.

8.2. ACKNOWLEDGMENTS

I am grateful for the assistance of Carl L. Hubbs, Wheeler J. North and the late Conrad Limbaugh. Field observations were aided by the Institute of Marine Resources SCUBA divers, James R. Stewart, Earle G. Cunnison, Charles T. Mitchell, Lois I. Rushing, Nan B. Limbaugh, and Marjorie M. Rydell. Richard H. Rosenblatt, Carl M. Boyd, and William D. Clarke, also donated considerable time to the project. H. George Snyder made the majority of food analyses, and also assisted in wall-net collections.

Large samples of kelp bass were made available through the cooperation of several San Diego sportfishing companies and their boat skippers. I am grateful to H and M Sportfishers for permission to accompany the *Mascot III* on trips to the kelp areas, and for permission to use the catch data for analysis. Special gratitude is due to the skipper, Manuel P. Sylva, for assistance during the trips and for his observations on the fishery. *Mascot III* catch statistics were made available by Edward C. Greenhood, Biostatistical Section, California Department of Fish and Game, Terminal Island. Numerous specimens were also obtained through the cooperation of Chili Troester and John Taylor, skippers of the Seabiscuit and *Jet*, respectively, Mission Bay Sportfishing Company.

8.3. MATERIALS AND METHODS

Observations were gathered during approximately 200 SCUBA dives in the inshore and island waters of southern and Baja California from 1958 to 1960. Food and gonad condition were determined on more than 1700 specimens, obtained principally while sampling about sportfishing boats and by spearfishing. Population estimates were based on wall-net and belt-transect data, discussed in Chapter 6.

8.4. ECOLOGY

The kelp bass is a medium-sized generalized carnivore occupying a relatively wide variety of environmental situations. Some physical relief in the form of rocks, debris, or plant materials characterized the usual habitat. The attractiveness of the environment increases as it becomes more broken or encrusted or overgrown with large laminarian algae. Environmental situations attractive to kelp bass include sparse Zostera beds on sandy bottoms, cobble regions, areas of broken rock, submarine canyons, cliffs, and Macrocystis beds with bottoms varying from substrates of mud and sand to highly broken rock.

Adult kelp bass occur over a wide bathymetric range, from the surf zone to depths of 130 feet or more. Large adults near La Jolla are common about the submarine canyons which begin at 100 feet and extend downward. They are commonly taken by hook-and-line from depths of 90 to 100 feet by passengers aboard sportfishing boats. Although juveniles and small adults are usually abundant in the surf zone, they are rare in intertidal collections (only one individual occurred in 36 collections by the Scripps Institution of Oceanography and the University of California at Los Angeles). No size-segregation with depth was obvious in kelp beds: adults and juveniles both occurred near the bottom as well as among surface fronds. The deeper bathymetric limits are not definitely known, but kelp bass are rarely reported by divers below 150 feet, and are rare in hook-and-line catches at that depth. A 240-mm adult was taken at 188 feet at Guadalupe Island, Mexico, in January 1960 (Carl L. Hubbs and Allan J. Stover, Jr., personal communication).

Roedel (1953) gave the geographic range of the kelp bass as Monterey Bay, central California, to Abreojos Point (south of 27°N), Baja California, but states that individuals are rare north of Point Conception. The late Conrad Limbaugh noted (personal communication) that individuals were common about all offshore islands of southern California, including the northernmost, San Miguel. He also observed individuals at Alijos Rocks (24° 57' N, 115° 45' E), far off southern Baja California. I have found this species in abundance on Guadalupe Island, off the Pacific coast of Baja California, and about the rocks and kelp of the San Benitos Islands and Punta Eugenia (approximately 28° N), near the southern limits of the recorded range.

8.5. Population Density

Estimates of the population density of this species for various regions, habitats, and intensity of fishing are presented in Chapter 6. The kelp bass is the most obvious fish inhabitant of the kelp beds and rocky areas, and was noted the most consistently during dives. However, usually it is not the most abundant species in these habitats. Individuals tend to aggregate about broken areas, but definite schools were encountered only rarely. One such concentration included approximately 70 large adults at Guadalupe Island, Mexico, in February 1960. Limbaugh (1955) noted a large spawning aggregation in the kelp beds at La Jolla.

Data from the sportfishery, discussed below, suggest that adults are not restricted to specific territories but shift in response to site preference and lowered population density at the preferred sites. Densities from near-average to higher-than-average were encountered at certain sites frequented by the sportfishing boats, even at the end of a fishing season. One such site gave an estimate of 16 adults per acre after the end of a fishing season, although at least 200 adults had been taken weekly from the site during several preceding 2-month periods by the *Mascot III.*

8.6. BEHAVIOR

The kelp bass is strongly curious, and usually will be encountered in the vicinity of some kind of cover. In the La Jolla region, where spearfishing is frequent, the distance maintained from a diver by a kelp bass is usually directly proportional to the bass size: large juveniles typically approach to within a yard, adults will usually stay a yard or more away, and large adults in general remain more than 12 feet distant. In several regions about La Jolla such as the mouths of the submarine canyons (not frequented by spearfishermen), large adults may easily be obtained with an 8-foot pole spear. Small adults will often accompany a diver, swimming several feet to his side or behind. When the diver turns to face the fish they usually move to a greater distance. In the upper water layers about the kelp canopy, the bass seem more reluctant to leave the vicinity of cover to inspect the diver and usually remain within a few feet of the kelp columns, obviously keeping the diver under observation. In all regions juveniles and young adults stay within a shorter radius of cover than adults. When approached in the canopy, the younger fishes move down the kelp column. I have "herded" young bass through a strong thermocline in such manner. Numerous other observations indicate that kelp bass rely on the kelp for cover. Small adults wounded by a spear sometimes dart into a column of kelp stipes and fronds and align themselves, motionless, with the stipes. Larger adults may sometimes be approached more closely when they are among kelp fronds, even when the diver is under surveillance, because the fish apparently feel more secure near cover.

Kelp bass and other kelp-bed fishes can detect alignment of elongate objects, and often take evasive action when spears are pointed at them. Individual kelp bass, however, sometimes approach the five-tine spear head closely when it is not pointed at them. To see if the alignment cue was visual, a pole spear was fashioned with a 4-foot Lucite tip (Lucite has nearly the same optical and acoustical properties as water). The Lucite, however, was plainly visible to the divers underwater and kelp bass took the same evasive action. Movement and alignment are probably readily perceived by this species and probably play important roles in food-getting and defense. Narrowly missed or even lightly wounded juveniles and small adults return for several seconds to the immediate scene of the miss, with fins erect, before swimming away rapidly.

In agreement with Limbaugh's (1955) findings, aggressive actions between kelp bass were not noted in the field. A juvenile held in a 15-gallon glass aquarium with juvenile black croaker of similar size, however, displayed numerous degrees of aggressiveness. In order of apparent increasing aggressiveness the following actions were directed against the croaker: raising the dorsal spines when the other fish approached; stiffening the body, aligned head to tail with the other fish, with slight tail-slapping movements; actual combat, with very rapid action that was difficult to interpret. Approach by the croaker to a small cave normally used by the bass and live food in the aquarium evoked especially strong aggressive action by the bass. The only injury noted from the nearly daily combat between the fishes during 7 months was one corneal tear in the croaker, which healed within 1 week. The combat was witnessed and the damage was apparently inflicted by the bass's opercular or preopercular spine.

Digging actions by the aquarium-held specimen were noted, but were rare. The fish backed into a crevice between the rocks and moved sand forward with the pectoral fins. Several crevices between the sand and rock were used as hiding places when the aquarium was severely disturbed. Similar hiding behavior by injured fish was observed in the field.

Visibility probably determines the distance that kelp-bed fishes wander from cover. Adult bass were not seen beyond visibility range of permanent or semi-permanent landmarks such as the bottom, kelp columns, or kelp canopy. In very turbid water, bass were encountered only very close to cover, usually adjacent to rocks or in crevices between or under rocks. When the water was very turbid near the bottom however, bass and other kelp-bed fishes were frequently encountered well off the bottom, and about the kelp in the clearer waters above.

8.7. FISH MOVEMENT AND HOME RANGE

On the basis of a tagging and length-frequency study, involving nearly 4,000 marked fish, Collyer and Young (1953) concluded that the data "strongly suggest that the kelp bass fishery is based on a series of independent populations." Over 400 fish showed "no movement," 23 fish moved from a few hundred yards to 4 miles, and 16 kelp bass strayed a distance of 5 miles or more. In a related study near La Jolla, Limbaugh (1955) trapped, tagged, and released kelp bass in cut and uncut sections of a kelp bed to determine fish movements and possible preferences for harvested or unharvested kelp. Some fish moved for varying distances (Figure 24), but no preference for cut or uncut sections could be determined from the data. Recaptures approached the zero asymptote at around six units of about 470 feet, hence five units (slightly more then one-half mile) is a reasonable estimate for maximum range. If this distance is taken as the diameter of a circle, the actual area involved is approximately 100 acres. However, the bearing of these data on the home range of this species in offshore kelp beds is open to question because the prime bass habitat in the area investigated by Limbaugh was limited in part to a narrow rocky subtidal zone. The fish undoubtedly have differently shaped home

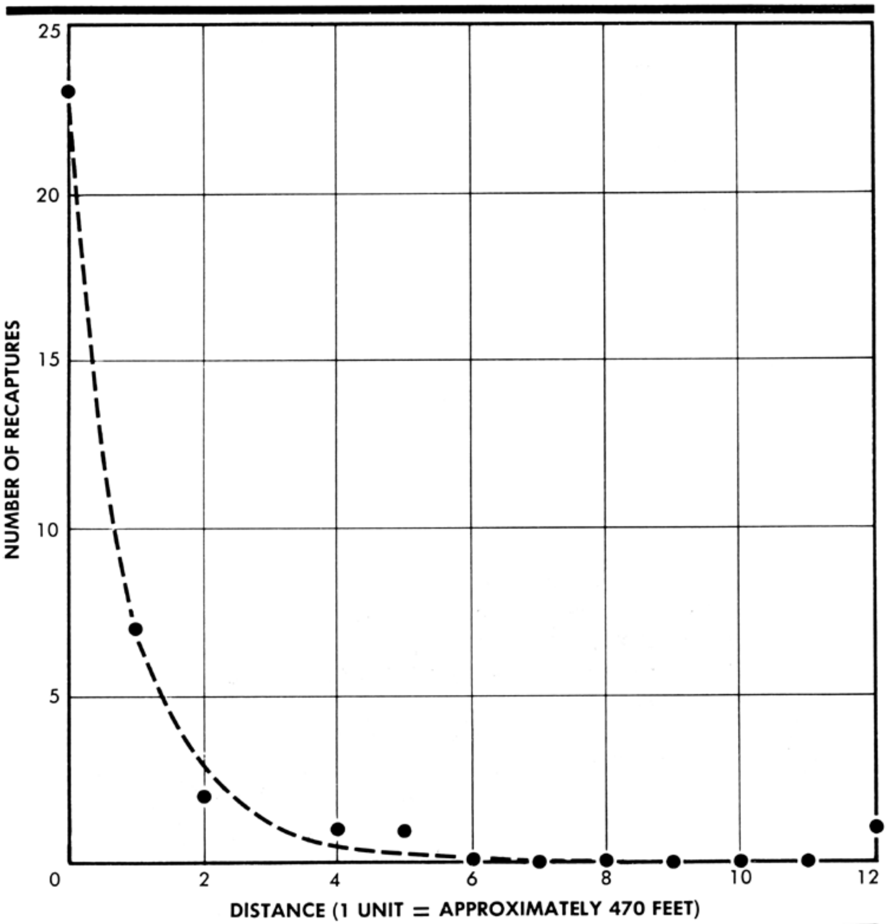


FIGURE 24. **Distance-of-recapture frequencies for tagged kelp bass. Data from Limbaugh (1955).**

ranges within offshore beds, possibly of less area than that calculated from Limbaugh's data.

FIGURE 24. ***Distance-of-recapture frequencies for tagged kelp bass. Data from Limbaugh (1955).***

ranges within offshore beds, possibly of less area than that calculated from Limbaugh's data.

8.8. FOOD

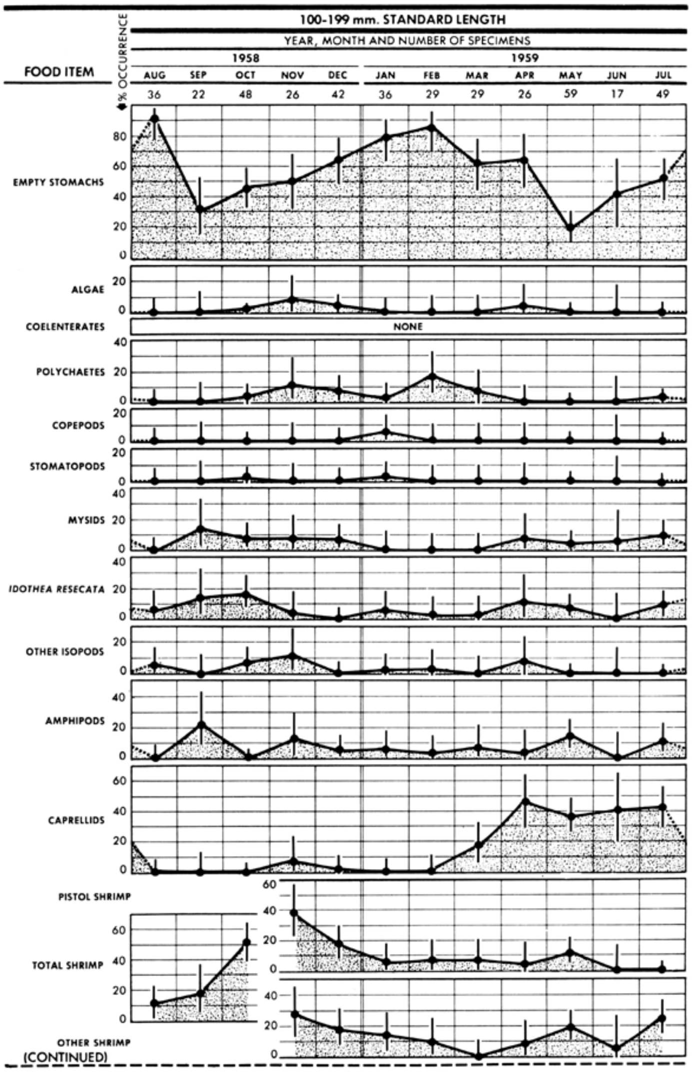
The majority of the approximately 1700 digestive-tract samples collected between August, 1958 and July, 1959 were obtained from sport-fishing boats: less than 25 percent were collected with spear and SCUBA. Approximately two-thirds of the sportfishing boat samples were from kelp beds at Point Loma, San Diego. Nearly all SCUBA samples were from kelp beds at La Jolla, 10 nautical miles northward.

A principal purpose of the SCUBA sampling was to expose any extreme bias in the sportfishing data, in addition to the known bias toward the northern anchovy, Engraulis mordax, used almost exclusively as live bait during the sampling period. The SCUBA samples were more variable than expected and sufficient kelp bass could not be obtained to permit reliable comparisons with sportfishing boats. Differences between the areas made valid comparisons difficult. The La Jolla and Point Loma beds are well separated and the two localities differ significantly in bottom character, wave exposure, and water quality (The Point Loma bed was frequently exposed to the relatively polluted waters of San Diego Bay). Sportfishing boats also operate near the La Jolla beds and release large quantities of live anchovies, some of which had undoubtedly been taken by the spear-collected specimens, complicating analysis. Because the SCUBA-obtained samples could not be evaluated satisfactorily, and because the samples generally resembled those from the sportfishing boats, the data from the two sources are lumped.

Food items from the digestive tracts were analyzed for frequency of occurrence by monthly samples, or by longer periods for small samples (Figures 25 26 27). Volumes were not used because large volumes for anchovy bait were common. Also remaining items, especially from the intestines, were frequently very well-digested. Stomachs only were examined during the first 2 months. Intestinal contents, however, were found valuable to the study and doubled or trebled the food data per fish. Intestinal items usually could be identified to class or family, and crustaceans frequently remained partly intact or had parts that could be identified even when they were nearly through the digestive tract. Axial skeletons of fishes frequently were sufficiently intact to be identified to family and some to species. Empty stomachs were frequent, even in the sportfishing catch, although the change in pressure on fishes brought from the bottom normally was not enough to evert their stomachs (average change was estimated as approximately 70 feet, equivalent to two atmospheres). Most frequent prey species are listed separately, but other items are grouped under higher taxa. For example, isopods were split into "Idothea resecata" and "other isopods", and shrimp into "pistol shrimp" (Alphaeus spp.) and "other shrimp". Five levels of utilization were based on frequency of occurrence: trace, indicated two percent or less; low, 3 to 24 percent; moderate, 25 to 46 percent; heavy, 47 to 68 percent; and very heavy, more than 68 percent.

8.8.1. 100-199 mm Fish (Figure 25)

The data for fish of this size range indicate that crabs and "other shrimps" are very important. The crab entries between August 1958 and January 1959 represent principally small spider crabs (approximately 1 cm or less from rostrum tip to posterior edge of carapace), which abound in the short algae of the bottom. Crab entries after January are almost entirely for red crabs, Pleuroncodes planipes, which were exceptionally abundant in coastal southern California and Baja California during that spring. Entries for "other shrimps" represented numerous small, poorly known, demersal species. Kelp isopods (Idothea resecata) , amphipods, and pistol shrimp appear consistently. Kelp isopods are frequently seen in abundance in the kelp canopy. The large adults, about 2.5 cm long, may be seen clinging to the fronds and stipes or swimming from stipe to stipe (when swimming, isopods hold the two large antennae together in front, possibly for streamlining). Little is known concerning the vertical abundance or


100-199 mm. STANDARD LENGTH
YEAR, MONTH AND NUMBER OF SPECIMENS
1958
1959
FOOD ITEM
% OCCURRENCE
AUG 36
SEP 22
OCT 48
NOV 26
DEC 42
JAN 36
FEB 29
MAR 29
APR 26
MAY 59
JUN 17
JUL 49
EMPTY STOMACHS
ALGAE
COELENTERATES
NONE
POLYCHAETES
COPEPODS
STOMATOPODS
MYSIDS
IDOTHEA RESECATA
OTHER ISOPODS
AMPHIPODS
CAPRELLIDS
PISTOL SHRIMP
TOTAL SHRIMP
OTHER SHRIMP
(CONTINUED)
0
20
40
60
80

FIGURE

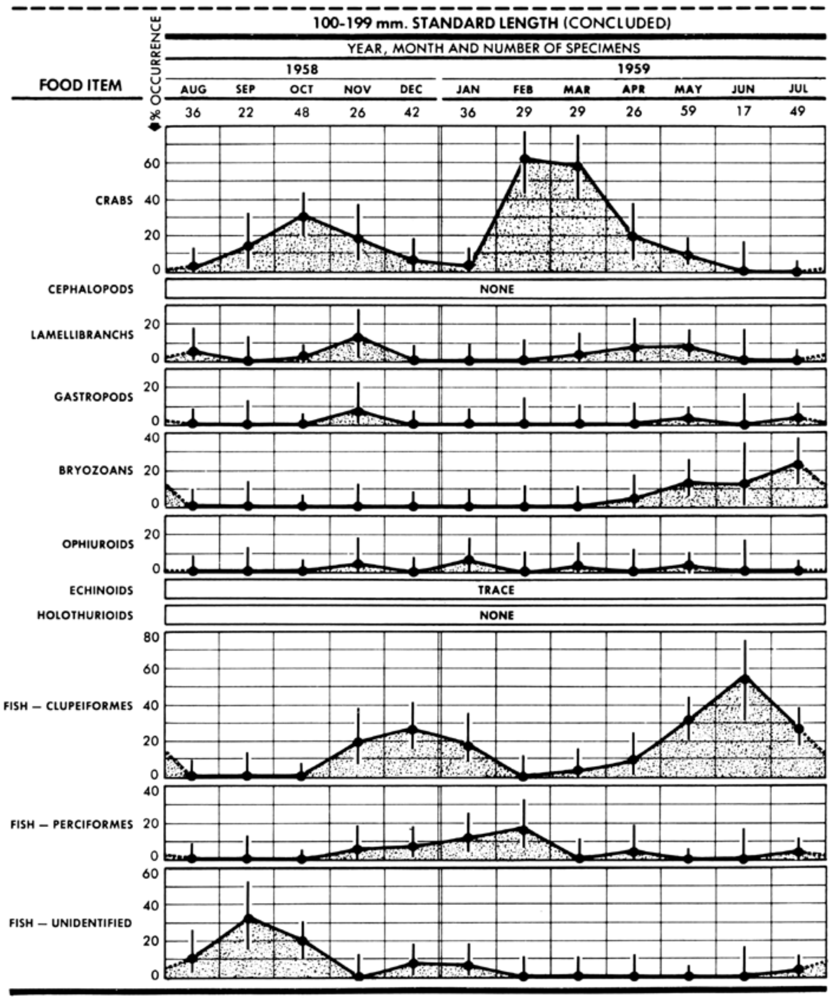


FIGURE 25. Food of 100–199-mm kelp bass. Data from specimens collected by hook-and-line and spear, from the San Diego region except for February, 1959, for which specimens were from the San Benito Islands (lat. 28° N.).

FIGURE 25. ***Food of 100-199-mm kelp bass. Data from specimens collected by hook-and-line and spear, from the San Diego region except for February, 1959, for which specimens were from the San Benito Islands (lat. 28° N.).***

life history of this important forage species. Gammarid amphipods abound in the kelp-bed environment and many species were noted in the digestive tracts. Both spider crabs and gammarid amphipods abound in the short algal growths of rocky bottoms and gammarid amphipods also occur on all parts of the kelp plants. Pistol shrimp inhabit burrows and crevices and are common about some kelp beds. Sometimes their steady noise, reminiscent of crackling cellophane, is audible through a skiff bottom. Although several species occur in kelp beds, adults of Alphaeus dentipes constitute the principal dietary contribution. Mysids and caprellids also are important. Caprellids and an associated tufted bryozoan, Bugula neritina, peak in the indicated diets during late spring and early summer. The caprellids then abound in the kelp canopy. The bryozoans probably were ingested incidentally with the caprellids.

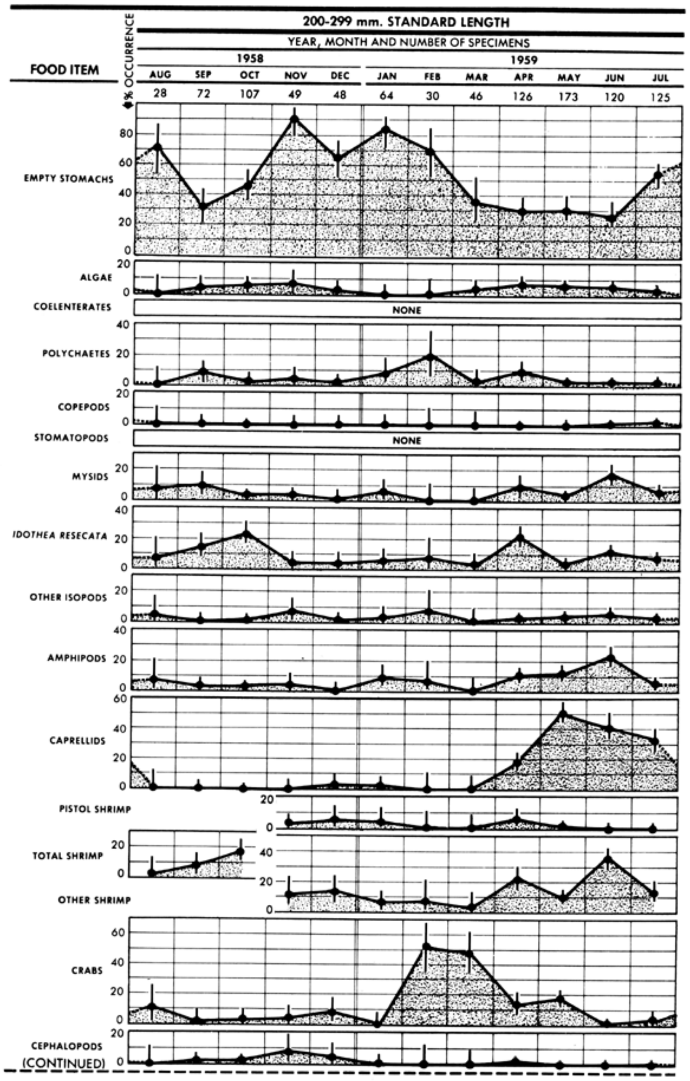
Fish constitute an important item on the food list and the northern anchovy, a clupeiform fish, is undoubtedly highly preferred. Live anchovies are the bait of choice for sportfishing boats in kelp beds and sometimes bass repeatedly break the water surface pursuing live bait when a sportfishing boat circles and establishes a "chum line" before anchoring. Anchovies were abundant adjacent to and within kelp beds during the year of study so presumably they also contributed importantly to the fish's natural diet. Perciform (spiny-rayed) fishes also were important, but most entries were unidentifiable to species. Among those identified were a flatfish, an eel-blenny, one goby, one kelp bass, five giant kelpfish, and three cottids (one Artedius sp.), all of relatively small size.

Summation of all categories revealed two general feeding peaks, one during fall and one during spring. Normally, ocean surface temperatures off La Jolla rise during April and May and lower abruptly sometime during November or December at the onset of winter storms. Nearly all food categories were represented in the fall feeding peak, possibly because a wide range of organisms was made available by the storms. The spring feeding peak was more restricted, and was characterized by an increase in caprellids, crabs and fish.

8.8.2. 200–299 mm Fish (Figure 26)

Frequencies resemble those of the first group above with the inhabitants of the kelp canopy possibly increasing slightly in importance. Kelp isopods occur most consistently but are never abundant, and polychaetes, gammarid amphipods, "other shrimps", and crabs are nearly as consistent. A nereid similar to a 5-cm species common in the canopy, predominated among polychaetes. Gammarid amphipods included the relatively large kelp curler, Ampithoe humeralis, also common in the canopy, as well as many smaller forms that are possibly from the kelp canopy as well. Sources of "other shrimps" are unknown. Habits of the various shrimp species have not been studied, but at least one, the "abalone" shrimp (Baeteus harfordi) includes the kelp canopy in its habitat. In contrast to the smaller size-class of kelp bass discussed above, demersal spider crabs were not important in the fall feeding peak. As for the smaller fish a spring crab peak was from the often-pelagic red crab, Pleuroncodes planipes, and entries for the demersal species remained infrequent. Fish again were very important with Clupeiformes in moderate to high occurrence, presumably because the samples were taken aboard sportfishing boats. Spiny-rayed fishes occurred at low levels, but undoubtedly are important because some items were relatively large in size. Included were giant kelpfish (with a frequency nearly as great as for all other identified spiny-rayed fishes), flatfishes, pholids, labrids, cottids, embiotocids, gobies, and kelp bass.

Two general feeding peaks are again apparent. The fall peak had a broad spectrum of food types, with the majority at low frequency, as well as moderate feeding on clupeiform fishes. The spring peak showed intensive feeding on caprellids and clupeiform fishes. Empty stomachs were less frequent during feeding peaks.


200-299 mm. STANDARD LENGTH
YEAR, MONTH AND NUMBER OF SPECIMENS
FOOD ITEM
% OCCURRENCE
1958
1959
AUG 28
SEP 72
OCT 107
NOV 49
DEC 48
JAN 64
FEB 30
MAR 46
APR 126
MAY 173
JUN 120
JUL 125
EMPTY STOMACHS
ALGAE
COELENTERATES
NONE
POLYCHAETES
COPEPODS
STOMATOPODS
NONE
MYSIDS
IDOTHEA RESECATA
OTHER ISOPODS
AMPHIPODS
CAPRELLIDS
PISTOL SHRIMP
TOTAL SHRIMP
OTHER SHRIMP
CRABS
CEPHALOPODS
(CONTINUED)
0
20
40
60
80

FIGURE

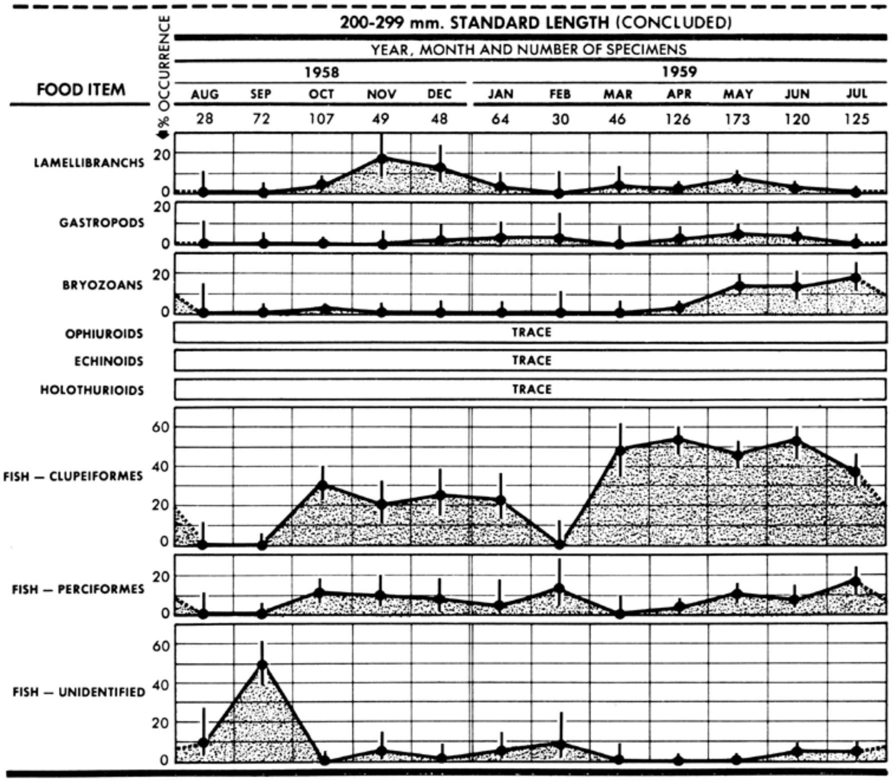


FIGURE 26. Food of 200–299-mm kelp bass. Data from specimens collected by hook-and-line and spear from the San Diego region except for February, 1959, in which specimens were from the San Benito Island (lat. 28° N.).

FIGURE 26. ***Food of 200–299-mm kelp bass. Data from specimens collected by hook-and-line and spear from the San Diego region except for February, 1959, in which specimens were from the San Benito Island (lat. 28° N.).***

8.8.3. 300–399 mm Fish (Figure 27)

Frequencies in general resemble the smaller class. Fishes made an important contribution during all months. Perciform items included flatfish, topsmelt, pipefish, and embiotocid, one goby, one small "giant" kelpfish, and a labrid. Small items, such as polychaetes, gammarid amphipods, and caprellids, continued to be taken, but at low frequencies.

Small pieces of kelp were quite common in this and succeeding sizes of bass. Because kelp bass are carnivorous and the algae never showed any evidence of being digested, it seemed probable that the "kelp-perch sized" fragments were mistaken for prey. Samples of this nature originated from sportfishing boats, and considerable quantities of kelp are sometimes fragmented by the propellers in the process of "chumming" and anchoring at a fishing site.

8.8.4. Fish 400 mm and Larger (Figure 28)

Fish and Macrocystis fragments predominate in the samples, and small invertebrates are nearly absent. Cephalopods (mainly octopus) were important. Giant kelpfish predominated among the perciform fishes, followed by blacksmith, and señorita; topsmelt, flatfish, cottids, rockfish, and pipefish were less frequent. The data are too few to indicate possible seasonal feeding peaks.

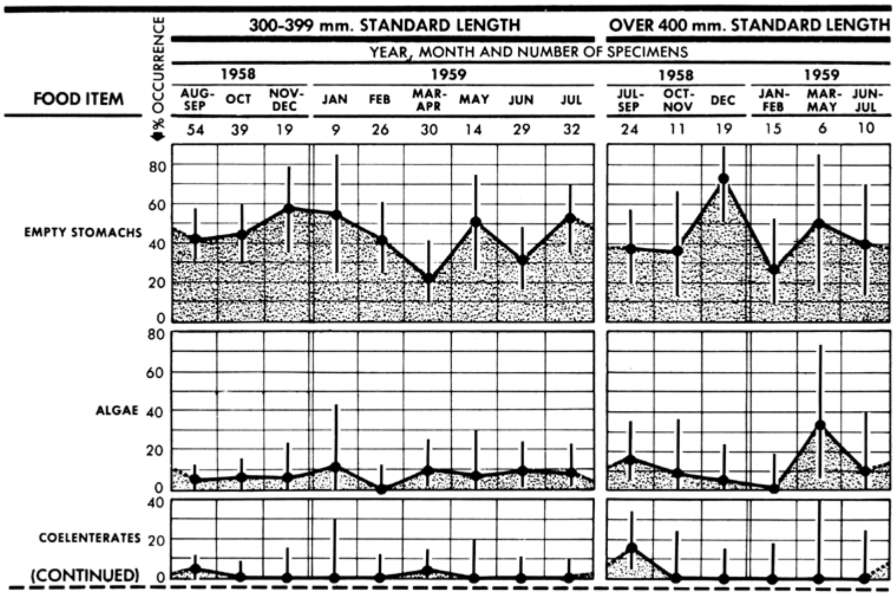
8.8.5. General Conclusions Regarding Diet

The kelp bass is apparently a generalized carnivore and utilizes a broad spectrum of the available foods. Judging from food frequency figures and the derived Table 26, there is a selection of larger, more motile prey, mainly fish and cephalopods, as the fish grow larger. Very small foods sometimes occur, however, and it is difficult to understand how the effort required to pick caprellids from kelp fronds may be rewarding to a fish as large as 200 mm SL. Similarly, solitary polychaetes shorter than 5 cm were taken by individuals 400 mm and larger, but cannot have been very rewarding at the low concentration at which the food organisms were observed. Also brine shrimp approximately 3 mm long were individually taken by a well-fed and actively growing aquarium held specimen of 115 mm TL. Probably these feeding activities represent relicts of earlier patterns in the fish's development.

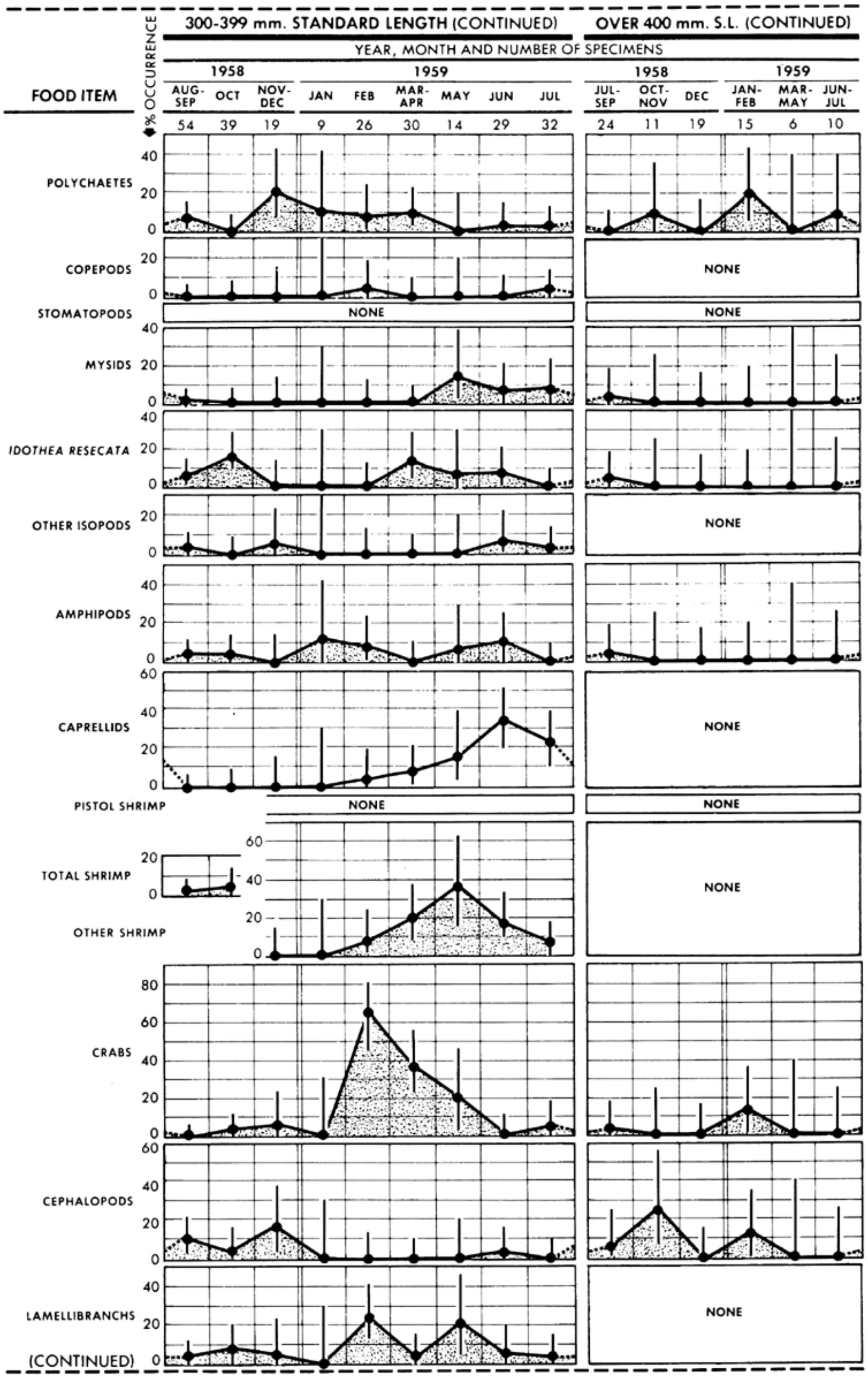
In terms of the general categories, the kelp bass diet remains broad up to the largest size-class, at which time it becomes more limited. The averages for number of food categories utilized by the size-classes are 9.7 for 100–199 mm, 11.4 for 200–299 mm, 10.9 for 300–399 mm, and 5.2 for fishes 400 mm or larger. Considerable food variety is, however, available within each category and the general data give no indication of breadth of utilization within the categories. Such an analysis requires that all items be identified to species, which was judged too time-consuming for the present study.

8.9. REPRODUCTION

The spawning season was first delineated by Clark (1933) as June, July, and August on the basis of specimens examined at the San Pedro commercial fish markets. She indicated the smallest size at maturity to be approximately 25 cm TL and that larger fish mature earlier than smaller ones. Collyer and Young (1953) found that some kelp bass



FIGURE



FIGURE

mature as early as April and also that a few smaller than 25 cm mature. In other respects their findings substantiated those of Clark.

Two methods were used for assessing maturity in the Kelp Program studies. Davies' (1956) subjective maturity categories (inactive, active, ripe, ripe and running, and spent) were recorded as fish were

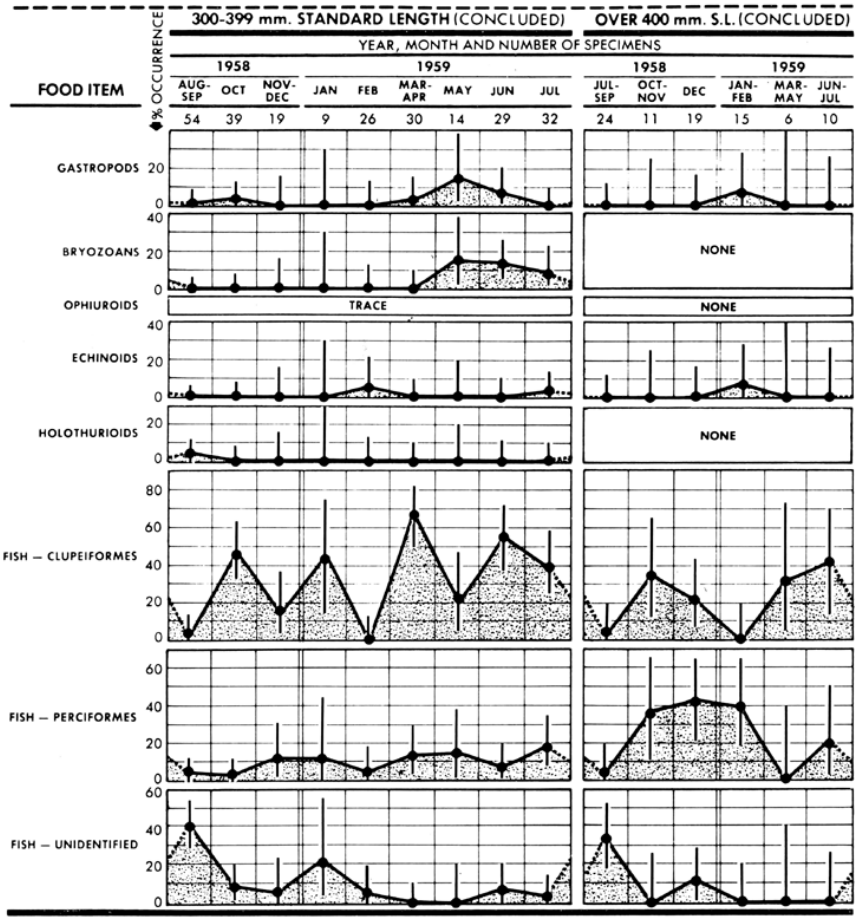


FIGURE 27. Food of 300–399 and 400 + mm kelp bass. Data from specimens collected by hook-and-line and spear from the San Diego region except for February, 1959, in which all specimens were from the San Benito Islands (lat. 28° N.).

FIGURE 27. ***Food of 300–399 and 400 + mm kelp bass. Data from specimens collected by hook-and-line and spear from the San Diego region except for February, 1959, in which all specimens were from the San Benito Islands (lat. 28° N.).***

gutted aboard sportfishing boats. Volumetric displacement was also taken on all gonads in the laboratory at the time the gut contents were examined. Volumetric displacement was converted to weight by assuming that 1 cc equaled 1 gram, considered approximately correct on the basis of weight-volume comparisons. of the two methods, the volumetric analysis was more valuable because it included more specimens and a greater size-range of samples (fish approximating or smaller than the 12-inch (300 mm) legal size were not gutted aboard the ship, but were preserved entire).

Graphical analysis of breeding condition (Figure 28) demonstrates that larger fish of both sexes mature earlier, are mature longer, and are mature in a greater percentage within the samples than smaller fish. Data for the largest females, are insufficient to determine whether the scattered points for June through September represent one or two modes; hence two spawning peaks may be indicated. Maturity evidence based on gonad weight as a percentage of whole body weight (Figure 29) agrees closely with the subjective data. The midrange analysis of

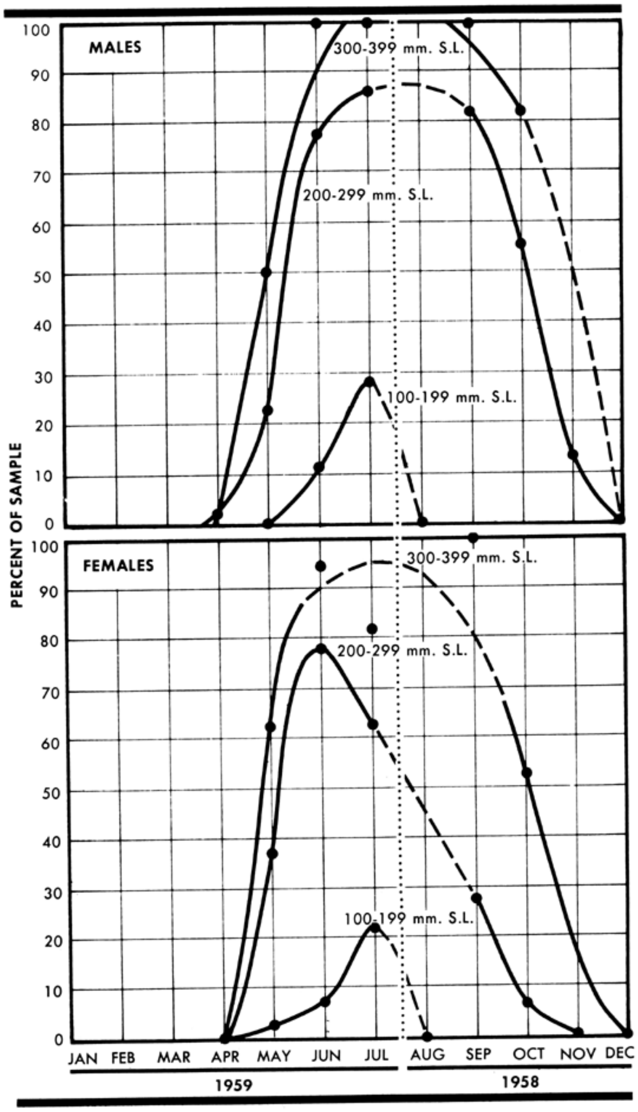


FIGURE 28. Percentages of kelp bass of all sizes in ripe condition (August 1958 through July 1959). Monthly sample sizes, 3–87 specimens.

FIGURE 28. ***Percentages of kelp bass of all sizes in ripe condition (August 1958 through July 1959). Monthly sample sizes, 3–87 specimens.***

Figure 29 (midrange is used because the data are not normally distributed within the months) shows peaks in gonad volume in June for all females and for the largest males. The short and broad peaks for males 200 and 250 mm long, compared to males larger than 300 mm, suggests that the largest males spawn more consistently in June.

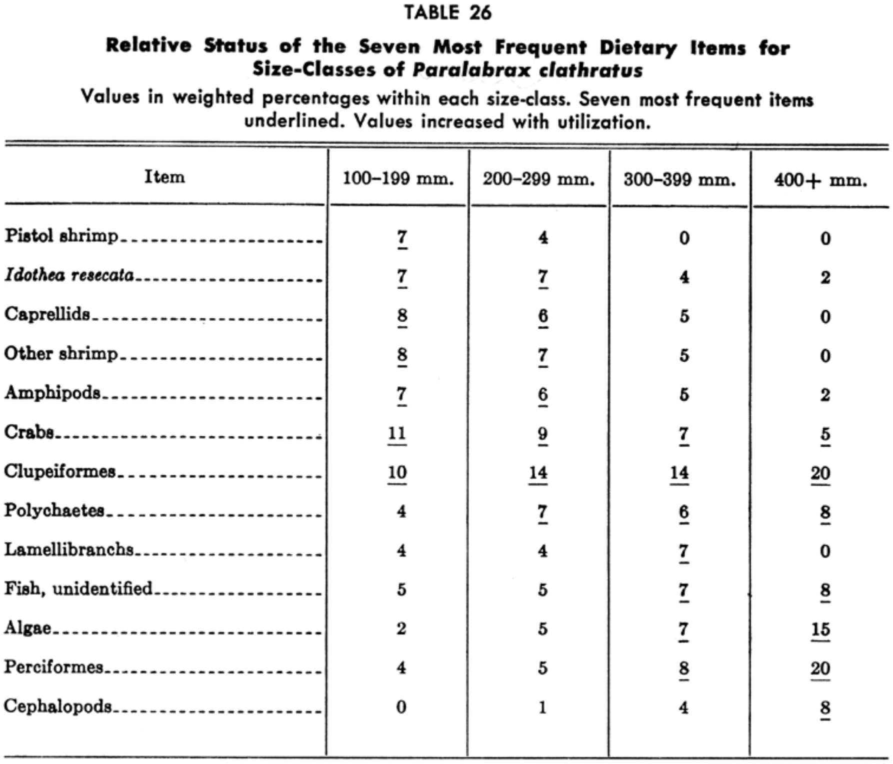


TABLE 26

Relative Status of the Seven Most Frequent Dietary Items for Size-Classes of *Paralabrax clathratus*

Values in weighted percentages within each size-class. Seven most frequent items underlined. Values increased with utilization.

Item	100–199 mm.	200–299 mm.	300–399 mm.	400+ mm.
Pistol shrimp	7	4	0	0
Idothea resecata	7	7	4	2
Caprellids	8	6	5	0
Other shrimp	8	7	5	0
Amphipods	7	6	5	2
Crabs	11	9	7	5
Clupeiformes	10	14	14	20
Polychaetes	4	7	6	8
Lamellibranchs	4	4	7	0
Fish, unidentified	5	5	7	8
Algae	2	5	7	15
Perciformes	4	5	8	20
Cephalopods	0	1	4	8

TABLE 26

Relative Status of the Seven Most Frequent Dietary Items for Size-Classes of Paralabrax clathratus

Relative gonad volume varies as much as three fold within the size-classes. Some of this variation is undoubtedly attributable to sources of errors in measurement, such as incomplete removal of gonads at time of gutting, sex products lost from ripe fish, and erroneous readings at the time of volumetric determination (several extreme and atypical readings ascribed to operator error were eliminated from consideration). Some variation may have arisen from the condition of the fish, although all appeared well fed and healthy. Probably the major part of the large variation found was caused by fish releasing only a portion of the sex products during any single spawning act. This would result in similar-sized fishes having various degrees of gonad fullness. Supporting evidence is derived from the fact that frequencies for ripe fish (Figure 28) remained high from July through September while gonad-volume declined (Figure 29). If sex products are completely released at spawning, the minimum value for gonad volume should be attained by some fish near the onset of spawning season, but this hypothesis is contradicted by data on the range of percentages (Figure 30).

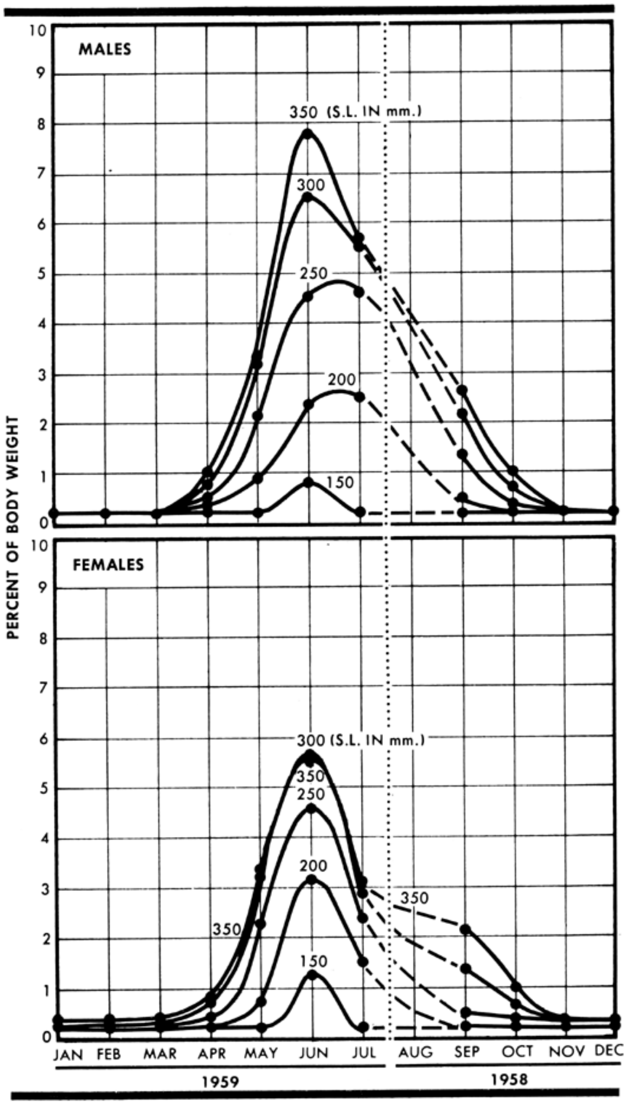


FIGURE 29. Midranges of gonad weights for selected standard lengths of kelp bass. Years transposed to illustrate trends.

FIGURE 29. **Midranges of gonad weights for selected standard lengths of kelp bass. Years transposed to illustrate trends.**

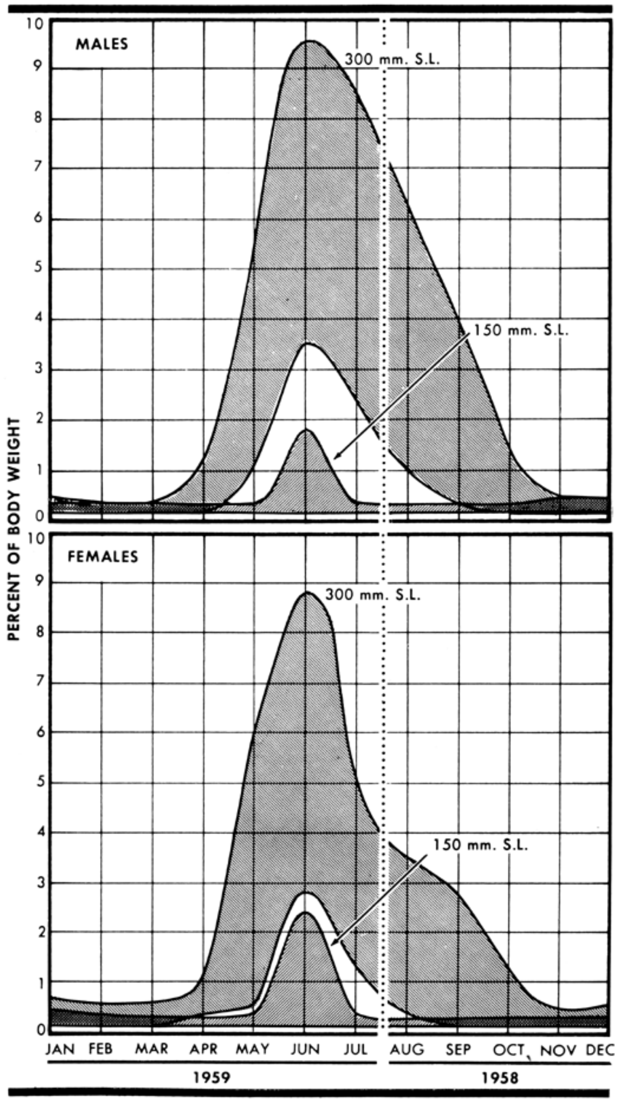


FIGURE 30. Seasonal variation in gonad weight for large and small adult kelp bass. Shaded areas are ranges in percentage of body weight. Years transposed to illustrate trends.

FIGURE 30. ***Seasonal variation in gonad weight for large and small adult kelp bass. Shaded areas are ranges in percentage of body weight. Years transposed to illustrate trends.***

No sudden spawning of the entire population is indicated, such as that described for Perca fluviatilis by Le Cren (1951).

The relationship between body size and maximum gonad volume is characterized by extreme allometry. The regression of maximum gonad volume on fish length for 140 to 178 mm specimens at the peak of breeding season (May, June, July) approximated log Weight = 18.9 log Length -41.8. For larger fish the slope of the regression declined steadily with size increase and formed a shallow curve with a slope of approximately 3.0 for specimens 270 to 300 mm long (for such a slope the increase in maximum gonad size is approximately proportional to increase in body weight). The slope then declined to approximately 1.21 at 400 mm. The significance of the abrupt change in slope near 178 mm is not certain, but this is the approximate length at first maturity, reached at the end of the second year. A slope exceeding 3.0 (or the cube) up to 270–300 mm indicates reproductive potential exceeding body-weight increase. At sizes greater than 300 mm the relative increase in reproductive potential declined and at 400 mm was proportional to length increase only (or the cube-root of weight increase). These relationships were very different from those in Perca fluviatilis, for which Le Cren (1951) stated "although there is some individual variation in the gonad: body-weight ratio, it tends to be constant at any one season for all sizes of fish of the same state of maturity." During the breeding season some males became golden on the snout. This color was most prominent in small adults during June and July, and appeared to be more dilute in large specimens. Occasionally, some large males also are prominently marked; several were seen at 60- to 70-foot depths with golden coloration sufficiently intense to be noted from several yards away.

Although numerous dives were made during the spawning season, no obvious spawning behavior by kelp bass was ever observed. Limbaugh (1955), however, saw several spawning aggregations and noted: “"The ripe adults tend to aggregate during spawning activities, usually in the kelp in relatively deep water. Hundreds of kelp bass and other fishes may aggregate in a small area while spawning goes on. Both ripe females and males have been taken from such aggregations. Ripe sand bass have also been found in these groups. The other fishes attracted to the activity include sargo, pileperch, kelpperch, blacksmith, señorita and sheepshead."”

8.10. OBSERVATIONS ON THE POINT LOMA FISHERY

8.10.1. Description of the Area

Pt. Loma is a high, narrow peninsula extending approximately 4 miles south of Ocean Beach, in San Diego. An extensive and relatively shallow shelf extends along the entire ocean side of the peninsula outward to an escarpment, at 50–60 feet depths, parallel to the coast and about 1 mile offshore. Although the shelf had supported considerable beds of kelp, the stand during the study was only a small fraction of the former standing crop. The underwater shelf is quite flat, but occasionally, considerable topographic relief is provided by rectangular boulders, in areas that vary in extent from several square feet to nearly an acre. Several areas of high relief (such as one called

New Hope Rock) are composed of flat surface bedrock overlain with desk- to house-sized rock outcrops that are heavily undercut and sometimes perforated by caves or channels. The cliff that terminates the platform on the ocean side was evidently a sea cliff during the lower sea levels of earlier geological periods.

8.10.2. Sportfishery of the *Mascot III*

Catch statistics for 1958 and 1959 were from the *Mascot III*, the only party sportfishing boat that consistently exploited the kelp-bass fishery in the Pt. Loma beds during the studies. Its operations were confined almost exclusively to this fishery. It accounted for an estimated three-fourths of the total take of kelp bass off Point Loma, including that by private boats. Some supplementary data were obtained from the La Jolla sportfishery, 10 nautical miles to the north.

The *Mascot III* was 65 feet long, of wood construction, and diesel-powered. Two large bait wells near the stern were loaded with live anchovies or sardines prior to a fishing trip. The boat made two trips daily between March and October, and some half-day trips during the remaining months. Stomachs and gonads were sampled weekly from kelp bass caught aboard the vessel. Three fishing sites were heavily utilized by the *Mascot III*. According to the skipper, the preferred sites are near points of the kelp bed projecting seaward, or in small "bays" along its outside edge. One site yielded large numbers of bass quite consistently, and was visited daily during several months in the spring. It continued to yield adult bass in quantity over periods of several weeks during summer and fall. The skipper estimated that a minimum of 200 fish were taken weekly from this site during a 2-month period in the spring. This weekly take was far in excess of the normal standing crop assayed at any site by belt transect or by wall net.

Sites were located by landmarks on the shore and by the fathometer. It was customary before anchoring to throw live anchovies in the ship's wake to establish a chum line that attracted fish to the boat. Chumming usually continued intermittently while the site was fished.

Definite preference was shown for sites near moderate to heavy kelp, although certain locations a half mile or more from the beds sometimes yielded large fish in considerable quantities. One very productive site, a point of kelp projecting seaward near the submarine escarpment, was inspected by SCUBA. The bottom there is at 80 feet and consists of fragmented rock with numerous crevices. Similar favored fishing sites near La Jolla kelp beds, also investigated by SCUBA, all have rocky bottoms with considerable relief.

Although kelp bass are available to the sportfishery at any season, the *Mascot III* normally operated between late March, or early April, and October or November. Length of season depended on the weather and passenger demand. Heaviest passenger loads normally occurred on weekends and business was at its best from June to September, when schools were vacant and tourist traffic high.

Catch per unit effort (fish per fisherman per half day) varied considerably from June through October 1958. Passengers averaged two to six bass during June, but the catch declined during July and reached lowest values (approximately 0.5) during the first 2 weeks of August. Fishing improved between late August and early September to approximately 2.0, after which (September 10–13) it declined again to 1.0. Catch then increased abruptly to 5.0 on September 15, and to 5.5 on September 24. During October averages declined below 2.0.

The seasonal fluctuations in catch per unit effort were puzzling, but did not appear to be random. Records of tides, weather, lunar phases, surface temperatures, and captures of other sportfishes kept concurrently on the vessel showed no important correlation with the fluctuations. Spawning condition of the kelp bass may be significant. The high average catch per unit effort during June (despite heavy passenger loads, which tend to lower the average) corresponded to the peak in breeding during that month.

Deflections in the curves for females during late August and early September corresponded to the second period of high catch per unit effort. The short-term highs in fishing success during mid- and late-September might have been caused by low passenger loads after public schools convened in the fall, discussed below.

Number of passengers on the boat must be considered when passenger catch per unit effort is analyzed. Catch data for the *Mascot III* indicated an inverse relationship between passenger load and fishing success (Table 27). Under crowded conditions passenger fishing areas overlap, with resultant gear interference. Also, crowding usually occurs on weekends and holidays when there is a higher proportion of novices.

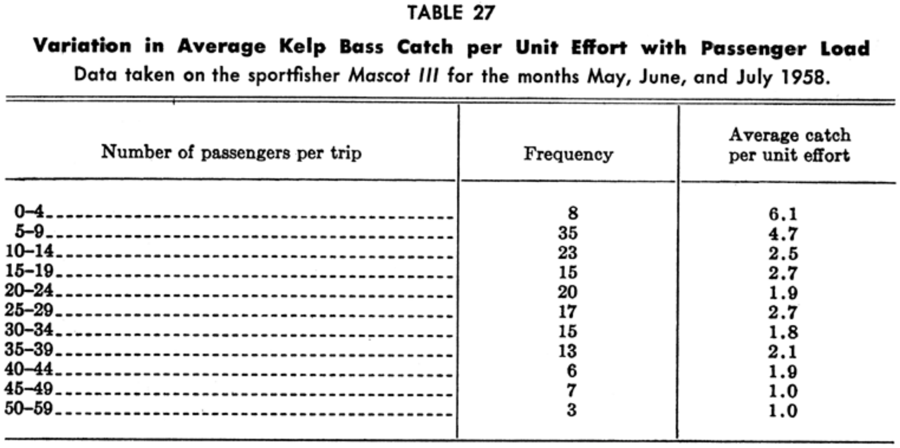


TABLE 27

Variation in Average Kelp Bass Catch per Unit Effort with Passenger Load

Data taken on the sportfisher *Mascot III* for the months May, June, and July 1958.

Number of passengers per trip	Frequency	Average catch per unit effort
0–4	8	6.1
5–9	35	4.7
10–14	23	2.5
15–19	15	2.7
20–24	20	1.9
25–29	17	2.7
30–34	15	1.8
35–39	13	2.1
40–44	6	1.9
45–49	7	1.0
50–59	3	1.0

TABLE 27

Variation in Average Kelp Bass Catch per Unit Effort with Passenger Load

Experienced fishermen normally attempt to avoid the crowded weekend trips.

8.10.3. Yield and Mortality for the Population

Yield of kelp bass for the Pt. Loma region during 1958–1959 was estimated from the *Mascot III* log sheets and from length-frequency data obtained from the catch. Nearly all bass taken, including the undersized, were examined and measured. Because weight vs. length measurements involved fresh weight for the legal fish and preserved weight for the undersized, weight change with preservation was measured. In 10 fish of three species, including P. clathratus, a preservation period of 2 weeks in four-percent formaldehyde resulted in a maximum individual gain of 3.1 percent and a maximum loss of 0.5 percent. Average change for the group was a gain of 1.0 percent, a difference judged negligible.

To determine weight-length relations 150 specimens 65 to 245 mm SL and 8 specimens 255 to 615 mm long were utilized (Figure 31). The regression of weight on length in the smaller fish, calculated by the least-squares method, was: log Weight = 3.256 log Length -5.178 which was similar in slope to a regression for all sizes calculated by Parke H. Young (personal communication). The data for the larger bass gave a slope of 2.725. The marked decrease in slope for the larger fish may reflect the decrease with growth in maximum relative gonad size, as noted previously.

An estimate of total weight of kelp bass taken by the *Mascot III* between July 1958 and July 1959 required both an estimate of the average weight of fish and the total number of fish taken. An average weight of 952.8 g was obtained by converting the size-frequencies observed during the sampling period (Figure 32) to weight-frequencies by the weight-length regressions. The *Mascot III* catch returns indicate that 17,026 kelp bass, weighing 18 tons, were taken during the study period.

By measuring the area between 1 and 15 fathoms on a contour chart of the Point Loma shelf (the northern and southern limits must be somewhat arbitrarily defined but have some basis in the extent of rocky habitat), the area from which the bass were taken is estimated, as a minimum, to be 3.17 square miles or 2,030 acres. On this basis, the annual take for the *Mascot III* is estimated to have been approximately 16 pounds per acre. On the assumption that the *Mascot III* catch constituted approximately three-fourths of the kelp bass taken in the Point Loma vicinity, the minimum annual yield between July 1958 and July 1959 is estimated to have been 21 pounds per acre.

Total mortality for the kelp-bass population was estimated from the size-class frequencies (Figure 32) and from the age and growth data presented by Collyer and Young (1953). Their values were converted from inches total length to millimeters standard length by a plot of duplicate measurements taken on laboratory specimens (Figure 33). Size-class frequencies for sampling periods during the year (Figure 32) were smoothed twice over three points, and intercepts for the various age classes (summer lengths) on the smoothed frequency plot were obtained by a Walford plot of the growth data (Table 28) . The intercepts represented theoretical frequencies for the various age-classes and gave an estimate of decline of year classes with time, or mortality, when plotted logarithmically. A visual fit of the regression data (Figure 34) indicated that the population experienced an average mortality of approximately 42% during the years prior to the study.

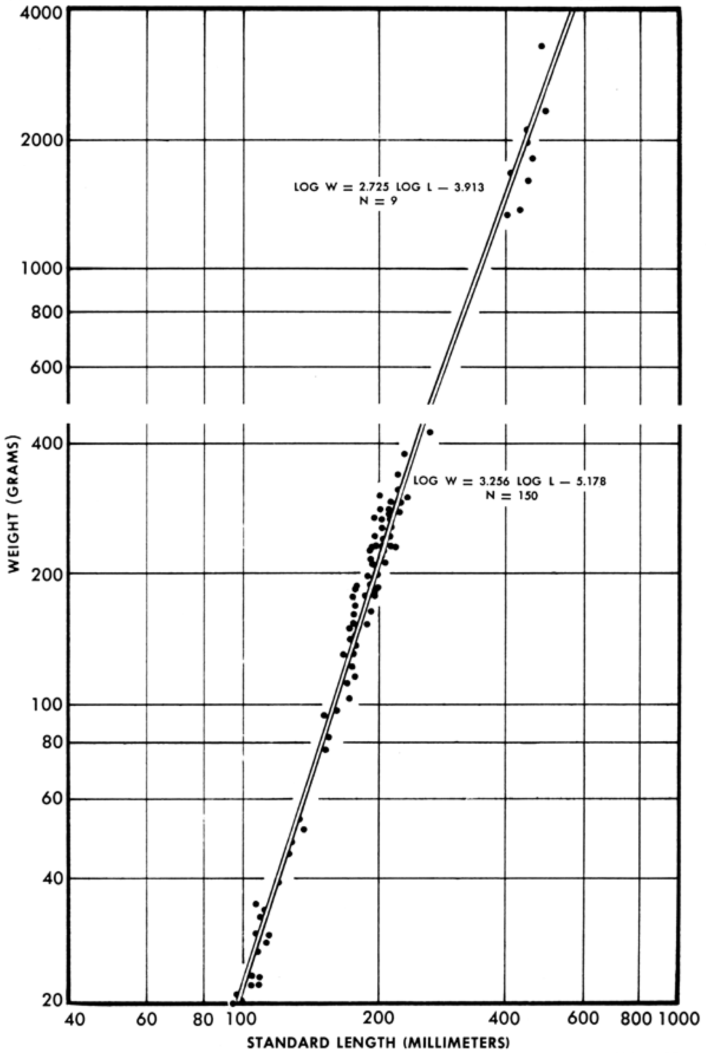


FIGURE 31. Regressions of weight on length for kelp bass from the La Jolla and Point Loma kelp beds. Upper line fitted by eye, the lower by least-squares.

FIGURE 31. ***Regressions of weight on length for kelp bass from the La Jolla and Point Loma kelp beds. Upper line fitted by eye, the lower by least-squares.***

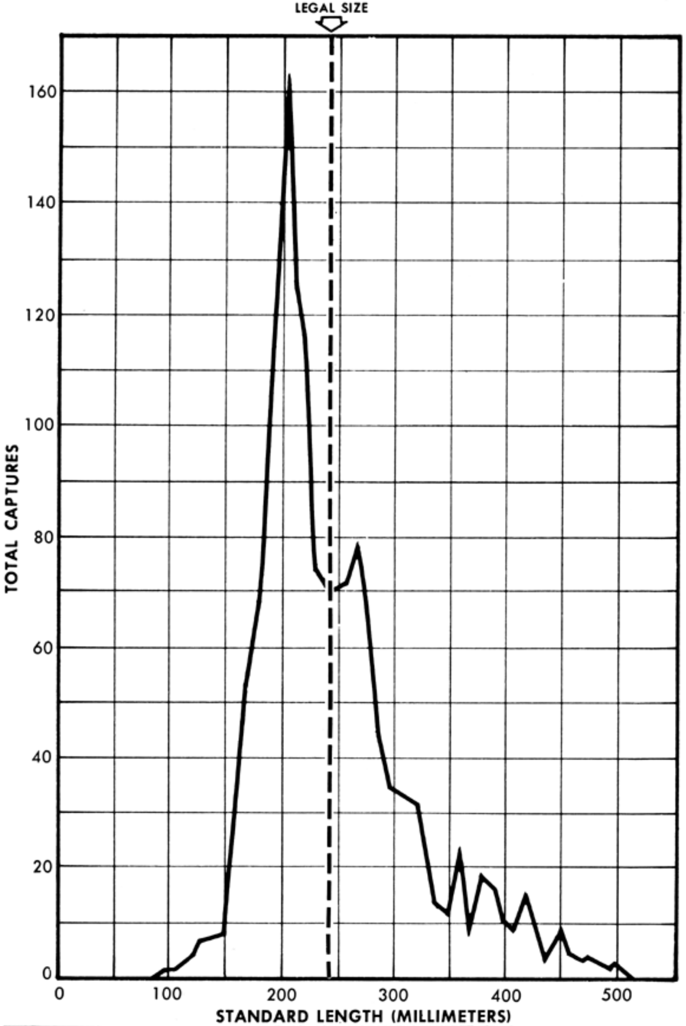


FIGURE 32. Cumulative size frequencies of kelp bass taken aboard the *Mascot III*.

FIGURE 32. ***Cumulative size frequencies of kelp bass taken aboard the Mascot III.***

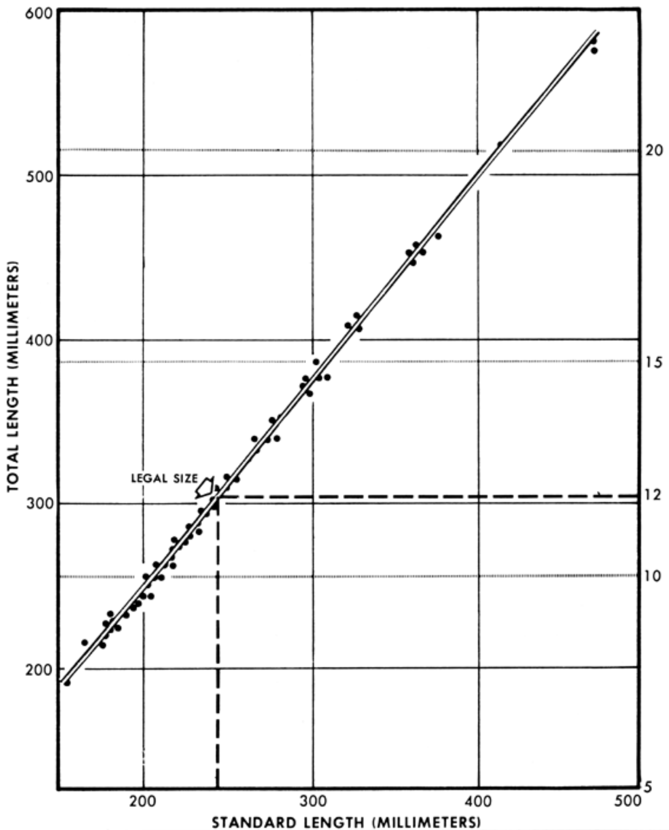


FIGURE 33. **Relationship between total length in inches and standard length in millimeters for the kelp bass.**

FIGURE 33. ***Relationship between total length in inches and standard length in millimeters for the kelp bass.***

TABLE 28

Theoretical Size and Frequency of Kelp Bass of Various Ages in the Point Loma Sportfishery During the Year July 1958–July 1959

Age (years)	Midpoint of size class at age (mm)	Observed frequency (smoothed)
1	80.0	0.5
2	149.8	10.5
3	210.8	118.0
4	264.1	58.6
5	311.1	29.5
6	351.7	11.0
7	387.3	8.0
8	418.4	7.0
9	445.7	4.0
10	469.8	2.5
11	490.7	1.0
12	508.6	0.5
13	524.4	0.0

TABLE 28

Theoretical Size and Frequency of Kelp Bass of Various Ages in the Point Loma Sportfishery During the Year July 1958–July 1959

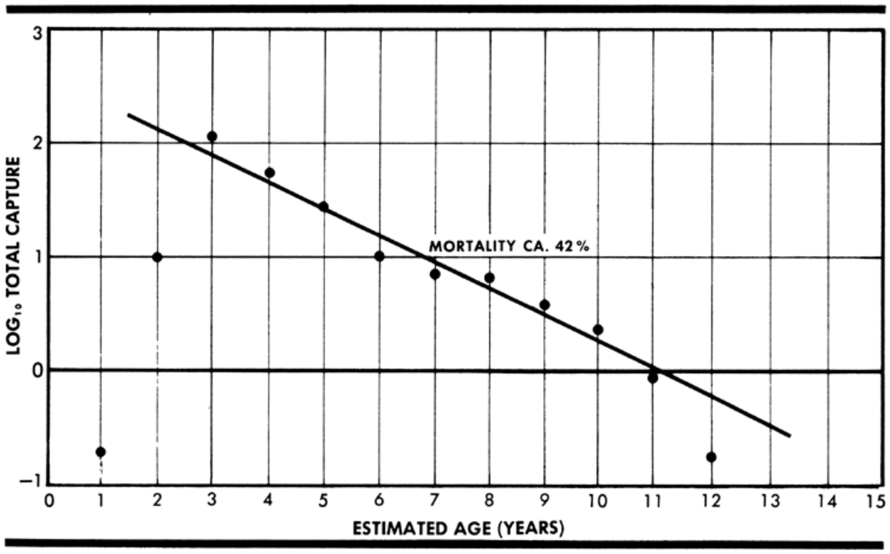


FIGURE 34. Estimated mortality for kelp bass in the Point Loma sport-fishery prior to 1959, based on specimens taken during the study. Regression fitted by eye.

FIGURE 34. ***Estimated mortality for kelp bass in the Point Loma sport-fishery prior to 1959, based on specimens taken during the study. Regression fitted by eye.***

8.11. SUMMARY

1. The kelp bass is an important demersal sport fish that is common in the rocky inshore zone of southern California and Baja California, and nearby islands.

2. A principal habitat requirement is some type of bottom relief, such as rock, plants, or debris. A rocky substrate is not an ecologic necessity providing that kelp or some other form of cover is present.

3. Although adults occur from the intertidal zone to nearly 200 feet, the greatest proportion of the population remains shallower than 100 feet.

4. The most consistently encountered species on the SCUBA surveys was the kelp bass. It was not, however, the highest in numerical abundance.

5. Adult bass probably move into the more attractive areas as the original inhabitants of these areas are removed by fishing.

6. Individuals become more cautious and probably occupy larger territories with growth.

7. Individuals are noticeably wary when objects align with them, a reaction presumed to be of protective advantage.

8. Although no interspecific or intraspecific aggression was noted in the field, an aquarium-held specimen displayed a variety of aggressive postures and actions against another species.

9. Calculations of home range from data of Limbaugh (1955) indicate a maximum radius of approximately 1175 feet for adults. This value undoubtedly varies considerably with size and the terrain.

10. Approximately 1,700 specimens, mostly caught by sportfishing boats, were examined for food contents.

11. On the basis of the food studies, it is concluded that the kelp bass is a medium-sized predator and that the adults are near the top of the inshore food chain. Intermediate-sized, usually vagile, prey items are taken. Young fish utilize small demersal crustaceans. As fish grow the diet shifts to larger prey, such as fish, squid, and octopus.

12. Two feeding peaks occur during the year, the first in spring, immediately prior to breeding, and the second in fall, at the end of the breeding season.

13. Gonads of large adults begin to enlarge in April, and those of all adults attain maximum size in June. The volume then decreases slowly until the end of the breeding season in November. Relative gonad volumes become disproportionately large in adults to a standard length of 300 mm, then decline sharply. Larger adults remain in breeding condition longer than younger ones.

14. Some male kelp bass become sexually colored during the breeding season by developing a golden region on the snout. Coloration is usually most prominent and consistent in the smaller adults, but some large adults also are conspicuously colored.

15. The sportfishery at Point Loma, San Diego provided information on the biology of the kelp bass.

16. Passenger catch per unit effort varied with the number of persons aboard the sportfishing boat as well as with their skill. Spawning condition of the fish may be associated with catch per unit effort.

17. A yield of approximately 21 pounds per acre per year was calculated for the Point Loma kelp-bass fishery for the period immediately preceding the study.

18. Total mortality for the kelp-bass population at Point Loma was estimated at approximately 42 percent.

9. 8. OBSERVATIONS ON THE FOOD OF THE KELP-BED FISHES

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9.1. INTRODUCTION

Data on the diets of southern California inshore fishes are scattered and incomplete. With the exception of Limbaugh's (1955), most studies have involved few specimens, a limited number of species, and restricted habitats, and have employed sampling methods that could have resulted in misleading data. Several studies involve only one sample taken at one place at one time of year. Frequently the samples were not broken down into size-classes of fish, despite *a priori* knowledge that fish diet changes with growth. Knowledge of food availability remains crude, and actual food preferences can only be guessed. Life histories of important prey invertebrates are undescribed.

In this section published data on the diets of southern California rocky inshore fishes are summarized, and supplemented by information from the Kelp Program research. Literature sources include Metz (1912), who examined some intertidally collected fish specimens for food, and also described their visceral anatomy; Mitchell (1953), who also studied intertidal specimens, but whose small collection was made with rotenone, introducing possibilities of considerable bias; Limbaugh (1955), who examined subtidal specimens taken by spear over a 5-year period (his work includes biological and ecological notes, but unfortunately does not give number and size of specimens examined); and Fitch (1960) and Baxter (1960), who presented additional information on food and biology, but borrowed heavily on Limbaugh and did not give sampling data.

9.2. ACKNOWLEDGMENTS

The studies were concurrent with those for the kelp bass (see Chapter 7) and the same persons gave their assistance. Nearly all food data were based on examinations by H. George Snyder. Charles T. Mitchell constructed preliminary drawings for the food figures. The research was supported principally by the State of California Department of Fish and Game, and in part by the Institute of Marine Resources, University of California.

9.3. METHODS

Approximately 1700 kelp bass and 500 representatives of other species were examined for food items. Each collecting method introduced its own bias and it was not practical to eliminate even the more obvious types. Foods from specimens taken on sportfishing boats contained high percentages of the northern anchovy, Engraulis mordax, because this species was used nearly exclusively for bait. Variable proportions of fishes from the wall-net collections, described in Chapter 6, probably fed on dying crustaceans before the fish themselves were affected by rotenone poisoning. Fishes taken by spear frequently had to be chummed with crushed sea urchins, so echinoderm percentages were too high in these samples. The data are nonetheless regarded as reasonably representative but care should be taken in interpretation. Identifiable bias sources are noted. The inclusion of intestinal food data adds additional weight to the truly representative foods. Differential digestion rates for different items are not regarded as an important source of error.

The entire digestive tract was examined because intestinal items could usually be identified at least to a higher taxon. Food data are presented by frequency-of-occurrence (Figures 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49). The 90-percent confidence limits (Tate and Clelland, 1957), are not presented for the purpose of actual significance tests, but rather as graphical indications of relative reliability.

9.4. FINDINGS

9.4.1. California Moray, Gymnothorax mordax (Figure 35)

All 19 specimens used were from a morning poison collection off Bathtub Rock, near Scripps Institution of Oceanography, in July 1959. Bottom was mixed sand and rock at 25 feet. Specimens displayed two size-frequency modes at 185 and 220 mm SL; all but three were shorter than 240 mm.

Shrimp and crab were principal dietary items, and the few data agreed with Limbaugh's finding (*l.c.*), that crustacea and small fish are heavily utilized. Red rock shrimp, Hippolysmata californica, thought by Limbaugh to be a cleaning organism (personal communication), were found in traces in both studies. Abalone represent a potential if not actual food, because morays are easily lured from crevices or caves during daylight when abalone are overturned. Data on nine tropical Gymnothorax species collected by Hiatt and Strasburg (1960) agreed closely with our findings on the California moray.

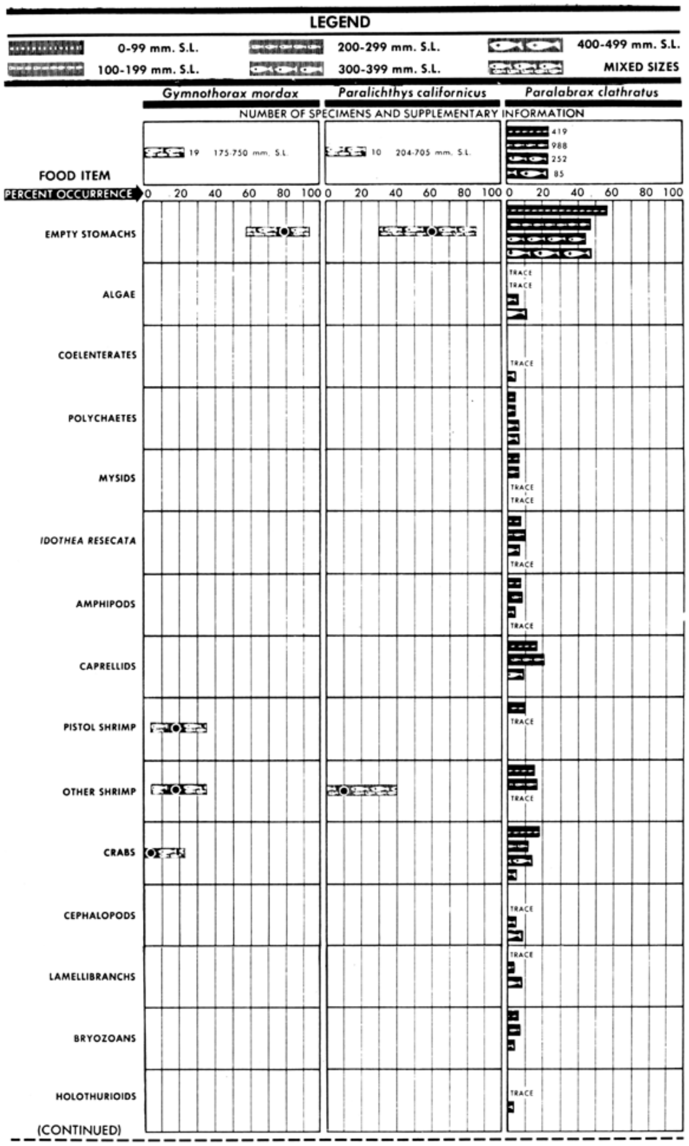
9.4.2. California Halibut, Paralichthys californicus (Figure 35)

Individuals were infrequent in kelp beds, but some dietary data were obtained. All specimens used were speared individually during spring and summer seasons over sand bottom at 30 to 80 feet. An almost completely piscivorous diet is indicated. Remains of engraulids, atherinids, and small flatfish were identified, similar to the findings of Limbaugh (*l.c.*).

9.4.3. Kelp Bass, Paralabrax clathratus (Figure 35)

This species is discussed in detail in Chapter 7, and only a summary is presented here. All seasons were represented. Since the majority of specimens used were from sportfishing boats, the values for clupeiform fishes probably are artificially high. Because of large samples, the 90-percent confidence limits were very narrow, and are not indicated.

Young fish fed principally on such demersal crustaceans as amphipods, spider crabs, and pistol shrimp. With growth, the food shifted


LEGEND
0-99 mm. S.L.
100-199 mm. S.L.
200-299 mm. S.L.
300-399 mm. S.L.
400-499 mm. S.L.
MIXED SIZES
Gymnothorax mordax
Paralichthys californicus
Paralabrax clathratus
NUMBER OF SPECIMENS AND SUPPLEMENTARY INFORMATION
19 175-750 mm. S.L.
10 204-705 mm. S.L.
419
988
252
85
FOOD ITEM
PERCENT OCCURRENCE
0 20 40 60 80 100
EMPTY STOMACHS
ALGAE
COELENTERATES
POLYCHAETES
MYSIDS
IDOTHEA RESECATA
AMPHIPODS
CAPRELLIDS
PISTOL SHRIMP
OTHER SHRIMP
CRABS
CEPHALOPODS
LAMELLIBRANCHS
BRYOZOANS
HOLOTHURIOIDS
TRACE
(CONTINUED)

FIGURE

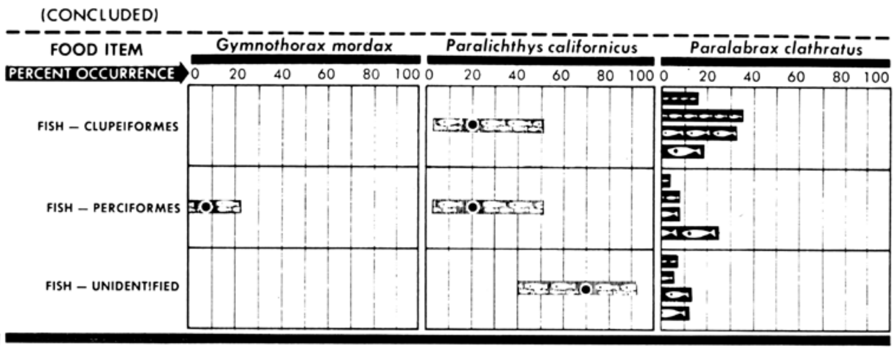


FIGURE 35. Food of California moray, California halibut, and kelp bass. Confidence intervals not presented for the kelp bass because of the large number of specimens.

FIGURE 35. ***Food of California moray, California halibut, and kelp bass. Confidence intervals not presented for the kelp bass because of the large number of specimens.***

to larger, more motile prey, such as fishes and cephalopods. Contrary to the implications in its accepted common name, the species normally occurs in habitats with physical relief in any form, whether or not kelp is present.

9.4.4. Sand Bass, Paralabrax nebulifer (Figure 36)

The specimens used, representing all seasons, nearly all came from sportfishing boats in or near kelp beds. Depth of capture was 30 to 60 feet.

Sand bass are more demersal than kelp bass; all sightings were within several feet of the bottom. They were noted in greatest abundance near the "edge" habitats, where rocky and sandy areas meet. Shrimp, crabs, ophiuroids, and fish were principal foods. Shrimp occurred in variety, but pistol shrimp were rare. Crabs were mainly spider and cancroid types; the pelagic red crab, Pleuroncodes planipes, was relatively infrequent. Nearly all ophiuroids were Ophiothrix spiculata, a common form. Probably fish were an important prey, but the data were badly biased toward clupeiform entries by the collection methods. Perciform fishes included Artedius sp., Runula sp., and unidentifiable fragments. Limbaugh (*l.c.*) noted "squid, small fish, and (once) the eggs of the tubenose (Aulorhynchus flavidus) ."

9.4.5. Topsmelt, Atherinops affinis (Figure 36)

Specimens in the smaller size-group were seined from schools in large rocky tide pools during March and April 1960; fishes in the larger group were speared about kelp and rock-and-sand habitats during all seasons. Adults school and typically feed within 10 to 15 feet of the surface over shallow rocky areas or in kelp beds. Schools were common about clearings in the beds and also in the lee of isolated kelp-plant canopies when winds developed surface currents.

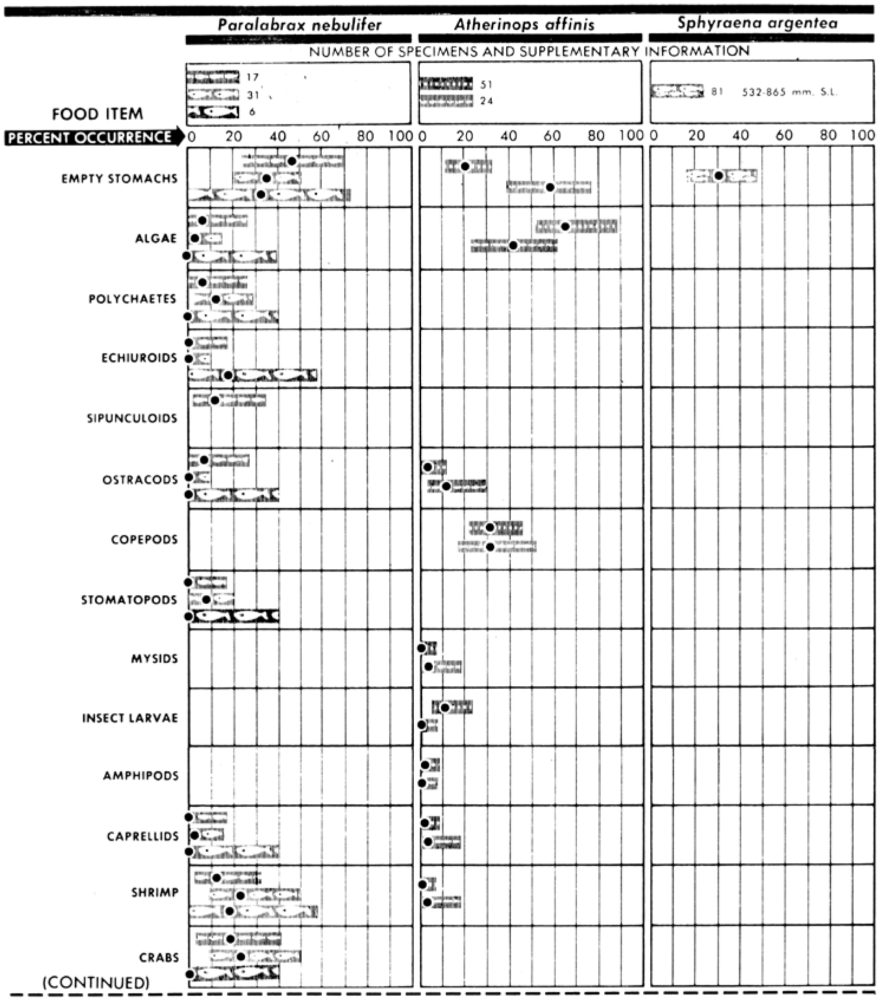
Minute planktonic Crustacea were the principal adult foods. Bryozoans indicated were pelagic larvae. Juveniles and small adults from tide pools contained quantities of small algae and fly larvae (presumably from a kelp fly, noted in great numbers about the splash zone). Limbaugh (*l.c.*) concluded that topsmelt "feed on the many small crustaceans that live in the [kelp] canopy, as well as the planktonic forms that drift into the kelp."

9.4.6. California Barracuda, Sphyraena argentea (Figure 36)

This species occurs only incidentally in kelp beds. Specimens used were taken from sportfishing boats adjacent to kelp beds in August 1958. Food was entirely fish, principally anchovies (used as bait and "chum" by the sportfishing boats). Perciform items included señorita (Oxyjulis californica) and a juvenile queenfish, Seriphus politus. In addition to fish, Limbaugh (*l.c.*) found squid in their diet, and Fitch (*l.c.*) listed anchovies and other small pelagic fishes.

9.4.7. Sargo, Anisotremus davidsoni (Figure 37)

Nine of 11 specimens used measured 100 to 199 mm; all but one were taken from rock-and-sand habitats. Specimens were speared during all seasons. Principal foods were small isopods, amphipods, shrimp, and kelp scallops, Pecten latiauratus. Limbaugh (*l.c.*) reported "small crustaceans and mollusks, including clams and a chiton."



FIGURE

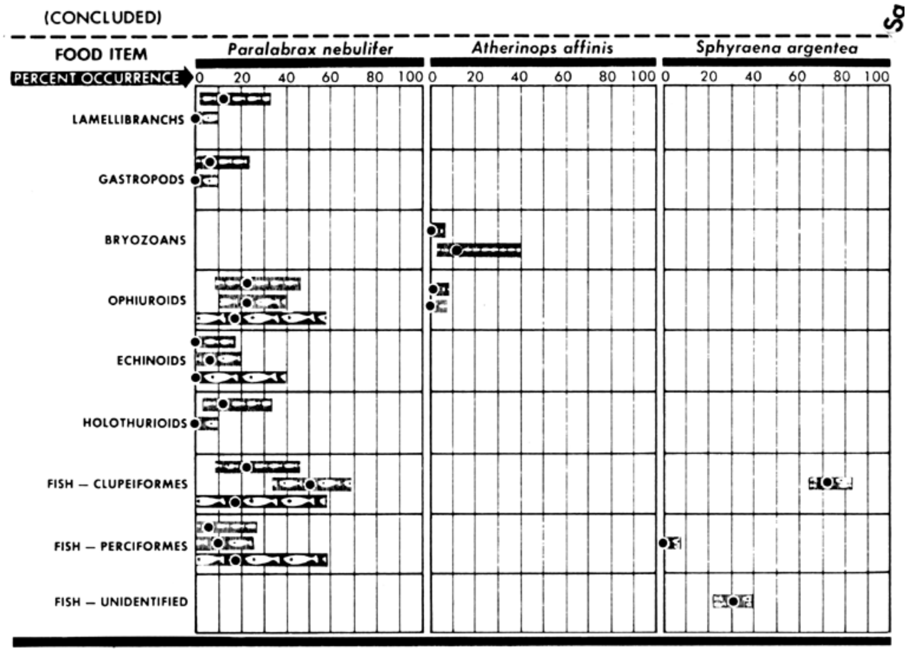


FIGURE 36. Food of the sand bass, topsmelt, and California barracuda.

FIGURE 36. **Food of the sand bass, topsmelt, and California barracuda.**

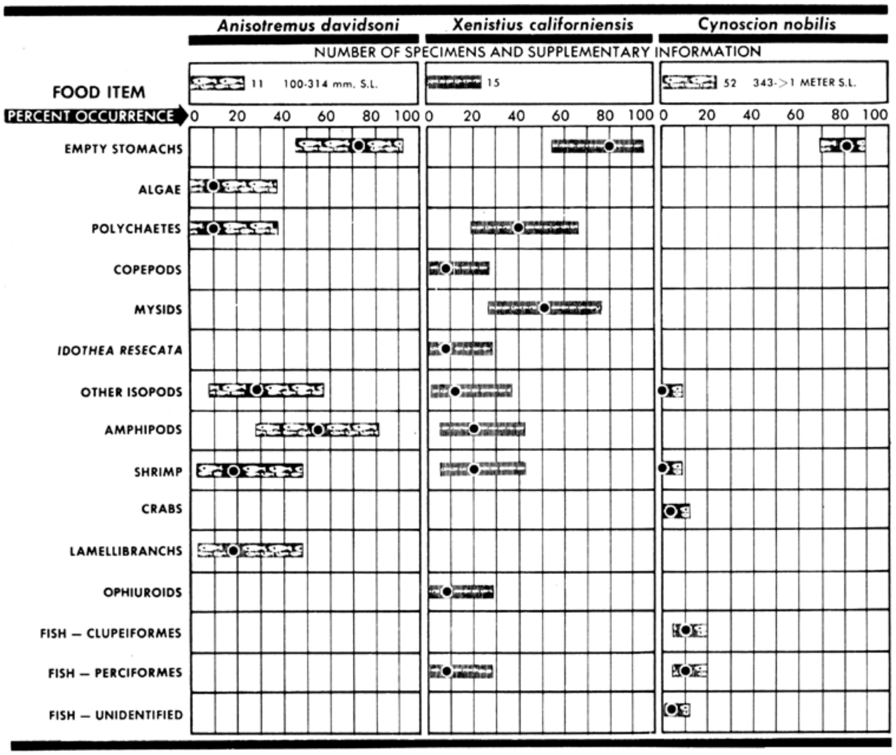


FIGURE 37. Food of the sargo, salema, and white seabass.

FIGURE 37. **Food of the sargo, salema, and white seabass.**

9.4.8. Salema, Xenistius californiensis (Figure 37)

Entire sample, poisoned by rotenone in July 1959, was from a young kelp bed 25 feet deep, with mixed sand-and-rock substrate. The food data were of questionable validity because of the collecting methods. Mysids and polychaetes, common about kelp fronds, may have become unusually available due to poisoning before the fish succumbed. The bottom-inhabiting ophiuroids, however, probably were ingested prior to the collection.

9.4.9. White Seabass, Cynoscion nobilis (Figure 37)

Although many specimens were obtained from sportfishing boats using anchovies for "chum" and bait during summer and winter, the food data are few, because empty stomachs were unusually frequent. Probably the bait was not swallowed by the specimens and was lost before they were brought aboard. Limbaugh (*l.c.*) reported "squid and small fish, such as anchovies and sardines" from their stomachs. Fitch (*l.c.*) reported that some large individuals had fed exclusively on Pacific mackerel (Scomber japonicus diego) .

9.4.10. Black Croaker, Cheilotrema saturnum (Figure 38)

Specimens used were collected during summer and fall in water shallower than 30 feet; three were obtained by rotenone, the remainder by spear. Bottom-dwelling crustaceans were indicated as a principal food in the small sample. Kelp isopods (Idothea resecata) were from poisoned fish and may not be representative. Limbaugh (1961) concluded from an intensive study that individuals “"feed exclusively on crustaceans, and mainly on rock-dwelling crabs, such as the lumpy crab, Paraxantheas taylori Stimpson and young moss-covered crabs, Loxorhynchus crispatus Stimpson. The lumpy crab seems to be favored. Red-and-white shrimp, Hippolysmata californica Stimpson and various amphipods are also consumed. In general, the black croaker is nocturnal in its feeding and other behavior."” Skogsberg (1939) "guessed" a broader diet for the species, and was supported by our findings, which included fish remains, polychaetes, and algae.

A juvenile specimen held in an aquarium for 6 months with a similar-sized kelp bass retained its juvenile pattern of horizontal black stripes until it died from unexplained causes at a total length of 130 mm. Its high activity during the day contrasted with the cryptic diurnal habits of the dark-colored adults. It successfully established a territory that encompassed about two-thirds of the sand bottom. Threat behavior against the kelp bass was frequent and consisted of swimming with the body axis inclined head downward (20–30° from horizontal) back and forth in front of the other fish. During threat activity swimming motions became noticeably "tighter" and more abrupt. "Tail slapping" and sidewise rocking of the body about a vertical axis preceded actual physical combat. Usually, the light areas of the croaker darkened during threat activity and after actual combat the juvenile usually became very dark and closely approximated the adult pattern.

Before the juvenile croaker took food items into the mouth, they were nearly always touched by the chin and (presumed) sensory elements. Considerable daytime activity was devoted to swimming slowly over the sand with the chin approximating or actually in contact with the bottom. In this fashion, the fish located and expertly extracted small sand crabs (Emerita analoga) from the sandy substrate. The fish also used the sensory structures on the chin to orient itself to an empty cockle shell on the bottom, prior to rubbing its sides against the shell.

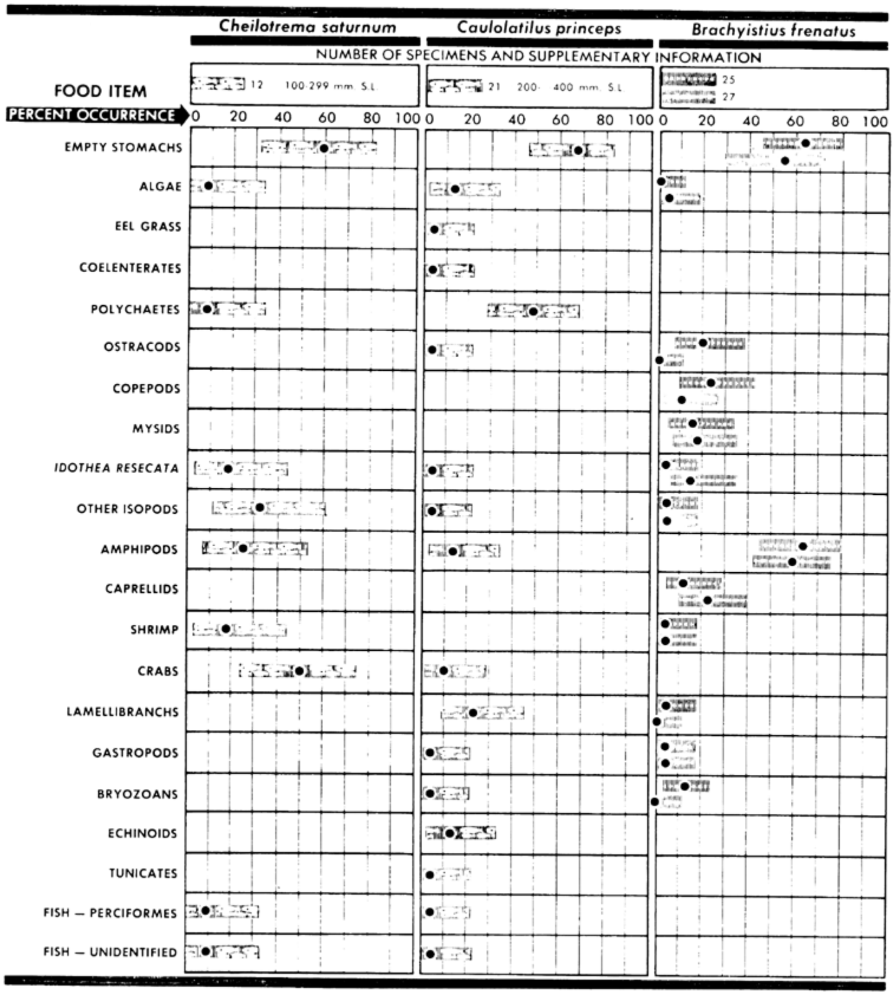


FIGURE 38. Food of the black croaker, ocean whitefish, and kelp perch.

FIGURE 38. ***Food of the black croaker, ocean whitefish, and kelp perch.***

9.4.11. Ocean Whitefish, Caulolatilus princeps (Figure 38)

Specimens used, all but three from kelp-bed habitats, were speared during winter at depths of 30 to 110 feet. Four-fifths were between 300 to 500 mm SL. All items indicated bottom-feeding habits; tube-dwelling polychaetes were the principal food. Lamellibranch entries included razor clams, kelp-scallop shells, and small clams. Fitch (*l.c.*) noted they "eat just about anything they are capable of getting their mouths around—especially crabs, shrimp, and other crustaceans," and that small octopuses, squid, and assorted fish also enter the diet.

9.4.12. Kelp Perch, Brachyistius frenatus (Figure 38)

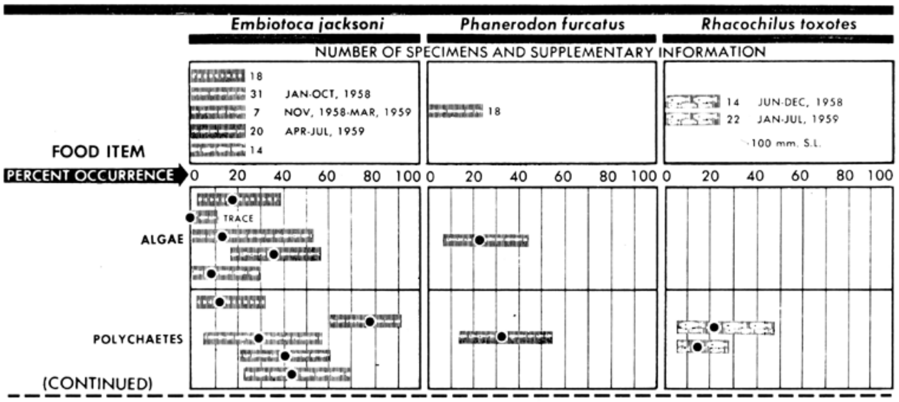
This fish is usually abundant in and about the kelp columns and canopy, and nearly all specimens used were obtained by rotenone from kelp beds, during summer, winter, and fall. The natural food probably resembles that found in the poisoned fish, and small crustacea associated with kelp plants are heavily utilized. Limbaugh (*l.c.*) stressed that the kelp perch is an important parasite picker on other fishes but limited observations in this study did not reveal such behavior. No external parasites were identified in the digestive tracts.

9.4.13. Black Perch, Embiotoca jacksoni (Figure 39)

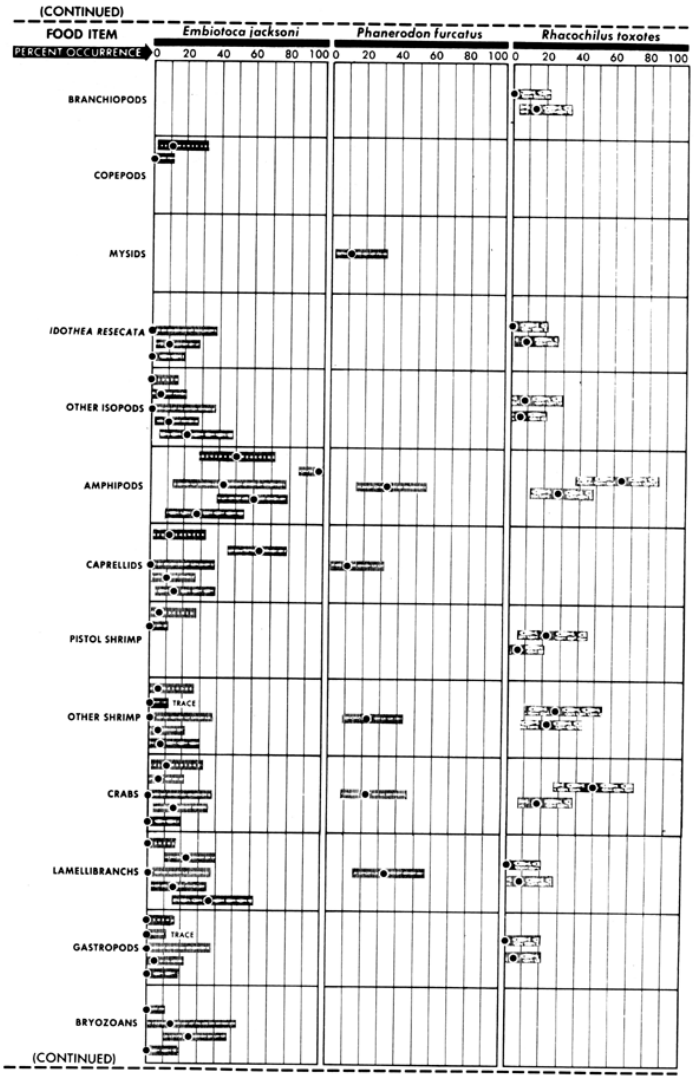
Approximately equal numbers were collected by spear and by rotenone. Individuals were typically seen roaming the bottom (the adults singly or in loosely associated groups of three to five), nearly always in association with tufted algae of rocky areas, from which they undoubtedly obtain their food. Principal foods were polychaete worms, gammarid amphipods, caprellids, and spider crabs, all of which abound in the tufted-algae habitat. Small amounts of algae noted undoubtedly were taken incidental to the capture of invertebrates. *Lima*, small Mytilus, and small Pecten, frequently taken entire, composed the lamellibranch entries. Limbaugh (*l.c.*) found "crustaceans, mollusks, bryozoans, and worms," in the black perch and also mentioned the presence of external parasitic fish crustaceans in their diets, but none were noted in the stomach contents of the specimens we examined.

9.4.14. White Seaperch, Phanerodon furcatus (Figure 39)

Data were from a single sample collected by rotenone in June 1958 from a kelp bed near Del Mar, California. Principal foods were bottom-dwelling small crustaceans, polychaetes, and bivalves. Numerous Macrocystis fragments were noted, some heavily encrusted by bryozoans. Crustacean entries included crabs, shrimp, caprellids, mysids, and assorted gammarid amphipods (many were elongate and had large chelae). Some polychaetes were enclosed by sand-encrusted tubes. Lamellibranchs



FIGURE


(CONTINUED)
FOOD ITEM
PERCENT OCCURRENCE
Embiotoca jacksoni
Phanerodon furcatus
Rhacochilus toxotes
0
20
40
60
80
100
BRANCHIOPODS
COPEPODS
MYSIDS
IDOTHEA RESECATA
OTHER ISOPODS
AMPHIPODS
CAPRELLIDS
PISTOL SHRIMP
OTHER SHRIMP
TRACE
CRABS
LAMELLIBRANCHS
GASTROPODS
TRACE
BRYOZOANS
(CONTINUED)

FIGURE

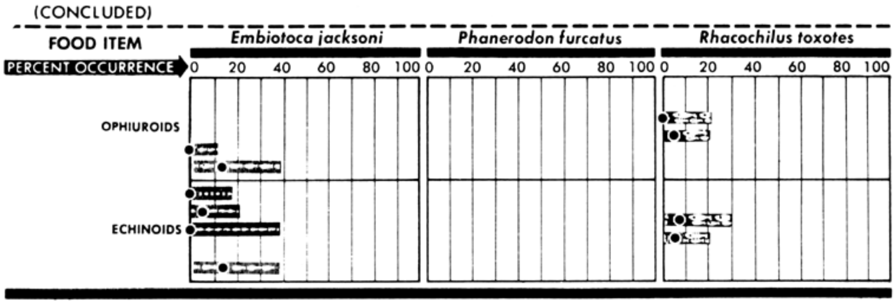


FIGURE 39. Food of the black seaperch, white seaperch, and rubberlip seaperch.

FIGURE 39. ***Food of the black seaperch, white seaperch, and rubberlip seaperch.***

included small mussels, taken entire, and kelp-scallop shells.

Because the data were based on a single poison collection, there is some doubt concerning reliability. Mysids, caprellids, and numerous small gammarid amphipods normally are present in the kelp canopy and may have become unusually available during the poisoning. The kelp fragments may have originated from outboard motors operated in the area prior to actual collection.

9.4.15. Rubberlip Seaperch, Rhacochilus toxotes (Figure 39)

Twelve specimens were taken by rotenone at the Del Mar kelp bed, the remainder were collected by spear. Food was very similar in rotenoned and speared specimens; small shrimp and gammarid amphipods were utilized heavily. Small crabs also were frequent. Two adult fish (300 mm SL) had fed nearly exclusively on marine branchiopods (Nebalia sp.). One 197-mm specimen contained late megalops crab larvae. Among other bottom-dwelling crustacea were a stomatopod (not depicted in the figure) and numerous pistol shrimp.

9.4.16. Pile Perch, Rhacochilus vacca (Figure 40)

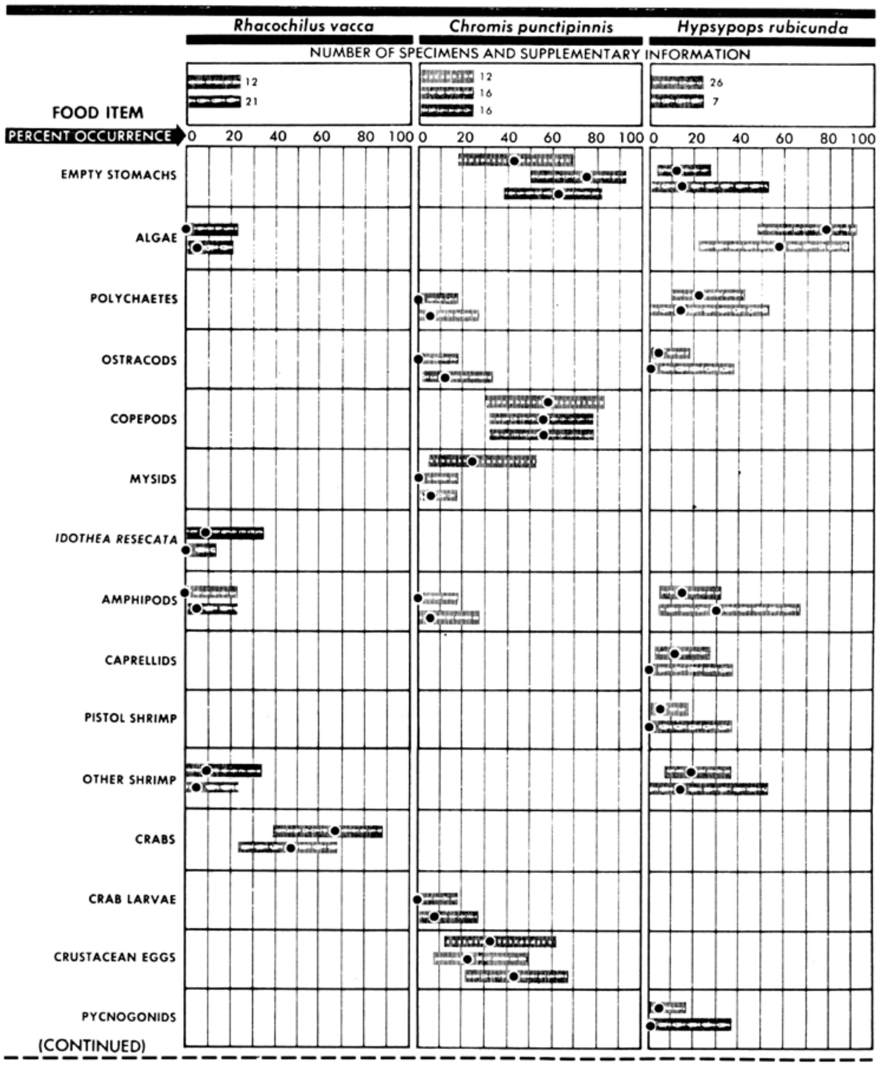
Two-thirds were from rotenone collections, the rest was collected by spear. All seasons are represented. Demersal shelled invertebrates, principally hermit crabs, were very important in all samples. Lamellibranchs included small forms, such as Chione, Donax, and small Mytilus. Gastropod frequencies apply mainly to crushed snail shells mixed with remains of the former hermit crab inhabitants.

Limbaugh (*l.c.*) also studied this species and came to slightly different conclusions regarding its diet. He stated, “"They feed on clams (such as mussels and bean clams), gastropods (including limpets, dove shells, cones, and smooth tops), chitons, decapods, other crustaceans, ophiuroids, and sand dollars. They are commonly observed around pilings pulling small mussels free, crushing them in their throats as they swallow them. A half-grown specimen was observed being forced into eating external fish parasites by a group of blacksmith."”

Probably Limbaugh's collections were taken principally from shallow water near Scripps in sand-and-rock or sand-and-pier-piling habitats, where this species sometimes abounds. Available food in these regions differs considerably from that at 30–80 feet in kelp beds.

9.4.17. Blacksmith, Chromis punctipinnis (Figure 40)

Seventeen specimens were taken by rotenone, the remainder speared. All seasons are represented. Principal foods are minute swimming crustacea and crustacean eggs and larvae gleaned from open-water spaces in kelp beds and over rocky areas. The topsmelt, with a similar diet, feeds in the surface regions normally above the zone of the blacksmith, although the two feeding levels may overlap. Limbaugh (1955) noted that blacksmith feed on "particulate plankton such as small fish, squid and crustaceans."



FIGURE

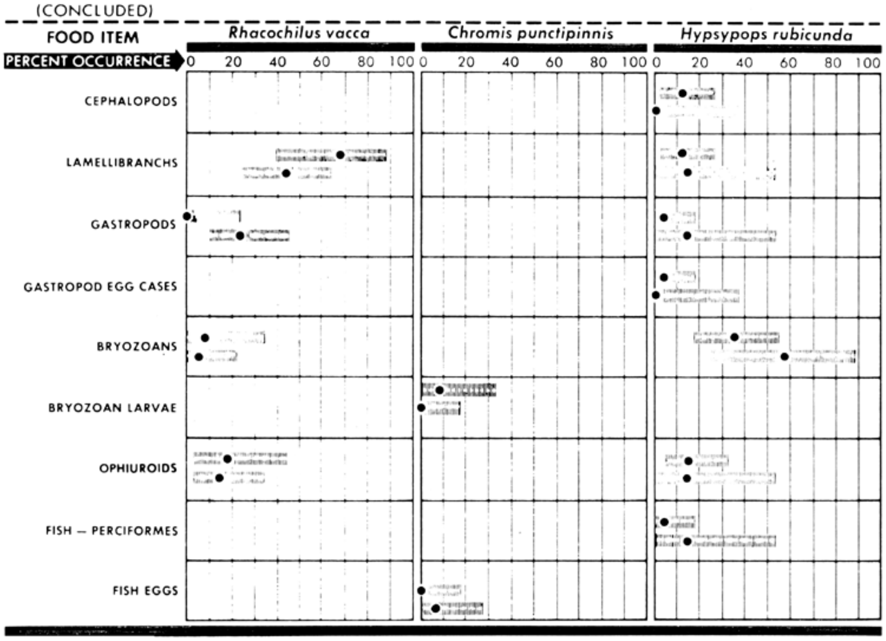


FIGURE 40. Food of the pile perch, blacksmith, and garibaldi.

FIGURE 40. ***Food of the pile perch, blacksmith, and garibaldi.***

9.4.18. Garibaldi, Hypsypops rubicunda (Figure 40)

Approximately one-third of the specimens used were spear-collected, the rest obtained by rotenone. Spring and summer are represented. Small flabellate and coralline red algae, brown and green algae, and upright bryozoans were the principal items. Polychaetes, shrimp lamellibranchs, gastropods, ophiuroids, and fish also were found. Shrimp entries were mainly the red rock shrimp Hippolysmata californica; these as well as the fish were obtained exclusively in the rotenone collections and may not represent the normal diet. Correct interpretation of the data is difficult because the male builds and guards a nest on a flat rock surface in the summer. All but a velvet-like red algae are removed and presumably eaten. However, algae were in the stomachs of both sexes and its presence therefore was not the sole result of nest construction and maintenance.

Limbaugh *(l.c.)* studied the breeding and food of the garibaldi and concluded that they "probably prefer bryozoans to other organisms. Other organisms found in their stomachs include sea anemones, worms, tiny crustaceans (crabs, shrimps, etc), clams, snail eggs, gooseneck barnacles, and even eggs of their own species." The data from both investigations indicate that the garibaldi probably is omnivorous. Although browsing short algae from rocks may contribute some nourishment, the entrapped invertebrates attached to the plants undoubtedly contribute substantially to nutrition.

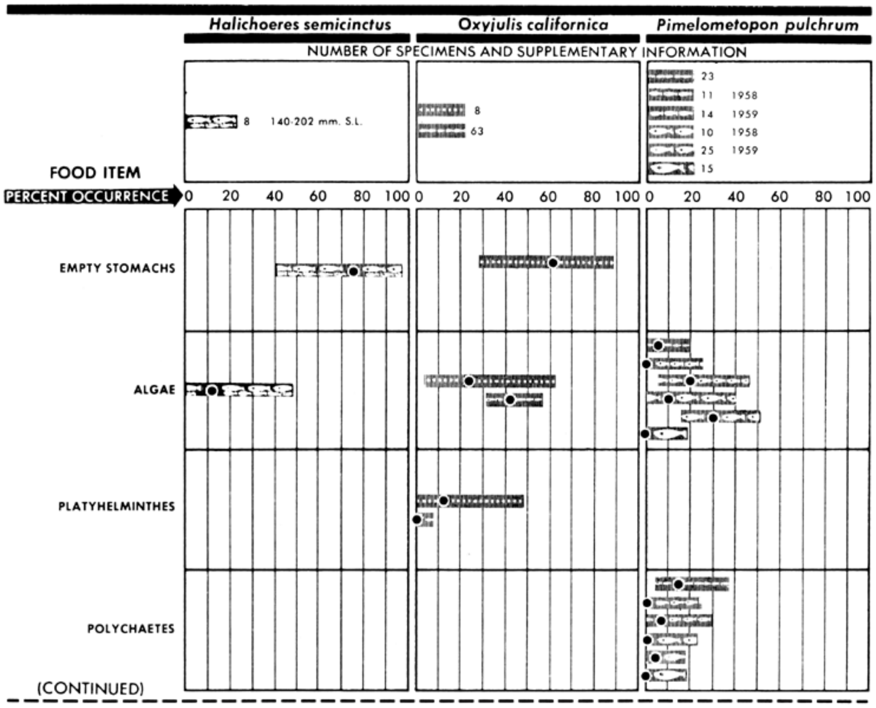
9.4.19. Rock Wrasse, Halichoeres semicinctus (Figure 41)

All specimens were collected from 25 to 35 feet deep, all but one by spear. Winter and summer are represented. Foods included algae, spider crabs, kelp scallops, dove snails, bryozoans, and the common serpent star, Ophiothrix spiculata. Because so few specimens were obtained, the analysis may not be highly representative. Limbaugh *(l.c.)* listed amphipods, small decapods, dove shells, and one slipper shell in the diet.

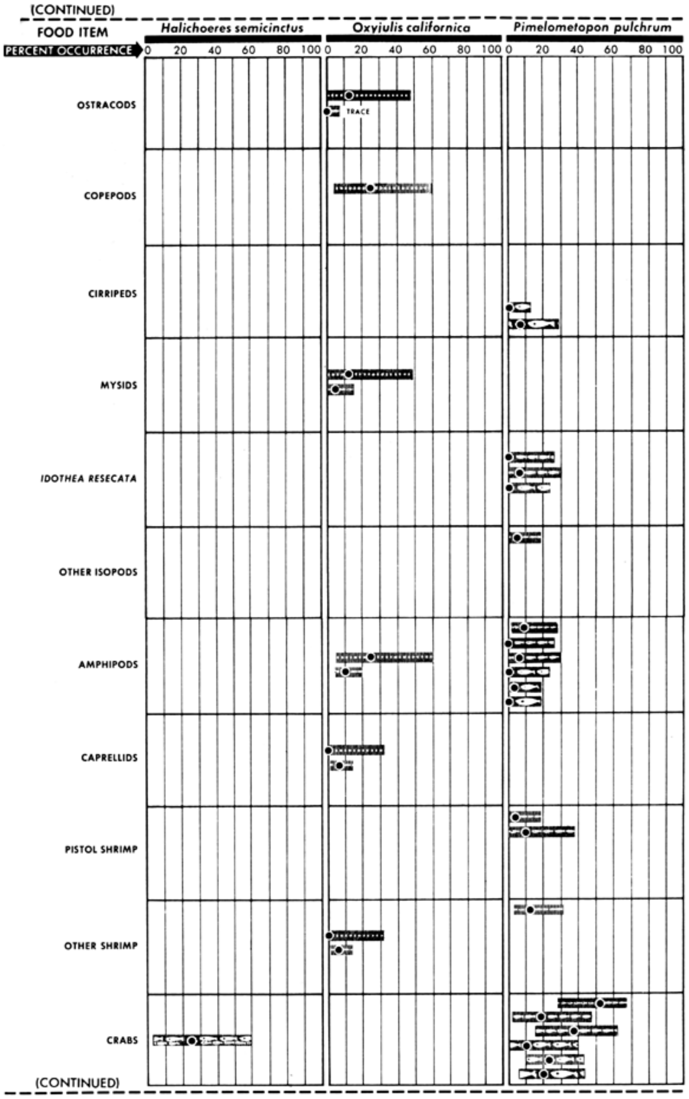
9.4.20. Señorita, Oxyjulis californica (Figure 41)

Approximately equal numbers were taken by spear and by rotenone. All seasons are represented. Principal foods were small gastropods and crustaceans commonly associated with algae. Macrocystis fragments were numerous in specimens from the Del Mar collection and may either have been taken incidentally to feeding on attached crustacea and gastropods or swallowed after the kelp was fragmented by outboard motors. The absence of crab and pistol shrimp in all collections suggested that bottom-feeding is infrequent. Small (50 to 60 mm SL) individuals fed heavily on copepods, ostracods, and small triangular bryozoan larvae (measuring approximately 0.3 mm on a side.)

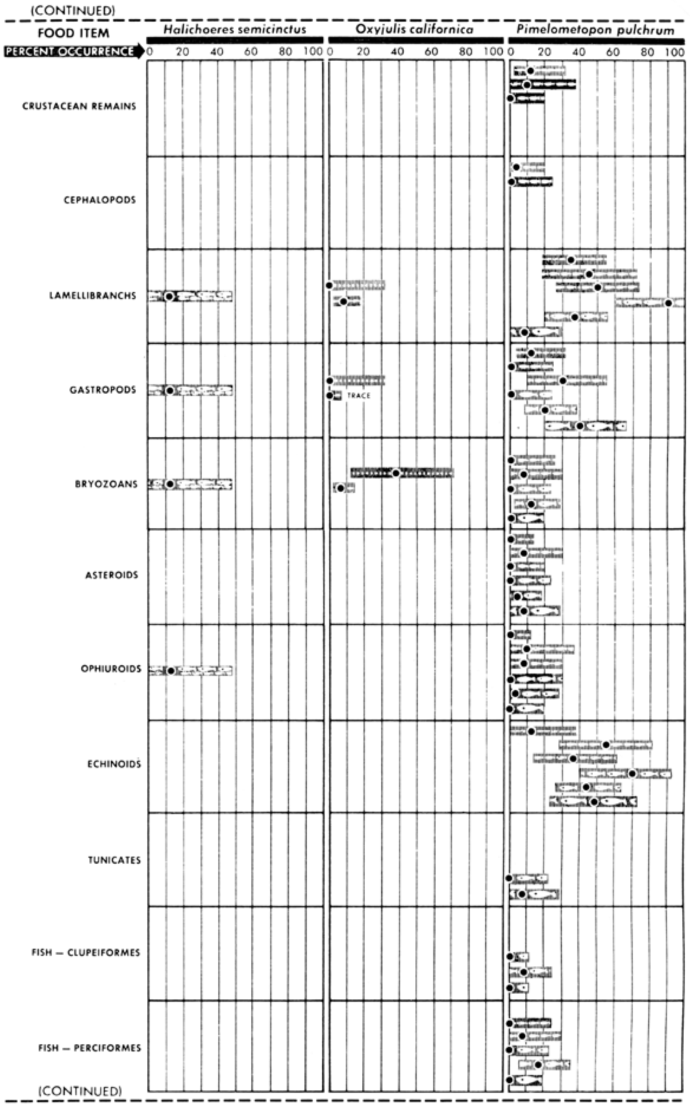
Limbaugh *(l.c.)*, who made extensive notes on the señorita habits and life history, concluded: “"Señoritas are omnivorous, carnivorous, feeding on almost any animal protein, continually picking at small objects on the bottom, on plants, other fishes, or from the water itself. When plankton is heavy with larval fish, squid, or small crustaceans, large schools of señoritas, along with blacksmith and topsmelt, often intercept the inflowing current in a kelp bed or in a bay entrance."”



FIGURE


(CONTINUED)
FOOD ITEM
Halichoeres semicinctus
Oxyjulis californica
Pimelometopon pulchrum
PERCENT OCCURRENCE
0
20
40
60
80
100
OSTRACODS
TRACE
COPEPODS
CIRRIPEDS
MYSIDS
IDOTHEA RESECATA
OTHER ISOPODS
AMPHIPODS
CAPRELLIDS
PISTOL SHRIMP
OTHER SHRIMP
CRABS
(CONTINUED)

FIGURE


(CONTINUED)
FOOD ITEM
PERCENT OCCURRENCE
Halichoeres semicinctus
Oxyjulis californica
Pimelometopon pulchrum
0
20
40
60
80
100
CRUSTACEAN REMAINS
CEPHALOPODS
LAMELLIBRANCHS
GASTROPODS
TRACE
BRYOZOANS
ASTEROIDS
OPHIUROIDS
ECHINOIDS
TUNICATES
FISH — CLUPEIFORMES
FISH — PERCIFORMES
(CONTINUED)

FIGURE

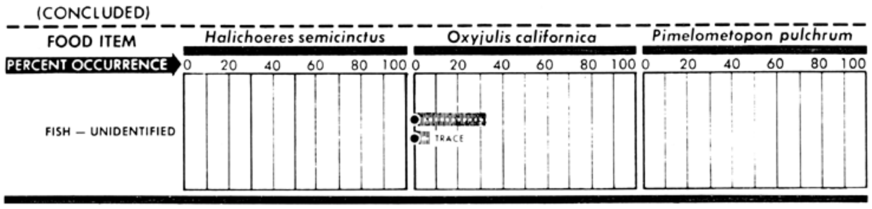


FIGURE 41. Food of the rock wrasse, señorita, and California sheephead.

FIGURE 41. ***Food of the rock wrasse, señorita, and California sheephead.***

9.4.21. California Sheephead, Pimelometopon pulchrum (Figure 41)

Specimens were taken principally from rocky-bottom habitats near kelp, at depths of 30 to 80 feet, nearly all by spear, a few by hook and line. All seasons are represented. Principal foods were fixed and slow-moving bottom invertebrates, such as tube-dwelling polychaetes, crabs, lamellibranchs, gastropods, and echinoids. Algae probably were taken incidentally to capture of small crabs and gastropods. Hermit crabs and Pleuroncodes occurred. Lamellibranchs included an abundance of kelp scallops, which were probably eaten entire and were common on the kelp during the studies. Other mollusks were *Lima*, Olivella, Mitrella, and turban snails (the turban-snail entries frequently coincided with hermit crabs.) High percentages for echinoids were due in part to baiting with crushed sea-urchins when fish were spear-collected. High sea-urchin frequencies for hook-and-line specimens may have been caused in part by sportfishing boats dragging their anchors and chains somewhat when fishing, thus undoubtedly crushing many sea-urchins on the bottom.

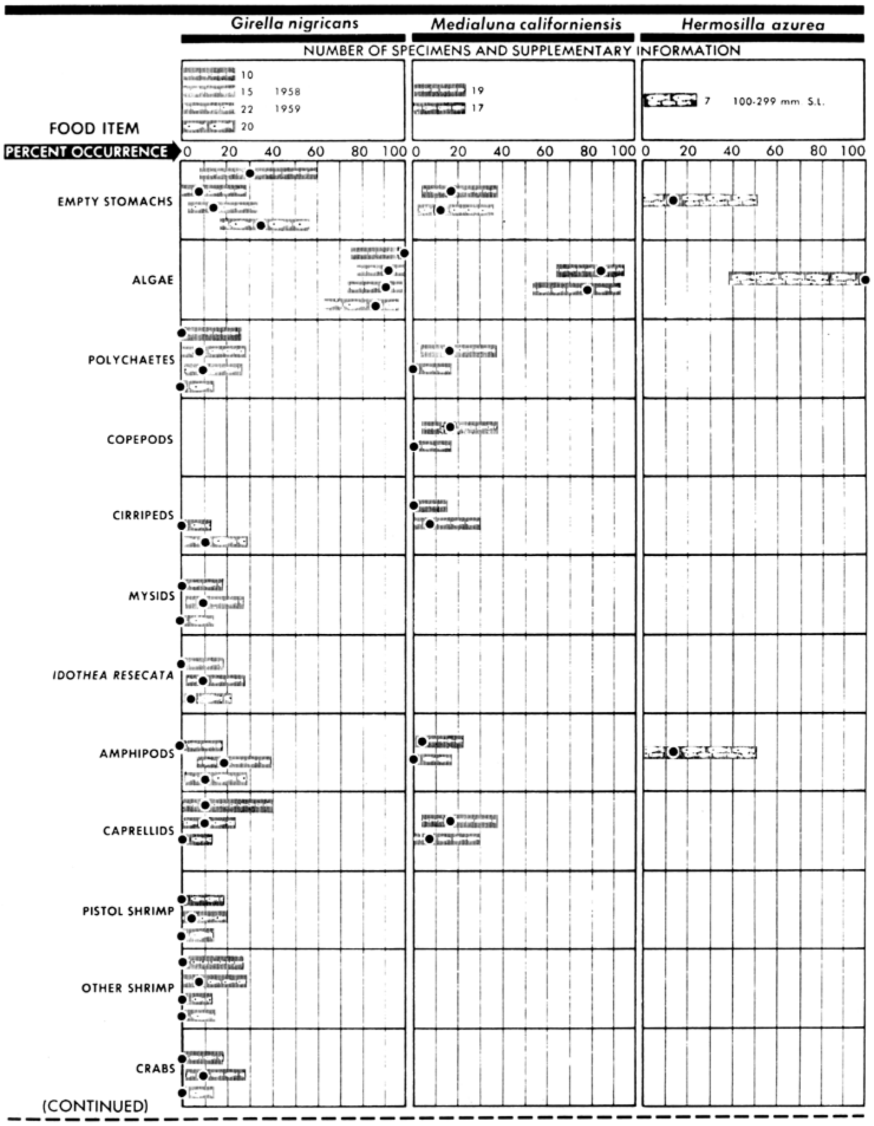
Limbaugh (1955) noted: “"the adults feed on sea urchins, mussels, crabs, large and small snails, squid, bryozoans, sand dollars, and sea cucumbers. They crush the food in their throats as they swallow it. On several occasions large adults were observed above water hanging onto mussels after a wave had retreated. Those found around mussel beds seem to attain the largest size."”

9.4.22. Opaleye, Girella nigricans (Figure 42)

Seven specimens were collected with rotenone, nearly all others by spear. All seasons are represented. Depths of collection were 30 to 80 feet. Even in fish with empty stomachs, the intestines were nearly always packed with algae (fleshy and coralline reds, as well as green and brown types). Flattened and filamentous reds predominated in occurrence and volume; next in frequency were flattened and filamentous greens. Although Macrocystis and coralline algae appeared in approximately equal frequencies, individuals containing Macrocystis usually had their digestive tracts packed with that kelp. Brown algae other than Macrocystis were least frequent. Some eelgrass (Phyllospadix) was also noted. Limbaugh (*l.c.*) noted ribbon kelp, giant kelp, sea lettuce, Gelidium, coralline algae, bryozoans, and sinistral worms.

Williams and Williams (1955) concluded that 23-to-32 mm young have a mixed plant-animal diet but that larger fish are primarily herbivorous because plant materials predominate in their digestive tracts.

However, both Williams and Williams (*l.c.*) and Limbaugh (*l.c.*) recognized that animal materials in the forage may be the principal source of nutrition for both young and adults despite the large bulk of algae. Several observations during the Kelp Program studies support this conclusion. Twelve small-adult opaleye, for example, were held in a large aquarium and restricted to a diet of clean Macrocystis. They failed to gain weight and died in approximately 1 month while single specimens held in similar aquaria thrived on diets of trout pellets or crustaceans. No alginase activity was evident in the gut of a fresh healthy adult specimen collected by spear (Reuben Lasker, personal



FIGURE

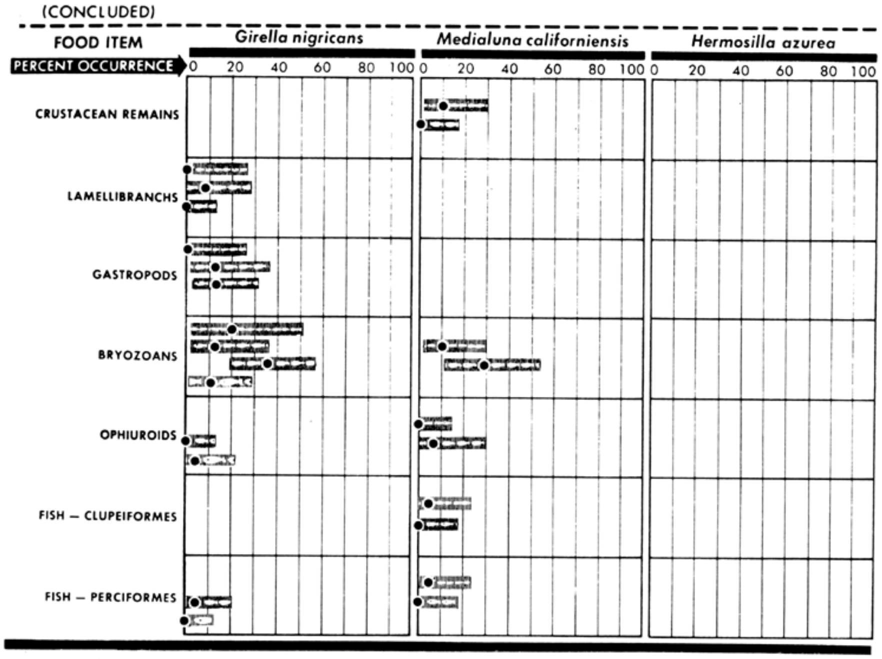


FIGURE 42. Food of the opaleye, California halfmoon, and zebraperch.

FIGURE 42. ***Food of the opaleye, California halfmoon, and zebraperch.***

communication), although similar methods gave strong positive results for the sea-urchin, Strongylocentrotus purpuratus (Eppley and Lasker, 1959).

Norris and Prescott (1959) concluded that the teeth of the opaleye probably are "a complex structural adaptation to a grazing or scraping type of food-getting," and that "the structures combine to allow individual teeth to move closely over the inequalities of rock surfaces as the animal scrapes loose encrusting algal scums or fine filamentous algae." I have observed that opaleye use a very different method while feeding on tufted algae and Macrocystis. While the alga is held in the mouth portions are severed by a strong sidewise motion of the head and body. Characteristic circular sections are removed from Macrocystis fronds in this fashion. Probably the alga is severed by the sawlike action of the teeth as the head is moved laterally.

9.4.23. Halfmoon, Medialuna californiensis (Figure 42)

Six specimens were collected by rotenone, the remainder by spear. All seasons are represented. Depths of capture ranged from 30 to 80 feet. Like the opaleye, this species was common about rocky inshore areas and kelp beds, but was usually much more abundant than opaleye in deeper beds, especially those at considerable distances offshore and about islands. The food resembled that of the opaleye and included a large variety of algae. Animals may also furnish the principal nutrition in this species. However, Follett, Gotshall, and Smith (1960) noted that some aquarium-held specimens apparently declined in condition after approximately 6 months on animal food, but returned to good health by feeding on algae, principally Macrocystis and Egregia. Limbaugh (*l.c.*) found red, green, and brown algae in their diet, as well as bryozoans and sponges.

9.4.24. Zebra Perch, Hermosilla azurea (Figure 42)

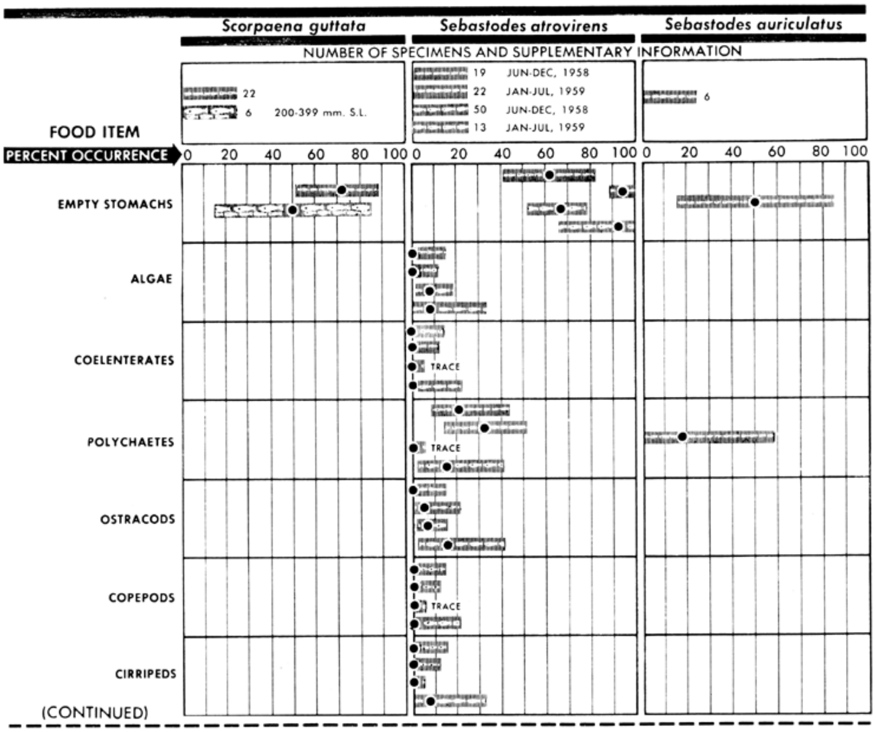
All specimens used were taken by spear; collections were scattered throughout the year. Individuals were seen only in shallow, warm waters near shore. Stomach contents resembled those of opaleye and halfmoon and principal nutrition probably was gained from animal material consumed with algae.

9.4.25. Sculpin, Scorpaena guttata (Figure 43)

Over three-fourths were taken by rotenone from kelp areas. All seasons are represented. Depths of capture ranged from 25 to 35 feet. Foods from 100 to 199 mm fish were mainly demersal crustaceans such as crabs, shrimp, and caprellids. Some squid and fish occurred. Fish and cephalopods increased in importance in the larger sizes. Adults take an artificial lure near the bottom, and once one grabbed the gloved hand of my diving partner. Limbaugh (*l.c.*) noted crabs, shrimp, octopus, and squid in their diet.

9.4.26. Kelp Rockfish, Sebastodes atrovirens (Figure 43)

The majority were taken by spear, the rest by rotenone and hook-and-line. All seasons are represented. Nearly all were from kelp beds at depths of 30 to 80 feet. Individuals ranged from the bottom to the kelp-bed canopy (visual notes), and apparently utilized all available



FIGURE

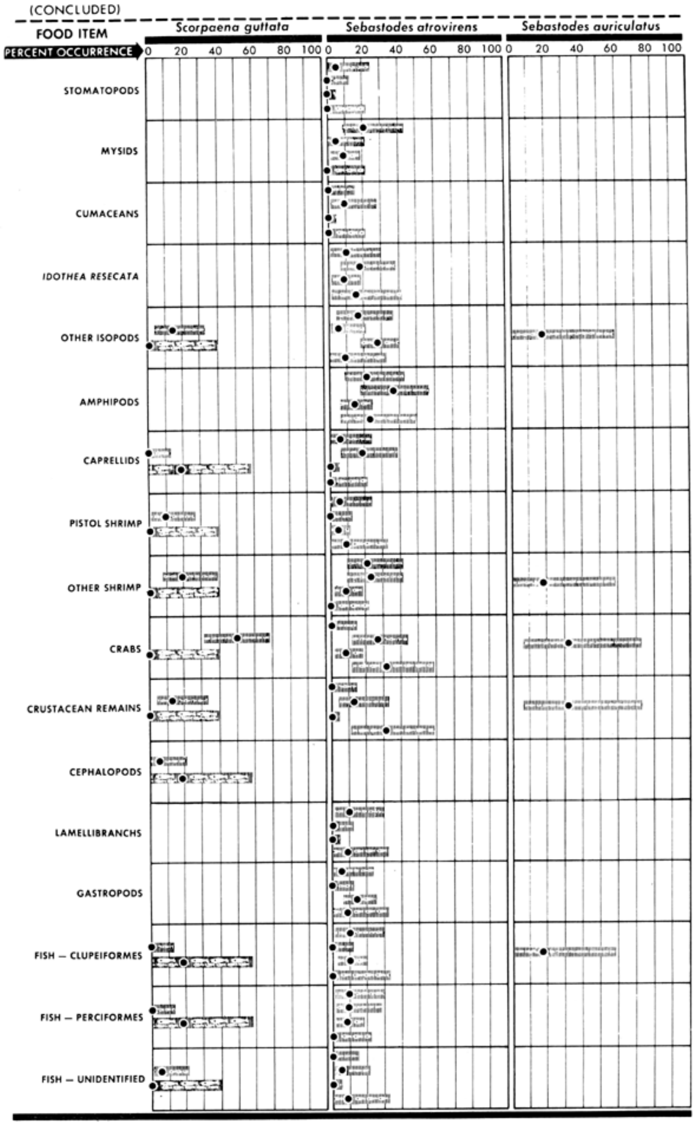


FIGURE 43. Food of the sculpin, kelp rockfish, and brown rockfish.

FIGURE 43. ***Food of the sculpin, kelp rockfish, and brown rockfish.***

foods in these regions. Diets of size-groups were similar, except possibly for "other shrimp." Possible seasonal differences in diet were indicated for polychaetes, mysids, Idothea resecata, other isopods, gammarid amphipods, caprellids, crabs, gastropods, and clupeiform fish. Limbaugh (*l.c.*) noted "crustaceans and small fish" as their food.

During the Kelp Program studies, individuals noted in the field appeared to be quite thin. Such an appearance may be normal for this species, but the high frequencies of empty stomachs and the broad variety of food items found may indicate malnutrition.

9.4.27. Brown Rockfish, Sebastodes auriculatus (Figure 43)

Five specimens were collected, between May and July, by hook-and-line from kelp beds at approximately 60 feet. Only crabs, shrimp, isopods, polychaetes, and clupeiform fish were indicated (the clupeiform entries probably from bait or "chum"). Limbaugh (*l.c.*) noted "crabs and small fish" in their diet.

9.4.28. Gopher Rockfish, Sebastodes carnatus (Figure 44)

Nearly all specimens used were speared between 30 to 80 feet, usually in kelp beds. All seasons are represented. Phillips (1957) distinguished S. carnatus and S. chrysomelas principally by color characteristics. Approximately two-thirds of our specimens fitted the description for S. carnatus and most of the rest satisfied the description for S. chrysomelas, but some were intermediate. Because the two nominal species may only be color variants, and because they frequently occur side by side, all data were lumped under the more common color type, S. carnatus.

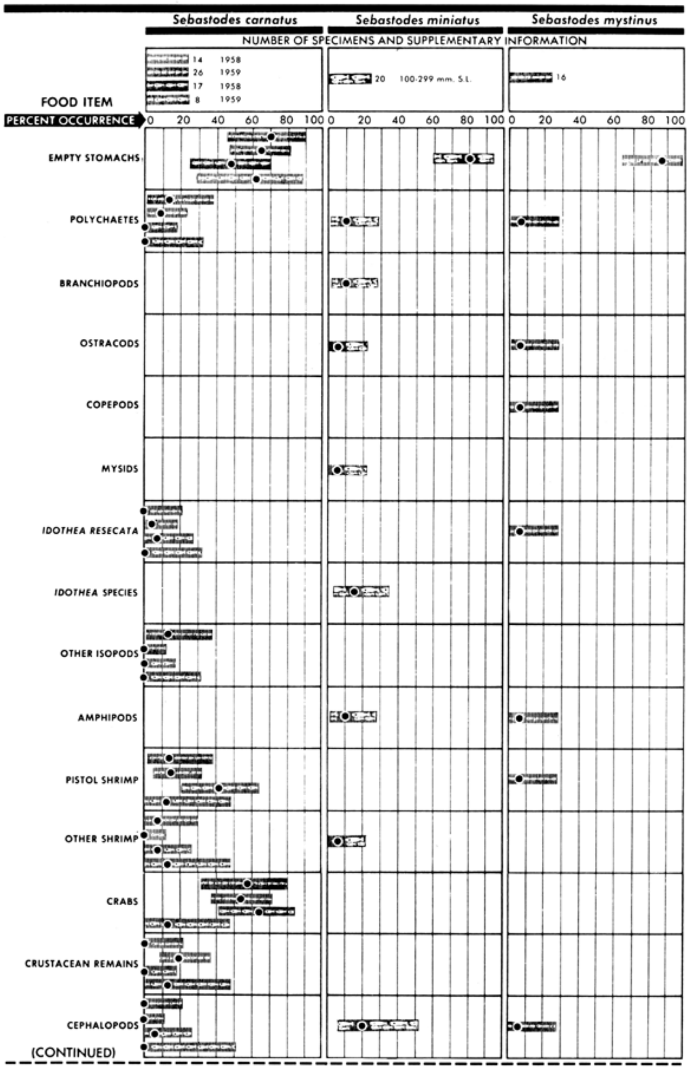
Principal foods were medium-sized crustacea, especially cancroid and spider crabs and pistol shrimp (Alphaeus dentipes) . Polychaetes, isopods, cephalopods, gastropods, and ophiuroids also occurred. All engraulids came from hook-and-line captures and probably were bait. Perciform entries were mostly small forms such as cottids. Gopher rockfish were relatively fearless and would commonly swim up to a diver, presumably attracted by parts of his attire or the air bubbles. Several times I observed them to swim several feet up from a rocky habitat to tug at a fish on a stringer. Limbaugh (*l.c.*) noted their food as crabs, small fish, and squid.

9.4.29. Vermilion Rockfish, Sebastodes miniatus (Figure 44)

Nearly all specimens used were speared at depths of 100 feet or greater, away from kelp beds. All seasons were represented. Although pressure changes when specimens were brought to the surface nearly always caused regurgitation of stomach contents, intestinal material usually yielded useful food information. Squid were quite important and small crustaceans such as mysids were sometimes encountered in considerable volumes (mysids nearly filled the stomach of one small adult). Other foods included Nebalia, polychaetes, ostracods, Idothea, amphipods, and shrimp. One lancelet, Branchiostoma sp., also was noted.

9.4.30. Blue Rockfish, Sebastodes mystinus (Figure 44)

Three specimens were obtained by hook-and-line, the remainder were speared. The food data were inadequate because specimens were


Sebastodes carnatus
Sebastodes miniatus
Sebastodes mystinus
NUMBER OF SPECIMENS AND SUPPLEMENTARY INFORMATION
14 1958
26 1959
17 1958
8 1959
20 100-299 mm. S.L.
16
FOOD ITEM
PERCENT OCCURRENCE
0 20 40 60 80 100
EMPTY STOMACHS
POLYCHAETES
BRANCHIOPODS
OSTRACODS
COPEPODS
MYSIDS
IDOTHEA RESECATA
IDOTHEA SPECIES
OTHER ISOPODS
AMPHIPODS
PISTOL SHRIMP
OTHER SHRIMP
CRABS
CRUSTACEAN REMAINS
CEPHALOPODS
(CONTINUED)

FIGURE

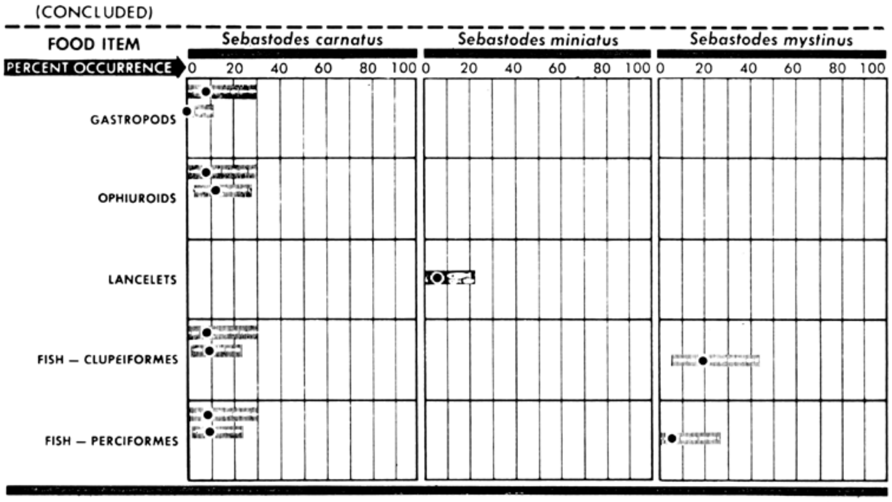


FIGURE 44. **Food of the gopher rockfish, vermilion rockfish, and blue rockfish.**

FIGURE 44. ***Food of the gopher rockfish, vermilion rockfish, and blue rockfish.***

few and digestive tracts were frequently empty. Anchovies and, occasionally, small crustaceans were noted. Perciform entries were based on ctenoid scales only.

Individuals swam in large schools that resembled schools of blacksmith, because the species is blue, and, in the San Diego region, of similar size. However, the blue rockfish were not as directly associated with rocky substrate and the fish normally were more widely spaced in the schools. No specimens of breeding size were ever seen and all gonads examined were immature. Visual records were for fish smaller than 200 mm SL and the largest one collected measured 176 mm. All, therefore, were below the size of first maturity given by Wales (1952). As with S. atrovirens, the fish appeared to be in poor condition. The blue rockfish may be poorly adapted to the environment of this region and the schools may comprise expatriate populations.

9.4.31. Grass Rockfish, Sebastodes rastrelliger (Figure 45)

Collections were obtained at all seasons, from regions shallower than 55 feet and in kelp beds. The species is rare at greater depths. Approximately equal numbers were taken by poison, spear, and hook-and-line. The anchovies that occurred only in hook-and-line specimens probably represented bait. Both cancroid and spider crabs and pistol shrimp were frequent. "Other" shrimp, a Conus californiensis, and a small perciform fish (clinid?) also were noted. Limbaugh (*l.c.*) found crabs and small fish in their stomachs, and Baxter (1960) noted a 5-inch white seaperch (Phanerodon furcatus) from a 16-inch specimen.

9.4.32. Olive Rockfish, Sebastodes serranoides (Figure 45)

Nearly all specimens used were from the kelp-bed habitat. Depths ranged from 30 to 110 feet, and all seasons are represented. Individuals were usually seen off the bottom at about mid-depth. At times they mingle there with kelp bass, which they resemble in form and coloration when alive. Food was similar to that of the kelp bass, and mainly comprised swimming forms and animals associated with

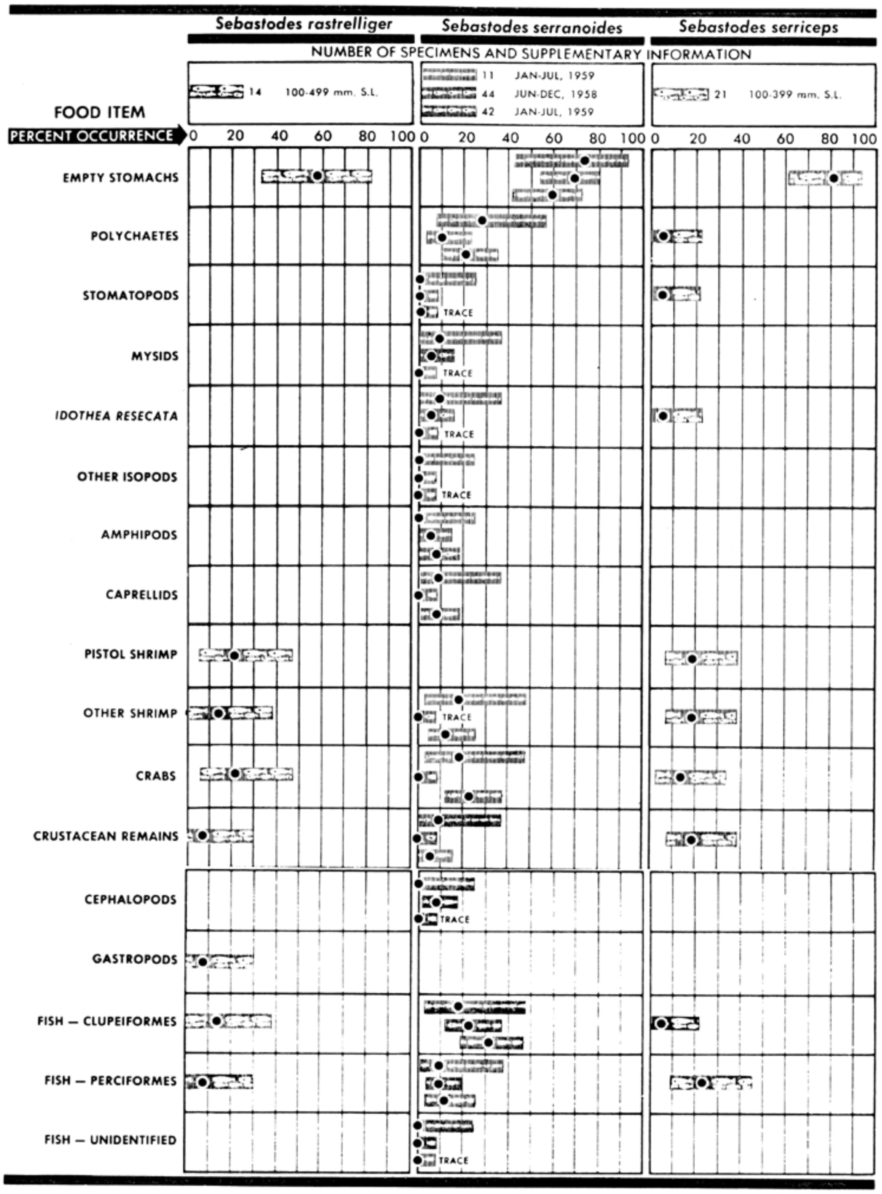


FIGURE 45. Food of the grass rockfish, olive rockfish, and treefish.

FIGURE 45. ***Food of the grass rockfish, olive rockfish, and treefish.***

the kelp canopy. Crab entries were mainly adult Pleuroncodes and megalops larvae. Squid and octopus occurred. Anchovies composed nearly all clupeiform entries and were regarded as either "chum" or bait because they occurred only in the hook-and-line specimens. Perciform prey included a flatfish and a juvenile giant kelpfish, each several inches in length. Limbaugh (*l.c.*) found crustaceans and smaller fish in their diet, and Fitch (*l.c.*) noted squid.

9.4.33. Treefish, Sebastodes serriceps (Figure 45)

One-fourth were collected by hook-and-line, the remainder were speared. All were from rocky areas at depths of 40 to 75 feet, during all seasons. Habitat broadly overlapped that of S. carnatus in the San Diego region yet the diet appeared to be much more restricted. Principal foods were shrimp (Alphaeus dentipes, A. bellimanus, Spirontocaris) , crabs (Pleuroncodes planipes, cancroid, and spider), and perciform fish (unidentified). As with S. carnatus, adults commonly leave their caves and crevices to investigate a diver.

9.4.34. Cabezon, Scorpaenichthys marmoratus (Figure 46)

Over one-half were collected by spear, the remainder by hook-and-line. All were from rocky areas at depths of 40 to 80 feet, and represent all seasons. Principal foods were cancroid and spider crabs, octopus, and squid. Also making important contributions were "shrimp" (including a juvenile spiny lobster), gastropods (spiral-shelled and nudibranchs), and fish (one eel-blenny, a juvenile giant kelpfish, and unidentified fish eggs). Algae, including fragments of reds and greens, were undoubtedly taken incidentally to the other items. These data agreed quite well with O'Connell's (1953) finding that crabs are the principal food. The indicated importance of abalone and limpets vs. cephalopods was reversed. Small perciform fishes and fish eggs were equally important in both studies. The general findings also agreed with those of Limbaugh (*l.c.*). No other investigators have recorded the occasional presence of rocks in cabezon stomachs, as noted by Limbaugh (personal communication).

9.4.35. Lingcod, Ophiodon elongatus (Figure 46)

Eleven were taken by hook-and-line and six by spear, during all seasons. Specimens came from rocky areas at depths of 25 to 125 feet. The diet was almost entirely fish and squid. Algal fragments occurred together with the remains of one large percoid fish and probably represent food from the prey (another lingcod taken at the same time contained a fresh halfmoon which typically contains large quantities of algae). Engraulids occurred only in the hook-and-line captures and some were well-digested. Perciform entries included one topsmelt. Fitch (*l.c.*) noted that the young feed on shrimp and other crustaceans. The lingcod is strictly demersal and lacks an air bladder. Adults commonly rest motionless on rocky ridges or rises. They swim with a sinuous motion.

9.4.36. Painted Greenling, Oxylebius pictus (Figure 46)

Nine specimens were poisoned, the remainder speared. All seasons are represented. Collections came from rocky areas at depths of 30 to 80 feet. Only one size-group was taken (the three bars figured represented collections from different seasons). The data represented by each lowermost bar-diagram should be interpreted with caution, because the fish were mainly from a collection in which the kelp canopy was inadvertently poisoned nearly a half-hour before effects reached the bottom, so that some canopy invertebrates, especially Idothea resecata, probably became unusually available. Principal foods were

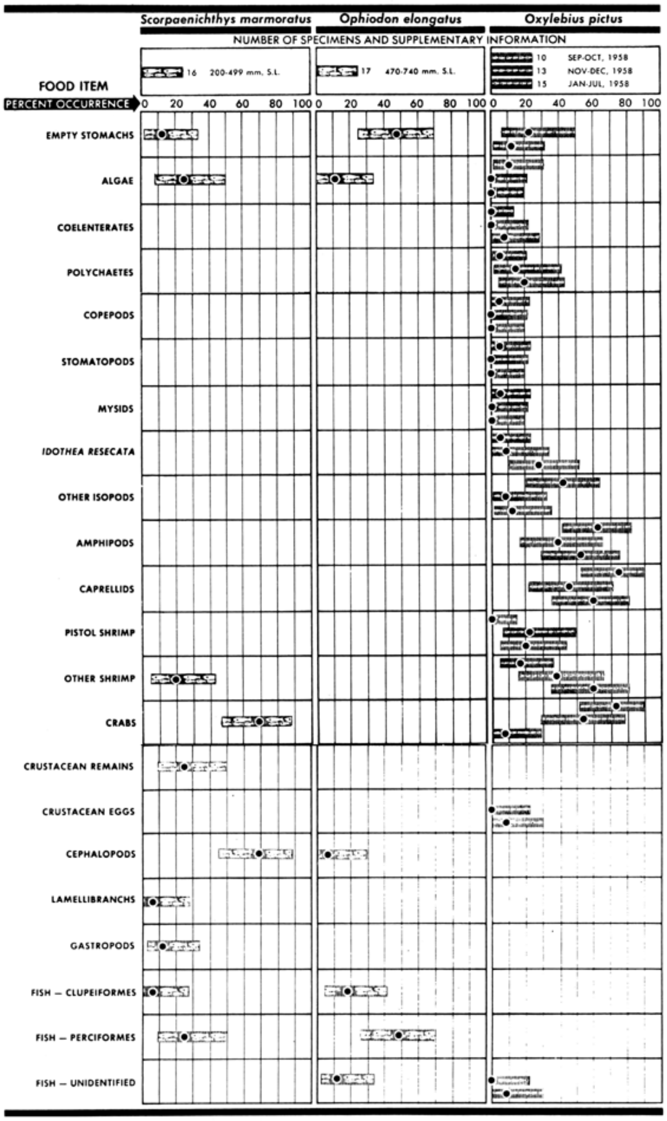


FIGURE 46. Food of the cabezon, lingcod, and painted greenling.

FIGURE 46. ***Food of the cabezon, lingcod, and painted greenling.***

small demersal crustaceans and polychaetes. Cancroid and spider crabs were represented nearly equally. Shrimp included bent-back Spirontocaris, Betaeus spp., and pistol types (Alphaeus dentipes and A. bellimanus) . A wide variety of other amphipods occurred, including Caprella sp. and many elongated forms with large chelae. Isopods were principally flabelliferan. The single fish entry was for eggs in the eyed stage. Similar to cottids, this species is strictly demersal and lacks an air bladder. Although sometimes common about rocky floors under kelp beds, they were never observed separated from rocky substrate. The males are pugnacious and have been observed to dart a foot off the bottom to nip a passing fish many times their size.

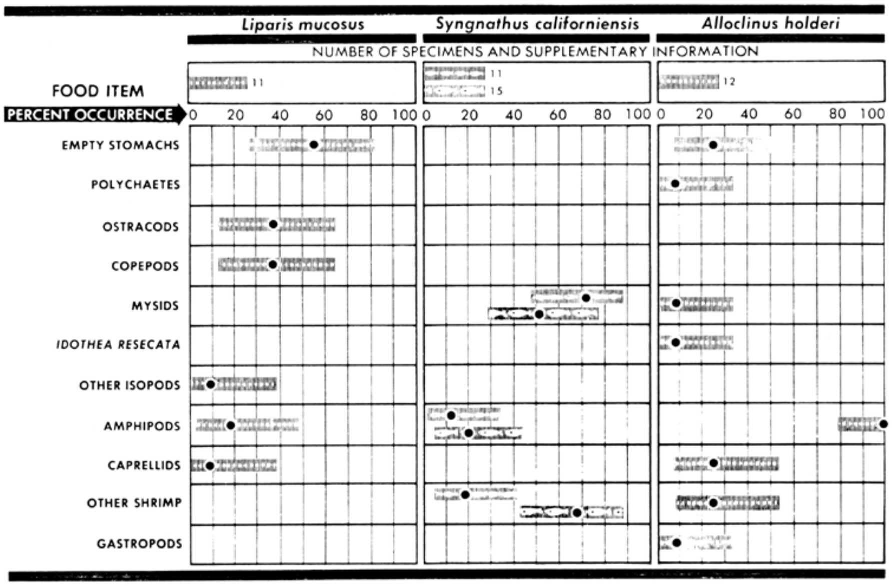


FIGURE 47. Food of the slimy snailfish, kelp pipefish, and island kelpfish.

FIGURE 47. ***Food of the slimy snailfish, kelp pipefish, and island kelpfish.***

9.4.37. Slimy Snailfish, Liparis mucosus (Figure 47)

All specimens used were collected by rotenone from the Papalote Bay kelp bed, 10 August 1959. Depth of capture was 32 feet. This species occupied kelp holdfasts, and the Papalote Bay specimens probably originated from this habitat. A microcarnivorous diet was indicated, with feeding mainly on small surface-associated crustaceans, probably made available by the poisoning.

9.4.38. Kelp Pipefish, Syngnathus californiensis (Figure 47)

All specimens used were picked from freshly cut kelp being taken aboard a kelp harvester near Gaviota on 26 May 1960. Stomach fullness was not assessed because a definite stomach is lacking. Principal foods were mysids and small shrimp, both of which abounded in the kelp canopy at the time of collection. Small amphipods were also frequent. Limbaugh (*l.c.*) noted chiefly mysids and small amphipods for this species.

9.4.39. Island Kelpfish, Alloclinus holderi (Figure 47)

Specimens used were taken by rotenone at 32 feet in the Papalote Bay kelp bed on 10 August 1959. The species is bottom-dwelling. Because the kelp-bed canopy was accidently poisoned first, the data may be seriously biased toward canopy-inhabiting crustaceans. All specimens had eaten small gammarid amphipods; small shrimp and caprellids were of secondary importance.

9.4.40. Spotted Kelpfish, Gibbonsia elegans (Figure 48)

Samples were obtained by rotenone from kelp beds, in July, August, and November 1959. Both G. elegans and G. metzi mimic habitat coloration and a color analysis of the Papalote Bay specimens suggested that the majority of the G. elegans specimens came from the kelp columns and coralline algae (82 of 106 specimens were mottled red-and-black or red-and-white, a pattern normal for the coralline-algae habitat; 14 had light-tan "kelp" coloration, and probably were residing in the kelp sporophylls or stipes, and 10 were dark-red and may have been residing in holdfasts or crevices). An aquarium-held specimen obtained from a holdfast (70-foot depth) was dark-red but changed to a mottled grey, similar to that of the aquarium substrate, within 2 or 3 days. In contrast, all specimens of G. metzi from the Papalote Bay collection were light-tan or mottled tan, suggesting that the entire sample was from the kelp columns.

Principal food was small flabelliferan isopods. of secondary importance were polychaetes, small Idothea resecata (and *I.* spp.), gammarid amphipods, caprellids, shrimp (pistol and other types), crabs (megalops, hermit, spider), and small gastropods (dove shells). The data should be interpreted with caution, however, because all specimens were collected by rotenone methods. Limbaugh (*l.c.*) listed crustaceans and mollusks, and similar observations were made by Mitchell (1953) on 72 intertidally-collected specimens. Metz (1912) noted small mollusks (especially limpets), crustaceans (crabs, amphipods, etc.), minute worms, and foliose red algae in tidepool specimens.

9.4.41. Striped Kelpfish, Gibbonsia metzi (Figure 48)

The sample was obtained by rotenone at Papalote Bay, 10 August 1959. Specimens probably had resided off the bottom in the kelp, because they were uniformly kelp-colored, in contrast to the predominant coralline coloration of G. elegans (described above), and because only this species is taken by the kelp harvesters, and is consistently so taken (Carl L. Hubbs, personal communication). Principal foods were Idothea spp. (mainly resecata) , and assorted small amphipods. Small isopods, shrimp, and copepods were secondary in importance. Unidentified fish eggs also were noted.

In comparison with G. elegans, the food composition for G. metzi appears richer in items known to be abundant about kelp fronds and stipes, particularly Idothea resecata. The absence of mysids from the diet of both Gibbonsia species is unexplained. Limbaugh (*l.c.*) stated only that G. metzi feeds on small crustacea in the canopy biotope. Mitchell (1953) identified Idothea (three spp.), assorted amphipods, shrimp (two spp.), and worms, in 17 tidepool specimens.

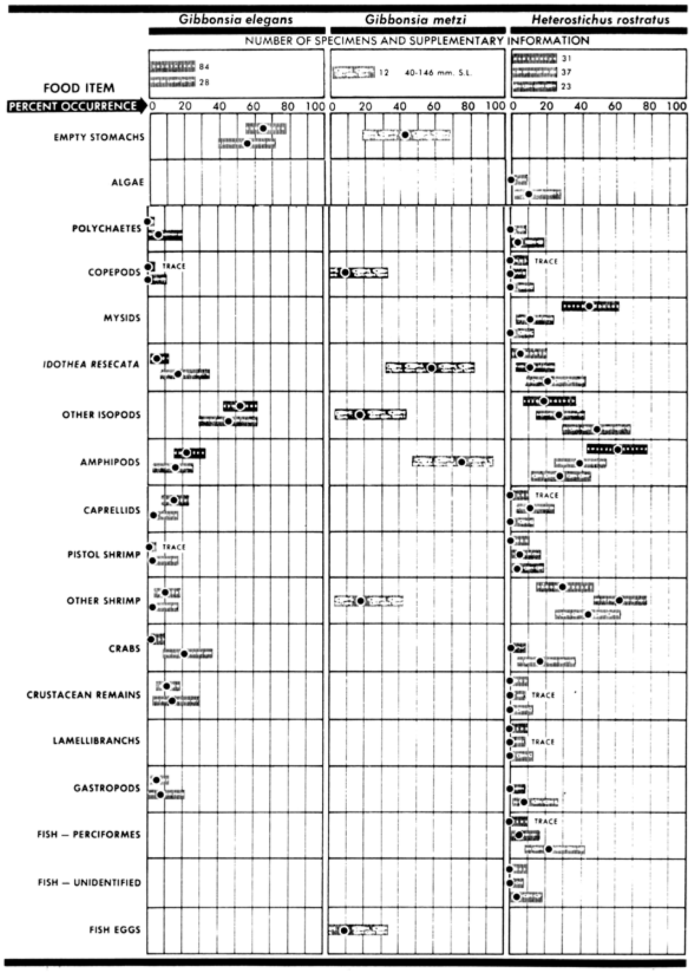


FIGURE 48. Food of the spotted kelpfish, striped kelpfish, and giant kelpfish.

FIGURE 48. ***Food of the spotted kelpfish, striped kelpfish, and giant kelpfish.***

9.4.42. Giant Kelpfish, Heterostichus rostratus (Figure 48)

Nearly all specimens used were from three kelp-bed rotenone collections in July, August, and November 1959. Depths ranged from 25 to 35 feet. Giant kelpfish attain high concentrations in kelp columns and canopies, but individuals are not readily seen, because they resemble kelp fronds in both shape and coloration. Individuals also are common about laminarian algae and eel grass on the bottom. They are expert mimics of their habitats, which they match in pattern, hue, and value, and often in attitude.

Principal foods were mysids, isopods (including I. resecata) , amphipods, and shrimp (other than pistol shrimp), all of which abound about kelp. Pistol shrimp were secondary in importance but indicated that some individuals forage near the bottom. Mysids and small amphipods became less important with increase in fish size but consumption of isopods and fish increased. Fish items included Rimicola eigenmanni, señorita (small-sized), giant kelpfish (postlarval), kelp perch (juvenile), cottids, and slimy snailfish. Crab entries were principally spider forms. Limbaugh (*l.c.*) noted crustaceans as important in their diets, and small fish and mollusks also occurred. Metz (1912) found "soft crustacea (amphipods and isopods)" in a few intertidal specimens.

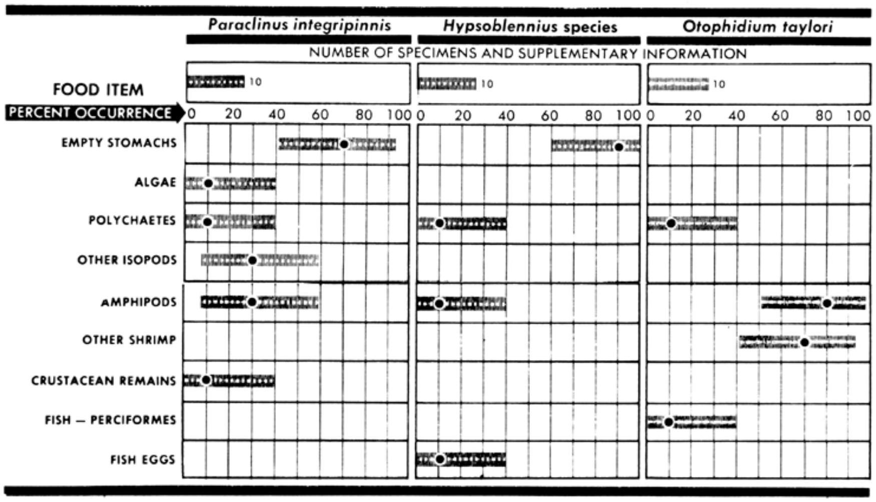


FIGURE 49. Food of the reef finspot, mussel blenny, and spotted cusk-eel.

FIGURE 49. ***Food of the reef finspot, mussel blenny, and spotted cusk-eel.***

9.4.43. Reef Finspot, Paraclinus integripinnis (Figure 49)

Specimens used were poisoned in a kelp bed 25 feet deep in July 1959. Little is known concerning the habits of this species, but the specimens probably inhabited short algae at the collection site. Small isopods and amphipods were principal foods.

9.4.44. Mussel Blenny, Hypsoblennius sp. (Figure 49)

Specimens used were poisoned in a kelp bed 25 feet deep in July 1959. Nearly all specimens had empty stomachs. One contained polychaetes, another amphipods, and a third unidentified eyed fish eggs.

9.4.45. Spotted Cusk-eel, Otophidium taylori (Figure 49)

All specimens used were from the Papalote Bay collection in August 1959. Specimens originated from a region of mixed sand and rock at 32 feet. Important food items were shrimp (other than pistol shrimp) and small amphipods. Other foods included the remains of a polychaete and a 16-mm (SL) cottid. Because sections of the kelp canopy were inadvertently poisoned first, normal forage items may have been contaminated with canopy organisms.

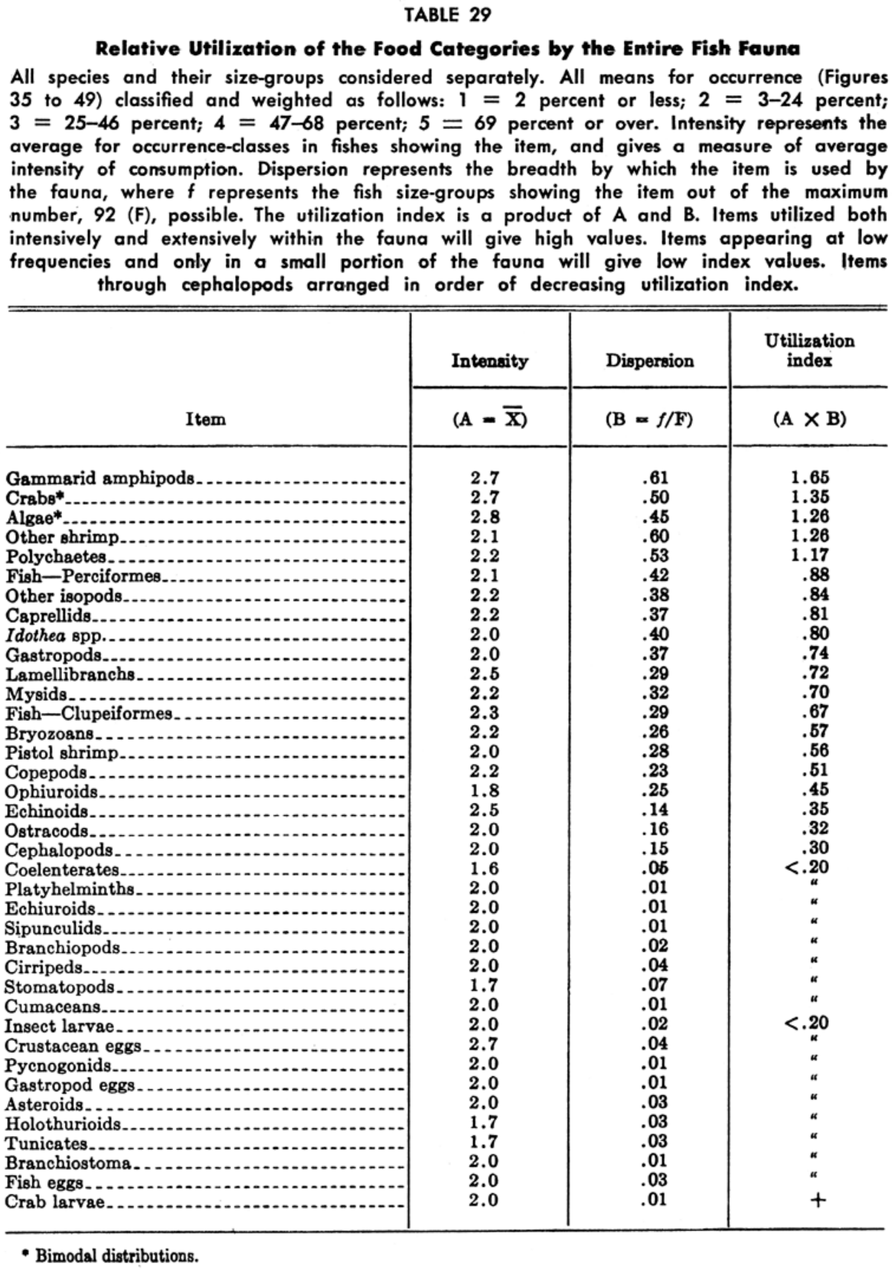


TABLE 29

Relative Utilization of the Food Categories by the Entire Fish Fauna

All species and their size-groups considered separately. All means for occurrence (Figures 35 to 49) classified and weighted as follows: 1 = 2 percent or less; 2 = 3–24 percent; 3 = 25–46 percent; 4 = 47–68 percent; 5 = 69 percent or over. Intensity represents the average for occurrence-classes in fishes showing the item, and gives a measure of average intensity of consumption. Dispersion represents the breadth by which the item is used by the fauna, where *f* represents the fish size-groups showing the item out of the maximum number, 92 (F), possible. The utilization index is a product of A and B. Items utilized both intensively and extensively within the fauna will give high values. Items appearing at low frequencies and only in a small portion of the fauna will give low index values. Items through cephalopods arranged in order of decreasing utilization index.

Item	Intensity	Dispersion	Utilization index
	$(A = \bar{X})$	$(B = f/F)$	$(A \times B)$
Gammarid amphipods	2.7	.61	1.65
Crabs*	2.7	.50	1.35
Algae*	2.8	.45	1.26
Other shrimp	2.1	.60	1.26
Polychaetes	2.2	.53	1.17
Fish—Perciformes	2.1	.42	.88
Other isopods	2.2	.38	.84
Caprellids	2.2	.37	.81
Idothea spp.	2.0	.40	.80
Gastropods	2.0	.37	.74
Lamellibranchs	2.5	.29	.72
Mysids	2.2	.32	.70
Fish—Clupeiformes	2.3	.29	.67
Bryozoans	2.2	.26	.57
Pistol shrimp	2.0	.28	.56
Copepods	2.2	.23	.51
Ophiuroids	1.8	.25	.45
Echinoids	2.5	.14	.35
Ostracods	2.0	.16	.32
Cephalopods	2.0	.15	.30
Coelenterates	1.6	.05	<.20
Platyhelminths	2.0	.01	"
Echiuroids	2.0	.01	"
Sipunculids	2.0	.01	"
Branchiopods	2.0	.02	"
Cirripeds	2.0	.04	"
Stomatopods	1.7	.07	"
Cumaceans	2.0	.01	"
Insect larvae	2.0	.02	<.20
Crustacean eggs	2.7	.04	"
Pycnogonids	2.0	.01	"
Gastropod eggs	2.0	.01	"
Asteroids	2.0	.03	"
Holothurioids	1.7	.03	"
Tunicates	1.7	.03	"
Branchiostoma	2.0	.01	"
Fish eggs	2.0	.03	"
Crab larvae	2.0	.01	+

* Bimodal distributions.

TABLE 29

Relative Utilization of the Food Categories by the Entire Fish Fauna

9.5. IMPORTANCE OF THE FOODS

If frequencies of the food items are considered, as well as the number of species and size categories utilizing them, a general hierarchy of utilization may be constructed (Table 29) . Because the data are not weighted for relative nutritional value, volumes, and digestion rates, only general trends are indicated.

Gammarid amphipods had the highest index of utilization in the study. Representatives of this group were nearly ubiquitous in the inshore environment and were abundant in bottom algae, kelp hold-fasts, and about kelp fronds and stipes. Sixty-one percent of the frequency diagrams recorded their presence. They were very heavily utilized by some or all samples of black perch, island kelpfish, striped kelpfish, and spotted cusk-eel. Also utilizing gammarid amphipods heavily, but to a lesser degree, were California sargo, kelp perch, rubberlip perch, painted greenling, and giant kelpfish.

Crabs had a utilization index nearly as high. They differed from gammarid amphipods in having a bimodal frequency distribution of intensity-of-usage values. Modes occurred at 2.5 and 4.5 which indicated that in addition to utilization at medium rates by many species, several fish concentrated heavily on this item. Interpretation of the values is complicated because the pelagic red crab was abundant both in the kelp beds and in the stomach samples during spring, 1959. Fish that contributed to the 4.5 mode for intensity were black croaker, rubberlip perch (one size-group), pile perch (two size-groups), California sheephead (100–199 mm size-groups), gopher rockfish (two size-groups), and painted greenling (two samples). As noted previously, crab entries for pile perch were principally hermit crabs.

Algae also gave a bimodal frequency distribution for intensity-of-usage classes. An upper mode (5.5) reflected high occurrence in top-smelt (specimens less than 99 mm, seined from tidepools), garibaldi (all size-groups), and the reputed herbivores, the opaleye, halfmoon, and zebraperch. Algae entries contributing to the lower frequency mode (2.5) seem accountable to accidental ingestion with animal prey items and fragments being mistaken for fish prey.

Shrimp other than pistol shrimp gave a high index of utilization. This was to be expected because, like gammarid amphipods, shrimp are widespread and abundant in the inshore environment. Shrimp were heavily utilized by kelp pipefish and kelpfish among the kelp-inhabiting fishes and by the spotted cusk-eel and painted greenling (one sample) among bottom-dwelling species.

Polychaetes showed high occurrence only once (black perch, 100 to 199 mm, June to October 1958). In general the polychaete data were not very conclusive because of the diverse forms and ecology of the group and the scant remains usually recovered (some identifications were based on setae only). Perciform fishes showed narrower utilization by the fauna, as would be expected; a considerable variety of prey species was represented. Isopods other than Idothea spp. were heavily utilized by the giant kelpfish, which abounds in the kelp columns and canopy, and the spotted kelpfish, a bottom dweller. Although caprellids were abundant in the kelp canopy during some seasons, they were heavily utilized only by the black perch (100 to 199 mm size-group, for June to October 1958) and the painted greenling, both bottom inhabitants. Moderate frequencies for Idothea spp. occurred in the striped kelpfish only, and gastropods were not heavily utilized by any fishes. Lamellibranch entries were frequent in the pile perch and California sheephead, both of which have crushing pharyngeal plates. Principal lamellibranch species were kelp scallops and the swimming clam, *Lima*. Mysids were heavily utilized by California salema, kelp pipefish, and one adult specimen of vermilion rockfish. Clupeiform entries were of high frequencies only in sand bass of the 300 to 399 mm size-group and barracuda, and the data may represent bait or "chum." Bryozoans and pistol shrimp were not frequent in any fishes. Pistol shrimp, however, may be important to some such as the kelp bass, because of the relatively large size and continuous low-level utilization. Copepods were taken in abundance only by blacksmith and ophiuroids were not utilized intensively by any fish species. Echinoids were of high occurrences in California sheephead and of low frequencies in numerous species. As noted previously, the recorded frequencies are probably biased toward high values in both hook-and-line and spear-collected specimens. Ostracods were infrequent in all species, and cephalopods were relatively common only in the cabezon.

10. 9. EFFECTS OF KELP HARVESTING ON THE FISHES OF THE KELP BEDS

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10.1. INTRODUCTION

The beds of giant kelp along the Pacific coast of southern California and of Baja California, Mexico, represent important recreational areas to residents and visitors, as well as an important source of industrial products. These beds are focal points for commercial and private sportfishing parties in search of kelp bass, white seabass, and other bottom fishes, as well as such pelagic fishes as the yellowtail and barracuda. At times, especially on week-ends and holidays, the sportfishing boats crowd the areas in and about the beds. In addition, increased numbers of skin divers and SCUBA divers are discovering the beautiful underwater vistas of the kelp beds and their abundant and varied fishes. Scenes comparable to those of the lush redwood forests of the Pacific Northwest are available a mere few hundred or thousand feet from the semi-desert shores of the Californias. Although the kelp beds are important recreational areas today, they will become vital in the future, when vastly greater numbers of people make southern California their home or recreation center.

With the development of SCUBA, the world of the kelp beds has been made available not only to the spearfisherman, artist, and photographer, but also the biologist. For well over a decade now, the kelp-bed environment has been studied by diving biologists at the Scripps Institution of Oceanography and other centers of marine research. Primary motivation has been the requests from two groups vitally concerned with the welfare of the kelp beds and their fauna; the companies harvesting kelp and the organizations of sportfishermen. A principal factor spurring research has been the necessity for information on any effects harvesting may have on kelp and on the rich fish fauna of the beds. The knowledge gained in answering this problem, however, has gone beyond merely outlining the interrelationships between kelp harvesting and the fishes. Basic knowledge has also been gained toward the intelligent management of a large segment of the fish resource of California, in anticipation of the much heavier usage the resource will surely receive in the future.

This report summarizes previous knowledge on this problem and findings of the 5-year IMR Kelp Program. In general, the studies continue those of Conrad Limbaugh, pioneer underwater naturalist at Scripps. Detailed reports of the scientific findings forming the basis for this summary are given in Chapters 5 through 8 of this bulletin.

The Limbaugh report, "Fish life in the kelp beds and the effects of kelp harvesting" (Limbaugh, 1955) summarized investigations conducted from 1948 to 1954, primarily by this single acute investigator.

The kelp environment was surveyed, qualitative studies were made on the food and biology of the fishes, and kelp harvesting was analyzed for direct effects. In his summarizing report Limbaugh stated, "As a result of these long and thorough studies, it is concluded that kelp harvesting, as currently practiced, has no seriously detrimental effects on fishing." Because Limbaugh's studies were of a survey nature many questions were not conclusively answered. "Seriously detrimental effects" were not defined. The food studies are of limited value because no indication was given concerning the number of specimens examined, and because the food data are not evaluated in regard to collection methods, seasons represented, or whether both the stomach and intestine were examined. However, the work was very important as a first step in the ecological studies of kelp beds and their fishes.

A succeeding study on the problem was conducted by David H. Davies, after a year with the kelp program and constitutes the following Chapter (10) of this bulletin. Comparisons were made between amounts of kelp harvested commercially and numbers of fish taken by fishermen aboard sportfishing boats. Statistics were compared within the boundaries of oceanic statistical squares used by the California Department of Fish and Game to delineate all fishing waters along the coast of southern California and include all of the kelp beds as well. Data for 1947 through 1956 were analyzed by means of graphical and correlation analysis. Davies concluded "there is no apparent adverse relationship between the total sportfish catch per unit effort and the amount of kelp harvested" and "the frequency of harvesting operations in the kelp beds has no adverse effect on sportfishing." The findings of Davies did not eliminate the need for further research and in any case the fishery statistics are difficult to evaluate accurately. However, the general conclusions are justified and agree with those of Limbaugh.

Because many gaps of knowledge remained in regard to the central question, further studies were undertaken by the Kelp Program. Quantitative studies were made on the food of the kelp-bed fishes, with particular attention to the kelp bass, and on the size, composition, and habitats of the fish crop.

10.2. FINDINGS

In commercial kelp harvesting, the kelp in the surface 4 feet of water is cut from the plant below by a large set of mower-like blades, of special harvesting vessels, drained of excess water, and loaded by means of conveyer belts into a storage area for transportation elsewhere. The numerous ways in which such an operation may conceivably affect the kelp-bed fishes are discussed below, beneath the appropriate question headings. Effects on yellowtail, barracuda, and bonito, are not treated because these fishes are mainly pelagic and occur about kelp beds only incidentally.

1. *Does the harvesting of kelp destroy significant amounts of the eggs and larvae of fish species of actual or potential sport value?* This problem is discussed in detail in the Limbaugh report and my subsequent observations have substantiated his findings. No fishes of the sport category

attach their eggs to kelp. One forage species, the giant kelpfish, does attach its eggs to kelp, and also to seaweeds on the ocean bottom intertidally and subtidally. This species, though abundant in kelp beds, constitutes only a small fraction of the diet of sportfishes; removal of a small fraction of kelpfish progeny would presumably have little effect upon food chains leading to sportfishes. The giant kelpfish, while taken by the kelp bass in limited quantities, does not seem either to be as available or desirable as other similar-sized prey items such as squid, octopus, crabs, anchovy, and other fishes.

Although the larvae of fish may occasionally reach high concentrations in the kelp canopy, probably only a minimal fraction of their number is taken aboard a kelp cutter. The forward motion of the ship or barge creates strong currents and eddies about the kelp in the mowing blades, and these forces undoubtedly sweep a major portion of the swimming fishes and motile invertebrates from the blades and stipes. Also, the kelp is drained before it is stacked aboard the cutter, giving trapped organisms a second chance to return to the sea. Some of the kelp canopy is usually missed by the cutter, and some new canopy appears in the cutter's wake because the freshly cut plants are less bent by the pull of surface currents on their surface fronds. Both the kelp that remains or appears on the surface and the kelp remaining a few feet below are available as refuge to the displaced motile residents of the original canopy.

2. *Does the kelp cutting operation frighten sportfish from the area?* This question is also discussed by Limbaugh who states "Fishes are not driven away during harvesting operations. Diving has revealed them to be extremely plentiful just behind the kelp harvesters. Many species, including the kelp bass, are attracted by such disturbances in the kelp, and probably find extra food at that time." My observations verify those of Limbaugh. At normal kelp-bed depths fish show little concern when boats are operating overhead. Fish were observed to show no more fear of a kelp cutter than of a sportfishing boat, and the fish actually may be less disturbed by a kelp cutter because it operates at lower speeds. Even if fish were frightened unusually by the cutting operation and left the bed, they would undoubtedly return to their original surroundings when the disturbance ceased.

3. *Are significant amounts of fish food in the form of kelp, the organisms attached to the fronds and stipes of the plant, and trapped swimming invertebrates and fishes, removed by the harvesting operation?* This question was studied by Limbaugh and was also quantitatively investigated by Clendenning and Wing. Limbaugh concluded "The amount of invertebrate material brought on board attached to the kelp is so small in comparison with that left on the plants below the canopy that its absence can have little effect on the available food supply of the few fishes that feed on this material. Most of the free-swimming crustaceans and other fish-food organisms fall back through the screen." Studies by Clendenning and Wing showed that approximately one-third of the motile invertebrate animals that are associated with kelp fronds are taken aboard the kelp harvester. This value probably should be reduced to one-fourth or possibly less when

all forage animals are considered, because small fish are common in the canopy but were not included by the sampling procedure.

The relationship between kelp harvesting and the forage of the sportfishes may be roughly calculated, giving consideration to the probable effects of the most severe harvesting conditions. Both North and Clendenning (personal communication) agree that such circumstances are extreme and are probably rarely attained in actual practice; the calculations are presented merely to indicate maximal possible effects. In this calculation, it is assumed that 90 percent of the forage animals in a kelp bed are in the kelp canopy (Clendenning believed that 65 percent is a more reasonable upper limit), that the population of forage animals in the canopy is fully reconstituted in 3 months, and that the bed is cut three times a year. Under these conditions, for every 10 pounds of forage animals in the bed, 9 pounds are susceptible to removal. of the 9 pounds of animals on the cut kelp, one-third or 3 pounds would be taken aboard the harvester and 6 pounds would return to the bed, leaving 7 pounds or 70 percent of the original animal material. On the basis of yearly loss, this 30 percent removal is roughly equivalent to a 15 percent loss when averaged over the 3-month period required for reconstitution of the canopy fauna (assuming that reconstitution is proportional to time). If three cuttings occur yearly, the maximum yearly loss would amount to:

$$\frac{\text{percent lost} \times \text{period of loss} \times \text{number of loss periods}}{\text{total time}}$$

or:

$$\frac{0.15 \times 3\ \text{(months)} \times 3\ \text{(harvests)}}{12\ \text{(months)}}$$

equals:

$$\text{11 percent}$$

FIGURE

It must be emphasized that these figures represent maxima and include numerous assumptions too extreme for average conditions. Other assumptions that are included in the above calculations, but might be questioned, include the importance to sportfishes of the 3-month period allowed for full canopy recovery. It is possible that the canopy may be in its prime as a food source for fishes when it is quite open and long before it is fully recovered. A thin canopy may encourage the penetration of such forage fishes as topsmelt, anchovy, and sardine into the bed, and may render the inhabitants of the canopy more available to predaceous fishes.

Even the most severe conditions outlined above, in which the kelp bed is suddenly deprived of 30 percent of its forage animals, should not be seriously deterimental to the sportfishes, because they are surrounded by ample reserves in the form of motile animals that are either displaced from the canopy by the harvester or unaffected by the harvesting. For the kelp bass, these reserves in fishes alone, with examples of numbers found in underwater surveys, include kelp perch (up to 800 per acre), topsmelt (100–200 per acre), jack mackerel (100–500 per acre), giant and other species of kelpfish (150–550 per acre), pipefish, and numerous other species. Such reserves may be expected to buffer resident sportfishes adequately over the temporary periods of food shortage that are postulated.

Some kelp enters the diet of the fishes by way of intermediate animals, such as the kelp isopod (Idothea resecata) , the kelp burrowing isopod (Limnoria sp.), and other invertebrate items such as gammarid amphipods and polychaete worms. The trophic relationships between these animals and kelp is described in California Water Quality Control Board, 1964. However, no fish is critically dependent on any of these invertebrates, and numerous alternative foods normally are available when any one item is absent. Among the kelp-eating forage items the kelp isopod is utilized most heavily by the kelp bass. Frequency-of-occurrence of this item ranges up to 20 percent (this food present in one out of five digestive tracts), but normally averages somewhere about 10 percent. Although large numbers of this isopod are frequent in the portion of a kelp bed that is harvested, the isopods are good swimmers and a large proportion of those that are in the canopy undoubtedly escape the kelp harvesters. Kelp isopods have been observed in good abundance in a kelp canopy approximately 1 week after the bed was harvested.

Kelp has been observed in quantity in the digestive tracts of only three species of fishes that are commonly associated with the kelp beds; opaleye, halfmoon, and señorita. Usually, adult opaleye are abundant about inshore rocky areas (from the surf zone to depths of 80 feet) and nearly every individual examined has its digestive tract packed with algae. Kinds of plants in the digestive tracts vary with the locality from which fish are taken. In shallow water, near the surf, adults usually contain moss-like reds and browns, while adults from kelp beds are usually stuffed with kelp. Similarly, kelp is frequently found in the digestive tracts of the halfmoon, but to a lesser degree than in the opaleye. Sometimes kelp may also occur in considerable quantities in señorita. However, the role of kelp in the diet of the three fishes is problematical, because examination of ingested kelp at the beginning and end of the digestive tract discloses that the kelp is altered remarkably little by the digestive process. Several attempts to demonstrate an enzyme capable of digesting kelp in the opaleye had negative results. A dozen half-grown fish confined in a tank and restricted to a diet of unencrusted kelp, gained no weight and died, apparently of starvation, within a month (see Chapter 8, this bulletin). Although these results are not conclusive, they offer some evidence that the kelp itself is not sought as food and that the three species may ingest algae primarily for the abundant animal materials present on its surface. of the three fish species, the opaleye utilizes kelp most extensively and is of greatest importance to the sportfishery. It is taken primarily by surf fishermen in rocky areas. Population studies indicate that opaleye are usually most abundant from the shallower edge of the kelp beds to the surf, and it is unlikely that kelp harvesting would affect their populations adversely.

As a final note in regard to the relationship between kelp harvesting and the food of the kelp-bed fishes, it should be stated that thin specimens have not been encountered among the kelp bass, California sheephead, or opaleye that were sampled or observed. The observations include an intensive study made in an area that declined from a heavy bed of kelp to a barren region between the beginning of the study and 2 years later.

4. *Does harvesting of the kelp decrease the amount of fishes that can be carried by a kelp bed?* Studies by the Kelp Program disclose that kelp beds may carry over 300 pounds of fish per acre. However, nearly the same amounts of fish may be present in regions that are completely devoid of kelp but contain a rocky substrate of high relief, such as the underwater boulder slopes of Guadalupe Island. In contrast, the dense kelp bed at Gaviota, California, with an apparent abundance of animal foods in the canopy (mysids, kelp isopods) gave measurements of between 2 and 35 pounds of resident fish per acre, presumably because of the detrimental influences of a mud and sand substrate, or the bay-like environment. In regions with similar rocky substrates of low or moderate relief, the areas with kelp give estimates of the standing crop of fishes that is two to three times as great as that of similar habitats barren of kelp. These data indicate that kelp is not essential for the presence of large numbers of fishes in an area, but that it is conducive to a larger standing crop of fishes.

A favorable influence of kelp on the standing crop of fishes stems from the circumstance that the tall plants encourage bottom fishes to rise out of visual range of the ocean floor. The kelp columns serve as reference points away from the bottom in cloudy or murky water. Fish species that would be confined to the immediate vicinity of the bottom in a barren area are led, where kelp is present, to utilize the food resources present in the entire water column and at the surface. The removal of the canopy from a kelp bed is not regarded as detrimental because the bottom fishes still have the kelp columns available to facilitate their use of the entire water column.

Removal of the kelp canopy opens the bed, with the probable result that more forage fish of the upper water regions become visible and available to the predators below because they are silhouetted against the sky. It is also likely that an opening of the beds encourages their invasion by important baitfishes, such as the anchovy, sardine, and topsmelt.

For these reasons, it appears doubtful that the removal of the canopy of a kelp bed by harvesting decreases the desirability of the kelp bed to sportfishes. The loss of a fraction of the food is probably compensated for by other positive factors, and the fish undoubtedly are able to adjust to the change. Limbaugh tagged kelp bass in both the cut and uncut portions of a kelp bed near La Jolla and concluded "Obviously the tagged fish (in the harvested section) showed no significant tendency to seek refuge in the uncut area, despite the fact that the handled, marked, and often somewhat displaced fish would be expected to wander more than fish not so disturbed."

10.3. CONCLUSIONS

This report is the latest of three dealing with the relationship between kelp harvesting and the fishes of the kelp beds. Each study utilized different approaches to the problem: Limbaugh's, a qualitive survey; Davies', an examination of kelp-harvest and fishery statistics; and Quast's, quantitative studies on the food and populations of the fishes as well as further observations on their biology and ecology. All three investigators arrived at the same conclusion, namely that, within the limits of the methods used for study, no evidence has been obtained that kelp harvesting has a measurable effect on the fish populations. Although none of the three studies furnish complete proof that kelp harvesting is not detrimental to the fish populations, the agreement between the three investigations in regard to the relationships between the two factors bears considerable weight and must be considered seriously. It must be emphasized, however, that these conclusions apply only to what may be considered routine or normal harvesting practice, in which not over one-half of the kelp plant (linear dimensions) is taken by the harvester and no single bed is harvested more than three times a year. Because the weight of fishes in a specified inshore area is undoubtedly augmented by the presence of kelp, any process, natural or artificial, that reduces the areal extent of a kelp bed may be expected correspondingly to reduce the crop of fishes.

11. 10. STATISTICAL ANALYSIS OF THE RELATION BETWEEN KELP HARVESTING AND SPORTFISHING IN THE CALIFORNIA KELP BEDS

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11.1. INTRODUCTION

The kelp beds and their associated fauna form one of the most complex biological communities known to man. There is reliable evidence from the food chain studies of the Kelp Program that Macrocystis tissues support fishlife in direct and indirect ways (see Chapters 4–8). The studies have also emphasized that the intricate environment formed by the plant structures may act as shelter for fishes and be of benefit in other ways. There can be no doubt that kelp beds are important to associated fishes.

Although kelp is useful to fishlife in the beds it does not necessarily follow that harvesting the canopy affects these fishes adversely. The situation is so complex and such a wide range of responses to harvesting could conceivably occur that no one can state *a priori* what the results of harvesting will be. It is a question that must be investigated exhaustively, utilizing every possible approach.

The ecology of kelp-bed fishes is treated at length by Jay C. Quast in Chapters 5–8 of this bulletin. An earlier study (Limbaugh, 1955) was also conducted at the University of California's Institute of Marine Resources. The information from both these studies is largely of a basic nature and has provided a good foundation and an extensive background for research on the kelp itself and on the fauna associated with it.

Likewise in Limbaugh's report and in Chapter 9 of this bulletin, attention is directed toward whether the harvesting of kelp has a detrimental effect on fish life and sportfishing in the kelp beds. Limbaugh expressed his judgment that "kelp harvesting, as currently practiced, has no seriously detrimental effects on fishing," and Quast agreed in this conclusion (Chapter 9). The investigations leading to the formation of this opinion were of considerable extent, and included many field observations.

A great quantity of data possibly bearing on the relation between harvesting and sportfishing, was available from the Department of Fish and Game. The Department gathers detailed statistics on sportfish catches from party boats and has a grid system of numbered squares, 10 nautical miles on a side, to identify location of all activities (Figure

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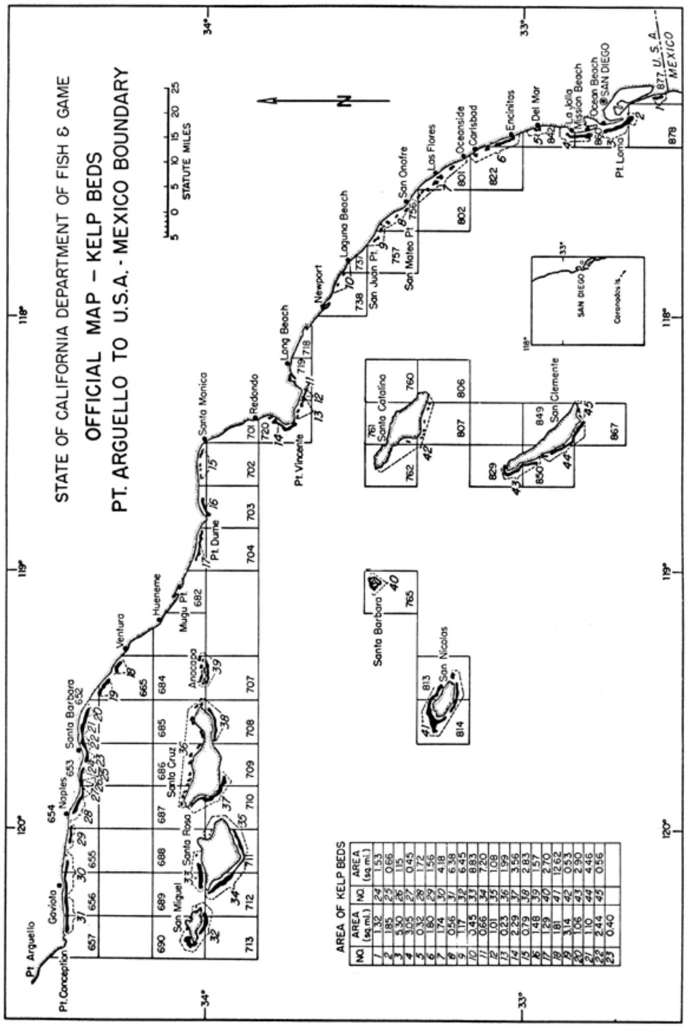
[1] Deceased, Nov. 1965



AREA OF KELP BEDS

NO.	AREA (sq. mi.)	NO.	AREA (sq. mi.)
1	1.32	24	1.53
2	1.85	25	0.66
3	5.30	26	1.15
4	3.05	27	0.45
5	0.32	28	1.72
6	1.80	29	1.56
7	1.74	30	4.18
8	0.56	31	6.38
9	1.17	32	6.45
10	0.45	33	8.83
11	0.66	34	7.20
12	1.01	35	1.08
13	0.23	36	1.99
14	2.29	37	3.56
15	0.79	38	2.83
16	1.48	39	1.57
17	1.29	40	2.70
18	1.81	41	12.62
19	3.14	42	0.53
20	1.06	43	2.90
21	1.10	44	4.46
22	2.44	45	0.56
23	0.40		

FIGURE 50. Official map of the numbered kelp beds in southern California, and selected statistical areas, 10′ lat. x 10′ long. used for reporting fish catches.

FIGURE 50. ***official map of the numbered kelp beds in southern California, and selected statistical areas, 10' lat. x 10' long. used for reporting fish catches.***

50). Kelp harvest records are also kept. The different beds are assigned numbers so that the sources of the harvest can be specifically identified (Figure 50).

These data were subjected to detailed analysis to seek objective evidence, one way or the other, whether the commercial harvesting of kelp has a detrimental effect on sportfishing. It is considered that the analysis of the data has provided an answer to this problem.

To devise and carry out a research program that would provide as large a quantity of relevant statistical material as that already available in the form of kelp harvesting returns and the sportfish catch returns for a period as long as 10 years, would require the services of a large staff of scientific and technical personnel, very great expenditure, and many years of work, all of which were quite beyond the capacity of the Kelp Program. It is also doubtful whether the data thus obtained would be as good as those obtained from the State Fisheries Laboratory. It was indeed fortunate, therefore, that such material existed and could be utilized.

The sportfish catch data are by no means perfect and are subject to various types of error. For example, in the identification of kelp bass some confusion arises owing to the superficially similar appearance of certain rockfishes, particularly the olive rockfish Sebastodes serranoides. Catch returns may be rendered incorrect due to lack of care or to a tendency to exaggerate, and catches made from private boats are not ordinarily recorded. It is considered, however, that the sum of these errors does not seriously affect the conclusions drawn in this paper, largely because the material used was made up from a very considerable amount of data collected over a wide area during a period of 10 years. Many of the errors compensate for one another.

11.2. ACKNOWLEDGMENTS

I am indebted to the following members of the staff of the Scripps Institution of Oceanography and the Institute of Marine Resources of the University of California for reading and criticising this paper: Carl L. Hubbs, Professor of Biology; Charles D. Wheelock, previously Director of Marine Resources; Francis T. Haxo, Professor of Marine Botany; Denis L. Fox, Professor of Marine Biochemistry; and Wheeler J. North, Associate Professor, California Institute of Technology.

I also wish to acknowledge the advice given by Milner B. Schaefer, Director of the Institute of Marine Resources and the cooperation given by Parke H. Young of the California State Fisheries Laboratory; Raymond Cannon of the Ocean Fish Protective Association; Glen McCann of Philip Park, Inc. of San Pedro and Lee D. Pratt and the staff of the Kelco Company of San Diego.

11.3. THE KELP-HARVESTING INDUSTRY

Macrocystis beds vary considerably in size and may cover a surface area of several square miles (Figure 51). off the coast of southern California Macrocystis is harvested by means of specially built barges (Figure 52) designed to cut the surface canopy and at present permitted by the State to operate down to a depth of 4 feet. The barges, known as kelp harvesters, vary in size and can carry loads of wet kelp

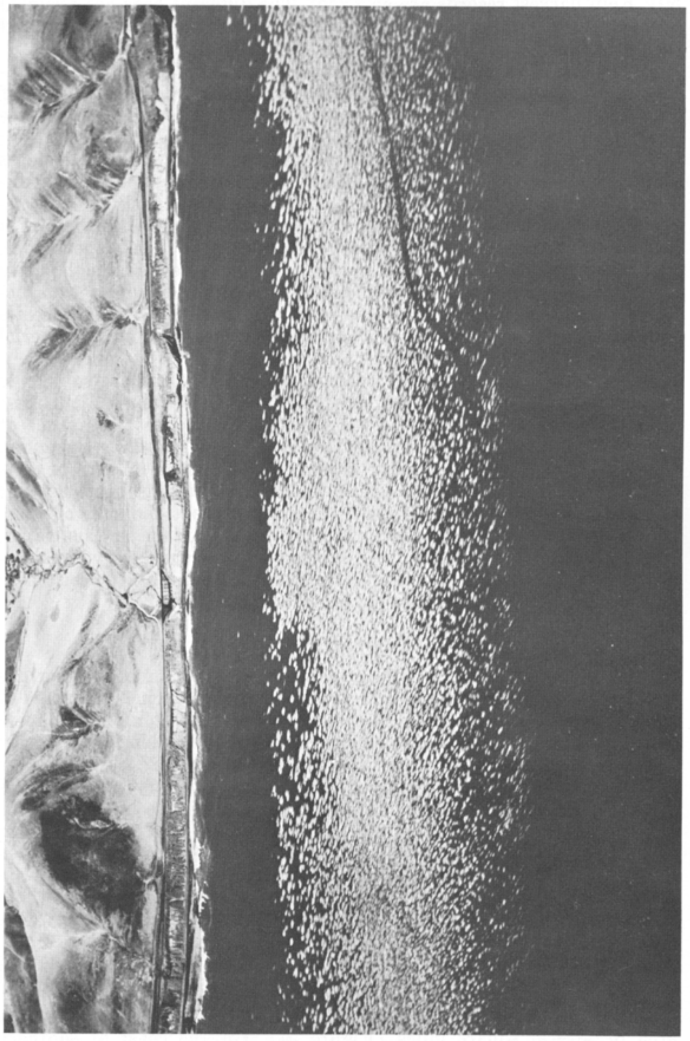


FIGURE 51. Infra-red serial photograph of a bed of giant kelp (Number 30). Courtesy of the Kelco Company.

FIGURE 51. ***Infra-red serial photograph of a bed of giant kelp (Number 30). Courtesy of the Kelco Company.***

as great as 300 tons. The kelp is transported from the cutting blades by a conveyor and automatically dumped into the open hold of the barge. Kelp harvesters are based at Port Hueneme, San Pedro, and San Diego.

FIGURE 52. **Kelp harvesting barges. Photos courtesy of Philip R. Park, Inc. (top) and Kelco Company (bottom).**

FIGURE 52. ***Kelp harvesting barges. Photos courtesy of Philip R. Park, Inc. (top) and Kelco Company (bottom).***

In general, cutting operations are planned in such a way that a full load of fresh kelp is brought in by each harvester to the processing plant each day, but the movements of the harvesters are naturally affected by such factors as adverse weather conditions, poor condition of the kelp beds, and the location of the kelp beds. Healthy kelp beds which are located near the home ports of the harvesters and which can maintain steady, thick growth are subjected to the most frequent harvesting. In certain beds harvesters may operate as many as 90 times during 10 months of the year, though any one area is not fully harvested more than 3 to 4 times per year. For various reasons the canopy of a bed is never entirely removed. According to the records of kelp-harvest returns, individual beds are capable of a high sustained yield produced by frequent harvesting, which is indicative of high productivity rather than any tendency toward overexploitation.

During the period 1947–56 the amount of kelp harvested off the coast of southern California increased considerably, and the total harvest in 1956 was more than one and one-half times greater than in 1947. Aerial surveys carried out in 1955, 1957, and 1958 revealed no overall decrease in the size or number of the kelp beds. Certain beds near metropolitan centers, however, were considerably reduced (California Water Quality Control Board, 1964). Considerable regression of kelp occurred in 1959 but this was believed to be the result of unusually high ocean temperatures. Most beds have recovered satisfactorily and annual harvest totals have continued to increase.

Kelp harvesters are unable to operate very close to the shore, i.e., in waters less than 25 feet deep. They remove the canopy to a depth of about 4 feet below the surface and in addition, they may leave intact an area of surface canopy that is not accessible. Further, Macrocystis is known to be capable of extremely rapid growth under favorable conditions. For these and other reasons (such as data obtained from aerial surveys) it is thought probable that the present rate of kelp harvesting is below its maximum sustainable yield.

The industry based on the harvesting of kelp off the coast of California is of considerable importance to the country, owing to the wide range of valuable products which are manufactured by the highly specialized plants and laboratories of the kelp companies. These products include algin, which, because of its hydrophilic, colloidal properties is widely employed in the preparation of numerous articles, including foods, drugs, cosmetics, and building materials. Kelp products are also used in the manufacture of stock and poultry feeds, pharmaceuticals, fertilizers, etc.

11.4. THE SPORTFISHING INDUSTRY

Sportfishing is one of the most popular recreational activities of the people inhabiting the west coast of the United States. Fishing is carried on from private boats and chartered boats of many types and sizes as well as from the beaches, rocks, breakwaters, and piers. Sportfishing has been popular off the coast of California for many years but during recent years its popularity has undergone a tremendous increase. This is well illustrated by the increase in the number of registered party boats which are regularly used for sportfishing; e.g., in 1946 there were 438 registered party boats but by 1952 this figure had risen to 987 (Figure 53).

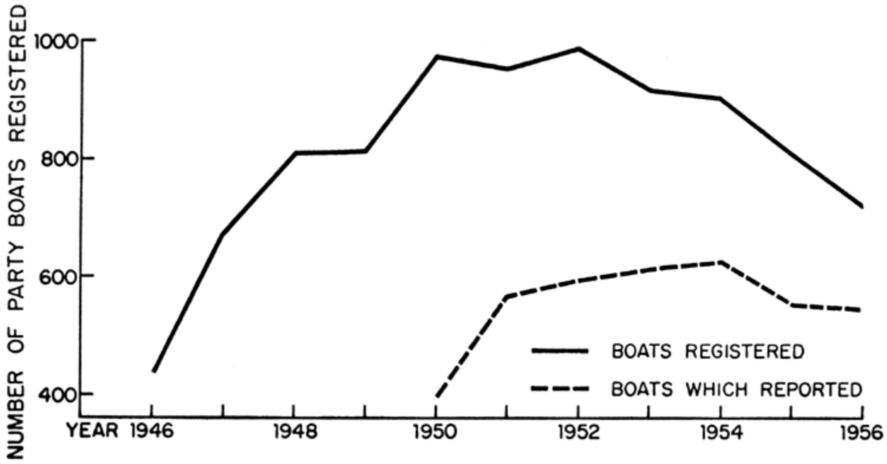


FIGURE 53. Numbers of partyboats registered, 1946 to 1956.

FIGURE 53. ***Numbers of partyboats registered, 1946 to 1956.***

At one time sportfishing was considered as an occupation of little or no significance in relation to the economy or well-being of the country, although it provided employment for a certain number of people. That time has passed, however, and sportfishing is now regarded not only as an incidental yet valuable source of supply of additional food of high protein value, but also as one of the most important recreational assets of the nation.

At the present, when the population of the United States is steadily increasing, the length of the working day becoming shorter, and the tempo of life becoming faster, the need for suitable recreation is becoming a matter of vital importance to the nation. Recreational facilities and resorts on land are becoming increasingly overcrowded, and more and more people are turning to the sea for their recreation. It is, therefore, in the national interest to conserve and develop as many marine recreational facilities as possible. of these, sportfishing is of the greatest importance.

It is reported that 25,000,000 people in the United States depend on sportfishing for their outdoor recreation, and that this activity results in a turnover of two billion dollars each year (Sport Fishing Institute, 1957). Much of the activity naturally occurs along the western seaboard, especially in California.

As has already been mentioned, fishing off the coast of California may be carried on from a variety of places ashore, and from various types of boats. An accurate recording of the catches from all these sources along hundreds of miles of coastline would be quite impossible. The staff of the State Fisheries Laboratory has, however, kept accurate records of the reports of catches made by a large number of the registered party fishing boats. An average of over 67 percent of all registered boats made returns of their catches during the last 5 years under consideration. Examples of these boats are shown in Figure 54. When it is considered that the owners of these boats depend on fishing for their livelihood, it is not unreasonable to assume that their efforts to locate and catch sportfish throughout the years will be optimal and on the average constant. Because of this and owing to the fact that the catch returns have been collected and conscientiously recorded and processed by the State Fisheries Laboratory, it is considered that these

FIGURE 54. Examples of party sportfishing boats (partyboats). Top: *Worrier VII* carries 23 passengers, is 48 feet long, and is powered by 450 hp twin diesel engines. Bottom: *New Mascot* carries 60 passengers, is 65 feet long, and is powered by 600 hp twin diesel engines. Courtesy H & M Sportfishers.

FIGURE 54. ***Examples of party sportfishing boats (partyboats). Top:*** *Worrier VII* ***carries 23 passengers, is 48 feet long, and is powered by 450 hp twin diesel engines. Bottom:*** *New Mascot* ***carries 60 passengers, is 65 feet long, and is powered by 600 hp twin diesel engines. Courtesy H & M Sportfishers.***

data reliably reflect the fluctuations in the numbers and availability of the major sportfishing species in the areas fished throughout the year.

The system devised by the State Fisheries Laboratory for the rendering of these returns in defined 10 x 10 mile squares has enabled the selection of sportfish catch returns from only those squares that contain kelp beds (Figure 50), so that the catches we will consider have been made in or in the immediate vicinity of the kelp beds. This is, of course, true not only along those parts of the main shore where the portion of the given square that is covered by the sea is all in or near the kelp, but also in other squares, since most of the fishing is done near the kelp.

Thus there are detailed data available that show not only the quantities of kelp harvested monthly from each bed, but also the numbers of sportfish caught monthly in or near those beds; it was considered that a careful analysis and comparison of these data would reveal the effect of one on the other, if indeed, any such effect existed.

Before proceeding to this analysis, it is of interest to list the main species of fish caught by the sportfishermen from the party boats in, or in the immediate vicinity of, the kelp beds off the coast of southern California. These are:

1. Kelp Bass, Paralabrax clathratus (Girard)
2. California Barracuda, Sphyraena argentea Girard P.
3. California Yellowtail, Seriola dorsalis (Gill) P.
4. Albacore, Thunnus alalunga (Bonnaterre) P.
5. Rockfish, Sebastodes spp.
6. Pacific Bonito, Sarda chiliensis (Cuvier) P.
7. Jack Mackerel, Trachurus symmetricus (Ayres) P.
8. Pacific Mackerel, Scomber diego Ayres P.
9. California Sheephead, Pimeolometopon pulchrum (Ayres)
10. White Seabass, Cynoscion nobilis Ayres
11. Black Sea Bass, Stereolepis gigas Ayres
12. Yellowfin Tuna, Thunnus albacares (Bonnaterre) P.
13. Skipjack Tuna, Katsuwonus pelamis (Lesson) P.
14. Bluefin Tuna, Thunnus thynnus (Linnaeus) P.
15. Sculpin, Scorpaena guttata Girard
16. Cabezon, Scorpaenichthys marmoratus (Ayres)
17. Kelp Topsmelt, Atherinops affinis cedroscensis Hubbs
18. Jacksmelt, Atherinopsis californiensis Girard
19. Ocean Whitefish, Caulolatilus princeps (Jenyns)
20. Queenfish, Seriphus politus Ayres
21. Seaperch, Embiotocidae, various
22. Lingcod, Ophiodon elongatus Girard
23. California Halibut, Paralichthys californicus (Ayres)
24. "Sole", Flatfishes, various
25. Sharks, various

P. indicates that the species is generally pelagic (wandering or migratory, usually schooling).

of the species listed above, the most important caught in or near the kelp beds is probably the kelp bass, since it is usually dominant in numbers, is available during the entire fishing season from spring through fall, is an excellent fighter, and is a good table fish. However, other species with superior sporting and edible qualities, such as barracuda, albacore, yellowtail, and white seabass are usually preferred when present.

11.5. COMPARISON OF KELP HARVESTING AND SPORTFISHING STATISTICS, 1947–56

11.5.1. Statewide Comparisons

The kelp-harvesting returns for the coast of California were plotted graphically together with the sportfish catch and catch per unit of fishing effort[2] for the period 1947–56 (Tables 30 , 31 , and Figure 55). During these 10 years the amount of kelp harvested increased each year with the exception of 1954 and 1956. The reason for the decline in the amount of kelp harvested in 1954 is not clear but may be attributable to a decreased availability caused by high water temperatures, together with a decreased demand for kelp products during that year. Surface temperature data for the coast of southern California (Table 32 and Figure 56) show that the mean surface temperature for 1954 was high, viz. 61°F, and that a maximum of 75°F occurred during the year at La Jolla. The latter temperature is frequently associated with the condition known as "black rot" which could have resulted in considerable mortality of kelp. Increased temperature is unlikely to have caused the slight decrease in the amount of kelp harvested during 1956.

The sportfish catch per unit of effort (Figure 55c) fluctuated considerably during the 10-year period. There was an increase from 1947 to 1948 and then a decline through to 1952. From 1952 onward, however, there was a tremendous increase, particularly from 1953 to 1954, after which the high level reached was maintained through 1956. It is possible that the very high catch per unit of effort recorded in 1954 was related to the higher temperatures of this year (Figure 56); yet a high catch per unit of effort was not obtained in 1947, when similar high temperatures were recorded. The fact that the maximum temperature for 1954 was higher than the maximum for 1947 may account for this difference.

The data on the total sportfish catch per unit of effort and the amount of kelp harvested were compared, and tested for correlation. No relationship is apparent from the graph (Figure 55c), and no correlation could be found. It was therefore concluded that there is no apparent overall relationship between the harvesting of kelp and sportfishing. The absence of such a general relationship does not necessarily imply that relationships might not exist between harvesting and a single species or group of species or between all species within a specific bed.

Since the term "sportfish" covers 30 or more commonly caught species, it was decided to extract the data for certain of the more important species and groups. The species selected were the following: kelp bass, barracuda, yellowtail, and all pelagic fish grouped together. These were treated separately to determine whether a relationship existed between any one of these groups and kelp harvesting, as this could have been hidden in the more general treatment of the data carried out above.

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[2] Calculated from the numbers of fish caught and the number of angler days taken to catch them.

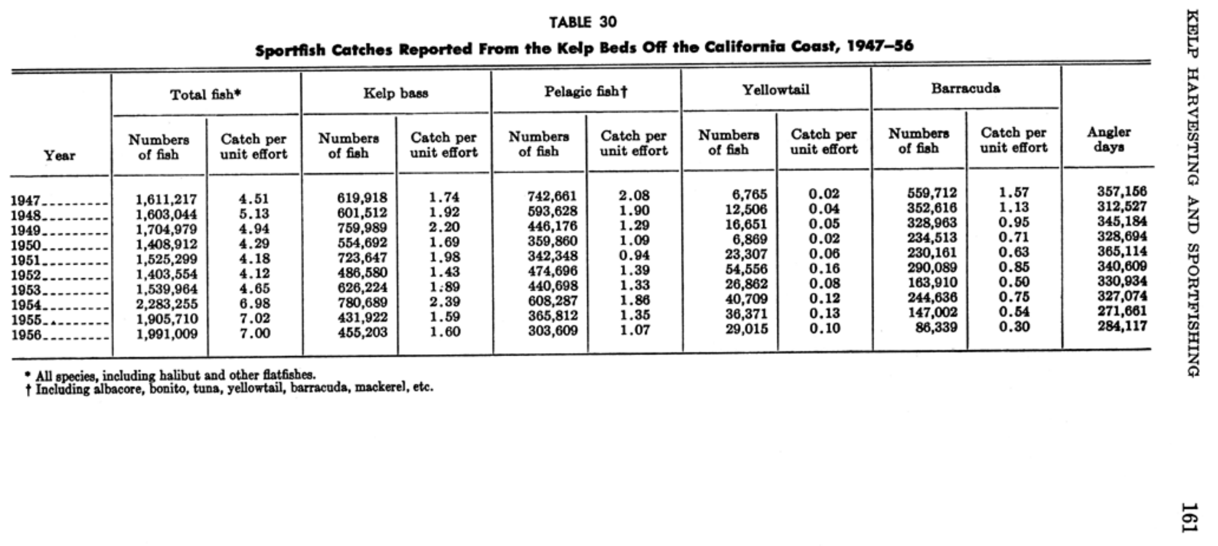


TABLE 30

Sportfish Catches Reported From the Kelp Beds Off the California Coast, 1947–56

Year	Total fish*		Kelp bass		Pelagic fish†		Yellowtail		Barracuda		Angler days
	Numbers of fish	Catch per unit effort	Numbers of fish	Catch per unit effort	Numbers of fish	Catch per unit effort	Numbers of fish	Catch per unit effort	Numbers of fish	Catch per unit effort	
1947	1,611,217	4.51	619,918	1.74	742,661	2.08	6,765	0.02	559,712	1.57	357,156
1948	1,603,044	5.13	601,512	1.92	593,628	1.90	12,506	0.04	352,616	1.13	312,527
1949	1,704,979	4.94	759,989	2.20	446,176	1.29	16,651	0.05	328,963	0.95	345,184
1950	1,408,912	4.29	554,692	1.69	359,860	1.09	6,869	0.02	234,513	0.71	328,694
1951	1,525,299	4.18	723,647	1.98	342,348	0.94	23,307	0.06	230,161	0.63	365,114
1952	1,403,554	4.12	486,580	1.43	474,696	1.39	54,556	0.16	290,089	0.85	340,609
1953	1,539,964	4.65	626,224	1.89	440,698	1.33	26,862	0.08	163,910	0.50	330,934
1954	2,283,255	6.98	780,689	2.39	608,287	1.86	40,709	0.12	244,636	0.75	327,074
1955	1,905,710	7.02	431,922	1.59	365,812	1.35	36,371	0.13	147,002	0.54	271,661
1956	1,991,009	7.00	455,203	1.60	303,609	1.07	29,015	0.10	86,339	0.30	284,117

* All species, including halibut and other flatfishes.

† Including albacore, bonito, tuna, yellowtail, barracuda, mackerel, etc.

TABLE 30

Sportfish Catches Reported From the Kelp Beds off the California Coast, 1947–56

TABLE 31

Total Kelp Harvest for the Cailfornia Coast, 1947–56

Year	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956
Percentage of Total Harvest for the Ten Year Period..	7	8	8	10	11	11	12	10	12	11

TABLE 31

Total Kelp Harvest for the Cailfornia Coast, 1947–56

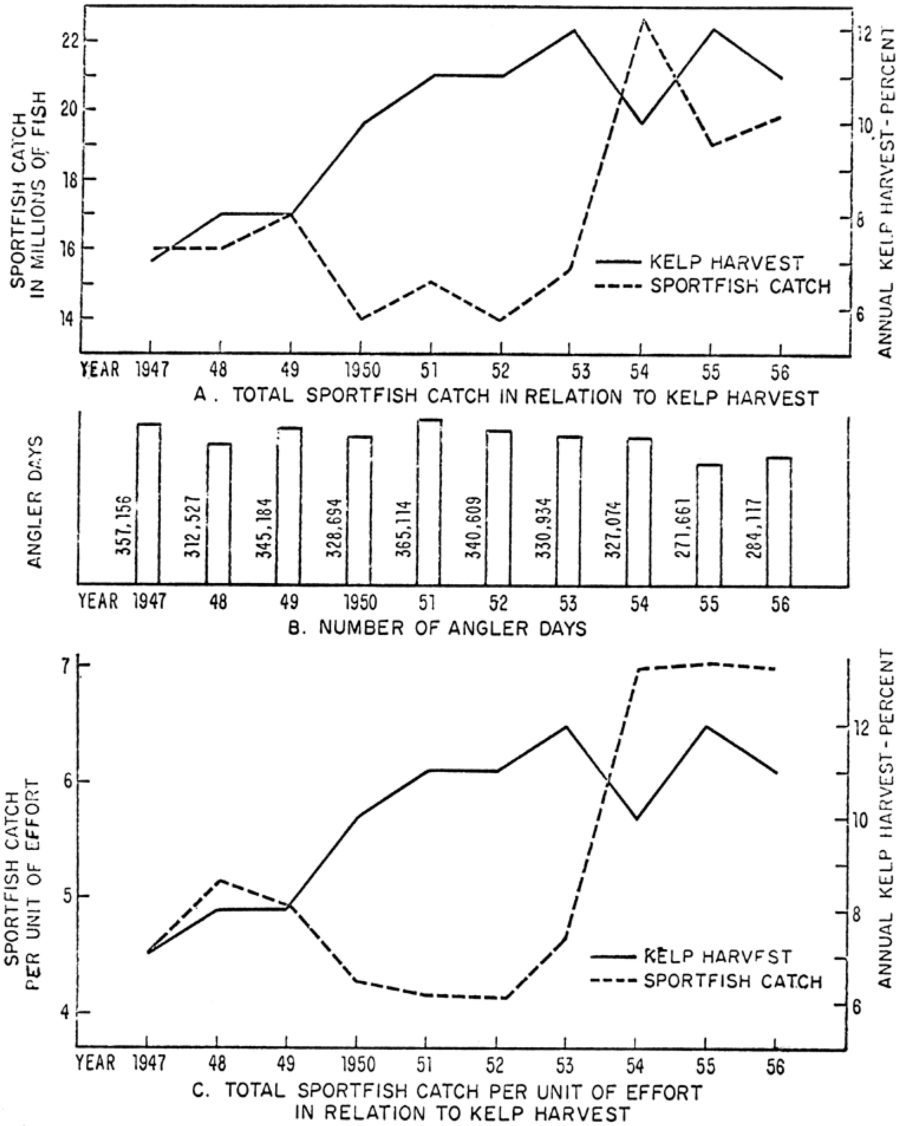


FIGURE 55. Annual statewide partyboat statistics and kelp harvest yields for 1947 to 1956. (a) Total catch vs. harvest. (b) Angler days per year. (c) Catch per unit of effort vs. harvest. Data from Department of Fish and Game.

*FIGURE 55. **Annual statewide partyboat statistics and kelp harvest yields for 1947 to 1956. (a) Total catch vs. harvest. (b) Angler days per year. (c) Catch per unit of effort vs. harvest. Data from Department of Fish and Game.***

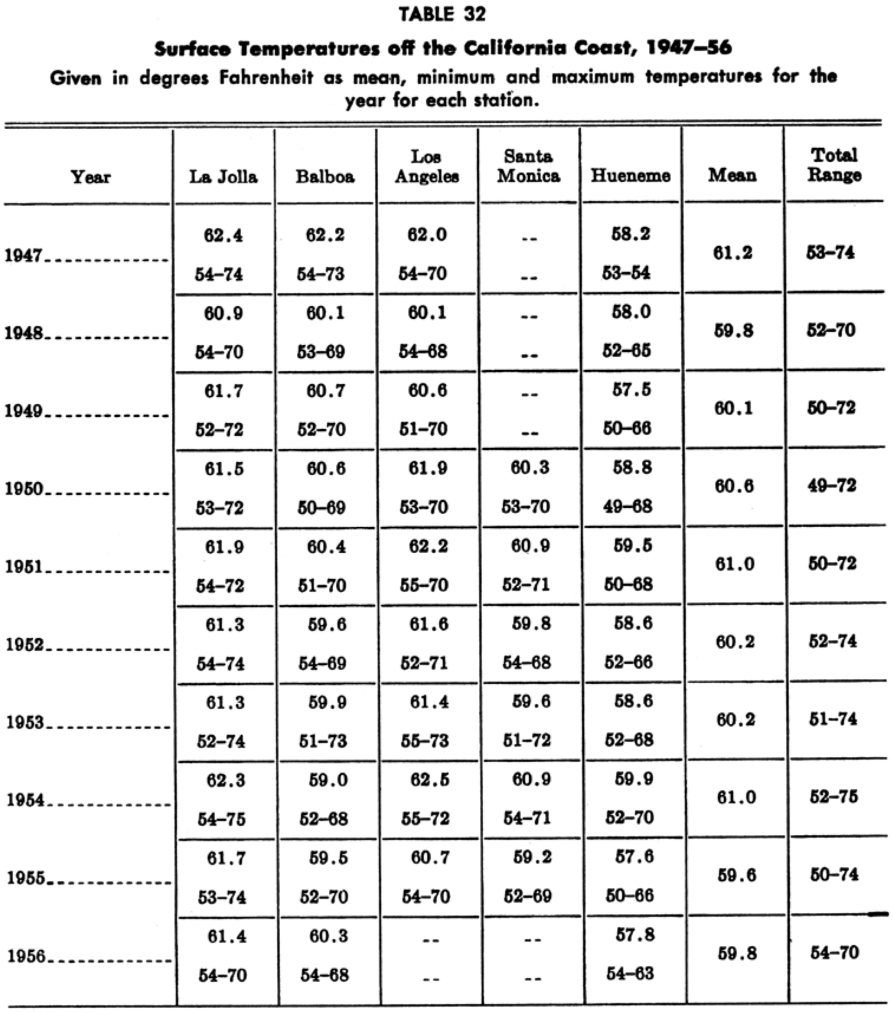


TABLE 32

Surface Temperatures off the California Coast, 1947–56

Given in degrees Fahrenheit as mean, minimum and maximum temperatures for the year for each station.

Year	La Jolla	Balboa	Los Angeles	Santa Monica	Hueneme	Mean	Total Range
1947	62.4	62.2	62.0	--	58.2	61.2	53–74
	54–74	54–73	54–70	--	53–54		
1948	60.9	60.1	60.1	--	58.0	59.8	52–70
	54–70	53–69	54–68	--	52–65		
1949	61.7	60.7	60.6	--	57.5	60.1	50–72
	52–72	52–70	51–70	--	50–66		
1950	61.5	60.6	61.9	60.3	58.8	60.6	49–72
	53–72	50–69	53–70	53–70	49–68		
1951	61.9	60.4	62.2	60.9	59.5	61.0	50–72
	54–72	51–70	55–70	52–71	50–68		
1952	61.3	59.6	61.6	59.8	58.6	60.2	52–74
	54–74	54–69	52–71	54–68	52–66		
1953	61.3	59.9	61.4	59.6	58.6	60.2	51–74
	52–74	51–73	55–73	51–72	52–68		
1954	62.3	59.0	62.5	60.9	59.9	61.0	52–75
	54–75	52–68	55–72	54–71	52–70		
1955	61.7	59.5	60.7	59.2	57.6	59.6	50–74
	53–74	52–70	54–70	52–69	50–66		
1956	61.4	60.3	--	--	57.8	59.8	54–70
	54–70	54–68	--	--	54–63		

TABLE 32

Surface Temperatures off the California Coast, 1947–56

11.5.1.1. Kelp Bass

The numbers of kelp bass caught during the period 1947–56 showed considerable fluctuations, which were to a large extent reflected in the catch per unit of effort (Table 30 and Figure 57).

Although the kelp bass is a most popular sportfish, there is no doubt that it takes second place as far as the sportfisherman is concerned at times when pelagic species such as barracuda, yellowtail, and albacore abound. To establish whether the fluctuations in the kelp-bass catch returns were in any way related to the presence and preferential catching of these pelagic species, data were extracted and graphs were drawn to show the catch per unit of effort of kelp bass and pelagic species for the whole period (Figure 58).

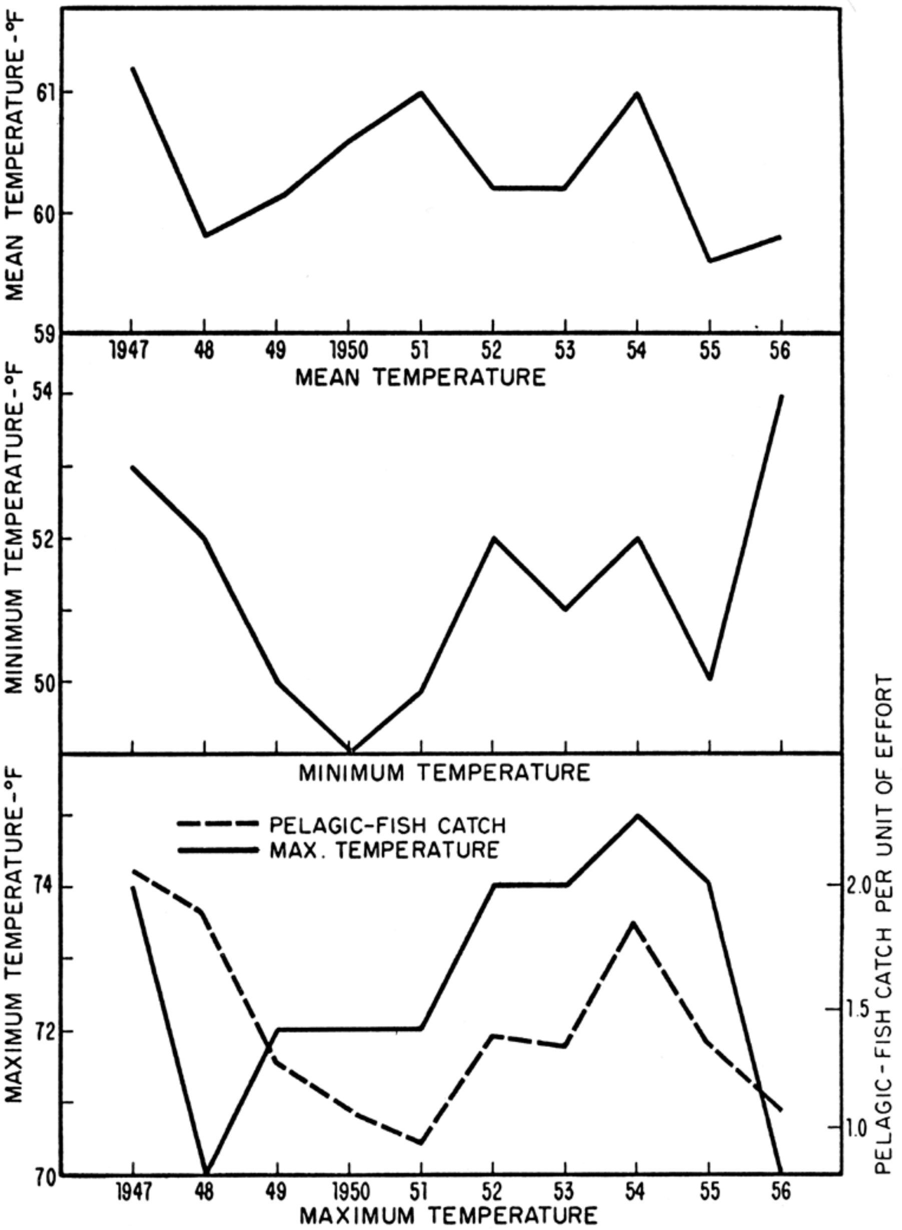
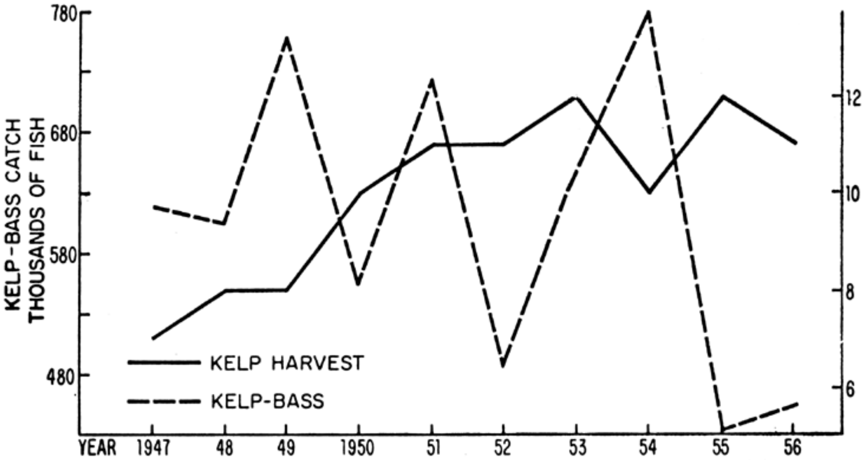


FIGURE 56. **Maximum, minimum, and mean sea surface temperatures off the California coast for 1947 to 1956.**

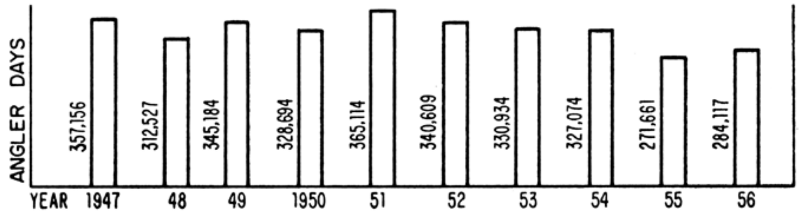
FIGURE 56. ***Maximum, minimum, and mean sea surface temperatures off the California coast for 1947 to 1956.***

From these graphs, it is evident that the catch per unit of effort was higher for kelp bass than for pelagic species in and near the kelp beds during every year of the 10-year period, except 1947. During most years, kelp-bass fishing was considerably better than fishing for pelagic species. There is evidence that some preferential fishing for pelagic species in place of kelp bass took place in 1947 and 1952, but not in 1954.

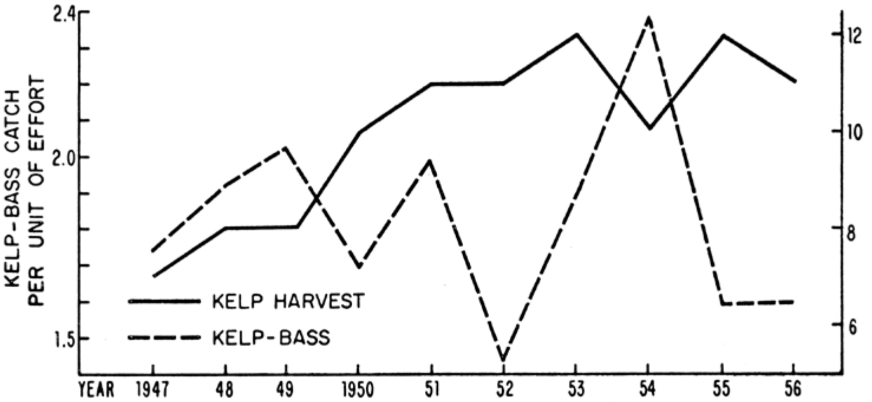
The data on the kelp-bass catch per unit of effort and the kelp-harvest returns (Tables 30 and 31) were plotted graphically (Figure 57) and tested for correlation. Extensive fluctuations of the kelp-bass catch per unit of effort are seen to have occurred in a manner which appears quite unrelated to the size of the kelp harvest for the years concerned. No correlation of these data was obtained. It may be stated, therefore, that there was no apparent relationship between kelp-bass fishing and the harvesting of kelp.



A. KELP-BASS CATCH IN RELATION TO THE KELP HARVEST



B. NUMBER OF ANGLER DAYS



C. KELP-BASS CATCH PER UNIT OF EFFORT IN RELATION TO THE KELP HARVEST

FIGURE 57. Annual statewide kelp bass catches by partyboats and kelp harvest yields for 1947 to 1956. (a) Total catch vs. harvest. (b) Angler days per year. (c) Catch per unit of effort vs. harvest. Data from Department of Fish and Game.

FIGURE 57. ***Annual statewide kelp bass catches by partyboats and kelp harvest yields for 1947 to 1956. (a) Total catch vs. harvest. (b) Angler days per year. (c) Catch per unit of effort vs. harvest. Data from Department of Fish and Game.***

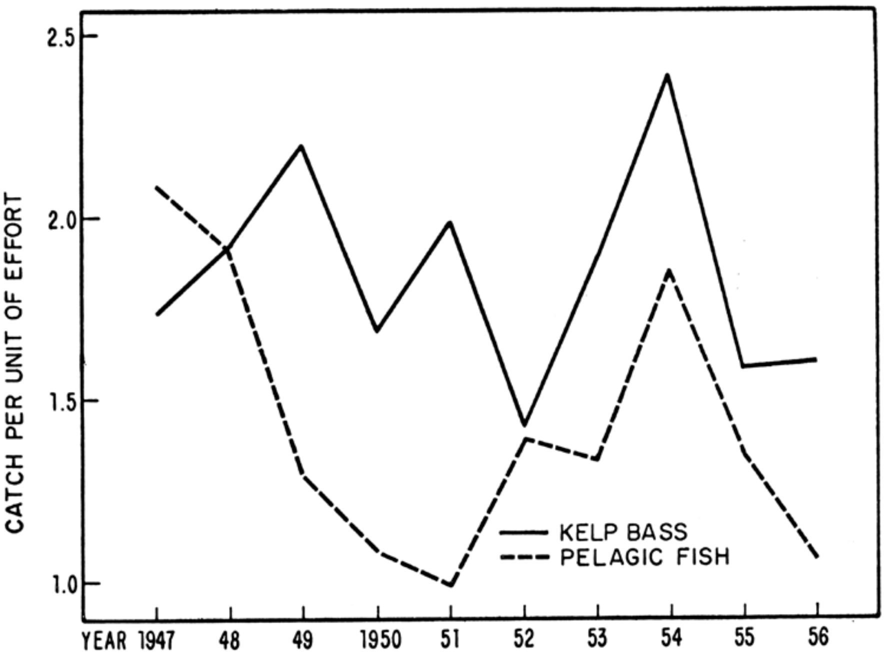


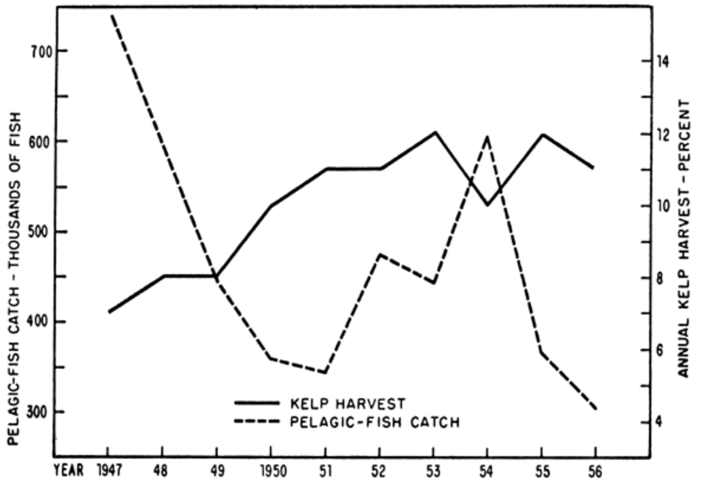
FIGURE 58. Annual statewide catch per unit of effort for pelagic fish and kelp bass for 1947 to 1956. Data from Department of Fish and Game.

FIGURE 58. ***Annual statewide catch per unit of effort for pelagic fish and kelp bass for 1947 to 1956. Data from Department of Fish and Game.***

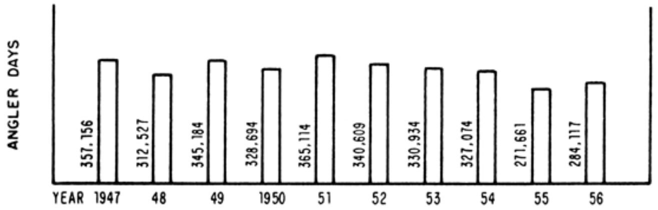
Collyer and Young (1953) considered that up to the end of their investigation in 1951 kelp bass were decreasing in abundance off the coast of southern California. From the catch data (Figure 57c), it seems that this tendency continued into 1952, but that catch per unit of effort increased in 1953 and 1954 with a high peak in 1954. A serious decrease again occurred in 1955 and continued in 1956. The kelp-bass fishery which seems to be based on a series of semi-independent populations (Collyer and Young, 1953), is apparently subject to marked fluctuations, with good recovery even after serious depletions.

11.5.1.2. Pelagic Fish

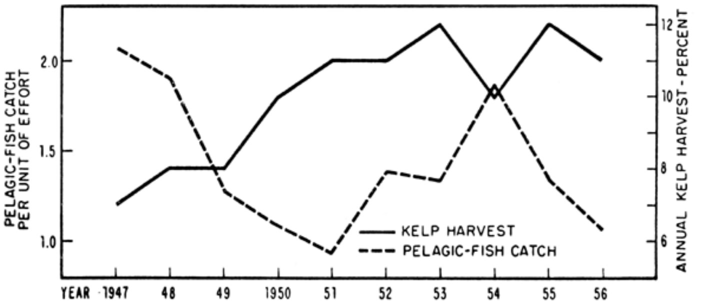
The recorded catches of pelagic fish were plotted graphically in the form of actual catches and catches per unit of effort, together with the kelp-harvest returns for the years 1947–56 (Figure 59). The relative positions of the graphs of the pelagic-fish catch per unit of effort (Figure 59c) and the total kelp-harvest returns immediately suggest the possibility of an inverse relationship. Tests for correlation of the data showed a correlation coefficient of -0.63, i.e., a considerable degree of negative correlation, which confirmed the fact that there was an inverse statistical, but not necessarily causal, relationship between the pelagic-fish catch per unit of effort and the amount of kelp harvested during the 10-year period 1947–56.



A. TOTAL PELAGIC-FISH CATCH IN RELATION TO THE KELP HARVEST



B. NUMBER OF ANGLER DAYS



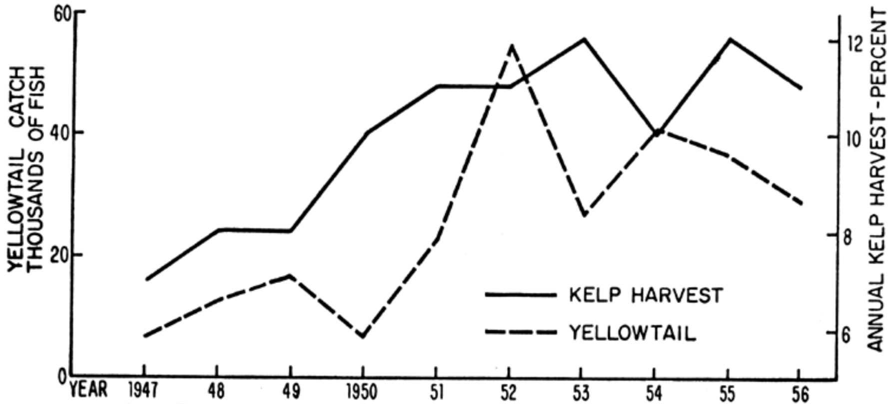
C. TOTAL PELAGIC-FISH CATCH PER UNIT OF EFFORT IN RELATION TO THE KELP HARVEST

FIGURE 59. Annual statewide pelagic fish catches by partyboats and kelp harvest yields for 1947 to 1956. (a) Total catch vs. harvest. (b) Angler days per year. (c) Catch per unit of effort vs. harvest. Data from Department of Fish and Game.

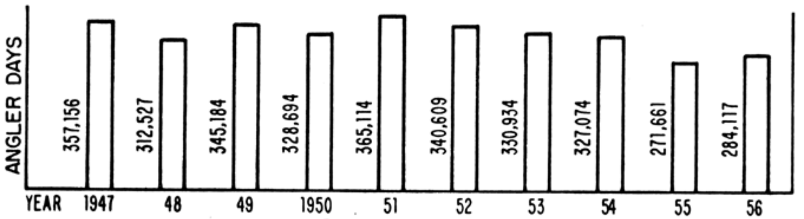
FIGURE 59. ***Annual statewide pelagic fish catches by partyboats and kelp harvest yields for 1947 to 1956. (a) Total catch vs. harvest. (b) Angler days per year. (c) Catch per unit of effort vs. harvest. Data from Department of Fish and Game.***

It is by no means easy to suggest why such a relationship should exist for pelagic fishes, since these are far less likely to be dependent on the kelp than, e.g., kelp bass. The most important pelagic species caught in or near the kelp beds are albacore, bonito, yellowtail, bluefin tuna, and barracuda. All these species are known to occur in areas where Macrocystis pyrifera is not found, and there are no reasons to assume that any of them is critically dependent on kelp.

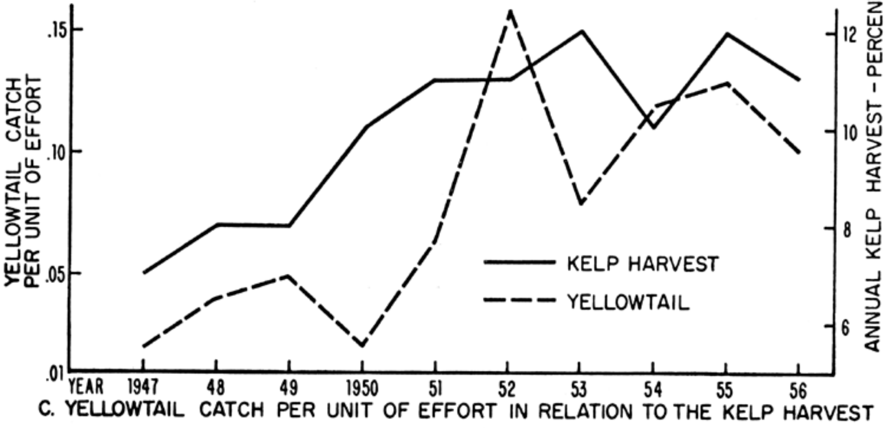
It is likely that an additional factor, such as temperature affects not only the growth and availability of kelp but also the migration of these pelagic fishes from the south into the study area and their concentration



A. YELLOWTAIL CATCH IN RELATION TO THE KELP HARVEST



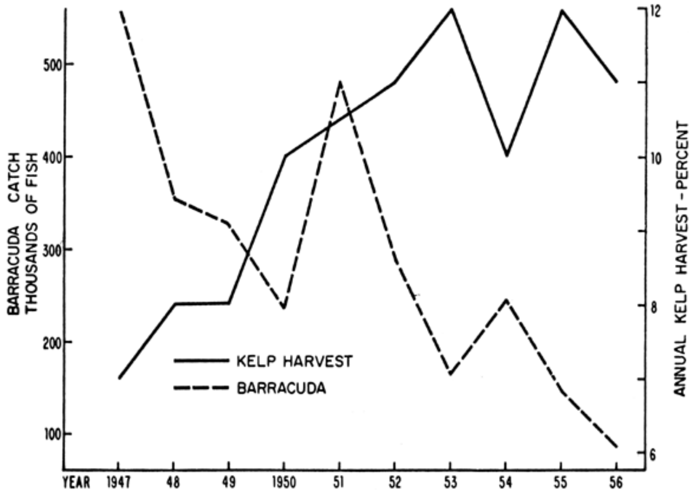
B. NUMBER OF ANGLER DAYS



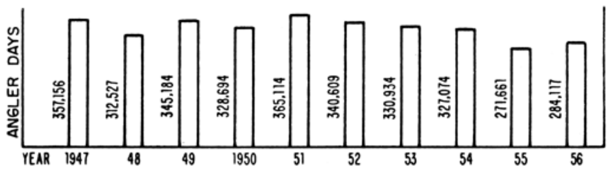
C. YELLOWTAIL CATCH PER UNIT OF EFFORT IN RELATION TO THE KELP HARVEST

FIGURE 60. **Annual statewide yellowtail catches by partyboats and kelp harvest yields for 1947 to 1956. (a) Total catch vs. harvest. (b) Angler days per year. (c) Catch per unit of effort vs. harvest. Data from Department of Fish and Game.**

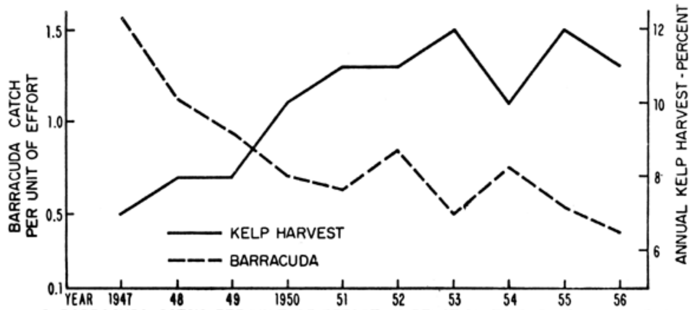
FIGURE 60. ***Annual statewide yellowtail catches by partyboats and kelp harvest yields for 1947 to 1956. (a) Total catch vs. harvest. (b) Angler days per year. (c) Catch per unit of effort vs. harvest. Data from Department of Fish and Game.***



A. BARRACUDA CATCH IN RELATION TO THE KELP HARVEST



B. NUMBER OF ANGLER DAYS



C. BARRACUDA CATCH PER UNIT OF EFFORT IN RELATION TO THE KELP HARVEST

FIGURE 61. Annual statewide barracuda catches by partyboats and kelp harvest yields for 1947 to 1956. (a) Total catch vs. harvest. (b) Angler days per year. (c) Catch per unit of effort vs. harvest. Data from Department of Fish and Game.

FIGURE 61. ***Annual statewide barracuda catches by partyboats and kelp harvest yields for 1947 to 1956. (a) Total catch vs. harvest. (b) Angler days per year. (c) Catch per unit of effort vs. harvest. Data from Department of Fish and Game.***

there. Examination of surface-temperature data (Figure 56), and comparison with the pelagic-fish catch per unit of effort and kelp-harvest return data (Figure 59c) showed a highly probable direct relationship between pelagic-fish catch per unit of effort and maximum surface temperature. A correlation test of the data for the entire period produced a correlation coefficient of only +0.3, but the same test carried out for the period 1951–56 produced a coefficient of +0.81, showing a strongly positive direct relationship. This is clearly shown in the graphs (Figure 56c), which follow an almost identical path for the 6-year period.

Except for a lag in 1948 and 1949, caused mainly by high barracuda catches, the pelagic-fish catch per unit of effort followed the graph of maximum temperature remarkably well. The significance of this correlation is increased by the fact that in all previous warm years, northerly extensions of the range of pelagic species have been observed. It is interesting to note that when the maximum temperature reached 75°F in 1954 there was a marked decrease in the amount of kelp harvested and a marked increase in the catch of pelagic fish.

The pelagic-fish catch data were broken down and the catch data on yellowtail and barracuda were examined separately in relation to the kelp-harvesting returns.

11.5.1.3. Yellowtail

The yellowtail catch per unit of effort data (Figure 60c) gave no indication of bearing any relationship to the kelp-harvest returns and comparison with temperature data (Figure 56) also revealed no indications of any relationships.

11.5.1.4. Barracuda

Barracuda catch per unit of effort data, on the other hand, showed an inverse relationship to the kelp-harvest returns (Figure 61c). The correlation coefficient was -0.88, indicating strong negative correlation; the barracuda data are mainly responsible for the negative correlation between the kelp-harvest returns and the pelagic-fish catch per unit of effort.

In spite of this rather striking mathematical relationship, however, it is considered unlikely that any causal relationship exists and that the fluctuations in the two graphs, relative to each other, may be attributed primarily to coincidence. It is important to consider that the general trend of barracuda fishing was downward throughout the 10-year period. The enormous increase in sportfishing during this postwar period may have resulted in some depletion of the barracuda stocks, and that recent (1957) improvement in barracuda fishing may have been brought about by increased migration from the south, encouraged by an unusually high water temperature.

There is no evidence that barracuda are in any way directly dependent on kelp, but it is likely that they are attracted to the kelp beds by the presence of large numbers of small fish and other food organisms. Kelp harvesting could possibly affect the small fish in some way and produce some reaction in the barracuda shoals.

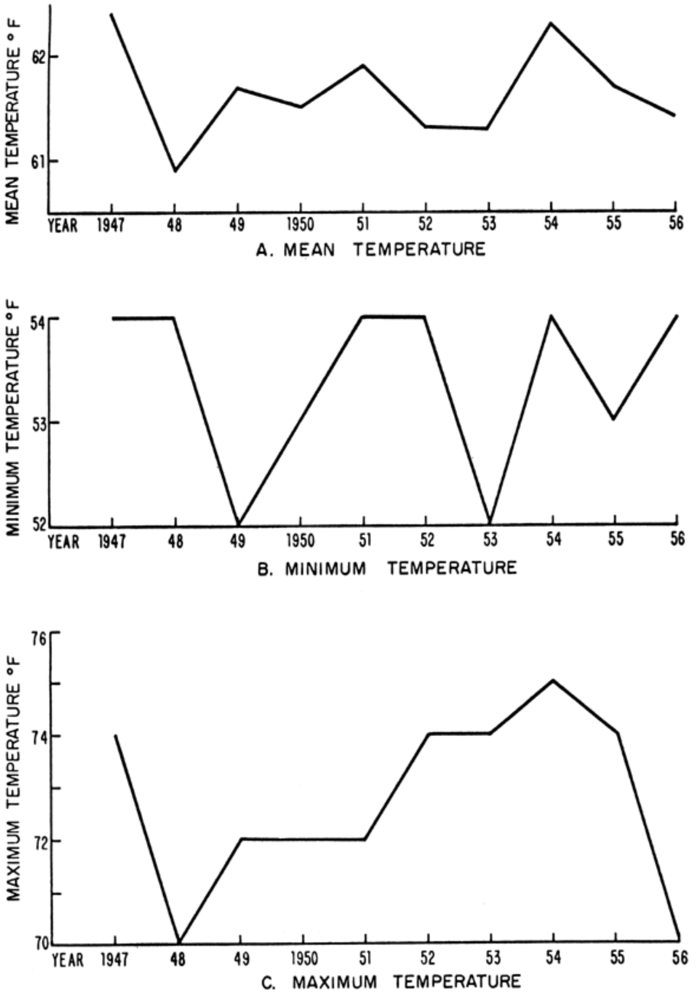


FIGURE 62. Maximum, minimum, and mean sea surface temperatures at the end of the pier at Scripps Institution of Oceanography for 1947 to 1956.

FIGURE 62. ***Maximum, minimum, and mean sea surface temperatures at the end of the pier at Scripps Institution of Oceanography for 1947 to 1956.***

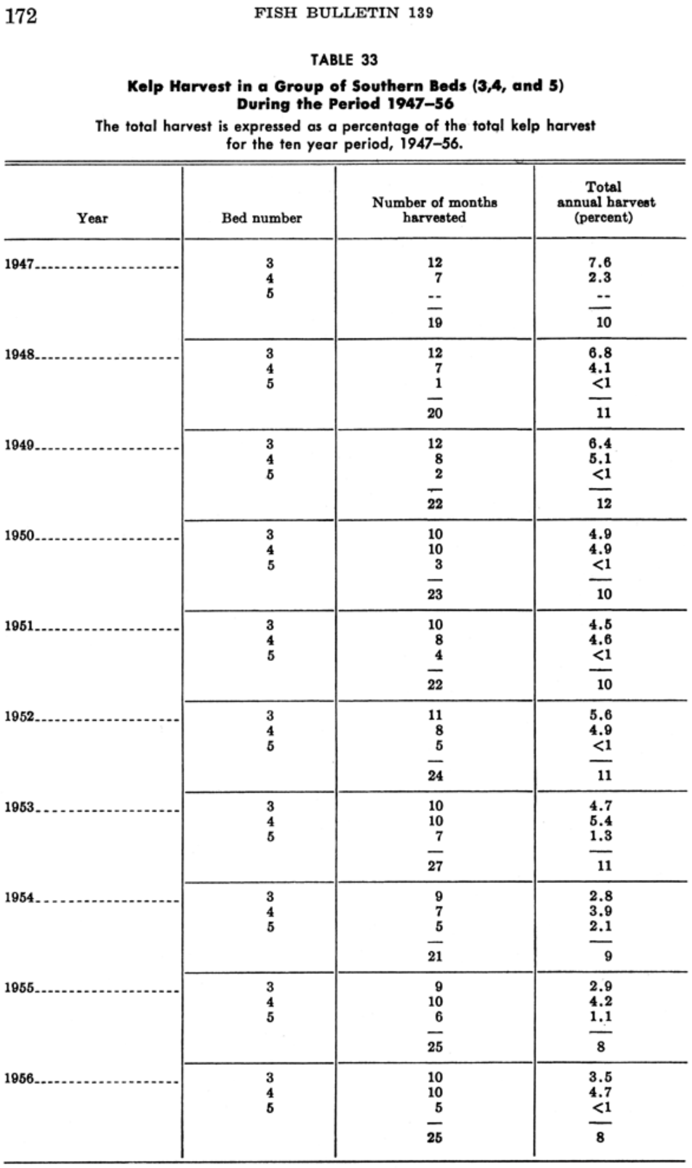


TABLE 33

Kelp Harvest in a Group of Southern Beds (3,4, and 5) During the Period 1947–56

The total harvest is expressed as a percentage of the total kelp harvest for the ten year period, 1947–56.

Year	Bed number	Number of months harvested	Total annual harvest (percent)
1947	3	12	7.6
	4	7	2.3
	5	--	--
		19	10
1948	3	12	6.8
	4	7	4.1
	5	1	<1
		20	11
1949	3	12	6.4
	4	8	5.1
	5	2	<1
		22	12
1950	3	10	4.9
	4	10	4.9
	5	3	<1
		23	10
1951	3	10	4.5
	4	8	4.6
	5	4	<1
		22	10
1952	3	11	5.6
	4	8	4.9
	5	5	<1
		24	11
1953	3	10	4.7
	4	10	5.4
	5	7	1.3
		27	11
1954	3	9	2.8
	4	7	3.9
	5	5	2.1
		21	9
1955	3	9	2.9
	4	10	4.2
	5	6	1.1
		25	8
1956	3	10	3.5
	4	10	4.7
	5	5	<1
		25	8

TABLE 33

Kelp Harvest in a Group of Southern Beds (3,4, and 5) During the Period 1947–56

11.5.2. COMPARISONS IN A GROUP OF SOUTHERN KELP BEDS

The selection of "typical" southern beds was no easy matter, as certain beds had declined or disappeared altogether during the 10-year period under consideration. Some were not regularly harvested and others were not regularly fished by the sportfishermen. The three adjacent beds chosen are located within two sportfish statistical squares. These beds are Nos. 3, 4, and 5, situated off Point Loma, La Jolla, and Del Mar respectively, and located within statistical squares 842 and 860 (Figure 50).

The kelp harvest for the southern beds underwent considerable fluctuations during the period 1947–56 (Table 33) . In particular, there was a rapid decline in the last 4 years (1953–56). Comparison with surface temperature data (Table 34 and Figure 62) revealed a small possible degree of inverse relationship between the kelp harvesting data amd mean temperatures (correlation coefficient -0.3). This was particularly noticeable in 1954, when the mean temperature was high and the maximum temperature recorded was 75° F. Probably this damaged the kelp beds and resulted in a decrease in the kelp harvest.

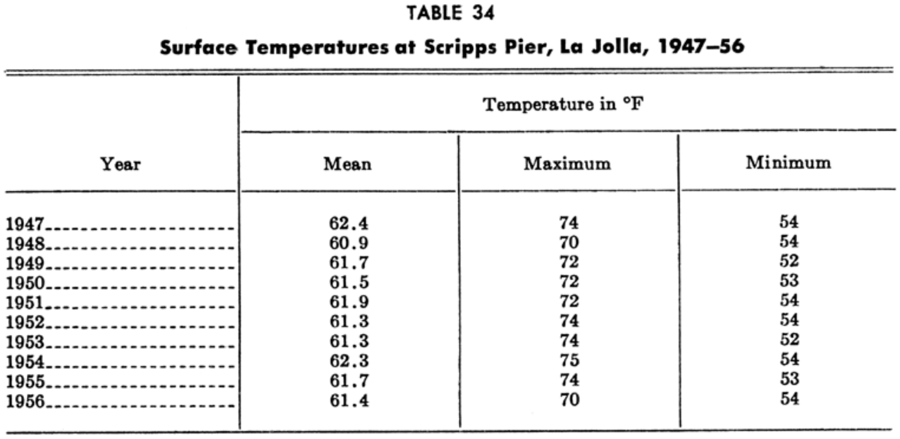


TABLE 34

Surface Temperatures at Scripps Pier, La Jolla, 1947–56

Year	Temperature in °F		
	Mean	Maximum	Minimum
1947	62.4	74	54
1948	60.9	70	54
1949	61.7	72	52
1950	61.5	72	53
1951	61.9	72	54
1952	61.3	74	54
1953	61.3	74	52
1954	62.3	75	54
1955	61.7	74	53
1956	61.4	70	54

TABLE 34

Surface Temperatures at Scripps Pier, La Jolla, 1947–56

The sportfish catch per unit of effort for the southern beds, in spite of considerable fluctuation at times, showed a marked tendency to increase during the 10-year period and reached a maximum in 1954 and 1956 (Table 35) . No clear relationship between sportfish catch per unit of effort and kelp harvest was evident. When sportfishing was at its best in 1954 and 1956, however, kelp-harvest returns were lowest. These low figures for kelp harvesting were doubtless related to extensive disappearance of kelp in the vicinity of Point Loma possibly due to the effects of pollution. The sportfish catch graph followed a course which was in many ways similar to that followed by the graph of mean temperature (Figure 62a). The increase in sportfish catches and the decline in the kelp harvest in 1954 were probably both related to the increase in temperature.

The kelp-bass catch per unit of effort was plotted graphically together with the pelagic-fish catch and the kelp-harvest returns (Figure

63b). The kelp-bass catch showed no clear relationship to the kelp-harvest returns. There was, however, a suggestion of a downward trend in both kelp harvest and kelp-bass catch during the entire period. From 1947 to 1952, kelp-bass fishing showed an inverse relationship to pelagic fishing, suggesting some degree of preferential fishing for pelagic species during these years. From 1952 to 1956 the relationship became direct, probably because sportfishing increased generally after 1952

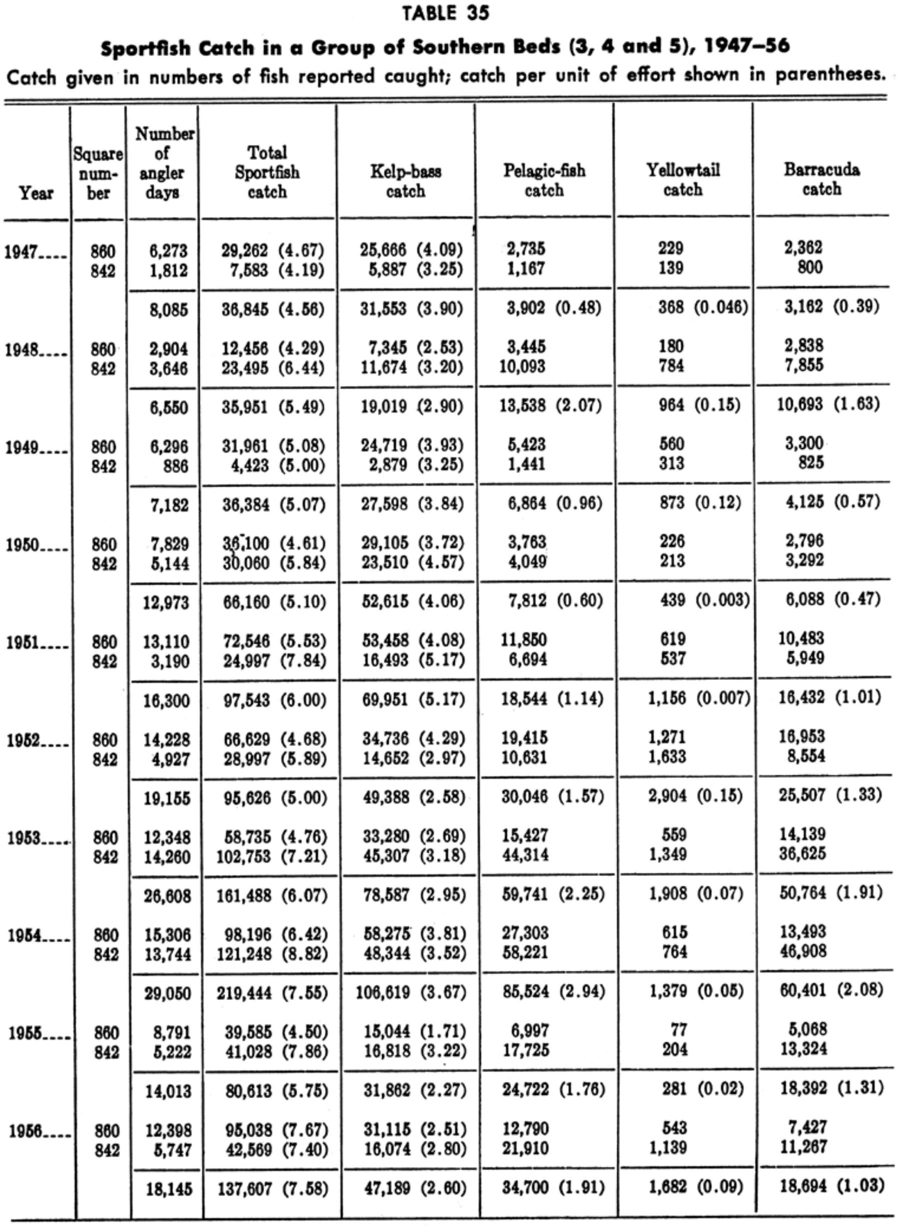


TABLE 35

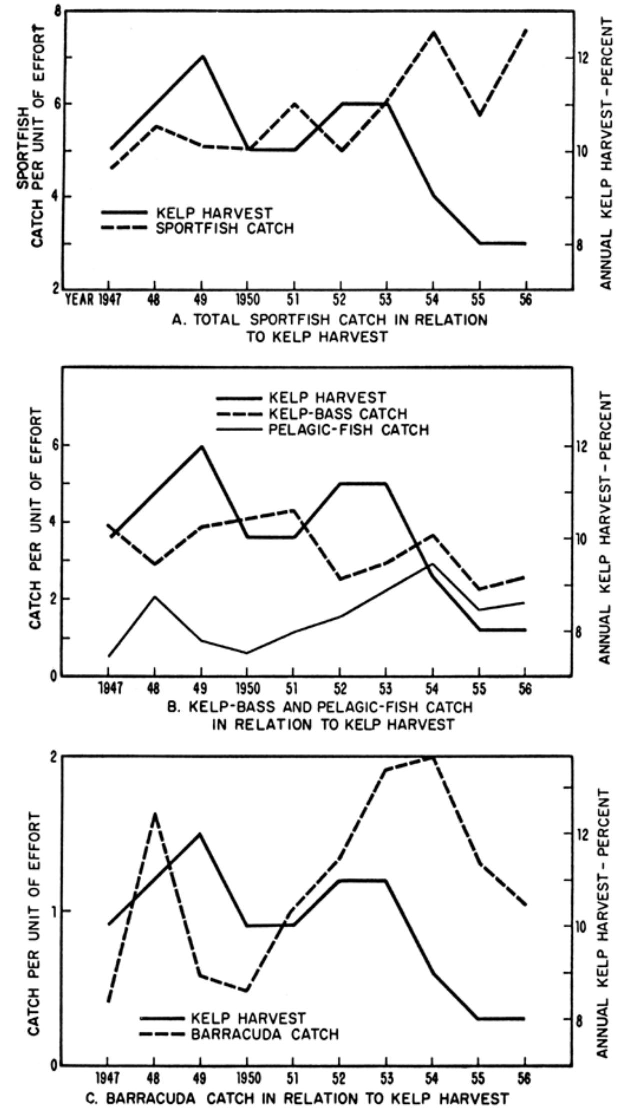
Sportfish Catch in a Group of Southern Beds (3, 4 and 5), 1947–56

Catch given in numbers of fish reported caught; catch per unit of effort shown in parentheses.

Year	Square number	Number of angler days	Total Sportfish catch	Kelp-bass catch	Pelagic-fish catch	Yellowtail catch	Barracuda catch
1947	860	6,273	29,262 (4.67)	25,666 (4.09)	2,735	229	2,362
	842	1,812	7,583 (4.19)	5,887 (3.25)	1,167	139	800
		8,085	36,845 (4.56)	31,553 (3.90)	3,902 (0.48)	368 (0.046)	3,162 (0.39)
1948	860	2,904	12,456 (4.29)	7,345 (2.53)	3,445	180	2,838
	842	3,646	23,495 (6.44)	11,674 (3.20)	10,093	784	7,855
		6,550	35,951 (5.49)	19,019 (2.90)	13,538 (2.07)	964 (0.15)	10,693 (1.63)
1949	860	6,296	31,961 (5.08)	24,719 (3.93)	5,423	560	3,300
	842	886	4,423 (5.00)	2,879 (3.25)	1,441	313	825
		7,182	36,384 (5.07)	27,598 (3.84)	6,864 (0.96)	873 (0.12)	4,125 (0.57)
1950	860	7,829	36,100 (4.61)	29,105 (3.72)	3,763	226	2,796
	842	5,144	30,060 (5.84)	23,510 (4.57)	4,049	213	3,292
		12,973	66,160 (5.10)	52,615 (4.06)	7,812 (0.60)	439 (0.003)	6,088 (0.47)
1951	860	13,110	72,546 (5.53)	53,458 (4.08)	11,850	619	10,483
	842	3,190	24,997 (7.84)	16,493 (5.17)	6,694	537	5,949
		16,300	97,543 (6.00)	69,951 (5.17)	18,544 (1.14)	1,156 (0.007)	16,432 (1.01)
1952	860	14,228	66,629 (4.68)	34,736 (4.29)	19,415	1,271	16,953
	842	4,927	28,997 (5.89)	14,652 (2.97)	10,631	1,633	8,554
		19,155	95,626 (5.00)	49,388 (2.58)	30,046 (1.57)	2,904 (0.15)	25,507 (1.33)
1953	860	12,348	58,735 (4.76)	33,280 (2.69)	15,427	559	14,139
	842	14,260	102,753 (7.21)	45,307 (3.18)	44,314	1,349	36,625
		26,608	161,488 (6.07)	78,587 (2.95)	59,741 (2.25)	1,908 (0.07)	50,764 (1.91)
1954	860	15,306	98,196 (6.42)	58,275 (3.81)	27,303	615	13,493
	842	13,744	121,248 (8.82)	48,344 (3.52)	58,221	764	46,908
		29,050	219,444 (7.55)	106,619 (3.67)	85,524 (2.94)	1,379 (0.05)	60,401 (2.08)
1955	860	8,791	39,585 (4.50)	15,044 (1.71)	6,997	77	5,068
	842	5,222	41,028 (7.86)	16,818 (3.22)	17,725	204	13,324
		14,013	80,613 (5.75)	31,862 (2.27)	24,722 (1.76)	281 (0.02)	18,392 (1.31)
1956	860	12,398	95,038 (7.67)	31,115 (2.51)	12,790	543	7,427
	842	5,747	42,569 (7.40)	16,074 (2.80)	21,910	1,139	11,267
		18,145	137,607 (7.58)	47,189 (2.60)	34,700 (1.91)	1,682 (0.09)	18,694 (1.03)

TABLE 35

Sportfish Catch in a Group of Southern Beds (3, 4 and 5), 1947–56



A. TOTAL SPORTFISH CATCH IN RELATION TO KELP HARVEST

B. KELP-BASS AND PELAGIC-FISH CATCH IN RELATION TO KELP HARVEST

C. BARRACUDA CATCH IN RELATION TO KELP HARVEST

FIGURE 63. Partyboat catch statistics and kelp harvest yields for a group of southern kelp beds (Numbers 3, 4, and 5) from 1947 to 1956. (a) All sportfishes vs. harvest. (b) Kelp bass and pelagic fishes vs. harvest. (c) Barracuda vs. harvest. Data from Department of Fish and Game.

FIGURE 63. **Partyboat catch statistics and kelp harvest yields for a group of southern kelp beds (Numbers 3, 4, and 5) from 1947 to 1956. (a) All sportfishes vs. harvest. (b) Kelp bass and pelagic fishes vs. harvest. (c) Barracuda vs. harvest. Data from Department of Fish and Game.**

(Figure 63a) and available fish of all species were caught. It is interesting that in 1954 and 1955 a decrease in mean temperature (Figure 62a) was accompanied by a decline in the kelp harvest and in the success of fishing for kelp bass and for pelagic species (Figure 63).

Total barracuda catch per unit of effort for all the kelp beds of southern California was described above as inversely related to total kelp-harvest data (Figure 61c), but a similar relationship was not found for the selected group of southern kelp beds. In fact, to some extent, an opposite relationship was found, viz. a direct relationship which, from 1951 onward, was also related to increased maximum temperatures (Figure 62c).

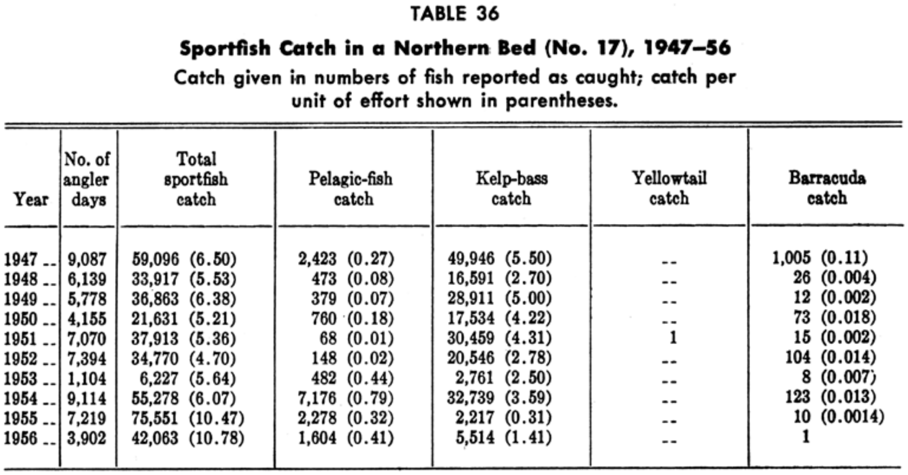


TABLE 36

Sportfish Catch in a Northern Bed (No. 17), 1947–56

Catch given in numbers of fish reported as caught; catch per unit of effort shown in parentheses.

Year	No. of angler days	Total sportfish catch	Pelagic-fish catch	Kelp-bass catch	Yellowtail catch	Barracuda catch
1947	9,087	59,096 (6.50)	2,423 (0.27)	49,946 (5.50)	--	1,005 (0.11)
1948	6,139	33,917 (5.53)	473 (0.08)	16,591 (2.70)	--	26 (0.004)
1949	5,778	36,863 (6.38)	379 (0.07)	28,911 (5.00)	--	12 (0.002)
1950	4,155	21,631 (5.21)	760 (0.18)	17,534 (4.22)	--	73 (0.018)
1951	7,070	37,913 (5.36)	68 (0.01)	30,459 (4.31)	1	15 (0.002)
1952	7,394	34,770 (4.70)	148 (0.02)	20,546 (2.78)	--	104 (0.014)
1953	1,104	6,227 (5.64)	482 (0.44)	2,761 (2.50)	--	8 (0.007)
1954	9,114	55,278 (6.07)	7,176 (0.79)	32,739 (3.59)	--	123 (0.013)
1955	7,219	75,551 (10.47)	2,278 (0.32)	2,217 (0.31)	--	10 (0.0014)
1956	3,902	42,063 (10.78)	1,604 (0.41)	5,514 (1.41)	--	1

TABLE 36

Sportfish Catch in a Northern Bed (No. 17), 1947–56

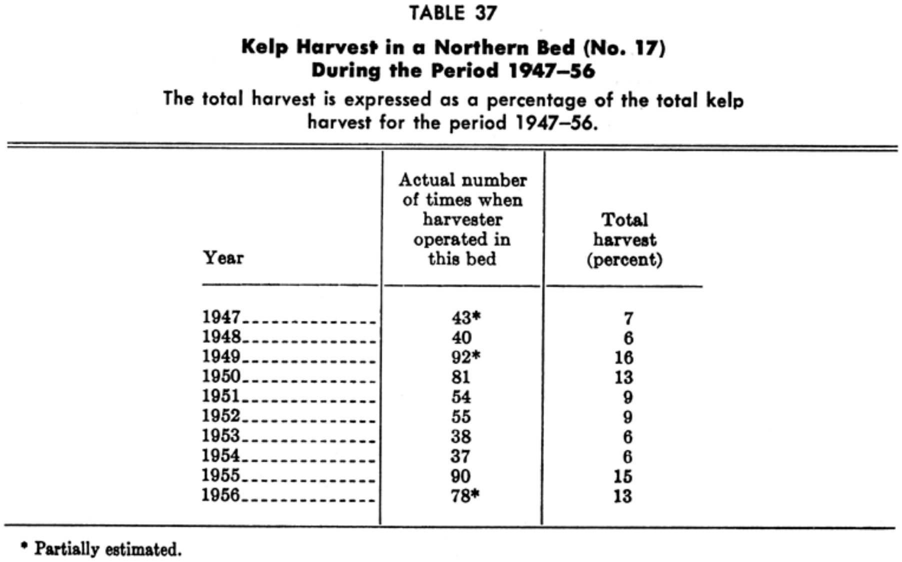


TABLE 37

Kelp Harvest in a Northern Bed (No. 17)
During the Period 1947–56

The total harvest is expressed as a percentage of the total kelp harvest for the period 1947–56.

Year	Actual number of times when harvester operated in this bed	Total harvest (percent)
1947	43*	7
1948	40	6
1949	92*	16
1950	81	13
1951	54	9
1952	55	9
1953	38	6
1954	37	6
1955	90	15
1956	78*	13

* Partially estimated.

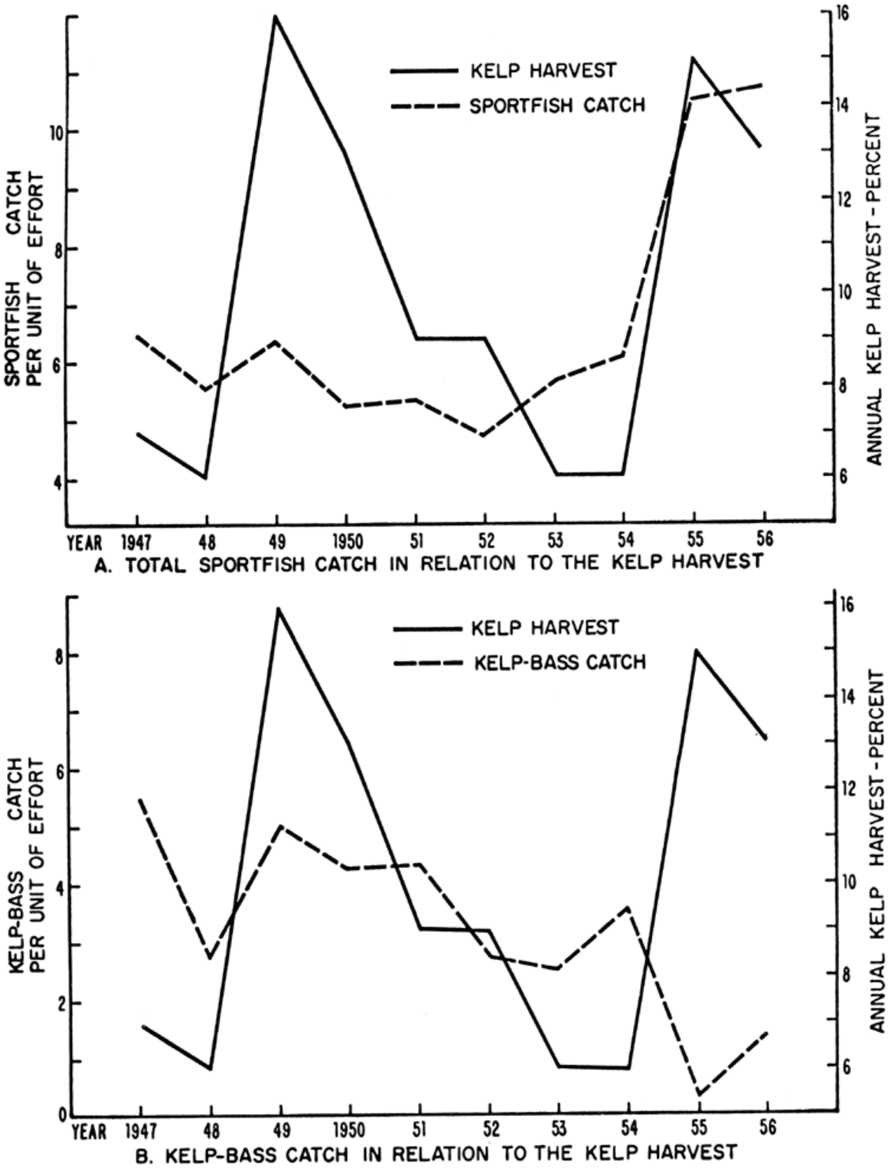
TABLE 37

Kelp Harvest in a Northern Bed (No. 17) During the Period 1947–56

11.5.3. COMPARISONS IN A NORTHERN KELP BED

As an example of a kelp bed situated in the northern part of the area in which kelp is harvested, bed No. 17 was selected. It lies in the vicinity of Point Dume and is contained by statistical square No. 681 (Figure 50). This bed is one which is regularly harvested and is in an area frequently visited by sportfishermen.

The kelp-harvest returns for the northern bed showed very considerable fluctuations during the period 1947–56 (Tables [36] and 37 and

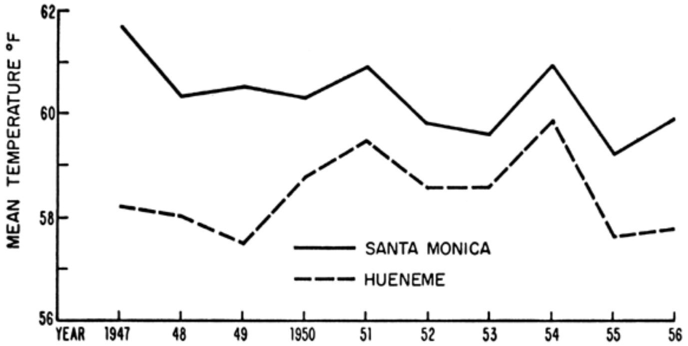


A. TOTAL SPORTFISH CATCH IN RELATION TO THE KELP HARVEST

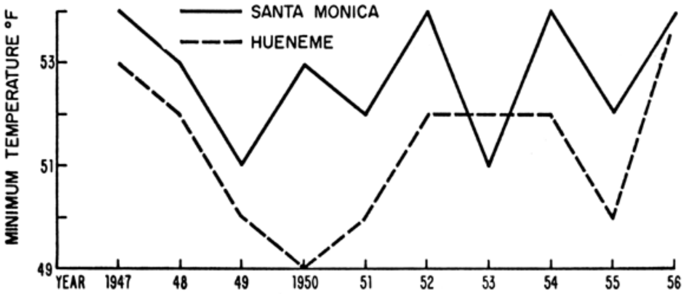
B. KELP-BASS CATCH IN RELATION TO THE KELP HARVEST

FIGURE 64. Partyboat catch statistics and kelp harvest yields for a northern kelp bed (Number 17) from 1947 to 1956. (a) All sportfishes vs. harvest. (b) Kelp bass vs. harvest. Data from Department of Fish and Game.

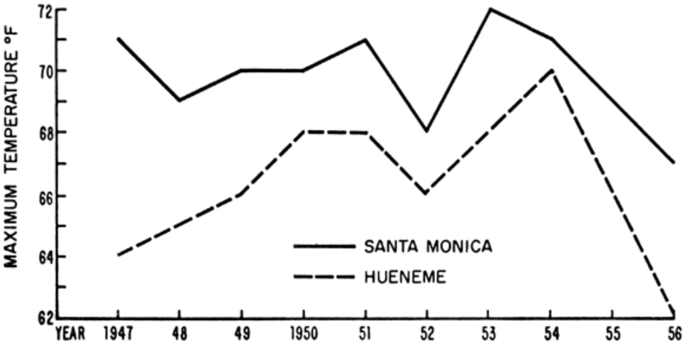
FIGURE 64. ***Partyboat catch statistics and kelp harvest yields for a northern kelp bed (Number 17) from 1947 to 1956. (a) All sportfishes vs. harvest. (b) Kelp bass vs. harvest. Data from Department of Fish and Game.***



A. MEAN TEMPERATURE



B. MINIMUM TEMPERATURE



C. MAXIMUM TEMPERATURE

FIGURE 65. Maximum, minimum, and mean sea surface temperatures at Santa Monica and Port Hueneme for 1947 to 1956.

FIGURE 65. ***Maximum, minimum, and mean sea surface temperatures at Santa Monica and Port Hueneme for 1947 to 1956.***

Figure 64a), yet no clear relationship between these fluctuations and surface temperatures was evident (Table 38 and Figure 65). The kelp yield appeared to be related to the number of times a harvester operated in the bed (Table 37) .

The sportfish catch per unit of effort for this bed showed a general decline from 1947 to 1952, during which period the kelp harvest increased to a maximum and then decreased again. In 1954 and 1955 both sportfishing and kelp harvesting underwent a very considerable increase. In general, however, there appeared to be no relationship between sportfishing and the harvesting of kelp in the northern bed.

The kelp-bass catch per unit of effort (Figure 64b) showed a marked downward trend during the 10-year period and did not appear to be related to the kelp harvest in any way. There was, however, some similarity between the fluctuations in the kelp-bass catch per unit of effort and the variation in mean surface temperature for the area (Figure 65a, Table 38).

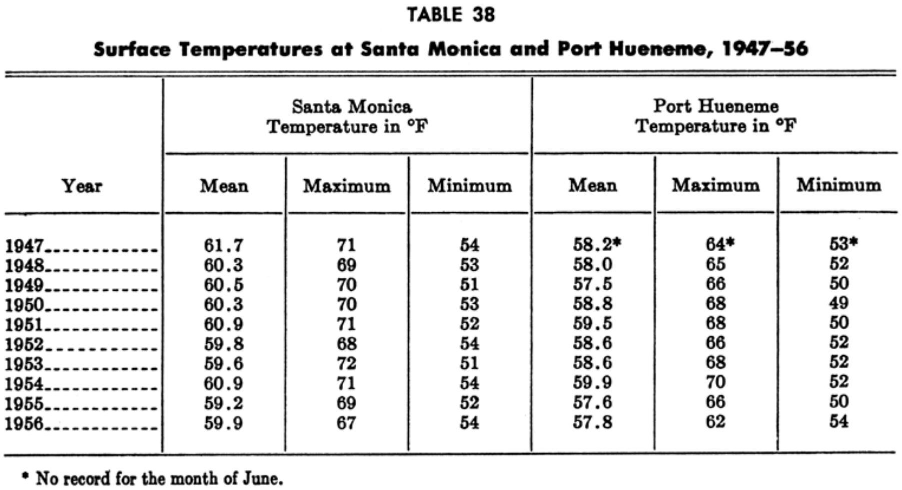


TABLE 38

Surface Temperatures at Santa Monica and Port Hueneme, 1947–56

Year	Santa Monica Temperature in °F			Port Hueneme Temperature in °F		
	Mean	Maximum	Minimum	Mean	Maximum	Minimum
1947	61.7	71	54	58.2*	64*	53*
1948	60.3	69	53	58.0	65	52
1949	60.5	70	51	57.5	66	50
1950	60.3	70	53	58.8	68	49
1951	60.9	71	52	59.5	68	50
1952	59.8	68	54	58.6	66	52
1953	59.6	72	51	58.6	68	52
1954	60.9	71	54	59.9	70	52
1955	59.2	69	52	57.6	66	50
1956	59.9	67	54	57.8	62	54

* No record for the month of June.

TABLE 38

Surface Temperatures at Santa Monica and Port Hueneme, 1947–56

Only one yellowtail and very few barracuda were recorded in the catches made in and near this bed during the entire 10-year period. This is to be expected, since the bed is in an area of cooler ocean temperatures.

11.5.4. COMPARISONS IN A GROUP OF ISLAND KELP BEDS

The kelp beds chosen to represent conditions found near an island were Nos. 43, 44, and 45, situated in statistical catch squares Nos. 829, 850, and 867 off San Clemente Island (Figure 50). Reliable data were available only for the 7-year period 1950–56 (Table 39) .

The kelp harvest for the island beds fluctuated widely from a small amount in 1950 to a maximum in 1951, and then declined sharply through 1952 to a minimum in 1953; this minimum was followed by a steady increase through to 1955 and a further decline in 1956 (Table 40) . There is little doubt that factors other than availability of kelp are important in harvesting operations off San Clemente. These factors

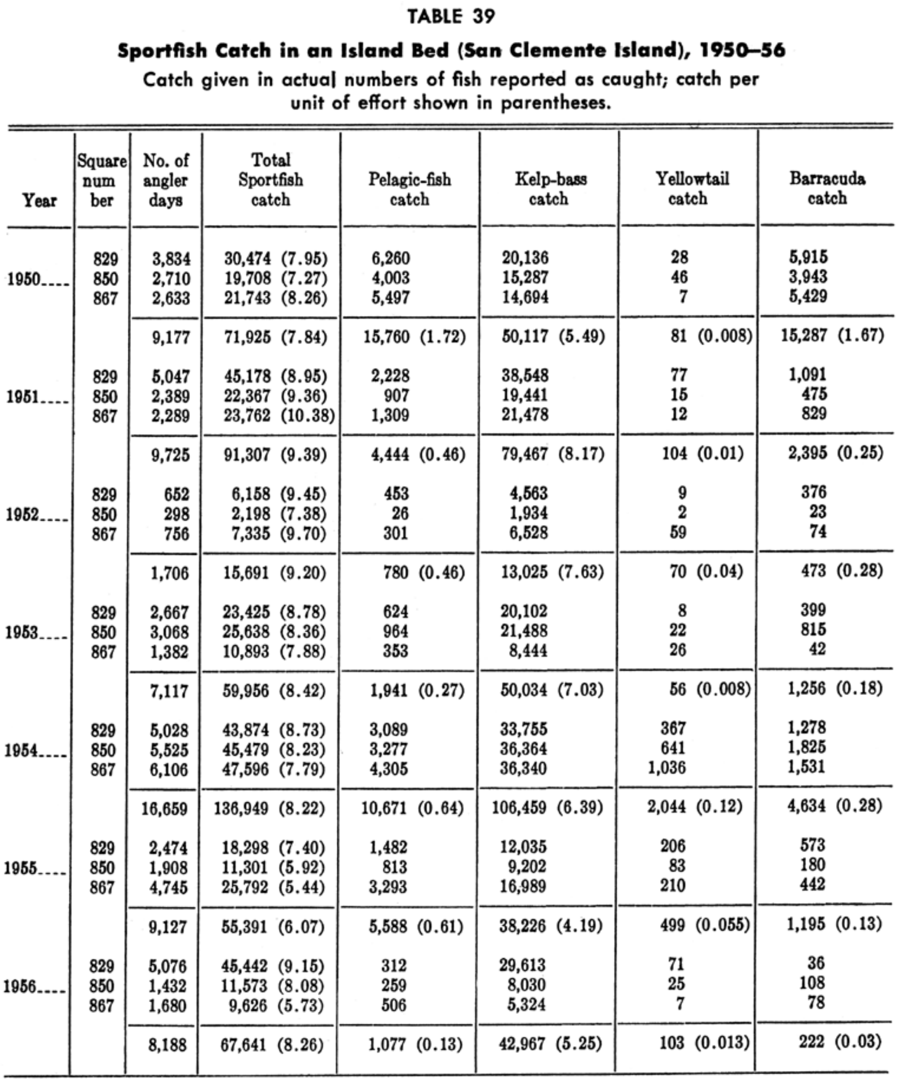


TABLE 39

Sportfish Catch in an Island Bed (San Clemente Island), 1950–56

Catch given in actual numbers of fish reported as caught; catch per unit of effort shown in parentheses.

Year	Square num ber	No. of angler days	Total Sportfish catch	Pelagic-fish catch	Kelp-bass catch	Yellowtail catch	Barracuda catch
	829	3,834	30,474 (7.95)	6,260	20,136	28	5,915
1950	850	2,710	19,708 (7.27)	4,003	15,287	46	3,943
	867	2,633	21,743 (8.26)	5,497	14,694	7	5,429
		9,177	71,925 (7.84)	15,760 (1.72)	50,117 (5.49)	81 (0.008)	15,287 (1.67)
	829	5,047	45,178 (8.95)	2,228	38,548	77	1,091
1951	850	2,389	22,367 (9.36)	907	19,441	15	475
	867	2,289	23,762 (10.38)	1,309	21,478	12	829
		9,725	91,307 (9.39)	4,444 (0.46)	79,467 (8.17)	104 (0.01)	2,395 (0.25)
	829	652	6,158 (9.45)	453	4,563	9	376
1952	850	298	2,198 (7.38)	26	1,934	2	23
	867	756	7,335 (9.70)	301	6,528	59	74
		1,706	15,691 (9.20)	780 (0.46)	13,025 (7.63)	70 (0.04)	473 (0.28)
	829	2,667	23,425 (8.78)	624	20,102	8	399
1953	850	3,068	25,638 (8.36)	964	21,488	22	815
	867	1,382	10,893 (7.88)	353	8,444	26	42
		7,117	59,956 (8.42)	1,941 (0.27)	50,034 (7.03)	56 (0.008)	1,256 (0.18)
	829	5,028	43,874 (8.73)	3,089	33,755	367	1,278
1954	850	5,525	45,479 (8.23)	3,277	36,364	641	1,825
	867	6,106	47,596 (7.79)	4,305	36,340	1,036	1,531
		16,659	136,949 (8.22)	10,671 (0.64)	106,459 (6.39)	2,044 (0.12)	4,634 (0.28)
	829	2,474	18,298 (7.40)	1,482	12,035	206	573
1955	850	1,908	11,301 (5.92)	813	9,202	83	180
	867	4,745	25,792 (5.44)	3,293	16,989	210	442
		9,127	55,391 (6.07)	5,588 (0.61)	38,226 (4.19)	499 (0.055)	1,195 (0.13)
	829	5,076	45,442 (9.15)	312	29,613	71	36
1956	850	1,432	11,573 (8.08)	259	8,030	25	108
	867	1,680	9,626 (5.73)	506	5,324	7	78
		8,188	67,641 (8.26)	1,077 (0.13)	42,967 (5.25)	103 (0.013)	222 (0.03)

TABLE 39

Sportfish Catch in an Island Bed (San Clemente Island), 1950–56

include weather conditions, the availability of kelp in beds more conveniently situated in relation to the home port of the harvesters, and military or naval operations. It is therefore doubtful whether any comparison between the fluctuations in the kelp harvest and the fish yield per unit of effort would be valid in this region.

A general examination was made of the data for total sportfish catch per unit of effort, kelp-bass catch, pelagic-fish catch, and barracuda catch per unit of effort, together with what surface temperature data were available (Figures 66 and 67, Table 41). There was no clear relationship between any of these items and kelp harvesting.

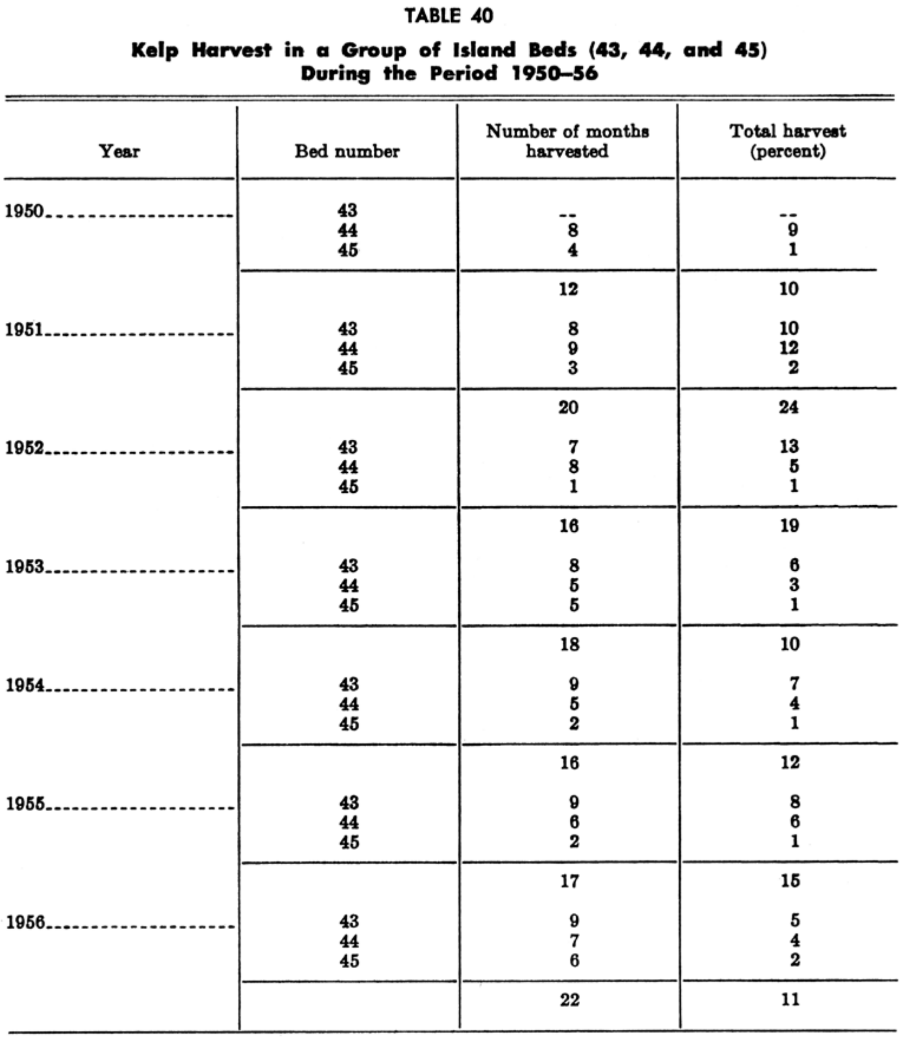


TABLE 40

Kelp Harvest in a Group of Island Beds (43, 44, and 45) During the Period 1950–56

Year	Bed number	Number of months harvested	Total harvest (percent)
1950	43	--	--
	44	8	9
	45	4	1
		12	10
1951	43	8	10
	44	9	12
	45	3	2
		20	24
1952	43	7	13
	44	8	5
	45	1	1
		16	19
1953	43	8	6
	44	5	3
	45	5	1
		18	10
1954	43	9	7
	44	5	4
	45	2	1
		16	12
1955	43	9	8
	44	6	6
	45	2	1
		17	15
1956	43	9	5
	44	7	4
	45	6	2
		22	11

TABLE 40

Kep Harvest in a Group of Island Beds (43, 44, and 45) During the Period 1950–56

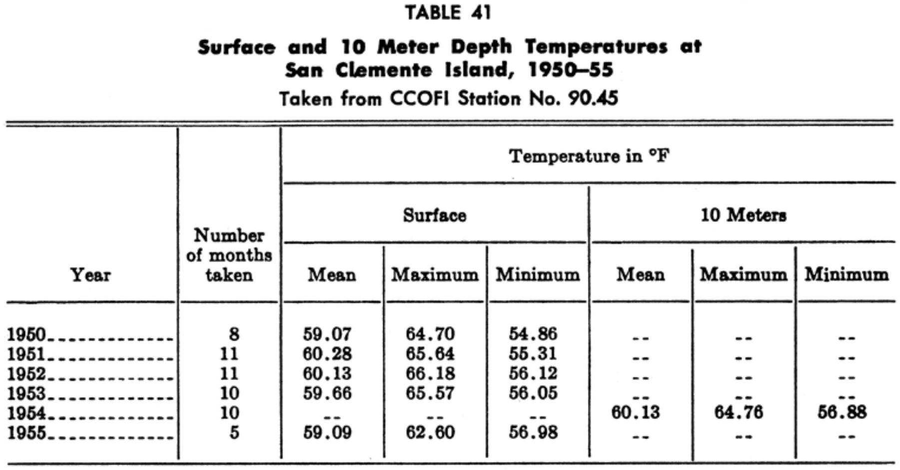


TABLE 41

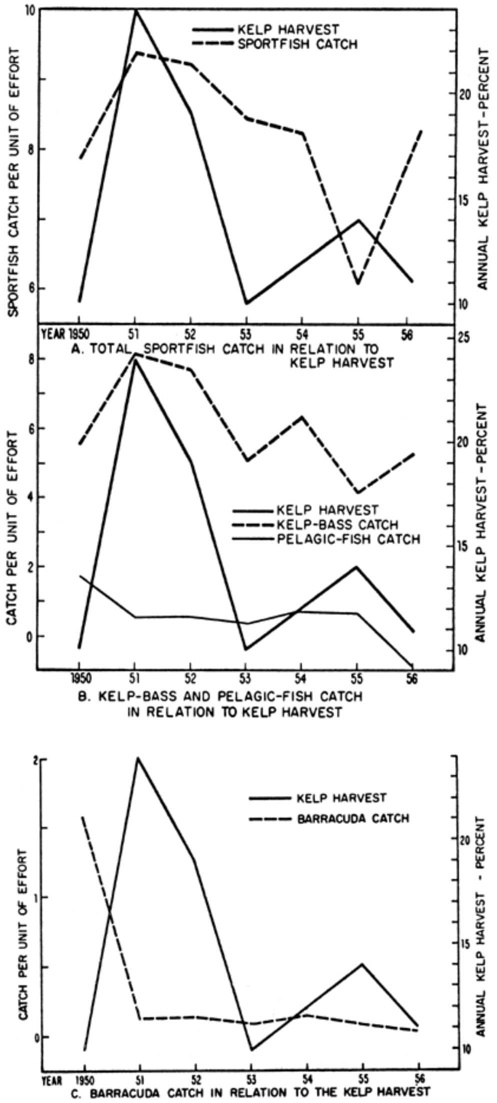
Surface and 10 Meter Depth Temperatures at San Clemente Island, 1950–55

Taken from CCOFI Station No. 90.45

Year	Number of months taken	Temperature in °F					
		Surface			10 Meters		
		Mean	Maximum	Minimum	Mean	Maximum	Minimum
1950	8	59.07	64.70	54.86	--	--	--
1951	11	60.28	65.64	55.31	--	--	--
1952	11	60.13	66.18	56.12	--	--	--
1953	10	59.66	65.57	56.05	--	--	--
1954	10	--	--	--	60.13	64.76	56.88
1955	5	59.09	62.60	56.98	--	--	--

TABLE 41

Surface and 10 Meter Depth Temperatures at San Clemente Island, 1950–55



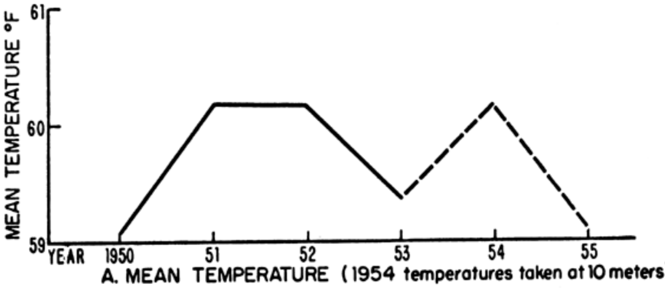
A. TOTAL SPORTFISH CATCH IN RELATION TO KELP HARVEST

B. KELP-BASS AND PELAGIC-FISH CATCH IN RELATION TO KELP HARVEST

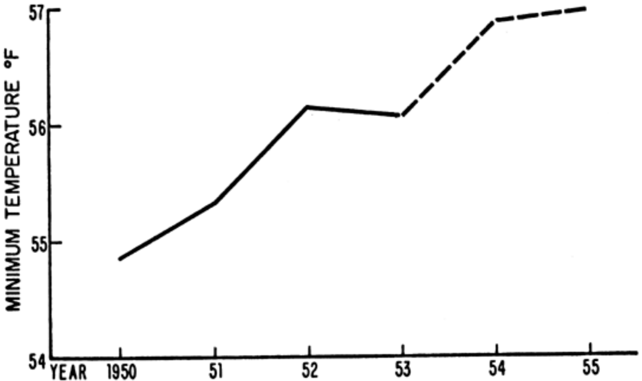
C. BARRACUDA CATCH IN RELATION TO THE KELP HARVEST

FIGURE 66. Partyboat catch statistics and kelp harvest yields for a group of island kelp beds (Numbers 43, 44, 45) from 1947 to 1956. (a) All sportfishes vs. harvest. (b) Kelp bass and pelagic fishes vs. harvest. (c) Barracuda vs. harvest. Data from Department of Fish and Game.

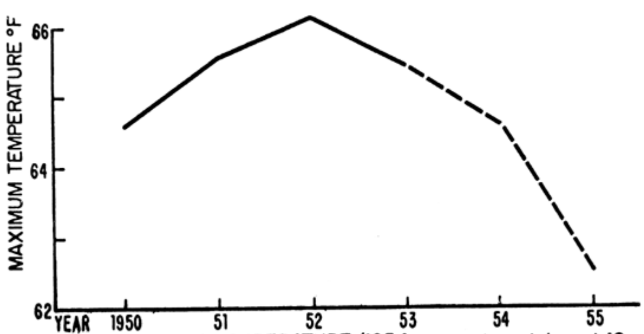
FIGURE 66. ***Partyboat catch statistics and kelp harvest yields for a group of island kelp beds (Numbers 43, 44, 45) from 1947 to 1956. (a) All sportfishes vs. harvest. (b) Kelp bass and pelagic fishes vs. harvest. (c) Barracuda vs. harvest. Data from Department of Fish and Game.***



A. MEAN TEMPERATURE (1954 temperatures taken at 10 meters)



B. MINIMUM TEMPERATURE (1954 temperatures taken at 10 meters)



C. MAXIMUM TEMPERATURE (1954 temperatures taken at 10 meters)

FIGURE 67. Maximum, minimum, and mean sea surface temperatures off San Clemente island from 1947 to 1956.

FIGURE 67. ***Maximum, minimum, and mean sea surface temperatures off San Clemente island from 1947 to 1956.***

11.6. KELP HARVESTING AS A DISTURBANCE FACTOR IN THE SPORTFISHERY

11.6.1. As Shown by the Frequency of Harvesting Operations

It has been claimed that the frequent cutting and removal of part of the canopy of a kelp bed by a harvester seriously disturbs the fish and results in poor sportfish catches. Certain fishes in the canopy might be disturbed during harvesting operations, and some of the smaller and apparently insignificant species which are unable to escape may be destroyed (Limbaugh. 1955; also *cf.* Chapter 9, this bulletin). It is difficult to devise a method for assessment of the general effects even after long periods of careful observation of the operations at sea.

It was decided therefore that for the 2 years, 1954 and 1955, for which more detailed kelp-harvesting records were available, a comparison of the data would be made between the entire sportfish catch, the kelp-bass catch separately, and the frequency of kelp harvesting (based on the numbers of months in the year when some harvesting occurred), for all the kelp beds off the coast of southern California (Tables [42] , [43] and [44]).

These data were treated on the basis of a comparison between kelp beds that had been harvested on a small scale, i.e., during 1–5 months in the year, and kelp beds that had been more actively harvested, i.e., during 6–12 months in the year. The sportfish catch per unit of effort

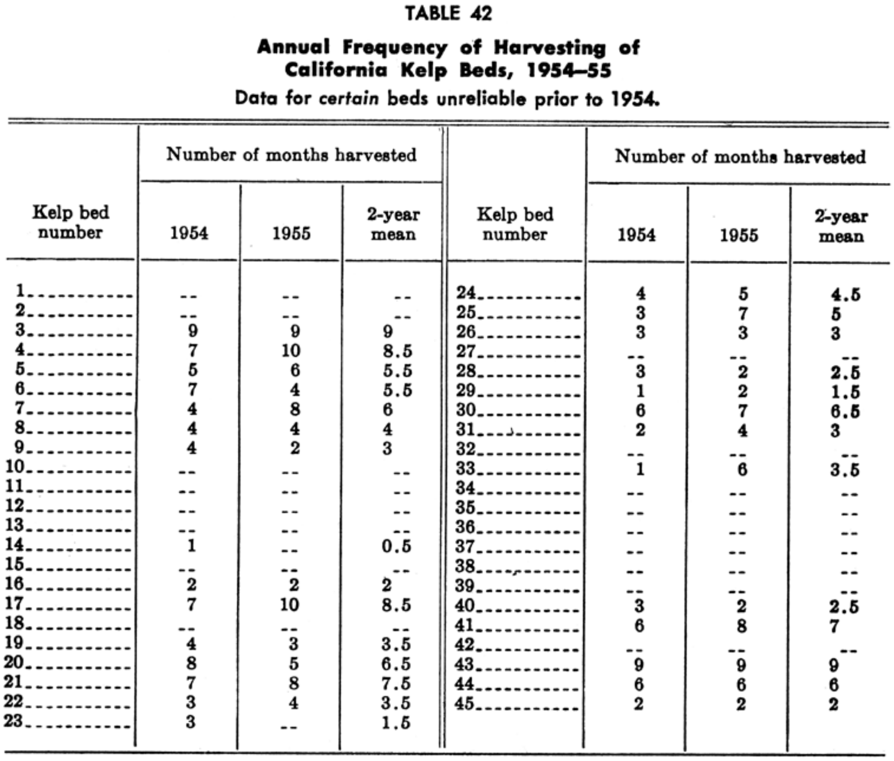


TABLE 42

Annual Frequency of Harvesting of California Kelp Beds, 1954–55

Data for *certain* beds unreliable prior to 1954.

Kelp bed number	Number of months harvested			Kelp bed number	Number of months harvested		
	1954	1955	2-year mean		1954	1955	2-year mean
1	--	--	--	24	4	5	4.5
2	--	--	--	25	3	7	5
3	9	9	9	26	3	3	3
4	7	10	8.5	27	--	--	--
5	5	6	5.5	28	3	2	2.5
6	7	4	5.5	29	1	2	1.5
7	4	8	6	30	6	7	6.5
8	4	4	4	31	2	4	3
9	4	2	3	32	--	--	--
10	--	--	--	33	1	6	3.5
11	--	--	--	34	--	--	--
12	--	--	--	35	--	--	--
13	--	--	--	36	--	--	--
14	1	--	0.5	37	--	--	--
15	--	--	--	38	--	--	--
16	2	2	2	39	--	--	--
17	7	10	8.5	40	3	2	2.5
18	--	--	--	41	6	8	7
19	4	3	3.5	42	--	--	--
20	8	5	6.5	43	9	9	9
21	7	8	7.5	44	6	6	6
22	3	4	3.5	45	2	2	2
23	3	--	1.5				

TABLE 42

Annual Frequency of Harvesting of California Kelp Beds, 1954–55

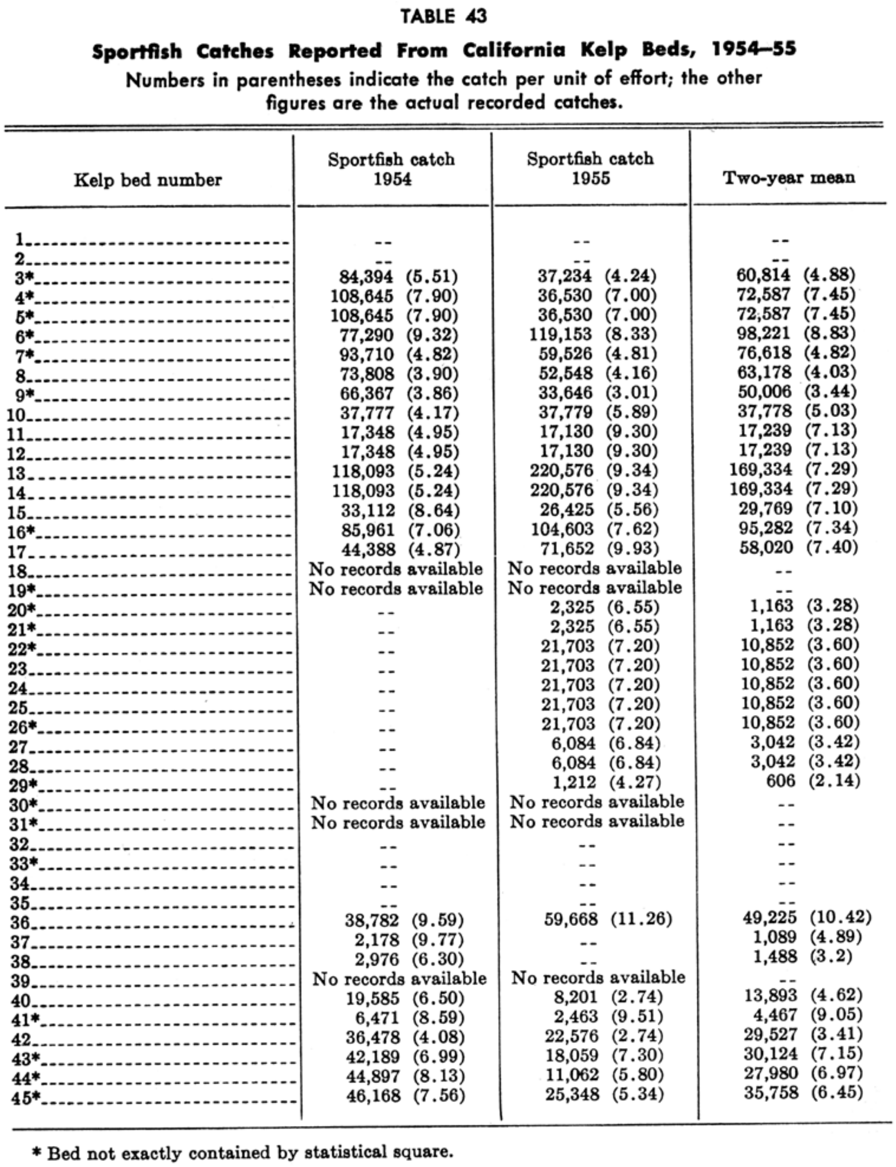


TABLE 43

Sportfish Catches Reported From California Kelp Beds, 1954–55

Numbers in parentheses indicate the catch per unit of effort; the other figures are the actual recorded catches.

Kelp bed number	Sportfish catch 1954	Sportfish catch 1955	Two-year mean
1	--	--	--
2	--	--	--
3*	84,394 (5.51)	37,234 (4.24)	60,814 (4.88)
4*	108,645 (7.90)	36,530 (7.00)	72,587 (7.45)
5*	108,645 (7.90)	36,530 (7.00)	72,587 (7.45)
6*	77,290 (9.32)	119,153 (8.33)	98,221 (8.83)
7*	93,710 (4.82)	59,526 (4.81)	76,618 (4.82)
8	73,808 (3.90)	52,548 (4.16)	63,178 (4.03)
9*	66,367 (3.86)	33,646 (3.01)	50,006 (3.44)
10	37,777 (4.17)	37,779 (5.89)	37,778 (5.03)
11	17,348 (4.95)	17,130 (9.30)	17,239 (7.13)
12	17,348 (4.95)	17,130 (9.30)	17,239 (7.13)
13	118,093 (5.24)	220,576 (9.34)	169,334 (7.29)
14	118,093 (5.24)	220,576 (9.34)	169,334 (7.29)
15	33,112 (8.64)	26,425 (5.56)	29,769 (7.10)
16*	85,961 (7.06)	104,603 (7.62)	95,282 (7.34)
17	44,388 (4.87)	71,652 (9.93)	58,020 (7.40)
18	No records available	No records available	--
19*	No records available	No records available	--
20*	--	2,325 (6.55)	1,163 (3.28)
21*	--	2,325 (6.55)	1,163 (3.28)
22*	--	21,703 (7.20)	10,852 (3.60)
23	--	21,703 (7.20)	10,852 (3.60)
24	--	21,703 (7.20)	10,852 (3.60)
25	--	21,703 (7.20)	10,852 (3.60)
26*	--	21,703 (7.20)	10,852 (3.60)
27	--	6,084 (6.84)	3,042 (3.42)
28	--	6,084 (6.84)	3,042 (3.42)
29*	--	1,212 (4.27)	606 (2.14)
30*	No records available	No records available	--
31*	No records available	No records available	--
32	--	--	--
33*	--	--	--
34	--	--	--
35	--	--	--
36	38,782 (9.59)	59,668 (11.26)	49,225 (10.42)
37	2,178 (9.77)	--	1,089 (4.89)
38	2,976 (6.30)	--	1,488 (3.2)
39	No records available	No records available	--
40	19,585 (6.50)	8,201 (2.74)	13,893 (4.62)
41*	6,471 (8.59)	2,463 (9.51)	4,467 (9.05)
42	36,478 (4.08)	22,576 (2.74)	29,527 (3.41)
43*	42,189 (6.99)	18,059 (7.30)	30,124 (7.15)
44*	44,897 (8.13)	11,062 (5.80)	27,980 (6.97)
45*	46,168 (7.56)	25,348 (5.34)	35,758 (6.45)

* Bed not exactly contained by statistical square.

TABLE 43

Sportfish Catches Reported From California Kelp Beds, 1954–55

for each of the beds harvested on a small scale was extracted and the mean found to be 4.36. For the kelp beds which were more frequently harvested, the mean sportfish catch per unit of effort was 6.61.

These figures indicate that sportfishing was considerably better in the beds which were most frequently harvested. This is not necessarily due to any beneficial effect on fishing caused by the harvesting operations. It may be that the kelp beds which are most frequently harvested are the largest and most productive and in consequence attract the largest numbers of sportfish. There is no indication, however, that the cutting of kelp has any adverse effect on sportfishing.

The kelp-bass catch per unit of effort for the years 1954 and 1955 were then compared in the same manner with the data on frequency of harvesting (Tables 42 and 44). For the beds less frequently harvested (1 to 5 months in the year), the mean kelp-bass catch per unit of effort for the 2-year period was 1.58. It was 3.58 for the beds harvested during 6–12 months in the year. Kelp-bass fishing was thus considerably better in beds which were more frequently harvested.

A similar assessment of the problem could not be made on the basis of actual numbers of fish caught, as there was no way to allow for differences in the size of the areas involved. On the basis of catch per

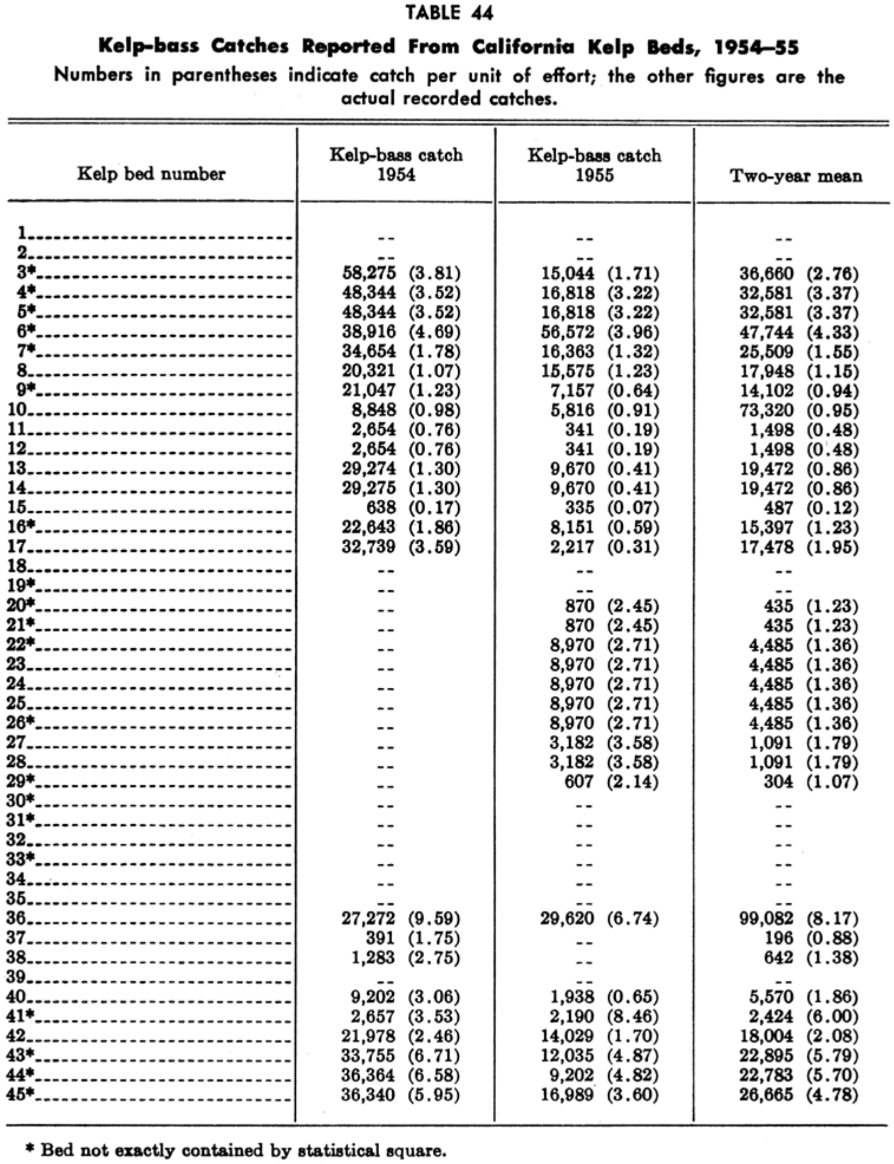


TABLE 44

Kelp-bass Catches Reported From California Kelp Beds, 1954–55

Numbers in parentheses indicate catch per unit of effort; the other figures are the actual recorded catches.

Kelp bed number	Kelp-bass catch 1954	Kelp-bass catch 1955	Two-year mean
1	--	--	--
2	--	--	--
3*	58,275 (3.81)	15,044 (1.71)	36,660 (2.76)
4*	48,344 (3.52)	16,818 (3.22)	32,581 (3.37)
5*	48,344 (3.52)	16,818 (3.22)	32,581 (3.37)
6*	38,916 (4.69)	56,572 (3.96)	47,744 (4.33)
7*	34,654 (1.78)	16,363 (1.32)	25,509 (1.55)
8	20,321 (1.07)	15,575 (1.23)	17,948 (1.15)
9*	21,047 (1.23)	7,157 (0.64)	14,102 (0.94)
10	8,848 (0.98)	5,816 (0.91)	73,320 (0.95)
11	2,654 (0.76)	341 (0.19)	1,498 (0.48)
12	2,654 (0.76)	341 (0.19)	1,498 (0.48)
13	29,274 (1.30)	9,670 (0.41)	19,472 (0.86)
14	29,275 (1.30)	9,670 (0.41)	19,472 (0.86)
15	638 (0.17)	335 (0.07)	487 (0.12)
16*	22,643 (1.86)	8,151 (0.59)	15,397 (1.23)
17	32,739 (3.59)	2,217 (0.31)	17,478 (1.95)
18	--	--	--
19*	--	--	--
20*	--	870 (2.45)	435 (1.23)
21*	--	870 (2.45)	435 (1.23)
22*	--	8,970 (2.71)	4,485 (1.36)
23	--	8,970 (2.71)	4,485 (1.36)
24	--	8,970 (2.71)	4,485 (1.36)
25	--	8,970 (2.71)	4,485 (1.36)
26*	--	8,970 (2.71)	4,485 (1.36)
27	--	3,182 (3.58)	1,091 (1.79)
28	--	3,182 (3.58)	1,091 (1.79)
29*	--	607 (2.14)	304 (1.07)
30*	--	--	--
31*	--	--	--
32	--	--	--
33*	--	--	--
34	--	--	--
35	--	--	--
36	27,272 (9.59)	29,620 (6.74)	99,082 (8.17)
37	391 (1.75)	--	196 (0.88)
38	1,283 (2.75)	--	642 (1.38)
39	--	--	--
40	9,202 (3.06)	1,938 (0.65)	5,570 (1.86)
41*	2,657 (3.53)	2,190 (8.46)	2,424 (6.00)
42	21,978 (2.46)	14,029 (1.70)	18,004 (2.08)
43*	33,755 (6.71)	12,035 (4.87)	22,895 (5.79)
44*	36,364 (6.58)	9,202 (4.82)	22,783 (5.70)
45*	36,340 (5.95)	16,989 (3.60)	26,665 (4.78)

* Bed not exactly contained by statistical square.

TABLE 44

Kelp-bass Catches Reported From California Kelp Beds, 1954–55

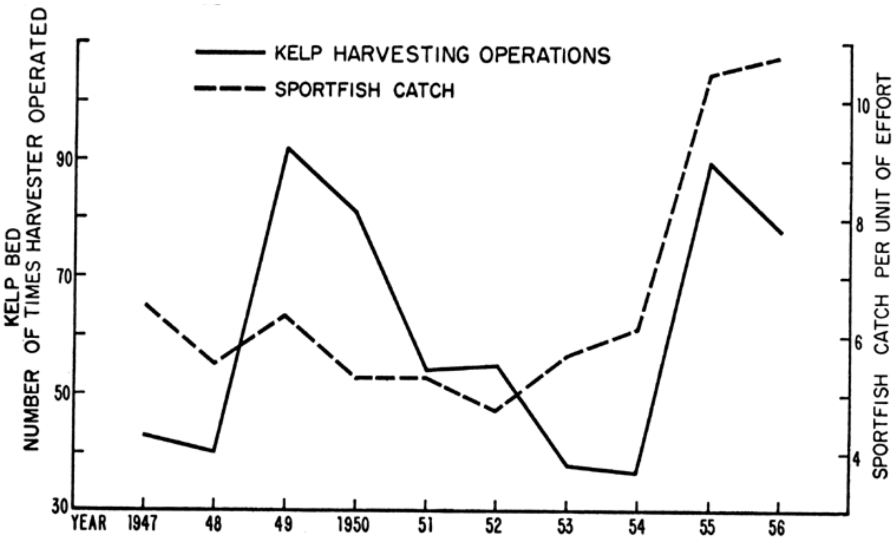


FIGURE 68. Comparison of partyboat catch per unit of effort for all sportfishes and the number of times a kelp harvester operated in the bed under consideration (Bed Number 17). Data from the Department of Fish and Game.

FIGURE 68. ***Comparison of partyboat catch per unit of effort for all sportfishes and the number of times a kelp harvester operated in the bed under consideration (Bed Number 17). Data from the Department of Fish and Game.***

unit of effort, however, the need for a comparison in terms of unit area was obviated.

To obtain further evidence on the question of whether frequency of kelp harvesting operations adversely affects sportfishing, an attempt was made to obtain more detailed data collected over a period longer than 2 years. These data were finally obtained for the 10-year period 1947–56 for kelp bed No. 17, near Point Dume (Figure 50).

A full record (Table 37) was obtained for each time the harvester operated in this bed during each of the 10 years (prior to 1954, the records for most beds gave no indication of the actual number of times each bed was harvested other than the number of months in the year in which harvesting occurred).

Increased frequency of harvesting was not accompanied by a decline in sportfishing (Figure 68). A much higher frequency of harvesting operations in 1955, when a harvester operated 90 times, was accompanied by greatly improved sportfishing. There is no indication that frequency of kelp-harvesting operations adversely affected sportfishing in general or kelp-bass fishing in particular.

11.6.2. As Shown by a Comparison of Catches in Harvested and Uncut Beds

To obtain further information on the question whether kelp harvesting adversely affects sportfishing the total sportfish catches obtained in harvested beds was compared with the catches in uncut beds. A similar comparison was made for kelp-bass catches in harvested and uncut kelp beds. The years 1954 and 1955 were chosen for these comparisons because of the greater accuracy of data available (Tables 45 and 46).

During 1954, among kelp beds in areas where regular sportfishing took place, 15 were harvested and 9 were left uncut (the remaining 21 kelp beds were not recorded as being fished by the sportfishermen). For the harvested kelp beds, the mean catch per unit of effort of

TABLE 45

Relationship Between Total Sportfish Catch Reported from Harvested and Uncut Kelp Beds in 1954 and 1955

In 1954, 15 beds were harvested and nine left uncut; in 1955, 22 beds were harvested and 10 left uncut.

Type of bed	Total sportfish catch (and mean catch per unit of effort)		Sportfish catch per bed	
	1954	1955	1954	1955
Harvested	1,020,611 (6.15)	715,313 (6.08)	68,040	32,514
Uncut	304,092 (6.27)	649,647 (6.97)	33,788	64,965

TABLE 45

Relationship Between Total Sportfish Catch Reported from Harvested and Uncut Kelp Beds in 1954 and 1955

TABLE 46

Relationship Between Total Kelp-bass Catch Reported from Harvested and Uncut Kelp Beds in 1954 and 1955

In 1954, 15 beds were harvested and nine left uncut; in 1955, 22 beds were harvested and 10 left uncut.

Type of bed	Total kelp-bass catch (and mean catch per unit of effort)		Kelp-bass catch per bed	
	1954	1955	1954	1955
Harvested	472,785 (3.48)	238,478 (2.73)	31,519	10,840
Uncut	94,992 (2.28)	81,974 (1.69)	10,459	8,197

TABLE 46

Relationship Between Total Kelp-bass Catch Reported from Harvested and Uncut Kelp Beds in 1954 and 1955

sportfish was 6.15 and for the uncut beds 6.27. In 1955, 22 of the kelp beds visited by the sportfishermen were harvested and 10 were left uncut (Table 45). Mean catch per unit of effort of sportfish was 6.08 in harvested beds and 6.97 in the uncut beds. Thus, for these 2 years, sportfishing was slightly better in the uncut beds than in the harvested beds. The difference is so small, however, that it can be ascribed little significance.

In terms of actual numbers of individual sportfish reported caught, the average for 1954 was 68,040 per harvested bed and 33,788 per uncut bed. In 1955, however, the reported numbers were reversed, 32,514 per harvested bed and 64,965 per uncut bed. It appears from the foregoing data that, in general, sportfishing is as good in harvested kelp beds as in uncut beds. No evidence was obtained that harvesting operations affected sportfishing adversely.

In 1954 the mean reported catch of kelp bass per unit of effort was 3.48 in the harvested beds and 2.28 in the uncut beds; in 1955, 2.73 in the harvested beds and 1.69 in the uncut beds. The results for kelp-bass fishing for these 2 years closely agree with each other and indicate that kelp-bass fishing was appreciably better in the harvested beds than in the uncut beds. In addition, in both 1954 and 1955, the average kelp-bass catch reported in actual numbers of fish caught (Table 46) was greater per harvested bed than per uncut bed. It appears, therefore, that kelp-bass fishing was generally better in the harvested kelp beds tested than in uncut beds. This does not necessary mean that harvesting operations improve fishing: the beds that are harvested may be more suitable for the fish.

It thus seems apparent that sportfishing was generally as good in harvested kelp beds as in uncut kelp beds, that kelp-bass fishing is better in harvested than in uncut kelp beds. It therefore seems unlikely that kelp harvesting adversely affects the sportfishery.

11.7. SPORTFISHING WHERE KELP BEDS HAVE DISAPPEARED

The analyses described above all deal with areas where kelp has persisted in considerable quantities throughout the period covered by the study. It is instructive to examine the fate of sportfishing during times when the beds have entirely disappeared or dwindled drastically. Such circumstances represent conditions far more severe than any removal of kelp by harvesting. If a close relation exists between kelp and any sportfish species, such that kelp is mandatory for survival of the fish, examination of these data should bring out this relationship clearly. The analysis would also serve to illustrate the maximum deterioration possible in a sportfishery when entire beds vanish.

Two widely separated regions in southern California have suffered extensive kelp losses in recent times. The Palos Verdes beds near Los Angeles and the Point Loma and Coronados Island beds near San Diego, have tended to decline greatly since the early 1940's. The progressive disappearance of kelp here has been documented through examination of harvesting returns and by historical charts and photographs (North, 1963). The losses have been attributed primarily to excessive grazing by hordes of sea-urchins, possibly encouraged by discharged wastes from the nearby metropolitan centers (California Water Quality Control Board, 1964). Since the wastes also spread into areas devoid of kelp, we will also examine sportfishing returns from those squares likely to be influenced by discharged wastes, but not supporting kelp, to see if substantial differences occur.

The main part of the analysis covers the period 1947 to 1957, representing the years when kelp regressed very seriously in these beds. By the end of 1957 all harvesting had ceased at Palos Verdes and the area covered by kelp was about five percent of its maximum in 1928. At Point Loma only trifling quantities of kelp were harvested after 1957 (until the restoration of these beds in 1964) and the area was about 10 percent of its former extent. Some factor, presumably warm ocean temperatures, operating from 1957 to 1959 destroyed virtually all kelp at Palos Verdes, La Jolla, Point Loma, and the Coronados Islands, except in a few scattered patches. It is particularly instructive to extend the statistical analysis through 1961 for the kelp bass, a species closely associated with kelp, to see if this final regression had any influence on fishing for an important and typical member of the kelp-bed fauna.

TABLE 47

Sportfish Catches Reported from Square 701, 1947–61

Year	Total fish*		Kelp-bass		Pelagic fish†		Barracuda		Halibut		Soles and Flatfish		Rockfish		Angler days
	No. of fish	Catch/ unit effort	No. of fish	Catch/ unit effort	No. of fish	Catch/ unit effort	No. of fish	Catch/ unit effort	No. of fish	Catch/ unit effort	No. of fish	Catch/ unit effort	No. of fish	Catch/ unit effort	
1947	64,990	4.5	12,287	0.8	34,613	2.4	18,714	1.3	8,008	0.6	130	0.1	539	0.04	14,559
1948	117,319	6.8	10,326	0.6	45,025	2.6	12,380	0.7	23,478	1.4	1,111	0.06	5,213	0.3	17,393
1949	89,885	7.0	11,741	0.9	7,144	0.6	588	0.1	25,251	2.0	335	0.03	22,114	1.7	12,911
1950	93,249	4.7	5,447	0.3	10,601	0.5	3,370	0.2	23,596	1.2	579	0.03	24,401	1.2	19,873
1951	78,730	5.3	13,512	0.9	13,296	0.9	10,532	0.7	8,424	0.6	5,432	0.4	31,149	2.1	14,851
1952	74,444	4.0	14,687	0.8	19,034	1.0	18,519	1.0	4,442	0.2	657	0.04	12,397	0.7	18,788
1953	79,263	4.1	13,133	0.7	34,083	1.8	1,249	0.1	4,256	0.2	4,636	0.24	12,460	0.6	19,273
1954	111,545	7.6	11,222	0.8	21,318	1.5	8,757	0.6	5,902	0.4	1,243	0.08	60,326	4.1	14,738
1955	102,490	11.0	5,400	0.6	2,885	0.3	823	0.1	5,014	0.5	3,230	0.35	78,808	8.2	9,282
1956	62,921	1.9	368	0.1	2,346	0.7	--	--	465	0.1	158	0.05	52,723	16.2	3,249
1957	35,902	8.0	3,019	0.7	29,840	6.7	18,359	4.1	52	0.01	102	0.02	2,530	0.6	4,484
1958	--	--	3,687	0.5	--	--	--	--	--	--	--	--	--	--	7,775
1959	--	--	5,294	0.4	--	--	--	--	--	--	--	--	--	--	14,099
1960	--	--	37,656	1.2	--	--	--	--	--	--	--	--	--	--	31,805
1961	--	--	11,847	1.6	--	--	--	--	--	--	--	--	--	--	7,342

* All species.
† Including albacore, bonito, tuna, yellowtail, barracuda, mackerel, etc.

TABLE 47
Sportfish Catches Reported from Square 701, 1947–61

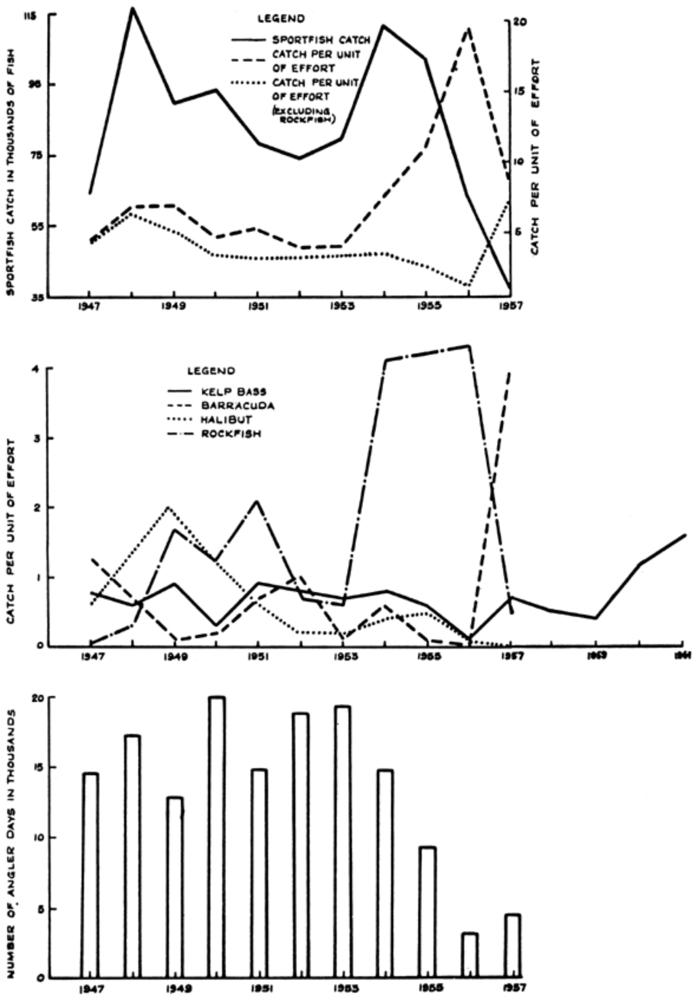


FIGURE 69. Sportfish catch statistics for Square 701 from 1947 to 1961. (a) Total catch, total catch per unit of effort, and catch per unit of effort excluding rockfish. (b) Catch per unit of effort for kelp bass, barracuda, halibut, and rockfish. (c) Angler days per year. Data from Department of Fish and Game.

FIGURE 69. ***Sportfish catch statistics for Square 701 from 1947 to 1961. (a) Total catch, total catch per unit of effort, and catch per unit of effort excluding rockfish. (b) Catch per unit of effort for kelp bass, barracuda, halibut, and rockfish. (c) Angler days per year. Data from Department of Fish and Game.***

11.7.1. Los Angeles Sportfish

The total catch of sportfishes was subdivided into six important categories, namely kelp bass, barracuda, halibut, rockfish, flatfishes, and pelagic fish as a group. It was felt that with this degree of subdivision, changes in abundance of the more important groups would be revealed.

11.7.1.1. Square 701

The total annual catch on party boats in square 701, representing the northern section of the area examined, between Santa Monica and Redondo Beach (Figure 50), during the 11-year period varied from 35,902 fish in 1957 to 117,319 fish in 1948. Little if any kelp has ever been noted in this area, and none has ever been harvested.

Fishing activity, as indicated by the number of angler days reported (Figure 69, Table 47), remained rather intensive, but with some fluctuations during the period 1947–53. The greatest activity was recorded in 1950 (19,873 angler days) and the least in 1956 (3,249 angler days).

The catch per unit effort for all fish in general trended downward from 1949 to 1953 (Figure 69). Fishing greatly improved from 1954 to 1956, however; then sharply declined. The improvement from 1954 to 1956 was due to an enormous increase in rockfish catches and kelp-bass, barracuda, and halibut fishing generally declined during the years prior to 1956 (Figure 69). Rockfish catches increased from 539 fish in 1947 to 78,808 in 1955. If rockfish are omitted for purposes of this consideration, the reported sportfish catches for square 701 declined almost steadily from 1948 through 1956. Catch per unit effort showed a similar decline (Figure 69). The improvement of barracuda fishing in 1957 was no doubt due to the higher water temperatures that year. The total catch and the catch per unit of effort for kelp bass increased markedly in 1960 and 1961.

It is concluded, therefore, that the sportfish productivity of square 701 underwent marked changes during the period 1947–57, with a general decline in the catches of such species as kelp bass, barracuda, and halibut. This deficiency was to a large extent made up by greatly increased catches of rockfish. Rockfish are considered inferior in quality to such species as kelp bass, halibut, and barracuda, however, and it may therefore be said that in terms of the more desirable species the sportfishery in square 701 deteriorated considerably in recent years. The fact that rockfish catches decreased and barracuda catches increased during 1957 may indicate that preferential fishing for barracuda took place and does not necessarily indicate a decline in the rockfish fishery.

11.7.1.2. Square 719

Square 719, bounded by White Point in the north and Long Beach in the south constituted the southern section of the area examined (Figure 50). Kelp beds formerly existed between White Point and Point Fermin.

The total annual sportfish catch made by party boats in this square during the 11-year period 1947–57 varied from 5,760 fish in 1956 to 47,811 fish in 1954. The general intensity of fishing as indicated by the number of angler days returned (Figure 70, Table 48) was lower than

TABLE 48

Sportfish Catches Reported from Square 719, 1947–61

Year	Total fish*		Kelp-bass		Pelagic fish†		Barracuda		Halibut		Soles and Flatfish		Rockfish		Angler days
	No. of fish	Catch/ unit effort	No. of fish	Catch/ unit effort	No. of fish	Catch/ unit effort	No. of fish	Catch/ unit effort	No. of fish	Catch/ unit effort	No. of fish	Catch/ unit effort	No. of fish	Catch/ unit effort	
1947	40,392	6.7	5,166	0.9	31,363	5.2	21,263	3.5	1,728	0.3	33	0.004	636	0.1	6,075
1948	47,811	4.5	8,456	0.8	25,178	2.4	16,110	1.5	8,622	0.8	396	0.037	1,391	0.1	10,643
1949	11,112	3.3	2,238	0.7	2,351	0.7	1,585	0.5	1,443	0.4	526	0.2	3,014	0.9	3,321
1950	23,063	3.8	4,381	0.7	4,961	0.8	1,223	0.2	2,011	0.3	159	0.03	2,479	0.4	6,075
1951	23,225	2.3	2,478	0.3	12,176	1.2	8,723	0.9	2,462	0.3	143	0.014	1,653	0.2	10,051
1952	13,173	3.4	1,853	0.5	7,006	1.8	4,357	1.1	540	0.2	96	0.025	1,339	0.4	3,872
1953	13,311	3.8	3,281	0.9	2,345	0.7	51	0.02	403	0.1	397	0.114	3,361	1.0	3,495
1954	28,781	8.2	2,654	0.8	7,138	2.0	2,093	0.6	2,832	0.8	868	0.20	10,690	3.1	3,507
1955	21,937	11.9	341	0.2	3,594	2.0	82	0.04	365	0.2	459	0.20	16,042	8.7	1,842
1956	5,760	7.4	279	0.4	4,833	6.2	14	0.02	100	0.1	124	0.16	4,023	5.1	783
1957	11,043	6.6	960	0.6	8,404	5.0	4,011	2.4	22	0.01	57	0.03	1,156	0.7	1,681
1958	--	--	2,614	1.4	--	--	--	--	--	--	--	--	--	--	1,875
1959	--	--	2,026	0.9	--	--	--	--	--	--	--	--	--	--	2,283
1960	--	--	5,097	2.5	--	--	--	--	--	--	--	--	--	--	2,029
1961	--	--	1,271	0.8	--	--	--	--	--	--	--	--	--	--	1,591

* All species.

† Including albacore, bonito, tuna, yellowtail, barracuda, mackerel, etc.

TABLE 48

Sportfish Catches Reported from Square 719, 1947–61

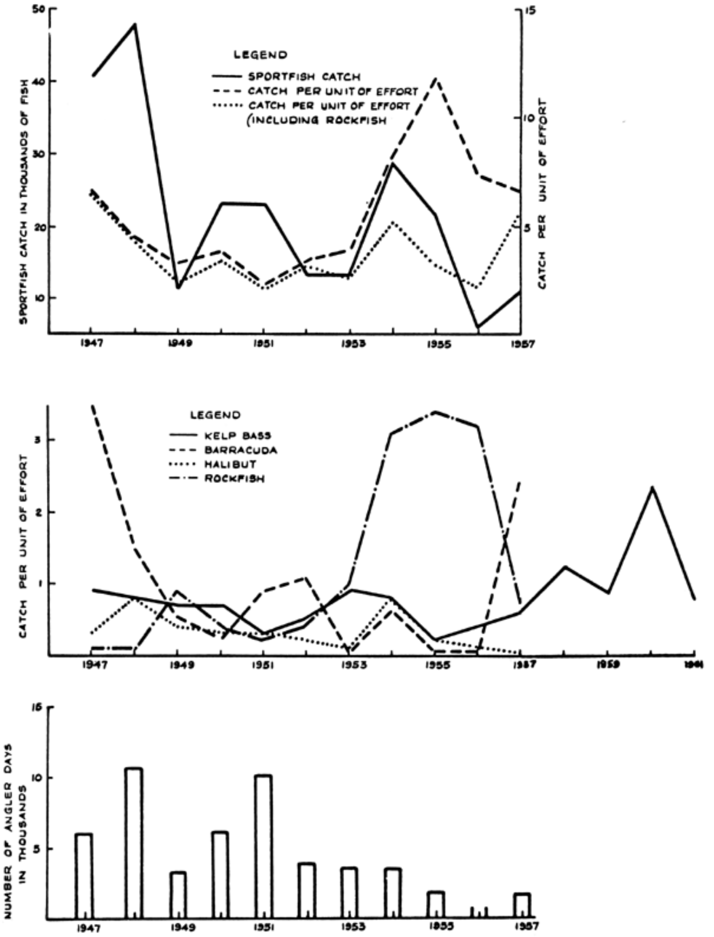


FIGURE 70. Sportfish catch statistics for Square 719 from 1947 to 1961. (a) Total catch, total catch per unit of effort, and catch per unit of effort excluding rockfish. (b) Catch per unit of effort for kelp bass, barracuda, halibut, and rockfish. (c) Angler days per year. Data from Department of Fish and Game.

FIGURE 70. ***Sportfish catch statistics for Square 719 from 1947 to 1961. (a) Total catch, total catch per unit of effort, and catch per unit of effort excluding rockfish. (b) Catch per unit of effort for kelp bass, barracuda, halibut, and rockfish. (c) Angler days per year. Data from Department of Fish and Game.***

TABLE 49

Sportfish Catches Reported from Square 720, 1947–61

Year	Total fish*		Kelp-bass		Pelagic fish†		Barracuda		Halibut		Soles and Flatfish		Rockfish		Angler days
	No. of fish	Catch/ unit effort	No. of fish	Catch/ unit effort	No. of fish	Catch/ unit effort	No. of fish	Catch/ unit effort	No. of fish	Catch/ unit effort	No. of fish	Catch/ unit effort	No. of fish	Catch/ unit effort	
1947	127,068	5.6	36,177	1.6	69,681	3.1	43,848	1.9	9,883	0.4	63	0.003	5,257	0.2	22,759
1948	50,860	5.2	17,384	1.8	37,107	3.8	3,748	0.4	6,947	0.7	888	0.09	6,713	0.7	9,730
1949	92,470	6.2	46,771	3.1	15,007	1.0	5,656	0.4	5,640	0.4	668	0.04	15,624	1.0	15,035
1950	103,339	4.7	21,007	1.0	14,857	0.7	1,075	0.1	3,615	0.2	1,237	0.06	56,131	2.5	22,125
1951	109 686	5.9	31,456	1.7	8,176	0.4	1,719	0.1	2,883	0.2	18,030	1.0	41,768	2.2	18,722
1952	78,269	4.9	15,027	0.9	29,657	1.8	21,840	1.4	3,149	0.2	1,949	0.1	23,373	1.5	16,064
1953	56,422	4.8	16,194	1.4	11,184	1.0	662	0.1	1,564	0.1	1,235	0.1	22,183	1.9	11,826
1954	140,906	6.3	29,274	1.3	31,874	1.4	12,878	0.6	2,824	0.1	703	0.03	72,607	3.2	22,535
1955	240,070	10.2	9,670	0.4	18,616	0.8	4,386	0.2	1,953	0.1	2,923	0.01	202,628	8.6	23,611
1956	256,979	12.7	15,828	0.8	8,106	0.4	1,653	0.1	780	0.04	529	0.03	228,165	11.2	20,313
1957	268,725	8.2	30,226	0.9	99,993	3.0	45,222	1.4	771	0.02	327	0.01	134,974	4.1	32,865
1958	--	--	26,435	0.8	--	--	--	--	--	--	--	--	--	--	31,754
1959	--	--	19,842	0.5	--	--	--	--	--	--	--	--	--	--	38,005
1960	--	--	23,858	0.7	--	--	--	--	--	--	--	--	--	--	36,506
1961	--	--	41,283	2.0	--	--	--	--	--	--	--	--	--	--	20,578

* All species.

† Including albacore, bonito, tuna, yellowtail, barracuda, mackerel, etc.

TABLE 49

Sportfish Catches Reported from Square 720, 1947–61

for square 701 and varied from 783 days in 1956 to 10,643 days in 1948. There was a general tendency for fishing activity to decrease from 1951 onward.

The sportfish catches for this square showed considerable fluctuation (Figure 70). Catch per unit of effort declined from 1947–49, improved in 1950, declined in 1951 and then improved very greatly through 1955, after which a further decline set in.

In spite of considerable fluctuations in the kelp-bass and halibut catch per unit of effort (Figure 70), the numbers of these species caught decreased very considerably during the 11-year period; for example, only 279 kelp-bass and 14 barracuda were caught in 1956 and 22 halibut in 1957. The reason for the great improvement in the overall catch per unit of effort from 1953 to 1955 was again largely due to an increased rockfish catch per unit of effort.

Rockfish catches increased from 636 fish in 1947 to 16,042 in 1955 and these catches together with large catches of Pacific mackerel made during the latter part of the period obviated what otherwise would have been an overall downward trend in sportfishing.

It seems evident that the availability of desirable sportfish in square 719 was not as great as in square 701 and continued to decrease. This resulted in greatly diminished fishing activity (Figure 70). Particularly during the years 1955–57, species such as kelp bass, halibut, and flatfish apparently became less abundant, and catches were supplemented with rockfish and Pacific mackerel. Decreased catches of rockfish in 1957 were unlikely to be related to any decrease in availability but probably indicate preferential fishing for pelagic species. Since 1957 the kelp-bass fishery fluctuated considerably in this square. Improvement appeared in 1960, corresponding to the data from square 701.

In general, it appears that square 719 deteriorated as an area of importance in relation to the more desirable resident species of sportfish, especially kelp bass, during the 11-year period 1947–57. This deterioration to some extent was made up by devoting increased attention to rockfish and by taking advantage of the periodic visits of pelagic species (barracuda and mackerel) into the area. Kelp-bass fishing improved somewhat in 1960.

11.7.1.3. Square 720

Square 720 comprised the central section of the area examined and was bounded by Redondo Beach in the north and White Point in the south (Figure 50). Kelp beds formerly were conspicuous along most of this coast.

The total annual catch on party boats in square 720 during the 11-year period 1947–57 was reported as varying from 50,860 fish in 1948 to 268,725 in 1957. The intensity of fishing, as indicated by the number of angler days reported by the party boats (Figure 71), was generally high throughout the period. The lowest intensities occurred in 1948 (9,730 angler days) and 1953 (11,826 angler days), but in 1957 the greatest fishing activity (32,865 angler days) was recorded.

Superficial study of the total catch and catch per unit effort graphs (Figure 71, Table 49) indicates that fishing for the period 1947–53

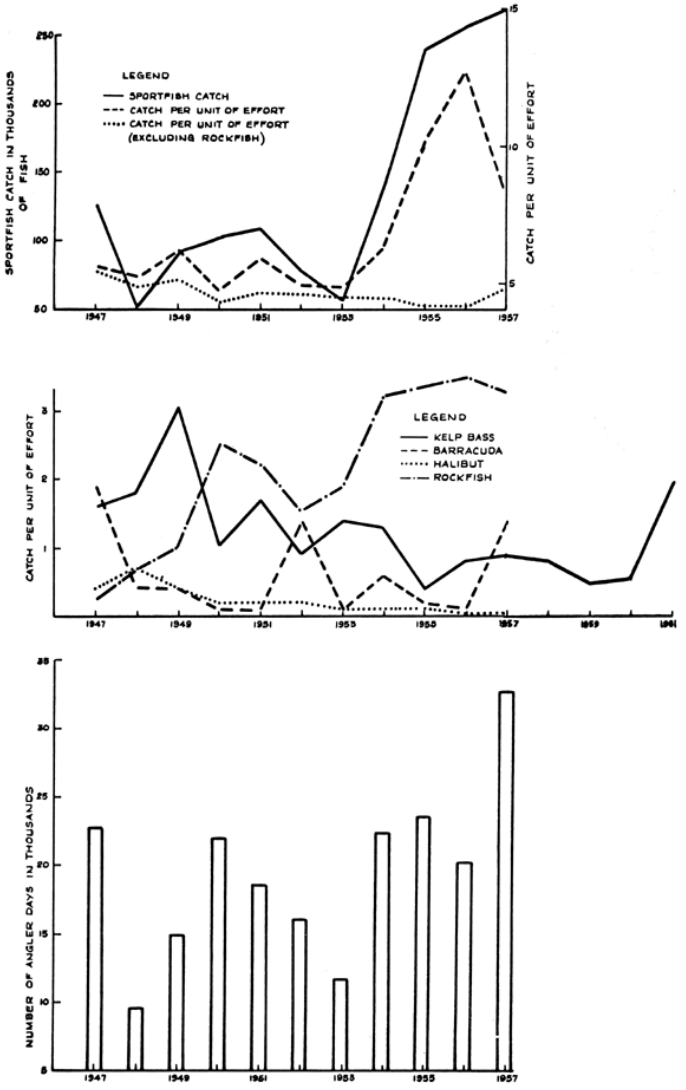


FIGURE 71. Sportfish catch statistics for Square 720 from 1947 to 1961. (a) Total catch, total catch per unit of effort, and catch per unit of effort excluding rockfish. (b) Catch per unit of effort for kelp bass, barracuda, halibut, and rockfish. (c) Angler days per year. Data from Department of Fish and Game.

FIGURE 71. ***Sportfish catch statistics for Square 720 from 1947 to 1961. (a) Total catch, total catch per unit of effort, and catch per unit of effort excluding rockfish. (b) Catch per unit of effort for kelp bass, barracuda, halibut, and rockfish. (c) Angler days per year. Data from Department of Fish and Game.***

was generally poor and that from 1954 onward tremendously improved. On closer examination, however, it is evident that if rockfish are omitted from the general consideration, fishing was indeed poor throughout the period and during the years 1947–56 tended strongly to decline. The improvement in 1957 was due to increased catches of pelagic fish, particularly barracuda, which accompanied the unusual environmental conditions of that year.

The more detailed treatment of the data up to 1957 (Figure 71) indicated that in spite of marked fluctuations and temporary improvements, the trend of kelp-bass fishing was strongly downward. Barracuda fishing showed no definite trend and fluctuated from very good to very poor. Halibut fishing showed a strong downward trend during the years 1948 to 1957. The pattern of fishing for rockfish, was widely different; a decline during the period 1951–53 was followed by great improvement, reaching a maximum in 1956 when 228,165 rockfish were caught. The slight upward trend in catch per unit of effort for kelp bass that commenced in 1960, was followed by a substantial increase in 1961.

It is evident, therefore, that sportfishing in square 720 underwent marked changes during the period 1947–57, and that a serious general decline of kelp-bass and halibut fishing in particular took place. This decline was more than compensated for by greatly increased rockfish catches. Rockfish fishing improved so much that the overall catch per unit of effort since 1954 showed a tremendous improvement in fishing in the area. As in squares 701 and 719, the kelp-bass fishery improved during years after virtually all the kelp had disappeared from the area.

11.7.1.4. Los Angeles Kelp

According to the California Fish and Game Department's official map of 1931, there were four kelp beds (Nos. 11, 12, 13, and 14) in the area between Santa Monica and Long Beach (Figure 50). Beds 11 and 12 were in square 719 off White Point, bed 13 was in square 720 off Portuguese Bend, and bed 14, within square 720, extended along the coast between Point Vicente almost to Redondo Beach.

Recent (1964) reports indicate that little remains of any of these four beds today and an examination of the kelp-harvest returns for the period 1947–57 showed that kelp-harvesting operations were discontinued in 1948 in bed 11 and in 1949 in beds 12 and 13; and further, that effective harvesting of bed 14 stopped in 1950, except for a small amount taken in 1954.

Until 1948 kelp beds 11, 12, 13, and 14 provided considerable quantities of harvestable kelp (Figure 72). The yield of this important marine resource had dropped to zero by 1950–51, due to the deterioration and disappearance of the beds, possibly attributable to the discharge of wastes.

11.7.1.5. Summary for Los Angeles

The area investigated underwent marked changes during the period 1947–57. In addition to the virtual disappearance of giant kelp from the area, the availability to the sportfisherman of the more desirable,

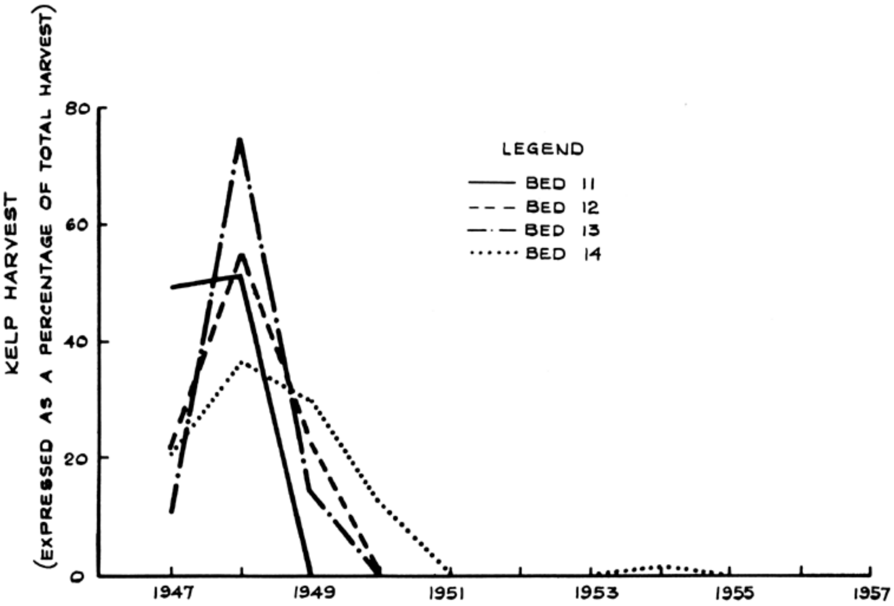


FIGURE 72. Kelp harvest returns for Beds 11, 12, 13, and 14 in relative units for 1947 to 1957. Data from Department of Fish and Game.

FIGURE 72. ***Kelp harvest returns for Beds 11, 12, 13, and 14 in relative units for 1947 to 1957. Data from Department of Fish and Game.***

normally resident species of fish, such as the kelp bass, declined steadily. This overall deterioration in sportfishing was more than compensated for by greatly increased catches of rockfish. The periodic abundance in the area of such pelagic species as barracuda apparently was not affected by the changes that have taken place.

The explanation for the abundance of rockfish is not known, but it is probable that rockfish were always abundant but were not caught to any extent by the sportfisherman due to established fishing practices or to a preference for other species. The changes that occurred may have favored the rockfish or, more probably rockfish may be little affected by the contaminating material discharged, due to the fact that the majority of species live at greater depths and remain near the bottom.

All three squares showed an improvement in fishing for kelp bass in 1960 or 1961. The reasons for the improvement are not known, but the fact that it occurred serves to indicate that the presence of large and healthy kelp beds is not mandatory for support of kelp-bass fisheries.

11.7.2. San Diego Sportfish

11.7.2.1. Square 860

Square 860, lying between La Jolla and Point Loma and including Mission Bay and part of San Diego Bay (Figure 50), embraces large kelp areas. The total annual fish catch made by party boats in this square during the 11-year period 1947–57 varied from 12,456 fish in 1948 to 98,196 fish in 1954 (Table 50, Figure 73). It is likely that party-boat fishing in this area was largely in and near the Point Loma kelp bed (No. 3) and the southern part of the La Jolla kelp bed (No. 4).

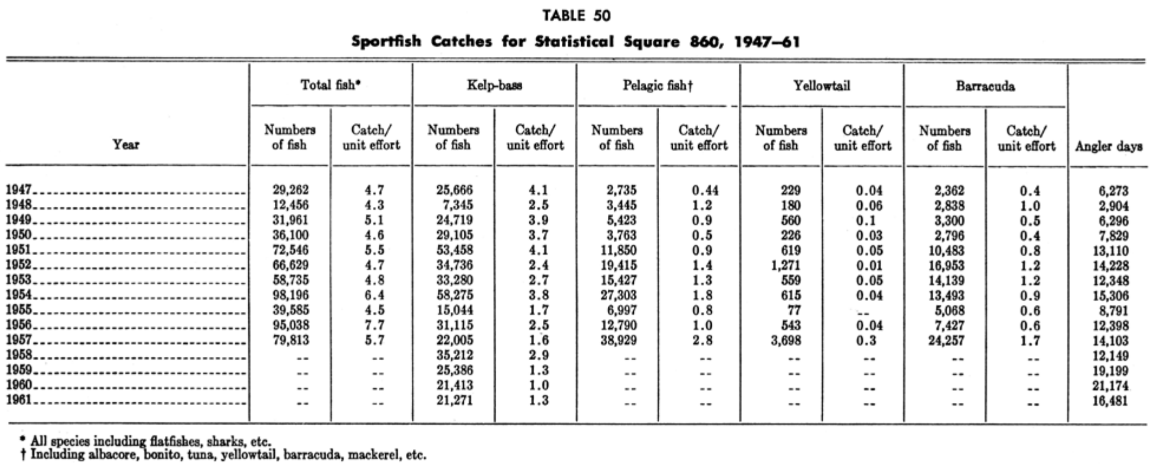


TABLE 50

Sportfish Catches for Statistical Square 860, 1947–61

Year	Total fish*		Kelp-bass		Pelagic fish†		Yellowtail		Barracuda		Angler days
	Numbers of fish	Catch/ unit effort	Numbers of fish	Catch/ unit effort	Numbers of fish	Catch/ unit effort	Numbers of fish	Catch/ unit effort	Numbers of fish	Catch/ unit effort	
1947	29,262	4.7	25,666	4.1	2,735	0.44	229	0.04	2,362	0.4	6,273
1948	12,456	4.3	7,345	2.5	3,445	1.2	180	0.06	2,838	1.0	2,904
1949	31,961	5.1	24,719	3.9	5,423	0.9	560	0.1	3,300	0.5	6,296
1950	36,100	4.6	29,105	3.7	3,763	0.5	226	0.03	2,796	0.4	7,829
1951	72,546	5.5	53,458	4.1	11,850	0.9	619	0.05	10,483	0.8	13,110
1952	66,629	4.7	34,736	2.4	19,415	1.4	1,271	0.01	16,953	1.2	14,228
1953	58,735	4.8	33,280	2.7	15,427	1.3	559	0.05	14,139	1.2	12,348
1954	98,196	6.4	58,275	3.8	27,303	1.8	615	0.04	13,493	0.9	15,306
1955	39,585	4.5	15,044	1.7	6,997	0.8	77	--	5,068	0.6	8,791
1956	95,038	7.7	31,115	2.5	12,790	1.0	543	0.04	7,427	0.6	12,398
1957	79,813	5.7	22,005	1.6	38,929	2.8	3,698	0.3	24,257	1.7	14,103
1958	--	--	35,212	2.9	--	--	--	--	--	--	12,149
1959	--	--	25,386	1.3	--	--	--	--	--	--	19,199
1960	--	--	21,413	1.0	--	--	--	--	--	--	21,174
1961	--	--	21,271	1.3	--	--	--	--	--	--	16,481

* All species including flatfishes, sharks, etc.

† Including albacore, bonito, tuna, yellowtail, barracuda, mackerel, etc.

TABLE 50

Sportfish Catches for Statistical Square 860, 1947–61

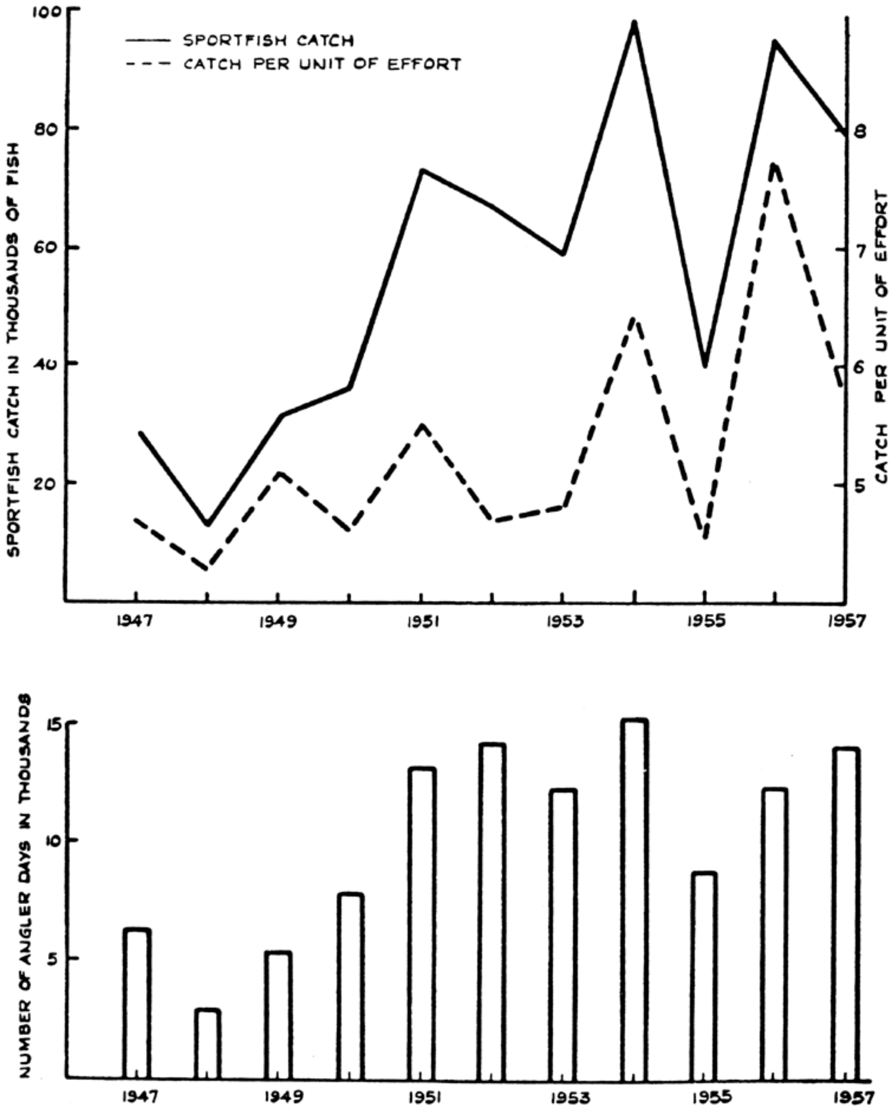


FIGURE 73. Sportfish catch statistics for Square 860 from 1947 to 1957. (a) Total catch and catch per unit of effort. (b) Angler days per year. Data from Department of Fish and Game.

FIGURE 73. ***Sportfish catch statistics for Square 860 from 1947 to 1957. (a) Total catch and catch per unit of effort. (b) Angler days per year. Data from Department of Fish and Game.***

Fishing activities increased markedly in 1951 (from 7,829 angler days reported in 1950 to 13,110 angler days in 1951) and have been intensive ever since, except in 1955. The largest number of angler days recorded was 15,306 in 1954, when the highest catch of fish (98,196) was made.

Kelp bass formed a very important part of the total fish catch throughout the period but pelagic species were also of considerable importance at times, for example, barracuda and yellowtail in 1957 (Table 50). The kelp-bass catch per unit of effort since 1957 tended to remain steady, except for a rather poor year in 1959.

TABLE 51

Sportfish Catches for Statistical Square 878 ,1947–61

Year	Total fish[1]		Kelp-bass		Pelagic fish[2]		Yellowtail		Barracuda		Angler days
	Numbers of fish	Catch/ unit effort	Numbers of fish	Catch/ unit effort	Numbers of fish	Catch/ unit effort	Numbers of fish	Catch/ unit effort	Numbers of fish	Catch/ unit effort	
1947	3,884	6.3	3,377	5.5	325	0.5	142	0.2	158	0.3	612
1948	251	3.8	90	1.3	12	0.2	2	0.03	6	0.09	67
1949	--	--	--	--	--	--	--	--	--	--	--
1950	20	0.7	2	0.06	14	0.5	--	--	--	--	31
1951	852	5.7	185	1.2	36	0.2	8	0.05	3	0.02	150
1952	774	6.3	52	0.4	14	0.1	13	0.1	1	0.01	123
1953	[3]10,789	9.6	90	0.1	106	0.1	2	0.002	5	0.004	1,125
1954	6,329	8.1	23	0.03	158	0.2	--	--	1	--	784
1955	7,524	4.9	21	0.01	[4]1,615	1.1	6	0.004	42	0.03	1,523
1956	[3]16,617	10.1	--	--	54	0.03	--	--	--	--	1,640
1957	[3]20,468	11.4	91	0.05	408	0.02	29	0.02	46	0.03	1,802
1958	--	--	809	0.3	--	--	--	--	--	--	2,738
1959	--	--	121	0.6	--	--	--	--	--	--	2,082
1960	--	--	58	0.3	--	--	--	--	--	--	221
1961	--	--	64	0.4	--	--	--	--	--	--	160

[1] All species including flatfishes, sharks, etc.
[2] Including albacore, bonito, tuna, yellowtail, barracuda, mackerel, etc.
[3] Mainly rockfish.
[4] Mainly albacore.

TABLE 51

Sportfish Catches for Statistical Square 878, 1947–61

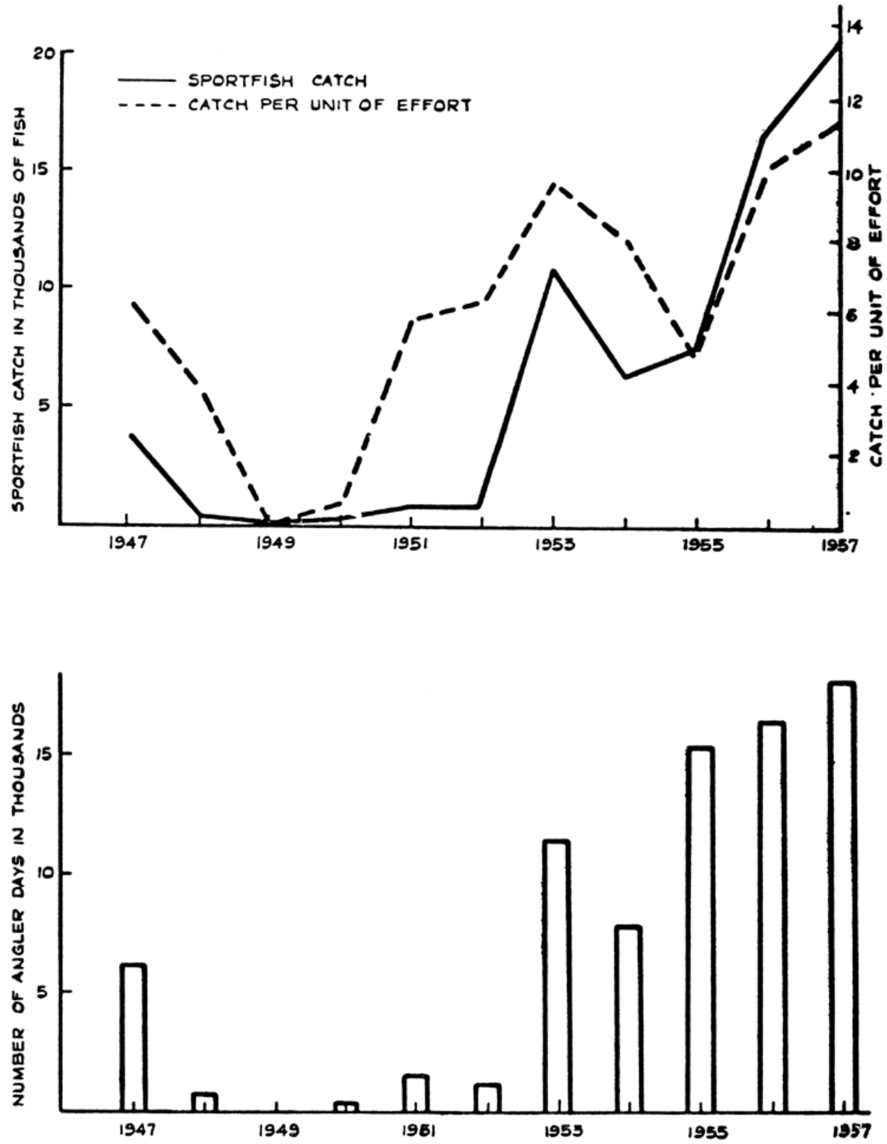


FIGURE 74. Sportfish catch statistics for Square 878 from 1947 to 1957. (a) Total catch and catch per unit of effort. (b) Angler days per year. Data from Department of Fish and Game.

FIGURE 74. ***Sportfish catch statistics for Square 878 from 1947 to 1957. (a) Total catch and catch per unit of effort. (b) Angler days per year. Data from Department of Fish and Game.***

Square 860 is a highly productive and important fishing area, containing both permanent and temporary habitats for many species. Large numbers of these fish are regularly caught by sportfishermen.

11.7.2.2. Square 878

Square 878, lying on the west or seaward side of close-to-shore square 877, is bounded in the north by Point Loma and extends beyond the level of the Mexican Border in the south (Figure 50). Some kelp formerly stood in this area. The total annual fish-catch made by party

TABLE 52

Sportfish Catches for Statistical Square 916, 1947–61

Year	Total fish*		Kelp-bass		Pelagic fish†		Yellowtail		Barracuda		Angler days
	Numbers of fish	Catch/ unit effort	Numbers of fish	Catch/ unit effort	Numbers of fish	Catch/ unit effort	Numbers of fish	Catch/ unit effort	Numbers of fish	Catch/ unit effort	
1947	40,077	1.7	14,765	0.6	14,931	0.6	5,388	0.2	8,361	0.4	23,332
1948	117,711	3.4	48,368	1.4	33,939	1.0	8,094	0.2	14,509	0.4	34,621
1949	139,651	3.4	48,163	1.2	38,265	0.9	11,904	0.3	20,948	0.5	40,789
1950	110,283	3.2	18,320	0.5	40,436	1.2	5,966	0.2	29,846	0.9	34,016
1951	114,746	2.6	29,471	0.7	51,858	1.2	20,091	0.5	26,617	0.6	44,182
1952	93,395	2.2	6,649	0.2	50,650	1.2	26,241	0.6	20,180	0.5	42,011
1953	69,121	1.7	13,564	0.3	27,664	0.7	14,558	0.4	10,049	0.3	39,758
1954	207,043	4.0	42,373	0.8	117,624	2.3	34,542	0.7	9,370	0.2	51,631
1955	152,899	2.9	12,025	0.2	97,793	1.9	33,876	0.7	18,712	0.4	52,241
1956	171,955	3.2	18,722	0.4	103,425	1.9	25,907	0.5	11,525	0.2	53,320
1957	266,353	3.2	12,676	0.2	237,494	2.8	162,905	1.9	22,967	0.3	84,556
1958	--	--	18,336	0.3	--	--	--	--	--	--	61,986
1959	--	--	12,937	0.3	--	--	--	--	--	--	39,133
1960	--	--	15,654	0.4	--	--	--	--	--	--	43,778
1961	--	--	9,748	0.5	--	--	--	--	--	--	21,301

* All species including flatfishes, sharks, etc.

† Including albacore, bonito, tuna, yellowtail, barracuda, mackerel, etc.

TABLE 52

Sportfish Catches for Statistical Square 916, 1947–61

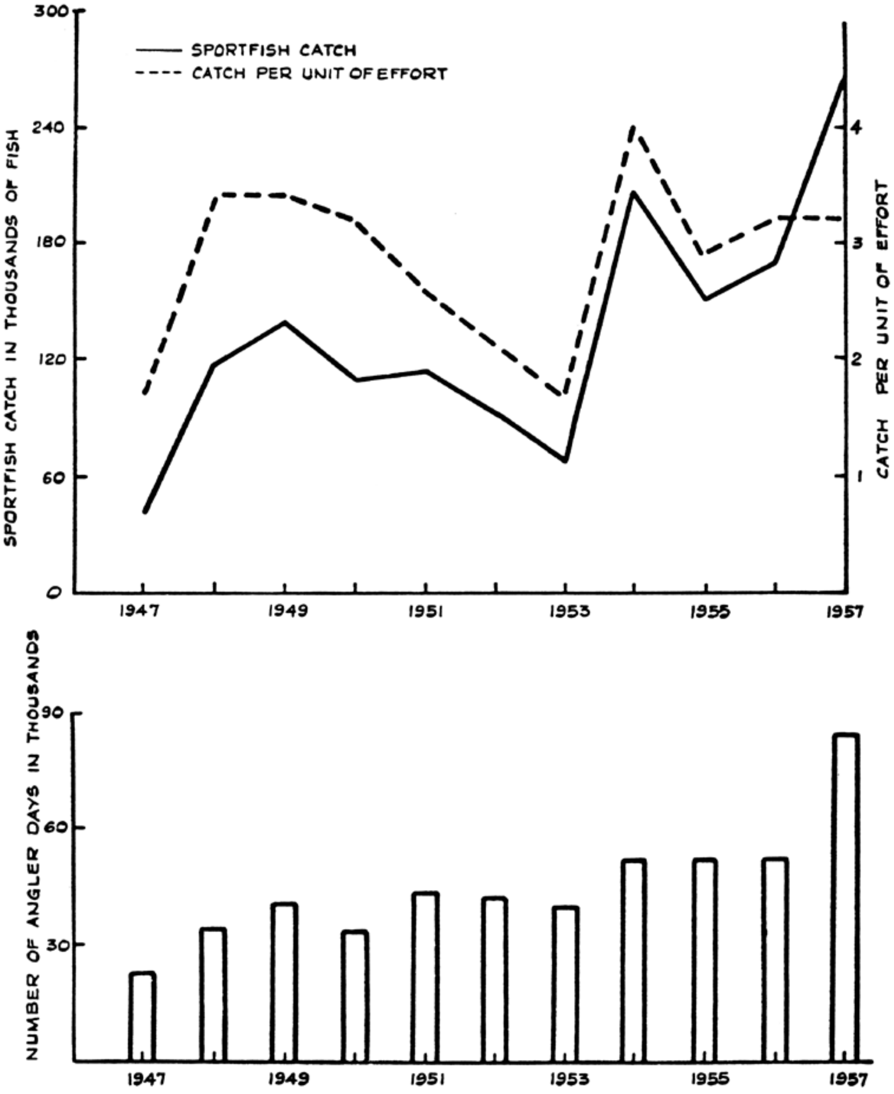


FIGURE 75. Sportfish catch statistics for Square 916 from 1947 to 1957. (a) Total catch and catch per unit of effort. (b) Angler days per year. Data from Department of Fish and Game.

FIGURE 75. ***Sportfish catch statistics for Square 916 from 1947 to 1957. (a) Total catch and catch per unit of effort. (b) Angler days per year. Data from Department of Fish and Game.***

boats in square 878 during the 11-year period 1947–57 varied widely, from no fishing recorded in 1949 and 20 fish recorded in 1950 to 20,468 fish in 1957 (Table 51, Figure 74).

After 5 years of little activity, fishing in this area increased markedly in 1953 (from 123 angler days reported in 1952 to 1,125 angler days in 1953) and apart from a lapse (784 angler days) in 1954, fishing remained intensive and increased through to 1957. From 1955 onward fishing greatly improved (Figure 74) and the total fish catch increased considerably.

Rockfish comprise probably the most important species caught and during 1956 and 1957 made up almost the entire catch for square 878 (Table 51). In 1947 kelp bass were caught in large numbers, but in subsequent years only small numbers of this species were regularly caught. of the pelagic species, albacore appear to be the most important. The catch per unit of effort for kelp bass improved somewhat over the years 1958 to 1961, but the total catch was so small that an assessment of general trends would be unreliable.

It is concluded that square 878 is an area of importance as a permanent habitat for such species as rockfishes, and as a temporary habitat for such pelagic species as albacore. Although it is not nearly as productive as square 860, it nevertheless provides a steady supply of fish for the sportfishermen who visit the area regularly.

11.7.2.3. Square 916

Square 916, located directly to the south of square 878 and lying off the coast of Mexico, and including the Coronados Islands, is an important fishing area (Figure 50). Variable amounts of kelp fringe the islands and continue to the southward. During the 11-year period 1947–57 the annual total number of fish caught here by party boats increased irregularly from 40,077 in 1947 to 266,353 in 1957 (Table 52) . Fishing activity increased rather steadily from 23,332 angler days in 1947 to a maximum of 84,556 in 1957 (Figure 75).

Throughout the 11-year period fishing activity was intensive, especially during the last 4 years (1954–57). The popularity of this area in the vicinity of the Coronados Islands for fishing is not surprising, since species such as kelp bass abound during most months of the year and at certain times pelagic species such as yellowtail and barracuda occur in very large numbers (Table 52). Following 1957 the catch of kelp bass per unit of effort improved slightly, but the total catches were much smaller than in 1948 and 1949. It seems doubtful that there was any basic trend toward improvement of the fishery. On the other hand, the data do not reveal any marked deterioration.

It is concluded that square 916 is an area of very great importance, which forms both permanent and temporary habitats for many species of fish. These form the basis of an extensive, permanent sportfishery.

11.7.2.4. San Diego Kelp

According to the official records, there are three kelp beds, numbers 1, 2, and 3, in the area between Mission Bay and the Mexican Border (Figure 50). Examination of the area showed however, that bed 1 was no longer in existence, and that during the study period relatively little remained of beds 2 and 3, in comparison with their former extent.

Examination of the kelp harvest returns for the period 1947–57 (Figure 76) showed that no kelp was harvested in bed 1 during any of these years; that kep was harvested during the years 1947–49, 1951, and 1957 in bed 2; and that bed 3 was regularly harvested each year.

The amount of kelp harvested in any 1 year from bed 3 (except 1949, when the harvests were equal) far exceeded that for any 1 year in bed 2. In 1947 the amount of kelp harvested in bed 3 was nearly seven

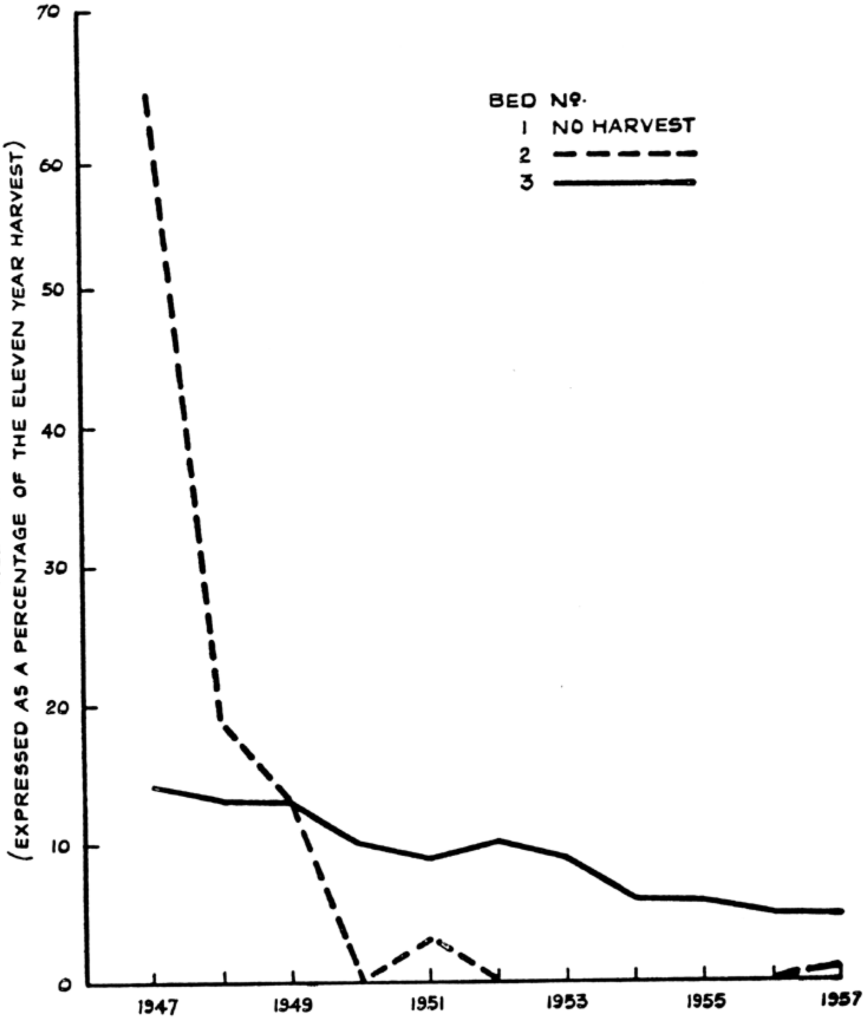


FIGURE 76. Kelp harvest returns for Beds 1, 2, and 3 in relative units for 1947 to 1957. Data from Department of Fish and Game.

FIGURE 76. ***Kelp harvest returns for Beds 1, 2, and 3 in relative units for 1947 to 1957. Data from Department of Fish and Game.***

times the amount harvested in bed 2, and constituted, according to the record, more than 60 percent of the total for the 11-year period.

From 1949 to 1963 the condition of bed 2 was such that hardly any kelp was harvested. This is in keeping with a noted decline and recession of this bed. Although considerable quantities of kelp were harvested from bed 3 during the 11 years, the amount of kelp harvested each year declined almost continuously (Figure 76).

11.7.2.5. Summary for San Diego

In the La Jolla, San Diego, and Coronados Islands stretch of coast the kelp beds did not deteriorate from 1947 to 1957 as drastically as at Palos Verdes and the fishing seems to have improved during this 11-year period, or to have maintained a steady rate. A substantial part of the improvement was due to success in catching pelagic species. The kelp-bass fishery declined or kept steady in contrast to the Palos Verdes region, which showed marked improvement in 1960 or 1961. Nonetheless, a similar conclusion may be drawn, namely that large beds of kelp are not essential to sustain a kelp-bass fishery.

11.8. GENERAL DISCUSSION

It is widely believed that the kelp beds are important in relation to the reproduction of sportfishes. The presence or absence of Macrocystis, however, is not essential for the spawning of any of the main species caught in the sportfishery; these include kelp bass, barracuda, yellowtail, albacore, rockfish, bonito, jack mackerel, Pacific mackerel, sheephead, the tunas, and others. As pointed out in Chapter 7, the large population of kelp bass resident around Guadalupe Island reproduces prolifically in spite of the fact that no Macrocystis grows there. The other sportfishes mentioned above, with the exception of rockfish and sheephead, are more or less pelagic, spawn in the open ocean, and inhabit some areas entirely lacking in giant kelp. All the rockfishes are viviparous, and both rockfishes and sheephead occur in areas where Macrocystis does not grow.

Although none of the main sportfishes is dependent on the kelp for its reproduction, it is possible that one or two smaller fishes of minor importance, such as the giant kelpfish (Heterostichus rostratus) and the kelp clingfish (Rimicola muscarum) , are dependent on Macrocystis and other marine plants in their reproduction. These and other small fish are of very minor importance as a source of food, for only certain of the sportfishes.

Although the importance of the giant kelp beds in the reproduction of the sportfishes has not been established, there is little doubt that the beds provide shelter and a refuge for certain of the larval and many of the juvenile stages of various fishes. This is especially true for the kelp topsmelt. The kelp beds harbor large numbers of small fish, both small species and the juveniles of larger species.

The immense kelp beds off the southern California coast provide shelter, an environment of high productivity, and a wonderfully complex habitat for a multitude of marine organisms ranging from bacteria and invertebrates to large fishes. The presence of these kelp beds provides ideal cover even for large fishes which, although they may also be found where Macrocystis does not occur, are attracted to the kelp beds, which provide much food and shelter. Whenever predation occurs, a suitable hiding place becomes a factor of primary importance in the survival of the prey. The giant kelp beds provide a habitat of such complexity that very large numbers of organisms can survive, whereas it is likely that far fewer could exist in the area without them. Shelter can also be provided by artificial means (*cf.* Carlisle *et al.*, 1964).

A total of 125 species of fish has been recorded in the kelp beds (Limbaugh, 1955). The majority of these are also found in areas where Macrocystis does not grow. Most or all have evidently become adapted to a temporary or permanent existence in the kelp beds. It seems probable that the large fish population off the coast of California is attributable to the presence of these kelp beds. Their elimination would doubtless very seriously affect the sportfishery. It is therefore in the interest of conservation of this vast public resource that the beds be preserved.

In general, this investigation has shown that sportfishing in the kelp beds continued to improve remarkably with a considerable simultaneous increase in the rate of commercial kelp harvesting, at least during the last 5 years of the period investigated. For the years prior to 1951, sportfish catch returns were fewer and the data were consequently less reliable. In addition, it has been indicated that there is no apparent adverse relationship between the total sportfish catch per unit of effort and the amount of kelp harvested, and that the frequency of harvesting operations in the kelp beds has no adverse effect on sportfishing. Additional, more detailed findings are confirmatory.

There is, therefore, no significant evidence that the commercial harvesting of kelp, as carried out in recent years, has had any measurable deleterious effect on the sportfishery in these locations. The commercial products and derivatives of kelp are of considerable importance to the well-being of the country, and sportfishing is an essential part of the American way of life. It is concluded that these two activities are carried on with no mutually harmful effects; and there is at present no reason to doubt that this situation will continue.

It should nevertheless be borne in mind that fluctuations both in the sportfishery and in the availability of kelp will occur for many reasons, such as changes in meteorological or oceanographic conditions, resulting in high temperatures. A situation could arise in which the harvesting of kelp would be deleterious to sportfishing. The effect might also be beneficial, for a change in the harvesting schedules or practices might lead to improved fishing; the kelp beds near the Coronados Islands almost disappeared during 1957, when sportfishing in that area was at its best.

There is some evidence that surface temperature influences both sportfishing and the kelp beds; for example, in 1954, when the maximum temperature recorded reached 75°F, there was a marked decrease in the total amount of kelp harvested and an equally marked increase in the catch of pelagic fish.

To ensure the continuation of these activities on the present basis, which is favorable to both sportfishing and the harvesting of kelp, there is a need for constant vigilance. The relationship between the two activities should be fully documented and the scope of these investigations widened to make certain that changes will be observed and suitable action taken if necessary.

Fortunately it is standard practice to leave a part of the surface canopy of each harvested kelp bed uncut. Perhaps some consideration could be given to the possibility of an increase in the depth of kelp cutting to allow harvesting of larger quantities with decreased destruction of canopy in relation to area, a step which could not be taken without extensive research. If this were considered advisable it might enable greater quantities of kelp to be harvested in periods of maximum availability, so that harvesting activities could be decreased at times when availability of kelp is at a minimum owing to conditions such as "black rot."

It is stressed that further research into the general biology of the fishes found in the kelp beds should be carried out in order to increase basic knowledge in a field of such considerable interest and importance.

Consideration should be given the possibility that at some future time sportfishing may indirectly have an adverse effect on kelp harvesting. The number of small fishing boats off the coast of southern California is constantly increasing. Many of these are equipped with powerful motors which operate the propellers at such high speed that they readily cut through the canopy of kelp beds. It may eventually be necessary to restrict the passage of these boats through the kelp beds in order to prevent extensive damage of this nature.

Both sportfishing and the commercial products derived from kelp harvesting are very important to the country; both activities should be permitted and encouraged to operate at the greatest rate compatible with the avoidance of mutually adverse effects.

11.9. RECOMMENDATIONS

This investigation has made it possible to assess the relationship between sportfishing and the commercial harvesting of kelp. Kelp harvesting does not at present appear to affect sportfishing in the kelp beds adversely. In order to ensure that this relationship will endure, it is recommended:

1. That the analysis of the relationship between the sportfish census and the harvesting of kelp be continued and re-evaluated at intervals, perhaps at the close of each year.
2. That carefully designed and competently conducted tests be run in certain beds to obtain data free from the sources of error inherent in the more general statistics utilized in this report.
3. That research on the general biology of the fishes found in kelp beds should be continued with particular reference to the collection of statistical data on the composition of the populations of the various species occurring in these areas.
4. That there be initiated investigations into the life histories and stocks of such important forage fishes as the topsmelt occurring in the kelp beds.
5. That experiments and pilot operations be undertaken to determine whether some form of harvesting (by strips) might not benefit fishing and kelp replacement.

11.10. SUMMARY

This report is based on an investigation into the relationship between sportfishing in and near the kelp beds and the commercial harvesting of kelp off the coast of southern California. These activities are described and analyzed. The main sources of data were the regular monthly returns of kelp harvested during the 10-year period 1947–56, together with the sportfish catch returns made by the registered party fishing boats during the same period, in the statistical areas containing the kelp beds.

The principal findings obtained from this investigation are briefly as follows:

1. The total tonnage of kelp harvested increased during the 10-year period: the harvest in 1956 was more than 1.5 times greater than in 1947. At the same time, however, sportfishing in the kelp beds improved from a catch per unit of effort of 4.51 in 1947 to 7.00 in 1956. During the last 5 years of this period, sportfishing in the kelp beds improved spectacularly.

2. Detailed comparison of the kelp-harvest returns with the total sportfish catch per unit of effort on an annual basis for the 10-year period showed no consistent relationship between sportfishing and the harvesting of kelp.

3. Kelp-bass fishing in the kelp beds (as measured by catch per unit of effort) was superior to that for pelagic species during the period 1948–56 and was, in consequence, the mainstay of the sportfishery in the kelp beds, despite some preferential fishing for pelagic species in place of kelp bass.

4. Although the kelp-bass fishery fluctuated considerably during the 10-year period, there was no apparent relation to kelp harvesting.

5. The catch of pelagic fish per unit of effort in the kelp beds and the amount of kelp harvested were inversely related: when the kelp harvest increased, the pelagic fish catch decreased. Further analysis of the pelagic-fish catch in relation to the important component species indicated that:

(i) There was no apparent relation between yellowtail fishing and the harvesting of kelp.
(ii) There was a striking inverse relationship between barracuda fishing and the harvesting of kelp.

It is therefore evident that the inverse relationship found for pelagic species in general was caused by the fact that the barracuda catch per unit of effort was far higher than for any other pelagic species. No explanation for this relationship was found, but it has not been substantiated that kelp harvesting was the responsible factor.

6. Data for three locations were analyzed in greater detail. The types of bed selected to cover the entire range were a group at the southern end of the commercial kelp harvesting area, a bed in the north, and a group of island beds. For the southern beds, no apparent relationship was found between sportfishing or kelp-bass fishing and the harvesting of kelp. Pelagic species were preferentially fished in place of kelp bass during the years 1947–52. The striking inverse relationship between total barracuda fishing and total kelp harvesting found for the whole area was not evident for the southern group of beds.

7. For the northern bed, no apparent relationship was found between kelp harvesting and either sportfishing in general or kelp-bass fishing. Quantities of yellowtail and barracuda caught were insufficient for comparison.

8. For the group of island beds no apparent relationship was found between the kelp harvest and sportfishing, kelp-bass fishing, pelagic fishing in general, or barracuda fishing in particular.

9. The frequency of harvesting operations in the kelp beds was found to have no adverse effect on sportfishing in general or on kelp-bass fishing in particular.

10. Kelp-bass fishing was found to be better in harvested beds than in uncut beds.

11. Sportfishing in general was as good in regularly harvested beds as in uncut beds.

12. Surface temperature is considered an important factor in the relationship between sportfishing and the kelp beds. There is some evidence that temperatures of 75° F and higher cause destruction of the kelp and at the same time attract greater numbers of pelagic fishes to the kelp beds.

13. Sportfishing returns were analyzed in areas where kelp beds were dwindling seriously or were disappearing altogether, namely Palos Verdes and the region of La Jolla, Point Loma, and Coronados Islands. These were areas exposed to the effects of discharged wastes from nearby metropolitan centers. Deterioration of sportfishing was noted in some areas but not in all, as the kelp beds regressed. Frequently, when fishing for one species became poor, effort was concentrated on other species. Detailed studies of a typical kelp-bed resident, the kelp bass, showed that even complete disappearance of kelp did not eliminate the fishery for this species.

12. 11. A COMPARISON OF THE ANNUAL HARVESTING YIELDS OF CERTAIN CALIFORNIA KELP BEDS, 1950–60

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12.1. INTRODUCTION

The effects of harvesting on the general well-being of kelp beds as a whole are of great practical interest. If the effects are adverse, it would be expected that the yield from harvested beds would decline with the passage of time, particularly in beds subjected to the greatest harvesting pressure. To study this question the annual kelp harvests from the individual kelp beds of California have been examined carefully for the 11-year period 1950 to 1960, inclusive. Primary data were the statewide harvesting returns provided by Marine Resources Operations, California Department of Fish and Game, with supplementary information for the years 1950 to 1953, inclusive, furnished by each of the kelp-harvesting industries. Kelp areas in the immediate vicinity of San Diego and Los Angeles (Palos Verdes) were omitted because of possible complications due to the discharge of wastes. The 38 kelp beds used in this study (Figure 50, Chapter 10) yielded practically all the kelp produced in southern California during this period.

These 38 beds during the 11 years, 1950–1960, provide for analysis a potential total of 418 kelp-bed-years, of which 119 involved no harvesting. Four beds (nos. 10, 32, 36, and 42) were not harvested for 10 or 11 years. An additional eight kelp beds (nos. 6, 18, 27, 34, 35, 36, 37, and 39) were not harvested for 5 to 9 years and even during years of harvesting yielded only small amounts. Thus, nearly one-third of the southern California kelp beds were left completely unharvested for 5 years or more during these 11 years.

The degree of utilization, in terms of tonnage removed per square mile, varied widely among the 30 kelp beds that were harvested to some extent during 6 or more of the 11 years. The tendency to utilize the most productive kelp beds preferentially needs to be taken into account in comparisons of the unharvested, lightly harvested and heavily harvested beds. However, some luxurious kelp beds were avoided by the harvesters, not because the supply of canopy was deficient, but for politico-economic reasons.

12.2. COMPARISONS

The harvests obtained from the different kelp beds were compared on the basis of actual tonnages recovered, or as percentages of the record harvest for each bed, or as tonnage per square mile of bed.

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[1] Deceased October, 1962

Since actual tonnages are kept confidential (in order not to disclose any specific firm's records) the only data included here are relative and percentage values.

First, the beds were ranked in order of increasing yield, using the criteria stated above. Nos. 10, 32, 36, and 42 were not harvested at all. Nos. 18, 37, 38, and 39 were harvested at a rate of about one percent on our scale. Sixteen beds (nos. 6, 9, 16, 19, 23, 24, 26, 27, 29, 31, 33, 34, 35, 40, 41, and 44) fell in the range of 1.0 to 10 percent on the same scale. The remaining 14 beds produced 69 percent of the total California kelp harvest during 1950 to 1960. In the order of increasing productivity (tonnage per square mile for the total 11 years), these top beds were nos. 43, 22, 7, 28, 30, 45, 4, 5, 8, 20, 17, 25, and 21. Approximately one-third of the beds provided two-thirds of the statewide harvest. Unharvested or lightly harvested kelp beds are available for comparison with these top producers in practically all California kelp areas. Six areas containing two or more beds will now be treated individually.

The California Department of Fish and Game took aerial photographs in 1955, 1956, and 1961 to determine the extent of the kelp beds compared with that shown by the map of the kelp beds (Figure 50).

12.2.1. Bed 16 (Paradise Cove) vs. Bed 17

Kelp beds 16 and 17 on opposite sides of Point Dume (Figure 50), of similar size and luxuriance, were subjected to widely different harvesting pressures during the 11 years. In deference to the wishes of the sportfishermen operating from Paradise Cove, harvests were consistently smaller from the Paradise Cove bed, no. 16 than from bed 17. Among all the California kelp beds, no. 17 ranks 26th. The yields per square mile from no. 17 ranged 12 to 14 times greater than the yields from no. 16, when both were harvested.

The yield from no. 17 was as large in 1960 as in 1950 and the year of maximum harvest was 1958 (Table 53) . For bed 16 the highest yields tended to lie in the earlier part of the study period and no kelp was harvested in 1960. These facts were not relevant to the comparison, however, since they may not have reflected the condition of the bed but only the policy of refraining from operating in the area.

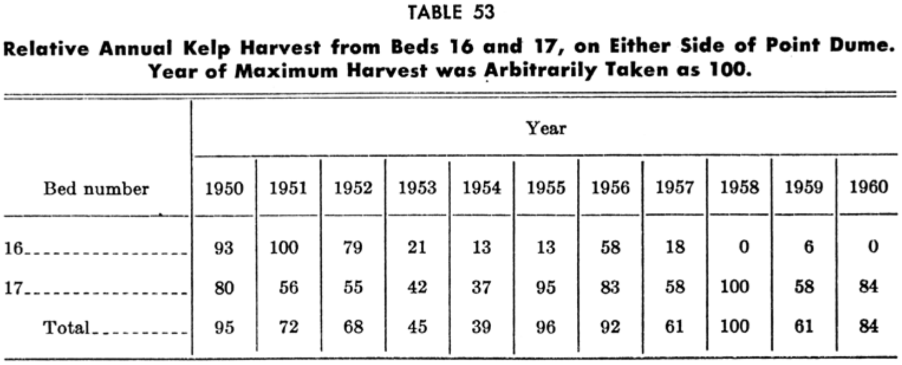


TABLE 53

Relative Annual Kelp Harvest from Beds 16 and 17, on Either Side of Point Dume. Year of Maximum Harvest was Arbitrarily Taken as 100.

Bed number	Year										
	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960
16	93	100	79	21	13	13	58	18	0	6	0
17	80	56	55	42	37	95	83	58	100	58	84
Total	95	72	68	45	39	96	92	61	100	61	84

TABLE 53

Relative Annual Kelp Harvest from Beds 16 and 17, on Either Side of Point Dume. Year of Maximum Harvest was Arbitrarily Taken as 100.

According to the area measurements made by the California Department of Fish and Game, based on aerial photographs taken in 1955 and 1957, the heavily harvested bed 17 increased in size (from 1.29 to 1.60 mi^2), whereas the lightly harvested bed 16 declined appreciably (from 1.48 to 0.98 mi^2) between 1910 and 1955–56.

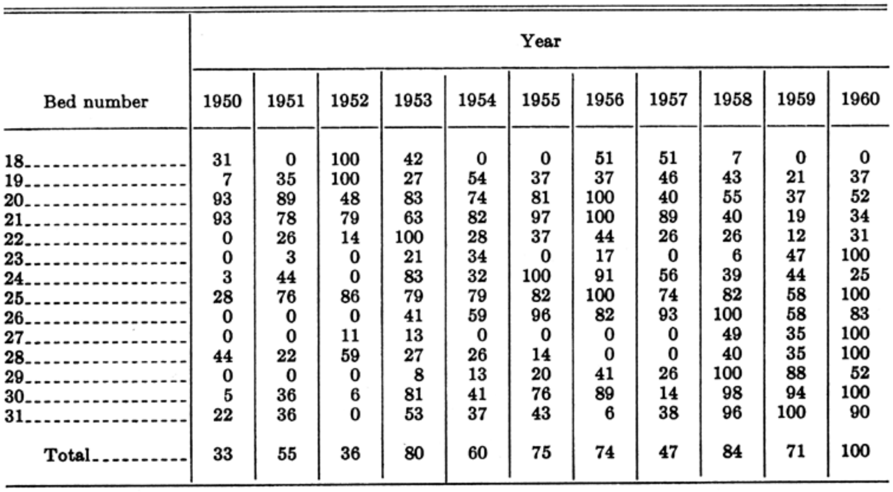
Intensive harvesting of bed 17 did not induce evident deterioration; its condition appears to have remained favorable. The yields remained close to their maximum to 1960, and the bed increased in area. Kelp beds 16 and 17 may be regarded as two experimental plots which were harvested to widely different extents during the 11 years under study. They are open for inspection by anyone interested in long-term effects of harvesting upon kelp and its associated fauna. The Paradise Cove kelp bed was studied earlier in the Kelp Investigations Program. Detrimental effects seemingly due to surface cutting were noted only in the boating channel in bed 16, where the kelp was cut at the surface continually by boat propellors, a treatment that appears to be vastly more severe than commercial cutting (North, 1957, 1958a).

12.2.2. Beds 18 to 21 (Ventura to Santa Barbara)

Useful contrasts in harvesting were offered by kelp beds 18 to 21, inclusive, of the Ventura to Santa Barbara portion of the coast. During the 11 years covered by the study, bed 18 was harvested lightly in 6 years, bed 21 was the most heavily utilized in California, and beds 19 and 20 were intermediate in yield (Tables 54 and 55). The two most lightly harvested beds (18 and 19) decreased in area, but beds 20 and 21 did not. During 1958 to 1960 harvests were relatively reduced in these beds, compared to the earlier years, but this was presumably a result of warm ocean temperatures, considered to be harmful to kelp (Table 38, Chapter 10). Intense harvesting in this area, as in bed 17, appears to have caused no deterioration.

TABLE 54

Relative Annual Kelp Harvests from Beds Between Ventura and Point Conception. Year of Maximum Harvest was Arbitrarily Taken as 100.



Bed number	Year										
	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960
18	31	0	100	42	0	0	51	51	7	0	0
19	7	35	100	27	54	37	37	46	43	21	37
20	93	89	48	83	74	81	100	40	55	37	52
21	93	78	79	63	82	97	100	89	40	19	34
22	0	26	14	100	28	37	44	26	26	12	31
23	0	3	0	21	34	0	17	0	6	47	100
24	3	44	0	83	32	100	91	56	39	44	25
25	28	76	86	79	79	82	100	74	82	58	100
26	0	0	0	41	59	96	82	93	100	58	83
27	0	0	11	13	0	0	0	0	49	35	100
28	44	22	59	27	26	14	0	0	40	35	100
29	0	0	0	8	13	20	41	26	100	88	52
30	5	36	6	81	41	76	89	14	98	94	100
31	22	36	0	53	37	43	6	38	96	100	90
Total	33	55	36	80	60	75	74	47	84	71	100

TABLE 54

Relative Annual Kelp Harvests from Beds Between Ventura and Point Conception. Year of Maximum Harvest was Arbitrarily Taken as 100.

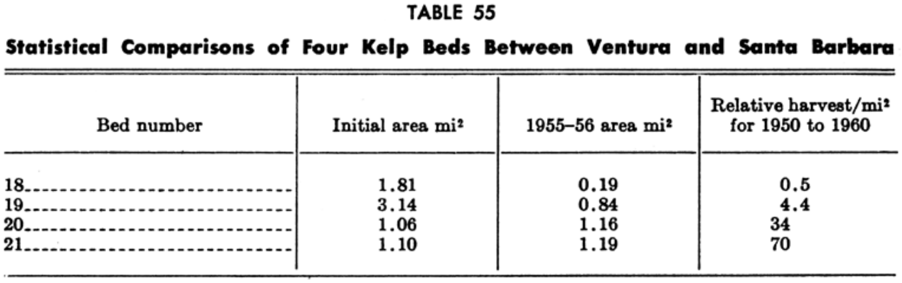


TABLE 55

Statistical Comparisons of Four Kelp Beds Between Ventura and Santa Barbara

Bed number	Initial area mi²	1955–56 area mi²	Relative harvest/mi² for 1950 to 1960
18	1.81	0.19	0.5
19	3.14	0.84	4.4
20	1.06	1.16	34
21	1.10	1.19	70

TABLE 55

Statistical Comparisons of Four Kelp Beds Between Ventura and Santa Barbara

12.2.3. Beds 24 to 26 (Santa Barbara)

During the 11-year period kelp bed no. 25 was harvested six times more extensively than beds 24 and 26 on either side (Figure 50). The 1960 harvest from the heavily utilized bed 25 was above its 11 year average. Determinations by the California Department of Fish and Game showed a large decrease in area of bed 24, but little changes in beds 25 and 26. No evidence of detrimental effects were revealed in the most heavily harvested of these three adjacent beds.

12.2.4. Beds 29 to 31 (Naples to Point Conception)

Over the 11 years kelp bed no. 30 was harvested thrice as extensively as bed 29 or 31, lying on either side. The year of maximum harvest for bed 30 was 1960 and 1958 and 1959 were also well above the long-term average (Table 54). Measurements of the California Department of Fish and Game showed a decrease of 23 percent for bed 29, but little change for 30 and 31. Again, the statistics reveal no adverse indications for heavily utilized beds, compared with nearby less utilized beds.

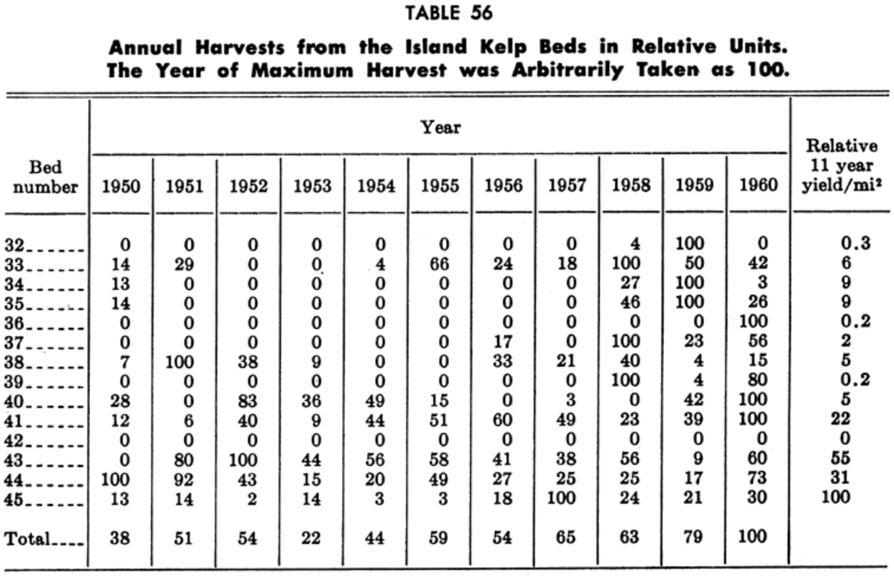


TABLE 56

Annual Harvests from the Island Kelp Beds in Relative Units. The Year of Maximum Harvest was Arbitrarily Taken as 100.

Bed number	Year											Relative 11 year yield/mi²
	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	
32	0	0	0	0	0	0	0	0	4	100	0	0.3
33	14	29	0	0	4	66	24	18	100	50	42	6
34	13	0	0	0	0	0	0	0	27	100	3	9
35	14	0	0	0	0	0	0	0	46	100	26	9
36	0	0	0	0	0	0	0	0	0	0	100	0.2
37	0	0	0	0	0	0	17	0	100	23	56	2
38	7	100	38	9	0	0	33	21	40	4	15	5
39	0	0	0	0	0	0	0	0	100	4	80	0.2
40	28	0	83	36	49	15	0	3	0	42	100	5
41	12	6	40	9	44	51	60	49	23	39	100	22
42	0	0	0	0	0	0	0	0	0	0	0	0
43	0	80	100	44	56	58	41	38	56	9	60	55
44	100	92	43	15	20	49	27	25	25	17	73	31
45	13	14	2	14	3	3	18	100	24	21	30	100
Total	38	51	54	22	44	59	54	65	63	79	100	

TABLE 56

Annual Harvests from the Island Kelp Beds in Relative Units. The Year of Maximum Harvest was Arbitrarily Taken as 100.

12.2.5. Beds 32 to 45 (offshore Islands)

Among the 14 island beds, nos. 41, 43, 44, and 45 were regularly harvested, while the remainder were utilized in only a few years (Table 56) . The four heavily harvested beds all provided larger harvests in 1960 than their 11-year averages. In terms of yield per unit area, bed 45 at San Clemente Island exceeded all other island beds. Its yield remained high and the area covered with kelp was approximately the same as when first surveyed. The other top producers (nos. 41, 43, and 44) likewise gave no indication of reduced yields in recent years beyond what may be considered normal fluctuation. There is thus no evidence of adverse effects appearing in the most heavily utilized of the island beds.

12.2.6. Beds 3 to 10 (San Diego to Newport)

This set of southern-mainland beds presumably suffered to the greatest extent from warm water in 1958 and 1959 and the harvests from all eight beds were below their 11-year average for 1950–1960 (Table 57). Eventual recovery from temperature injury is to be expected. Full recovery had not occurred, however, after more than 1 year at normal water temperature.

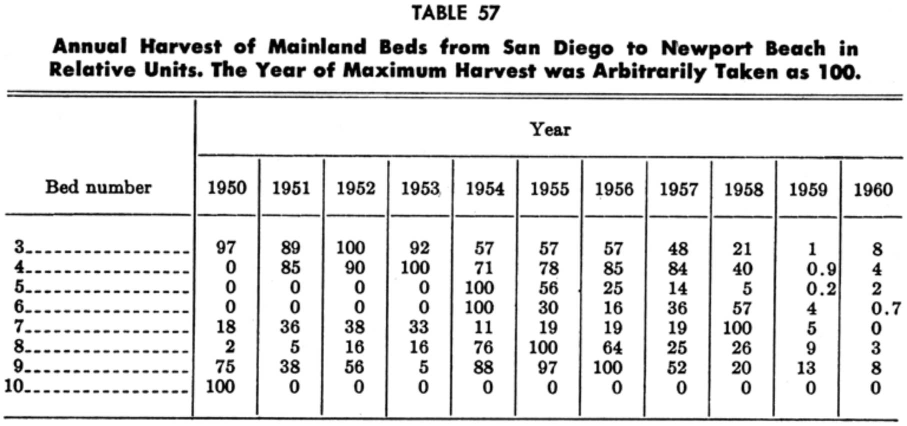


TABLE 57

Annual Harvest of Mainland Beds from San Diego to Newport Beach in Relative Units. The Year of Maximum Harvest was Arbitrarily Taken as 100.

Bed number	Year										
	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960
3	97	89	100	92	57	57	57	48	21	1	8
4	0	85	90	100	71	78	85	84	40	0.9	4
5	0	0	0	0	100	56	25	14	5	0.2	2
6	0	0	0	0	100	30	16	36	57	4	0.7
7	18	36	38	33	11	19	19	19	100	5	0
8	2	5	16	16	76	100	64	25	26	9	3
9	75	38	56	5	88	97	100	52	20	13	8
10	100	0	0	0	0	0	0	0	0	0	0

TABLE 57

Annual Harvest of Mainland Beds from San Diego to Newport Beach in Relative Units. The Year of Maximum Harvest was Arbitrarily Taken as 100.

12.3. CONCLUDING REMARKS

Leaving kelp beds unharvested for a period of years does not result in heavier surface canopies, as gauged by visual inspections or by harvesting statistics. The beds that have yielded the largest harvesting tonnages or tonnages per square mile, did so while being harvested each year. The fronds are known to have an average life span of only a few months (*cf.* North, 1961). Leaving the beds unharvested cannot result in any large increase in surface canopy because the fronds do not live from year to year.

13. 12. HARVESTING EFFECTS ON CANOPY INVERTEBRATES AND ON KELP PLANTS

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13.1. RETENTION OF MOTILE INVERTEBRATES DURING HARVESTING

In an effort to appraise the destruction of food organisms during kelp harvesting, water draining off the conveyor of a harvester operated by Kelco Co., San Diego, was sampled during the spring of 1960, while it was operating in kelp bed No. 29 near Santa Barbara. Motile invertebrates (identified by Bruce L. Wing) numbered, per U.S. gallon: 474 copepods, 83 ostracods, 70 cladocerans, 47 turbellarians, 24 nematodes, 14 gammarids, 6 caprellids, 4 mysids, 1 decapod, and 1 mollusc, comprising a total of 724 animals, not including unidentified eggs and larvae. Furthermore, this water also was turbid with microscopic algae and detritus.

Harvested kelp was sampled in duplicate at the same time. Motile animals per m^2 of clean blade surfaces were: 545–640 total animals, 323–411 copepods, 95–170 turbellarians, 37–55 gammarids, 7–42 ostracods, plus a few polychaetes, mysids, isopods, and molluscs, and two fish larvae.

Unharvested surface fronds were later collected in duplicate with associated water in this kelp area. Motile animals per m^2 of blades were: 6,250–10,800 total; 5,800–6,300 copepods, up to 2,650 molluscs, 1,200 gammarids, 390 turbellarians, 300 ostracods, 100 caprellids, 67 isopods, 13 polychaetes, 13 nematodes, plus unidentified eggs and larvae. The large number of motile kelp invertebrates found in the drainage water, and the much larger numbers found on the unharvested as compared with the harvested sampled indicate that a vary large proportion escapes in the water and drops off the conveyor during harvesting.

Fractionation of the motile kelp blade animals by harvesting was next examined quantitatively by collecting six entire surface fronds separately in plastic sacks which were then shaken free of sea water in an adequately large container. The animals that dropped off were then compared with the animals that remained on these six canopy fronds. Total motile invertebrates (for all six canopy fronds) that dropped off was 440,000, vs 160,000 that remained on the fronds. Percent retention on the blades during simulated harvesting was 30± 10 percent of the total population. The types of animals having the greatest tendency to escape were decapods, ostracods, mysids, and larvae; those retained on the blades to the greatest extent were molluscs (mainly nudibranchs), turbellarians, and nematodes. The remaining

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[1] Deceased, October, 1962

types (copepods, gammarids, isopods, caprellids, and polychaetes) did not differ significantly in this respect from the total population.

The 440,000 motile kelp animals that dropped off the six surface fronds in this harvesting experiment would be contaminated by the pelagic animals already in the sea water (about 100 liters) in which these fronds were collected.

The pelagic fraction is mainly recognizable, but to measure it separately, 220 liters of sea water was collected as three samples within a few yards of canopy at the same time that some of the kelp fronds were obtained. Per 100 liters of sea water, the pelagic-animal count was 640 total, comprising 178 copepods, 19 nematodes, 2 mysids, and 440 miscellaneous, mainly cladocerans and larvae. There were 10-fold variations between the triplicate pelagic samples, but the indicated error from this source in the harvesting experiment was very small.

13.2. PHYSIOLOGICAL CONSEQUENCES OF HARVESTING

Macrocystis pyrifera is better suited for mechanical harvesting than any other seaweed. It is the only seaweed that has yet been thus harvested anywhere to a significant extent. The colloidal, vitamin, and mineral constituents of the large brown algae are all quite similar, but the different kelps vary widely in their suitability for mechanical harvesting.

Macrocystis is especially suitable for mechanical harvesting because:

(a) Its deep-water habitat enables the use of large harvesting barges with corresponding gains in efficiency.

(b) Its surface canopy can be harvested several times per year without disturbing the submerged parts, in the underlying 30 to 80 feet of water. The sites of vegetative and sexual reproduction in this plant are located near the bottom.

(c) Photosynthesis, growth, and buoyancy are distributed along the entire frond; hence are not eliminated in the cut frond when the surface fraction is removed.

(d) The surface canopy is regenerated by the younger fronds that always grow beneath the surface. Every large Macrocystis plant I examined bore larger numbers of submerged juvenile fronds than of mature surface fronds.

(e) The stands being harvested are almost entirely of the one species. It is therefore not necessary to sort and grade the harvest, as is necessary for other seaweeds.

Disadvantages of Macrocystis as a crop include the following, some of which are closely linked with the advantages.

(a) Giant-kelp beds are wild crops that fluctuate widely under the influence of a host of factors. The quantity of kelp obtainable from any one kelp bed is essentially unpredictable years in advance.

(b) The beds are sensitive to the turbidity and quality of the coastal water. With increasing urbanization, industrialization, and harbor activities in southern California, the most conveniently located kelp beds near San Diego and Los Angeles receded. Increasingly, the kelp must now be harvested at considerable distances, with attending increases in harvesting costs, and composition of the kelp can change during lengthy transport.

(c) Conflicts have arisen because of the multiple uses of the kelp beds. Through their use as fishing and recreational areas, as well as for kelp harvesting, some of the coastal kelp beds are now serving widely different purposes simultaneously.

(d) The beds are publicly owned, and they are continuously in the public eye, which is not true of other useful seaweeds that develop inconspicuously on the bottom (Gelidium, Chondrus, Gracilaria, Laminaria, etc.). Questions have arisen concerning direct and indirect effects of Macrocystis harvesting on the plants themselves, on fishing, beach litter, beach erosion, etc.

13.2.1. Mature and Senescent Fronds

The Macrocystis harvest consists mainly of mature fronds that have completed their growth. With increasing time at the surface, sloughing and encrustation increases, and photosynthesis gradually declines. After attaining mature size and maximum photosynthetic capacity, the blades under experimental conditions became visibly senescent within 3 months (inflowing sea water maintained at 59° F.). The fronds are relatively short-lived, and under natural conditions they are periodically replaced. When mature and senescent fronds are harvested, two-thirds upwards of their individual blade supplies, photosynthetic capacities, and organic matter contents are removed. Their best blades are removed and do not grow or regenerate (except for some increase in length between blades). The remaining part of the cut mature frond consists of the stipe, pneumatocysts and about 50 older blades, many of which have already been lost. Photosynthesis in the meristoderm suffices at most for maintenance. The cut fronds assume a nearly vertical position, mainly within the stipe bundle, where they gradually disintegrate. Deteriorations of the cut ends of mature stipes in our experience is of very little consequence. The stipe is the most resistant part of the frond, remaining after the blades and pneumatocysts are lost. Accelerated decompostion of mature stipes after cutting has been observed only under unfavorable midsummer conditions, when control plants were also wasting.

13.2.2. Growing Surface Fronds

The harvest often includes ends of growing fronds that are just entering the canopy. These growing fronds retain capacity for photosynthesis and growth after cutting. If only the tip is cut off, they elongate subsequently just as when left intact. The consequences of harvesting the ends of these growing fronds vary with the number of blade primordia that are removed. It should be possible to cut off sections 3 feet long, bearing 60–100 blade primordia, without preventing the cut fronds from subsequently floating on the surface. Kelp harvesting causes no measurable "injury at a distance." Complete plants were collected from Paradise Cove, in a boating channel where surface cutting was continuous, and in a control bed that had not been harvested for over a year. The photosynthetic capacity of blades along the continuously cut stipes from the boating channel was the same as at corresponding positions on uncut fronds. No evidence was obtained of harvesting injuries at a distance in the cut fronds or submerged juvenile fronds. Naked senescent stipes were similarly abundant in stipe bundles from the continuously cut and from the unharvested portions of the Paradise Cove kelp bed.

13.2.3. Juvenile Fronds

Harvesting of the canopy affects the remaining submerged fronds chiefly through increased penetration of light and decreased translocation. Removal of the canopy eliminates it as a source of food, but this effect may be balanced by increased light penetration (Chapter 13). Which effect predominates depends on the length of the submerged juvenile fronds, the turbidity of the water column, and other factors, which may be constantly changing. If growing fronds closely approach the surface at the time of harvest, the canopy rapidly regenerates under favorable growth conditions. During plankton blooms (chiefly in late spring and summer), extra light made available by harvesting is mainly absorbed by the phytoplankton. This condition was carefully investigated in the northern end of the La Jolla kelp bed in 1958. The noon light intensity on clear days, measured at a bottom station periodically over a 6-month period, increased immediately after the canopy was harvested, but not enough to raise it above compensation. By sampling the overlying water at three depths, the cause of this low submarine light intensity after harvesting was identified as a phytoplankton bloom consisting mainly of the chain diatom Leptocylindrus, associated with 58 other species of phytoplankton.

13.2.4. New Sporophytes

Canopy cutting may have a favorable effect, through the increased penetration of light, also on the numbers and growth of juvenile sporophytes, whereby the kelp may not only regenerate *in situ*, but also increase in area. However, comparisons of the continuously cut and uncut areas of the Paradise Cove kelp by North (1958*a*) revealed similar numbers of juvenile sporophytes.

14. 13. EFFECTS OF CANOPY CUTTING ON KELP GROWTH: COMPARISON OF EXPERIMENTATION WITH THEORY

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14.1. INTRODUCTION

An unsolved problem in many areas where seaweeds are utilized is whether removal of substantial plant material influences any of the other associated marine resources. A variety of influences may be manifested, but it is intended here to restrict discussion to a single aspect, the effects that cutting may have on the growth of the giant kelp, Macrocystis pyrifera. Many of the other aspects are treated elsewhere in this bulletin.

Cutting is defined herein as any artificial process that severs stipes, pneumatocysts, or blades from their attachment to the parent organism. Different types and conditions of cutting, as we shall see, produce different results; hence the terms cutting and harvesting should not be used interchangeably, because commercial harvesting is performed under closely controlled conditions and is, therefore, a highly specialized form of cutting.

In spite of limiting ourselves solely to a consideration of the effects of canopy cutting on the growth of kelp, the problem is still extremely complex because a number of factors significantly modify effects. One cannot hope to investigate each possible result experimentally so it is necessary to develop sufficient theoretical knowledge to allow interpolation into uninvestigated areas. We have attempted this by constructing a mathematical model that describes changes in the photosynthetic capacity of a plant after the upper portion is cut and removed under different environmental conditions. The results of various cutting experiments are then described and are used to test predictions by the model. Although it has shortcomings and limitations, the model seems sufficiently accurate to be useful in predicting general responses by kelp to harvesting.

14.2. THE MATURE KELP PLANT

Since pattern of growth in individual Macrocystis fronds has been described by North (in press), specific details need not be repeated here. The plant as a whole consists of fronds of varying lengths (Figure 77). The maximum lifespan of a frond is only of the order of half a year (Brandt, 1923; Scagel, 1948; Cribb, 1954; North, 1961), so a plant must constantly replace senile tissues with new growth. This continually developing organism, therefore, has a total existence which is much longer than any of its separate parts. Certain tagged mature plants, under observation at La Jolla, required 3 years for ultimate destruction by storms or grazing. Most were very large at the start of the study, so they probably were at least 5 years of age when they vanished, or quite likely older.

Potentially the lifespan is very long, since each new frond generated by the mature plant of M. pyrifera is believed eventually to produce two additional fronds. Because of destructive agencies, however, (grazing, storms, adverse temperatures, etc.) the lifespan of an entire plant has been limited, wherever studied. Older plants disappear, to be replaced sooner or later by juveniles in cycles of ecological succession (North, 1963).

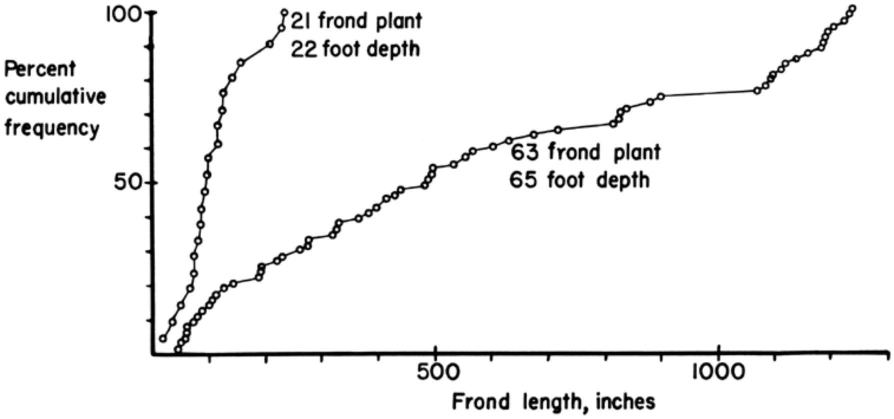

FIGURE 77. Curves for two *Macrocystis* plants showing the frequency distribution for different length fronds composing each plant. The two curves shown represent the most extreme ditsributions of 62 plants analyzed, that is all the other curves fell somewhere between the two depicted. The data illustrate that kelp plants are usually composed of fronds of many different lengths.

FIGURE 77. ***Curves for two Macrocystis plants showing the frequency distribution for different length fronds composing each plant. The two curves shown represent the most extreme ditsributions of 62 plants analyzed, that is all the other curves fell somewhere between the two depicted. The data illustrate that kelp plants are usually composed of fronds of many different lengths.***

Many size-distribution analyses of mature plants in different beds, using numbers of stipes as the size criterion, have shown a wide range, varying from nearly all small individuals, through mixtures of small and large, to predominantly large individuals (Figure 78). One can only say that a great variety exists in sizes and size distributions, and theories on the effects of cutting must recognize this fact.

Kelp plants and kelp beds are, therefore, dynamic, changing, and highly variable entities. The production and growth of new fronds is always a critical element in their continued welfare. This alone justifies studying the effect of canopy cutting on the growth of young fronds. These growth rates also provide a very convenient measure for checking predictions by the mathematical model.

14.3. PHOTOSYNTHESIS, LIGHT, AND SHADING

The production and growth of new fronds is related to the total photosynthesis accomplished by the plant, since material synthesized in one part of the plant (usually the well-illuminated canopy) can be translocated to other parts (usually the dimly-illuminated young

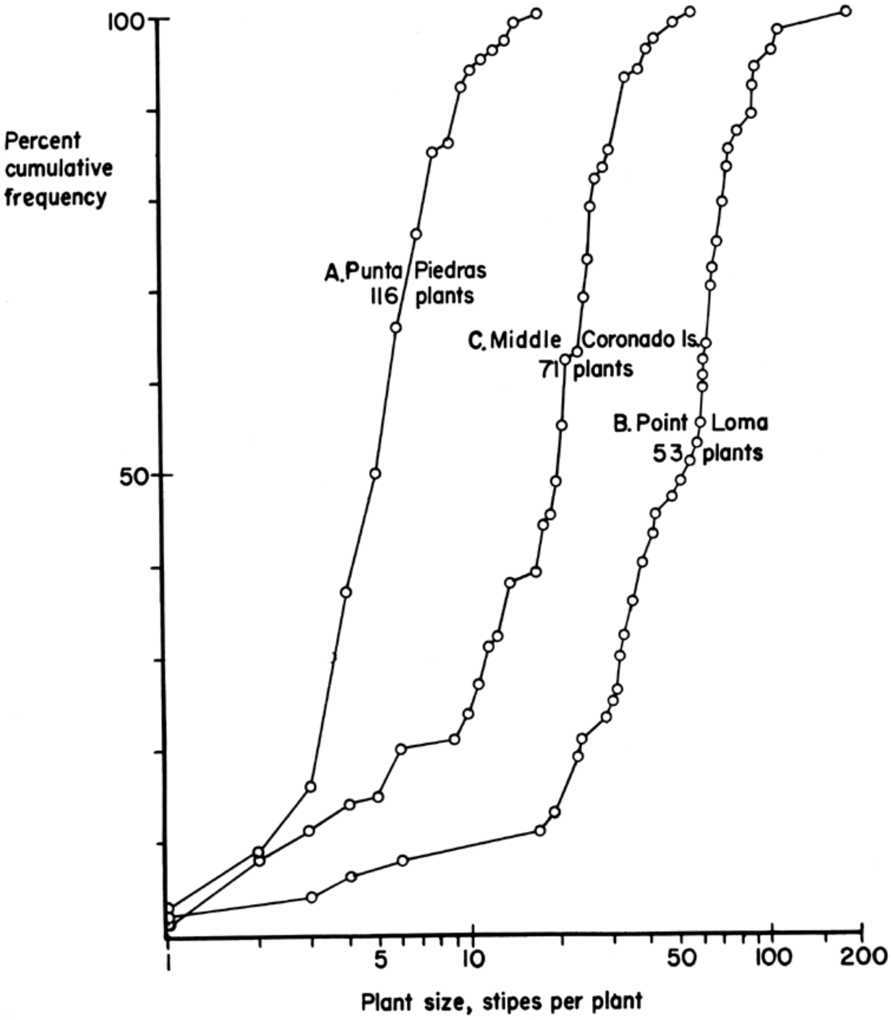

FIGURE 78. Size distribution curves for all *Macrocystis* plants found in areas sampled in different beds. The curves illustrate an area composed primarily of small plants (A), chiefly of large plants (B), and a heterogeneous sample (C), which tends to be the most common.

FIGURE 78. ***Size distribution curves for all Macrocystis plants found in areas sampled in different beds. The curves illustrate an area composed primarily of small plants (A), chiefly of large plants (B), and a heterogeneous sample (C), which tends to be the most common.***

fronds at the base) to support growth.[1] It has also been shown (Calif. Univ. IMR, 1963) that severing long fronds from kelp plants in the field causes marked decreases in the growth rates of the short young fronds. The basic premise of our study here is that any change in photosynthetic capacity due to cutting causes a proportional change in growth rate of young fronds, and that the relationship is direct and linear. The premise may not be entirely justified. Some of the products of photosynthesis support metabolism and growth of the canopy itself, and, because the proportions of tissues involved vary from plant to plant, the relative amounts of nourishment translocated downwards must also vary. Nonetheless, changes in growth rates observed in our

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[1] See Chapter 5 in "The Biology of the California Kelp Beds," J. Cramer, Germany, In Press.

cutting experiments correspond with fair accuracy to photosynthetic changes predicted by the mathematical model.

Clendenning (1957) studied the relation between light intensity and photosynthesis, and found that for mature kelp blades from the canopy, the process saturated at about 1600 foot-candles of white light (about # the intensity of daylight). The compensation point, wherein photosynthesis balances respiration, was about 15 foot-candles. Although immature blades or blades from substantial depths exhibit lower maximum photosynthetic rates, we will assume the relation developed by Clendenning (*l.c.*) for mature surface blades in all the computations that follow. This assumption seems entirely justified, for immature blades are usually only a small part of the total blade surface (ordinarily much less than 10 percent).

Several factors reduce submarine light in kelp beds: absorption by the water itself, absorption by the kelp tissues in mid-water, and an

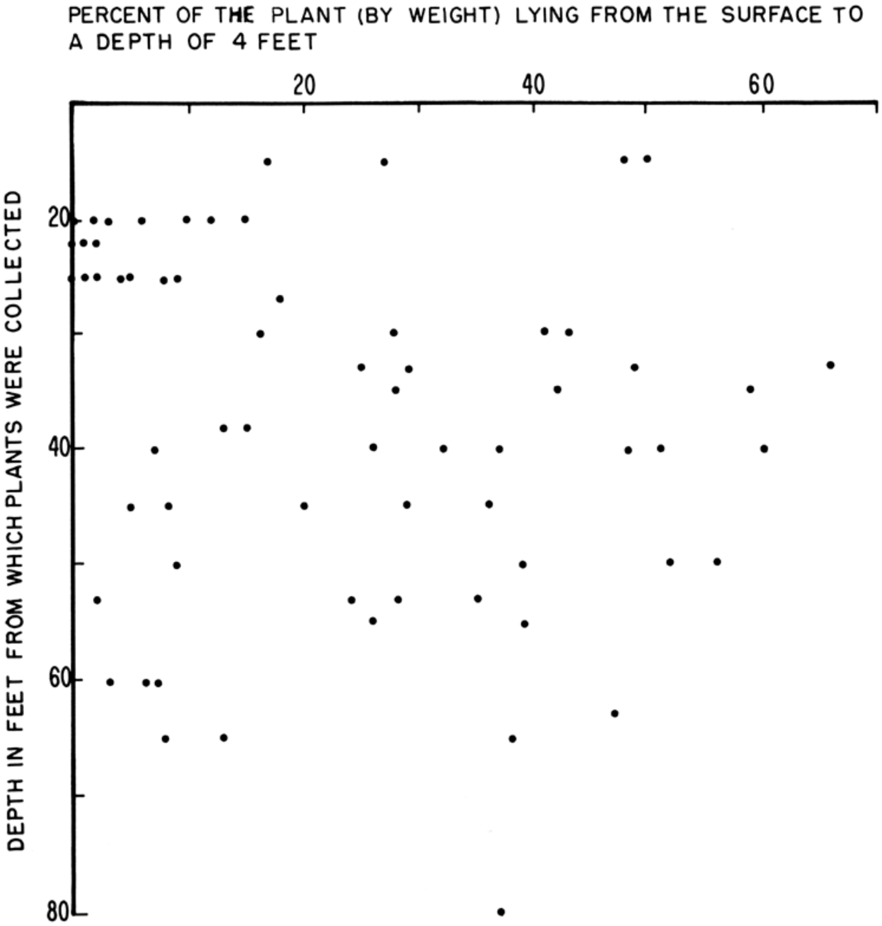

FIGURE 79. Graph showing percent of the total weight of *Macrocystis* plants lying between the surface and a depth of 4 feet (the portion which is taken by commercial harvesting). Points were plotted as a function of depth, but no relationship is apparent. Plants were all collected during the summer of 1958, a warm-water year which affected canopies adversely, hence the values may be somewhat lower than found in a normal healthy kelp area.

FIGURE 79. ***Graph showing percent of the total weight of Macrocystis plants lying between the surface and a depth of 4 feet (the portion which is taken by commercial harvesting). Points were plotted as a function of depth, but no relationship is apparent. Plants were all collected during the summer of 1958, a warm-water year which affected canopies adversely, hence the values may be somewhat lower than found in a normal healthy kelp area.***

initial reduction just below the surface by the kelp canopy. Reduction by water absorption is usually a simple exponential function of depth if the water is homogeneous, and this loss is easily computed.

Reduction by the kelp tissues in midwater has yet to be studied in detail. The determination is complex and requires a fairly uniform distribution of plants, as well as measurement of the density of the bed and measurements of light within the bed after any canopy has been stripped off, for comparison with similar measurements nearby in open water. We have conducted such a determination in a bed of 11 stipes/m^2 density (1 meter equals 39.37 inches), at a depth of 33 feet off La Jolla, and obtained a mean value of 0.25 percent absorption per meter of stipe.

Reduction of submarine light by canopy absorption, or selfshading, can cover a wide range of values, varying from almost nil to more than 99 percent, depending on the thickness of kelp floating at the surface. The proportion of tissues which a plant contributes to the canopy is also highly variable (Figure 79) and values from zero to over 60 percent of the total weight of the plant are commonly found. No quantitative data are available relating general canopy thickness to percent of a plant contained in the canopy, but considerable observation indicates that individual plants in a bed vary greatly, irrespective of canopy conditions. Thus plants with negligible canopies and individuals with massive canopies are usually easy to find in beds whether the general cover is light or whether it is heavy; all varieties of intermediate situations may also be found. The effect of shading within a bed must be quite different for a plant with a small canopy compared to a plant with a well-developed canopy and it is necessary that the mathematical model take this into account.

Cutting the canopy allows greater penetration of light, stimulating photosynthesis in areas formerly shaded. At the same time, cutting removes tissues which may be contributing very substantially to the total photosynthesis. Sometimes one factor dominates, whereas at other times the reverse is true. This raises the possibility that by the proper choice of conditions, cutting can be made to stimulate photosynthesis, increase growth rates in a bed, and thus be of overall benefit to the kelp resources.

14.4. THE MATHEMATICAL MODEL

General procedure in constructing the mathematical model involved computing the relative amount of photosynthesis accomplished by a given plant at a series of depth levels. The value computed for each depth depended on the influence of several variables (see below). The sum of all values over the entire depth range equaled the total photosynthesis accomplished by that plant.

When the canopy is removed by cutting, increased light values occur at the different depths and photosynthesis must be recomputed. Change will also result from the loss of canopy tissue. Summing the altered set of values yields a new photosynthetic capacity and the difference between the old and the new represent the change due to canopy cutting. The present model is the most sophisticated of several that have been devised.

The first model incorporated the four variables of depth, absorbency, variation in the proportion of the plant at the surface, and the relation of photosynthesis to light intensity (North, 1958*b*). This was subsequently refined by including a variable for shading (North, 1959), but neither model was able to predict observed changes in growth rates obtained from cutting experiments. The present model includes seven variables and has proven much superior in predicting results. Shortcomings still exist and many improvements are possible, but it is now clear that the present model is basically sound and that it has great potential usefulness. The model is already so complex that it has been computed only for the special cases of the cutting experiments conducted to test it. Any broader formulations or further improvements will almost certainly require the use of computers.

14.4.1. Variables Used in the Model

The seven variables incorporated in the present model are as follows:

1. Variation in photosynthetic rate with light intensity.
2. Variation in light intensity with depth for a given absorbency.
3. Variation in subsurface light for different depths as absorbency varies.
4. Variation in subsurface light for different percent absorption by the canopy.
5. Absorption of subsurface light by the vertical stipe bundles of the kelp plants.
6. Variation in distribution of the plant throughout the water column and at the surface.
7. Total photosynthesis accomplished by a plant vs. depth.

Because other variables have been ignored, results have been computed only on a relative basis but this was all that was required for this study. Several important factors, such as spectral absorption, variation in sunlight vs. time of day and season, effects of clouds and fog, effect of tissue age on light saturation, and temperature changes, must be incorporated into the model before absolute values can be computed.

14.4.2. Assumptions in the Model

Four assumptions were made in developing the model.

1. Photosynthetic capacity (or area) is linearly related to weight. Ordinarily area varies as the square of an average dimension and weight as the cube. A kelp frond, however, is composed roughly # by weight of thin flat blades, hence the asumption seems reasonable. Data for fronds longer than 3 m (approximately 10 feet), gathered in a bed at a depth of 20 m (approximately 67 feet) indicate that a linear relationship does exist between weight and blade area.

2. Weight of the plant, excluding the canopy, is uniformly distributed from surface to bottom. While only eight plants have thus far been analyzed (North, 1960; Sargent and Lantrip, 1952) as to the distribution of weight throughout the water column, indications are that the assumption is satisfactory.

3. The relation between photosynthesis and light intensity found by Clendenning (1957) for mature blades can be applied to the entire

plant. There is evidence that this assumption is not wholly justified (Clendenning, 1958), since young tissues from levels of low illumination saturate at lower intensities than older blades in the canopy. The error introduced is small, however (much less than 10 percent) and tends to be similar for all plants, hence comparisons on a relative basis would only be subject to very minor errors arising from this assumption.

4. Fronds extending into the canopy are free from imperfections that interfere with translocation. Canopy grazers sometimes attack the stipe so severely that translocation must be impaired or eliminated and the greater the age of the frond, the higher is the probability of such damage. A certain proportion of surface fronds, therefore, only shade and do not nourish the parent plant. Very little is known about this aspect and all that can be done at present is to state that for plants where stipe grazing is appreciable, the model will overemphasize photosynthetic losses due to cutting away the canopy. In our five cutting experiments, one clear case of overemphasis was found.

14.4.3. Computations

In computing the total photosynthesis accomplished by a plant (Table 58) , the depth for a given calculation is first selected and a table set up using preselected depth intervals (see column 1). In the second column light levels are entered as a function of depth computed from the Beers-Lambert law after a specific water absorbancy has been selected. (Absorbancy is here defined as the percent loss in light per meter of transit through the water.) The third column lists these light levels after being corrected for diminution of light by the vertically oriented stipe columns. The fourth column corrects the third for absorption of light at the surface by the canopy. The fifth column gives relative values of photosynthesis for the light intensities of the fourth column by using the photosynthesis vs. light intensity relation found by Clendenning (1957). The sixth column lists the assumed distribution of the plant throughout the water column as a percent of the total weight. These relative weights are multiplied by the corresponding values of relative photosynthesis from the fifth column and the product is listed in the seventh column. Addition of these values gives the total relative photosynthesis accomplished by the plant under the assumed conditions of light intensity and tissue distribution.

To calculate relative photosynthesis after the canopy has been removed by cutting, we return to the third column (which gave light intensities uncorrected for canopy absorption) and determine relative photosynthesis for these intensities, using the Clendenning relation, and enter the values as column eight. Multiplying these by the proper percent weights of column six, with the exception of the uppermost value (which is omitted because the canopy is now removed), yields the figures of column nine. Summing these gives the total photosynthesis of the cut plant. This is subtracted from and then divided by the total photosynthesis of the uncut plant (sum of column seven) to give the percent change in photosynthesis caused by cutting.

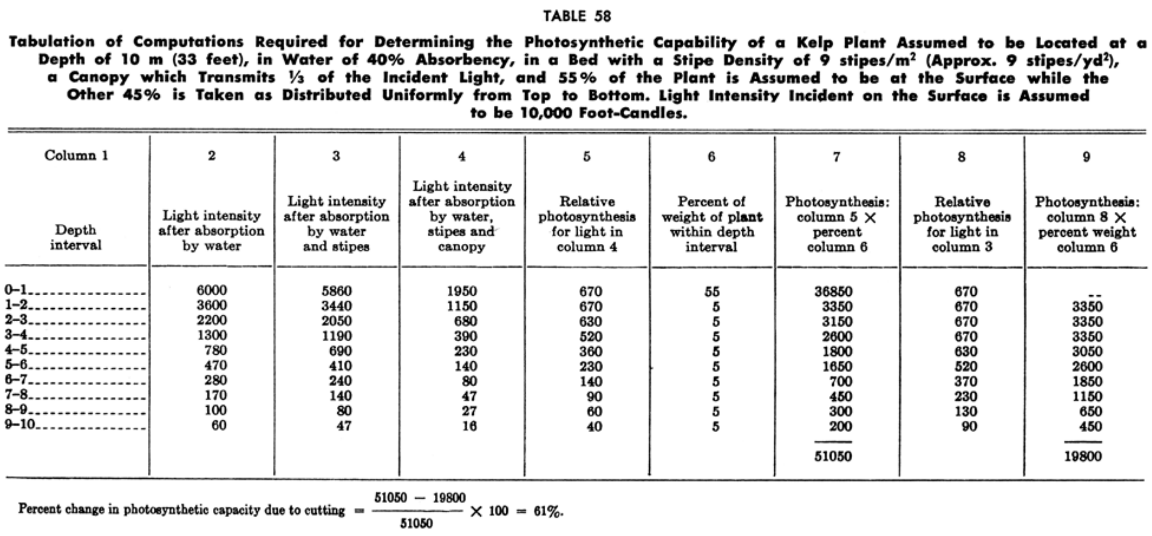

TABLE 58

Tabulation of Computations Required for Determining the Photosynthetic Capability of a Kelp Plant Assumed to be Located at a Depth of 10 m (33 feet), in Water of 40% Absorbency, in a Bed with a Stipe Density of 9 stipes/m^2 (Approx. 9 stipes/yd^2), a Canopy which Transmits ⅓ of the Incident Light, and 55% of the Plant is Assumed to be at the Surface while the Other 45% is Taken as Distributed Uniformly from Top to Bottom. Light Intensity Incident on the Surface is Assumed to be 10,000 Foot-Candles.

Column 1 Depth interval	2 Light intensity after absorption by water	3 Light intensity after absorption by water and stipes	4 Light intensity after absorption by water, stipes and canopy	5 Relative photosynthesis for light in column 4	6 Percent of weight of plant within depth interval	7 Photosynthesis: column 5 × percent column 6	8 Relative photosynthesis for light in column 3	9 Photosynthesis: column 8 × percent weight column 6
0–1	6000	5860	1950	670	55	36850	670	--
1–2	3600	3440	1150	670	5	3350	670	3350
2–3	2200	2050	680	630	5	3150	670	3350
3–4	1300	1190	390	520	5	2600	670	3350
4–5	780	690	230	360	5	1800	630	3050
5–6	470	410	140	230	5	1650	520	2600
6–7	280	240	80	140	5	700	370	1850
7–8	170	140	47	90	5	450	230	1150
8–9	100	80	27	60	5	300	130	650
9–10	60	47	16	40	5	200	90	450
						51050		19800

Percent change in photosynthetic capacity due to cutting $= \frac{51050 - 19800}{51050} \times 100 = 61\%$.

TABLE 58

Tabulation of Computations Required for Determining the Photosynthetic Capability of a Kelp Plant Assumed to be Located at a Depth of 10 m (33 feet), in Water of 40% Absorbency, in a Bed with a Stipe Density of 9 stipes/m^2 (Approx. 9 stipes/yd^2), a Canopy which Transmits # of the Incident Light, and 55% of the Plant is Assumed to be at the Surface while the Other 45% is Taken as Distributed Uniformly from Top to Bottom. Light Intensity Incident on the Surface is Assumed to be 10,000 Foot-Candles.

14.4.4. Two Graphical Examples

In order to compare the model with field data, calculations were made for two situations corresponding to the environments that existed during several cutting experiments off La Jolla. One environment was a dense bed of nine stipes/yd^2 at a depth of about 33 feet (10 meters) and the other was a sparse bed of one stipe/yd^2 at a depth of about 67 feet (20 meters). These model predictions of the effect on total photosynthesis as a result of cutting were conveniently displayed as families of curves (Figures 80 and 81). The lengthy computations, represented in Table 58, yielded only one point on one curve of Figure 81.

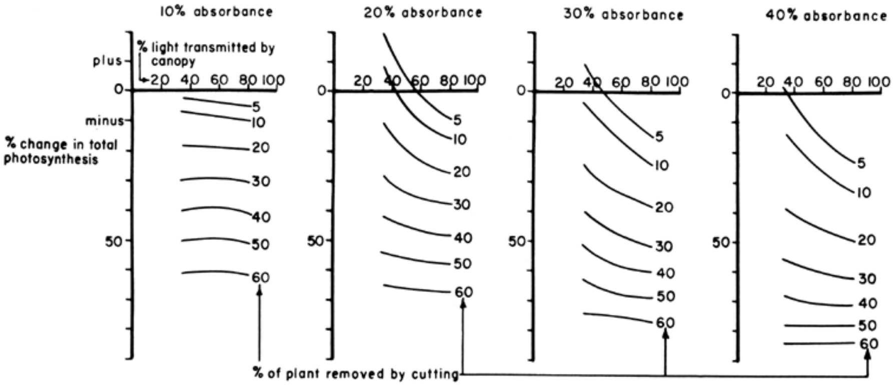

FIGURE 80. **Families of curves for different values of water absorbance and a kelp bed of density 1 stipe/m^2 (1 m = 39.37 inches), standing in water of depth 20 meters (67 feet) computed by methods described in the text. The curves relate changes in photosynthetic capability of a plant after cutting away all material from the surface to a 1 meter depth, and the general submarine light environment existing before cutting.**

FIGURE 80. ***Families of curves for different values of water absorbance and a kelp bed of density 1 stipe/m^2 (1 m = 39.37 inches), standing in water of depth 20 meters (67 feet) computed by methods described in the text. The curves relate changes in photosynthetic capability of a plant after cutting away all material from the surface to a 1 meter depth, and the general submarine light environment existing before cutting.***

Predicted responses cover a wide range varying from changes in photosynthetic capacity of more than 80 percent increase to more than 80 percent decrease. In general, the model predicts that plants in a thick bed but with small amounts of tissues at the surface tend to benefit from canopy cutting, especially as the canopy becomes denser, while plants in thin beds and with large amounts of tissues at the surface tend to lose photosynthetic capability.

In a natural situation, young and old plants are often intermixed with the older plants displaying the larger canopies. Harvesting would reduce or eliminate shading of the young individuals by the older plants and tend to aid survival of the younger.

To provide perspective it is worthwhile to indicate the ranges of conditions that would be expected to prevail in canopies suitably developed for harvesting. Such canopies must be sufficiently dense to justify expenses of the harvesting operation. The percent light transmitted by a thick canopy is typically low, ranging from 10 percent down to well below 1 percent.

The proportion of the plants removed by cutting undoubtedly varies widely. Logically it must be substantial, however, or the harvest would be uneconomical. This factor probably averages at least 30 percent in beds that are heterogeneous in the sizes of their plants. Bed density

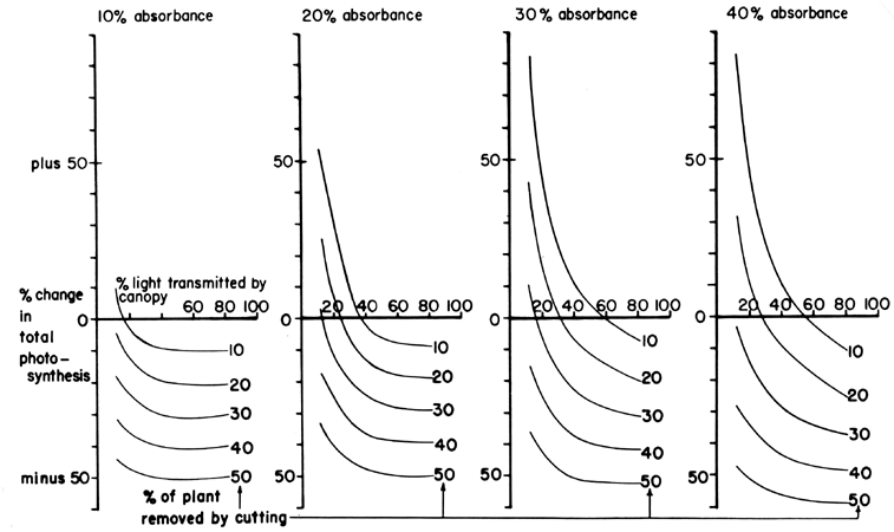

FIGURE 81. Families of curves for different values of water absorbance and a kelp bed of density 9 stipes/m^2 (1 m = 39.37 inches), standing within water depth 10 meters (33 feet), computed by methods described in the text. The curves relate changes in photosynthetic capability of a plant after cutting away all material from the surface to a depth of 1 meter, and the general submarine light environment existing before cutting.

FIGURE 81. ***Families of curves for different values of water absorbance and a kelp bed of density 9 stipes/m^2 (1 m = 39.37 inches), standing within water depth 10 meters (33 feet), computed by methods described in the text. The curves relate changes in photosynthetic capability of a plant after cutting away all material from the surface to a depth of 1 meter, and the general submarine light environment existing before cutting.***

doubtless tends to be high, since sparse stands do not develop coherent canopies. Beds less dense than three to four stipes per yd^2 are probably harvested only rarely.

Absorption of light by the water varies geographically and seasonally. The usual range for coastal beds is perhaps 20 to 40 percent absorption per meter (39.4 inches).

Under the circumstances wherein most harvesting occurs, it appears that very large losses of photosynthetic capacity are not to be expected. Predicted changes would tend to be moderate. Likewise, if appreciable stipe grazing had interfered seriously with translocation downward from the canopy, removal of the surface tissue would probably benefit photosynthesis.

14.5. CANOPY-CUTTING EXPERIMENTS

Previous to the present work, two smaller-scale cutting experiments had demonstrated that the growth rate of young fronds is intimately dependent on their connections to the mature stipes of the parent plant. These fronds presumably rely heavily on translocated nourishment to support growth. The results have been published elsewhere (California Water Quality Control Board, 1964), and are not detailed here, especially as they cannot be used to test the mathematical model.

Four experiments involved cutting plants 4 feet below mean sea level (the legal maximum depth at which harvesters can set their cutting blades). The level of cutting was determined by measuring the required distance upward from each plant holdfast. A fifth study employed the harvesting vessel *Elwood* to cut the experimental patch so that previous results could be checked against an actual harvesting operation.

Since each experiment differed significantly from the others in certain features (Table 59), the overall results portray a wide variety of conditions. Experimentation covered the commonest depths for coastal kelp. Plant concentrations ranged from sparse (0.05 plants/yd^2 and 1.1 stipes/yd^2), to dense (0.6 plants/yd^2 and 9.0 stipes/yd^2). Canopy densities ranged from almost nil to well-formed canopies that probably contained 30 to 60 percent of the total plant tissue in the bed (these were the thickest canopies readily available at the time of experimenting). Water clarities varied from extremely transparent fall conditions well offshore at Turtle Bay to highly turbid summer plankton blooms near-shore at La Jolla.

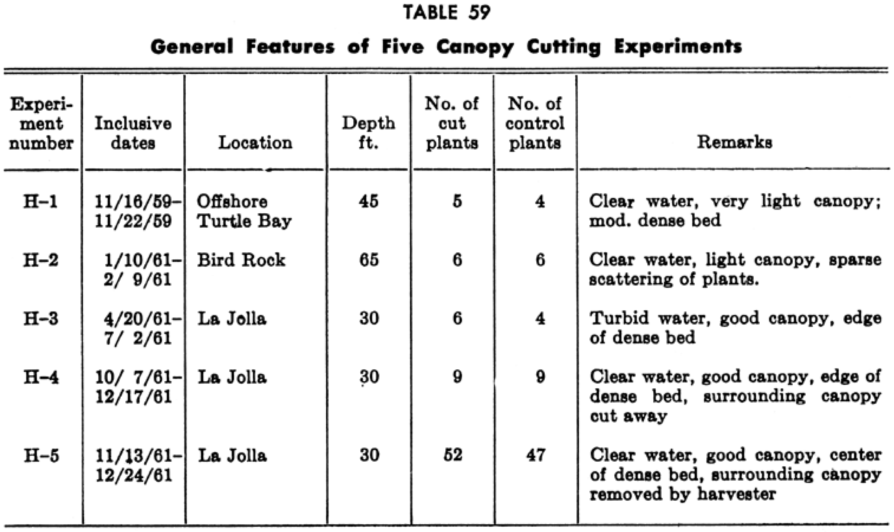

TABLE 59

General Features of Five Canopy Cutting Experiments

Experiment number	Inclusive dates	Location	Depth ft.	No. of cut plants	No. of control plants	Remarks
H–1	11/16/59– 11/22/59	Offshore Turtle Bay	45	5	4	Clear water, very light canopy; mod. dense bed
H–2	1/10/61– 2/ 9/61	Bird Rock	65	6	6	Clear water, light canopy, sparse scattering of plants.
H–3	4/20/61– 7/ 2/61	La Jolla	30	6	4	Turbid water, good canopy, edge of dense bed
H–4	10/ 7/61– 12/17/61	La Jolla	30	9	9	Clear water, good canopy, edge of dense bed, surrounding canopy cut away
H–5	11/13/61– 12/24/61	La Jolla	30	52	47	Clear water, good canopy, center of dense bed, surrounding canopy removed by harvester

TABLE 59

General Features of Five Canopy Cutting Experiments

14.5.1. Methods

North (In press) has described the technique and computations for determining standard growth rates for *Macrocystis* fronds. Such changes in standard growth rates were utilized as quantitative criteria for measuring the effects of cutting. The earlier cutting experiments were conducted concurrently with basic studies on environmental factors affecting kelp growth. These basic studies made it possible to incorporate improvements into the later cutting experiments.

The first cutting study involved 18 fronds. It became apparent that variability was such that more fronds were required to achieve significant results and the final study utilized more than 100 young fronds. The number of determinations of standard growth rates was also increased, as it proved worthwhile to study the plants for a period before cutting as well as for an extensive period after cutting. In order to eliminate as much influence from environmental change as possible (such as foggy days, layering of turbidity, sea state, currents, etc.) a set of control fronds was included in each experiment.

Two or three fronds were tagged on each selected plant. Fronds that became damaged or lost were replaced by tagging others on the same plant. In the later studies more fronds were tagged than required so that a large total would always be available for measurement even if losses occurred. Extremely slow-growing fronds were eliminated from the final calculations when means, variances, etc., were computed, because they probably represent abnormal growth. When data from control and cut groups were compared, variances were always tested for similarity by the Fisher Variance Ratio Test and differences in means were tested for significance by the *t* test (*cf.* Moroney, 1956). Probabilities of 0.05 were accepted as significant, that is, the event had a five percent or 1 in 20 probability of occurring purely by chance.

14.5.2. Results of Cutting Experiments

14.5.2.1. Study H-1, Turtle Bay, 45 feet

The first canopy cutting study was conducted at Turtle Bay, Baja California, in November 1959. Kelp beds in southern California had suffered extensive regression for 2 years, presumably because of warm water, so this bed, located in an upwelling area and composed of plants thought to be temperature-resistant, was used. It was vigorous, expanding, and displayed a well-formed canopy. The plants chosen for cutting and as controls were located near the edge of the bed for convenience and safety of the divers. Six plants were cut 4 feet beneath the surface on 16 November 1959 and the standard growth rates determined over a 6-day period on two young fronds per plant. Similar measurements were made on uncut controls (Table 60). Frond loss from natural attrition left only nine fronds of the cut group and eight of the controls at the end of the experiment. The fronds

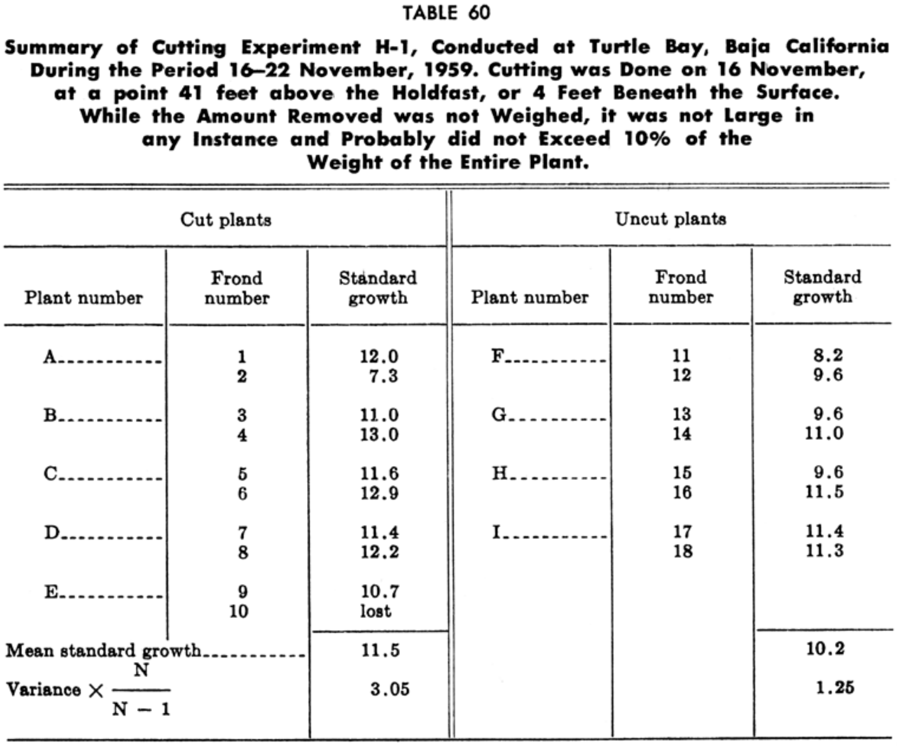

TABLE 60

Summary of Cutting Experiment H-1, Conducted at Turtle Bay, Baja California During the Period 16–22 November, 1959. Cutting was Done on 16 November, at a point 41 feet above the Holdfast, or 4 Feet Beneath the Surface. While the Amount Removed was not Weighed, it was not Large in any Instance and Probably did not Exceed 10% of the Weight of the Entire Plant.

Cut plants			Uncut plants		
Plant number	Frond number	Standard growth	Plant number	Frond number	Standard growth
A	1	12.0	F	11	8.2
	2	7.3		12	9.6
B	3	11.0	G	13	9.6
	4	13.0		14	11.0
C	5	11.6	H	15	9.6
	6	12.9		16	11.5
D	7	11.4	I	17	11.4
	8	12.2		18	11.3
E	9	10.7			
	10	lost			
Mean standard growth		11.5			10.2
Variance $\times \frac{N}{N-1}$		3.05			1.25

TABLE 60

Summary of Cutting Experiment H-1, Conducted at Turtle Bay, Baja California During the Period 16–22 November, 1959. Cutting was Done on 16 November, at a point 41 feet above the Holdfast, or 4 Feet Beneath the Surface. While the Amount Removed was not Weighed, it was not Large in any Instance and Probably did not Exceed 10% of the Weight of the Entire Plant.

from the cut group averaged standard growths of 11.5 percent vs. 10.2 percent for the controls. The variances, using Bessel's correction for small samples, of 3.05 and 1.25 respectively are not significantly different, nor are the means of the standard growths.

Later studies showed that this experiment suffered from its shortness. It might well be that with so few fronds being employed the control group, purely by chance, consisted of plants of rather low average growth rate, while the cut group had a high average growth rate. This might have masked any effect from the cutting. To eliminate this possibility, rates should have been determined for a suitable period before cutting and subsequent studies followed this procedure.

14.5.2.2. Study H-2, La Jolla, 65 feet

This deep-water study was more elaborate than the Turtle Bay experiment and involved one series of measurements before and two after the cutting. Cut material was recovered and weighed. Initially six plants, involving 12 young fronds, were chosen for the control group and a similar sample for the cutting group. By the end of the 6-week study there were 10 useable fronds left in the cut group but only 7 useable controls remained (Table 61) . The control group averaged

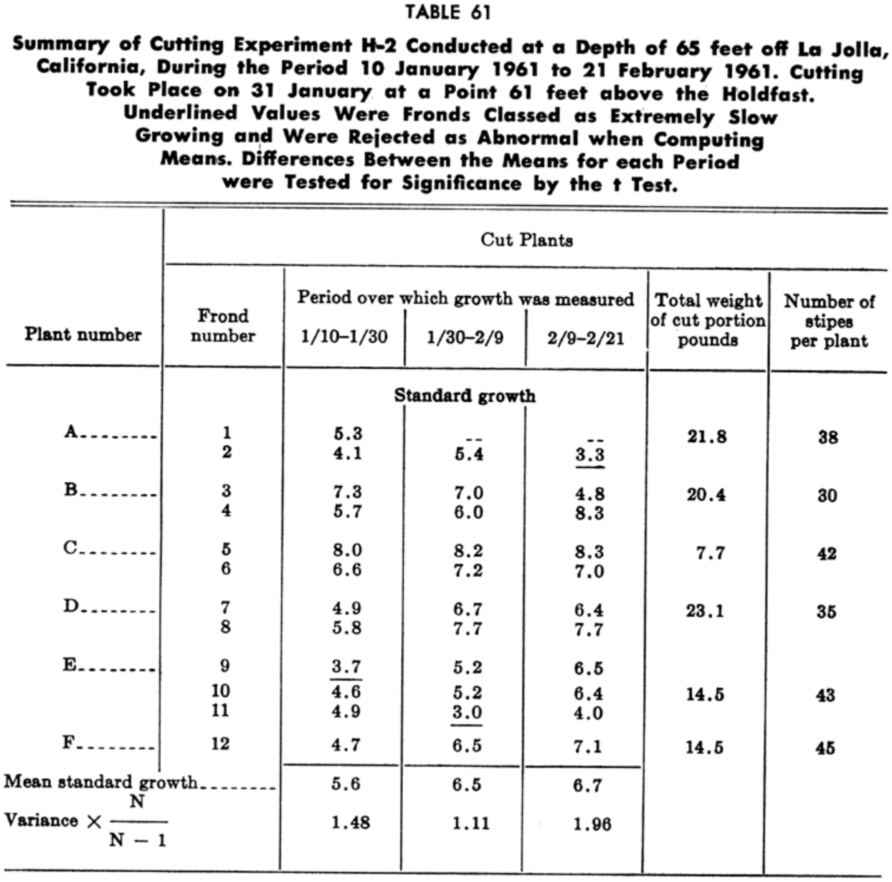

TABLE 61

Summary of Cutting Experiment H-2 Conducted at a Depth of 65 feet off La Jolla, California, During the Period 10 January 1961 to 21 February 1961. Cutting Took Place on 31 January at a Point 61 feet above the Holdfast. Underlined Values Were Fronds Classed as Extremely Slow Growing and Were Rejected as Abnormal when Computing Means. Differences Between the Means for each Period were Tested for Significance by the t Test.

Plant number	Cut Plants					
	Frond number	Period over which growth was measured 1/10–1/30	1/30–2/9	2/9–2/21	Total weight of cut portion pounds	Number of stipes per plant
		Standard growth				
A	1	5.3	--	--	21.8	38
	2	4.1	5.4	3.3		
B	3	7.3	7.0	4.8	20.4	30
	4	5.7	6.0	8.3		
C	5	8.0	8.2	8.3	7.7	42
	6	6.6	7.2	7.0		
D	7	4.9	6.7	6.4	23.1	35
	8	5.8	7.7	7.7		
E	9	3.7	5.2	6.5		
	10	4.6	5.2	6.4	14.5	43
	11	4.9	3.0	4.0		
F	12	4.7	6.5	7.1	14.5	45
Mean standard growth		5.6	6.5	6.7		
Variance $\times \frac{N}{N-1}$		1.48	1.11	1.96		

TABLE 61

Summary of Cutting Experiment H-2 Conducted at a Depth of 65 feet off La Jolla, California, During the Period 10 January 1961 to 21 February 1961. Cutting Took Place on 31 January at a Point 61 feet above the Holdfast. Underlined Values Were Fronds Classed as Extremely Slow Growing and Were Rejected as Abnormal when Computing Means. Differences Between the Means for each Period were Tested for Significance by the † Test.*

TABLE 61—Continued

Plant number	Frond number	Uncut Plants: Period over which growth was measured: 1/10–1/30	1/30–2/9	2/9–2/21
		Standard growth		
G	13	$\underline{3.3}$	$\underline{3.1}$	6.4
	14	4.1	$\underline{3.2}$	4.1
	15	--	--	--
H	16	4.8	5.7	8.8
	17	5.3	4.3	7.6
I	18	5.0	5.6	6.0
	19	6.4	$\underline{2.4}$	$\underline{1.8}$
J	20	6.0	6.2	7.5
	21	4.4	8.0	7.7
K	22	$\underline{0.4}$	$\underline{0.2}$	$\underline{1.3}$
	23	$\underline{0.5}$	--	--
L	24	--	--	--
Mean standard growth		5.1	6.0	6.9
Variance $\times \frac{N}{N-1}$		0.69	1.79	2.33
Stand. error of the difference		0.52	0.63	0.71
"t"		0.96	0.79	0.28
Significance level		>0.05	>0.05	>0.05

TABLE 61

Summary of Cutting Experiment H-2 Conducted at a Depth of 65 feet off La Jolla, California, During the Period 10 January 1961 to 21 February 1961. Cutting Took Place on 31 January at a Point 61 feet above the Holdfast. Underlined Values Were Fronds Classed as Extremely Slow Growing and Were Rejected as Abnormal when Computing Means. Differences Between the Means for each Period were Tested for Significance by the † Test.

a standard growth rate of 5.1 percent, initially; this increased to 6.0 percent, and then finally to 6.9 percent. Corresponding values for the cut group were 5.6 percent before cutting and 6.5, and 6.7 percent afterward. Percentage increases were virtually identical for corresponding periods, the variance ratio test showed no significant differences, and the means of the two groups did not differ. Hence the results were the same as for the Turtle Bay study: no effects of cutting were reliably demonstrated on the average values.

14.5.2.3. Study H-3, La Jolla, 27 feet

This study was conducted at a site inshore from, and about a mile north of H-2. The kelp canopy was well developed and was the densest in the entire La Jolla region at that time. It seemed likely that plants could be found that would have a substantial weight of tissues in the canopy, so a cutting experiment could be attempted which, in contrast to Study H-2, would remove a larger proportion of the plant from the surface. Twelve plants with large numbers of stipes and luxurious upper portions were chosen and two short fronds on each plant were tagged on 20 April 1961. Growth was followed until 8 May, when those 6 of the remaining 10 plants which were nearest the edge of the bed (to facilitate collection of the severed portions) were cut at a point 23 feet from the holdfast. During the next 12 days the mean growth of the control fronds decreased from 7.4 to 6.9, while the cut-group average decreased from 8.0 to 5.8 (Table 62) . The variance-ratio test showed no significant differences but the *t* test showed the two means to be significantly different at the 1 percent level. Over the 8-day period from 21 May to 29 May the cut group recovered to such an extent that the difference in the means was no longer significant at the 5 percent level, and, although the mean of the cut fronds remained lower than that of the controls through the entire series of measurements, the differences never became statistically significant. However, over half of the cut group became so retarded that they were classified as extremely slow growing and were thus automatically eliminated from the computations. None of the control fronds changed to this category, so it was concluded that under the conditions of the experiment, removal of this much of the plant (roughly 30 to 80 percent) initially produced a clearly defined growth retardation and may have adversely affected the further development of several fronds.

It is emphasized that this experiment differs from commercial harvesting in an important manner; the cut plants were surrounded by the canopy formed by their intact neighbors, and although they were near the edge of the bed, their remaining lower portions may have been substantially shaded. Commercial harvesting removes virtually all of the canopy, facilitating light penetration, so this experiment is considered more severe than commercial operations. It is of use, however, in evaluating the mathematical model and in identifying some of the factors causing abnormally slow growth.

14.5.2.4. Study H-4, La Jolla, 31 feet

This location was close to the third but different plants were used and the work was done during late fall. The dense canopy had persisted and 12 large, well-developed plants were chosen as before. Those six closest to the edge of the bed were selected for cutting, as an aid in removing the cut portion for weighing. Three young fronds per plant were tagged. After the selected six had been cut 27 feet above the holdfast and the severed portions collected, all plants within 75 feet were cut at the same level. The control group was located about 75 feet beyond and inside the uncut edge of the bed. This experiment, then, more closely approximated the conditions of commercial harvesting, although the cutting was much more precisely controlled.

The mean growth rate decreased immediately after the plants were cut, while the mean of the control group remained constant during this period (Table 63) . Subsequently the mean of the cut group increased until a month later it was well ahead of the controls (as it had been before cutting). The variance-ratio test indicated the variances of the two groups of data were not significantly different except for the period 2–17 December. The *t* test indicated significant differences in the means for the periods 14–21 October ($p < 0.05$), 21–29 October ($p < 0.005$), 29 October–7 November ($P = 0.01$), and 15–24 November ($P = 0.01$). The results agree with Study H-3 in that removal of a substantial portion of the plant (in this case, roughly 10 to 30 percent of the entire plant) brought an immediate retardation of growth in the young fronds. Recovery in both studies occurred in less than a

TABLE 62

Summary of Cutting Experiment H-3, Conducted at a Depth of 27 feet off La Jolla, California, During the Period 20 April to 2 July 1961. Cutting Took Place on 8 and 9 May at a point 23 feet Above the Holdfast. Underlined Values were Fronds Classed As Extremely Slow Growing and were Rejected as Abnormal when Computing Means. Differences Between the Means for Each Period were Tested for Significance by the t Test.

Plant no.	Frond no.	Cut Plants							Weight of cut portion pounds	No. of stipes per plant
		Period over which growth was measured								
		4/20–5/2	5/2–5/9	5/9–5/21	5/21–5/29	5/29–6/5	6/5–6/18	6/18–7/2		
		Standard growth								
	1	6.1	7.7	3.2	4.5	4.1	2.8	0.4	81	28
A	2	6.8	8.0	4.8	5.0	2.7	3.2	--		
	3	6.6	6.8	5.0	3.5	1.3	0.7	0		
B	4	5.9	9.5	4.9	3.9	1.5	--	--	40	19
	5	5.6	6.3	6.6	7.4	5.8	7.1	7.1		
C	6	5.8	7.0	7.0	6.0	6.3	7.3	--	44	30
	7	5.4	8.3	5.2	3.4	0.8	0.4	--		
D	8	4.0	11.1	6.9	7.2	5.8	8.2	--	38	29
	9	6.0	7.0	5.0	3.9	5.8	6.3	5.0		
E	10	6.2	8.3	6.2	6.0	6.9	6.3	5.5	113	31
	11	7.0	7.7	6.7	3.9	6.3	4.5	2.5		
F	12	5.8	7.9	5.6	5.4	5.3	3.3	2.1	50	28
Mean standard growth		6.0	8.0	5.8	6.9	5.8	6.6	5.9		
Variance × $\frac{N}{N-1}$		0.60	1.72	0.77	2.26	0.69	1.61	1.21		

TABLE 62

Summary of Cutting Experiment H-3, Conducted at a Depth of 27 feet off La Jolla, California, During the Period 20 April to 2 July 1961. Cutting Took Place on 8 and 9 May at a point 23 feet Above the Holdfast. Underlined Values were Fronds Classed As Extremely Slow Growing and were Rejected as Abnormal when Computing Means. Differences Between the Means for Each Period were Tested for Significance by the † Test.

TABLE 62—Continued

Plant no.	Frond no.	Uncut Plants						
		Period over which growth was measured						
		4/20–5/2	5/2–5/9	5/9–5/21	5/21–5/29	5/29–6/5	6/5–6/18	6/18–7/2
		Standard growth						
G	13	grazed	--	--	--	--	--	--
	14	6.0	7.2	6.5	5.0	5.2	5.6	--
	15	5.0	9.7	8.1	8.7	7.7	9.3	--
H	16	6.2	9.0	6.7	8.7	7.2	9.5	8.2
	17	4.6	5.9	7.1	7.4	6.6	8.6	11.4
I	18	4.3	6.8	6.6	6.9	6.8	7.2	--
	19	5.0	5.0	6.4	6.8	5.2	8.2	6.0
J	20	5.0	8.2	7.0	7.3	7.0	7.1	5.7
Mean standard growth		5.2	7.4	6.9	7.3	6.5	7.9	7.8
Variance $\times \frac{N}{N-1}$		0.49	2.82	0.34	1.61	0.94	1.92	6.92
Standard error of the difference		0.35	0.68	0.38	0.74	0.47	0.74	1.64
"t"		2.3	0.9	2.9	0.5	1.5	1.8	1.2
Significance level		<0.05	>0.05	0.01	>0.05	>0.05	>0.05	>0.05

TABLE 62

Summary of Cutting Experiment H-3, Conducted at a Depth of 27 feet off La Jolla, California, During the Period 20 April to 2 July 1961. Cutting Took Place on 8 and 9 May at a point 23 feet Above the Holdfast. Underlined Values were Fronds Classed As Extremely Slow Growing and were Rejected as Abnormal when Computing Means. Differences Between the Means for Each Period were Tested for Significance by the † Test.

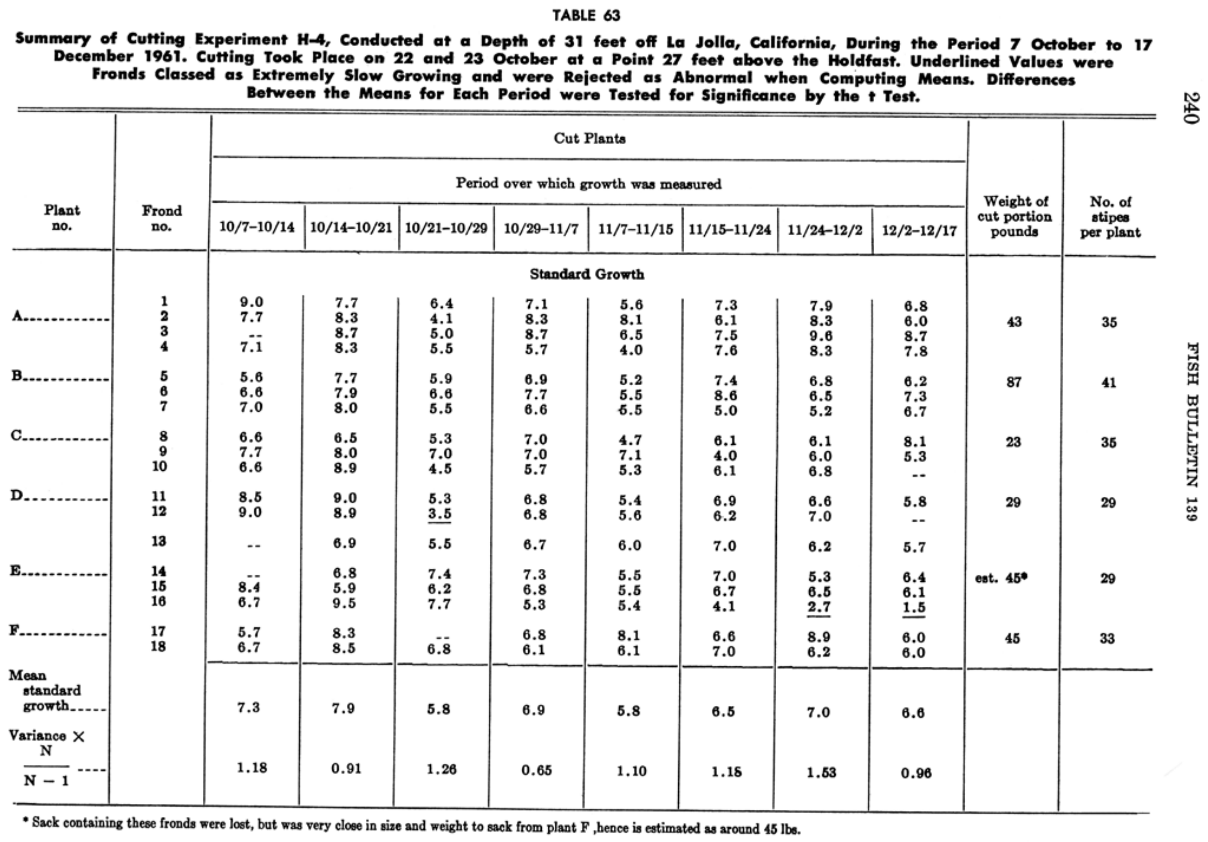

TABLE 63

Summary of Cutting Experiment H-4, Conducted at a Depth of 31 feet off La Jolla, California, During the Period 7 October to 17 December 1961. Cutting Took Place on 22 and 23 October at a Point 27 feet above the Holdfast. Underlined Values were Fronds Classed as Extremely Slow Growing and were Rejected as Abnormal when Computing Means. Differences Between the Means for Each Period were Tested for Significance by the t Test.

Plant no.	Frond no.	Cut Plants									
		Period over which growth was measured								Weight of cut portion pounds	No. of stipes per plant
		10/7–10/14	10/14–10/21	10/21–10/29	10/29–11/7	11/7–11/15	11/15–11/24	11/24–12/2	12/2–12/17		
		Standard Growth									
A	1	9.0	7.7	6.4	7.1	5.6	7.3	7.9	6.8	43	35
	2	7.7	8.3	4.1	8.3	8.1	6.1	8.3	6.0		
	3	--	8.7	5.0	8.7	6.5	7.5	9.6	8.7		
	4	7.1	8.3	5.5	5.7	4.0	7.6	8.3	7.8		
B	5	5.6	7.7	5.9	6.9	5.2	7.4	6.8	6.2	87	41
	6	6.6	7.9	6.6	7.7	5.5	8.6	6.5	7.3		
	7	7.0	8.0	5.5	6.6	5.5	5.0	5.2	6.7		
C	8	6.6	6.5	5.3	7.0	4.7	6.1	6.1	8.1	23	35
	9	7.7	8.0	7.0	7.0	7.1	4.0	6.0	5.3		
	10	6.6	8.9	4.5	5.7	5.3	6.1	6.8	--		
D	11	8.5	9.0	5.3	6.8	5.4	6.9	6.6	5.8	29	29
	12	9.0	8.9	3.5	6.8	5.6	6.2	7.0	--		
	13	--	6.9	5.5	6.7	6.0	7.0	6.2	5.7		
E	14	--	6.8	7.4	7.3	5.5	7.0	5.3	6.4	est. 45*	29
	15	8.4	5.9	6.2	6.8	5.5	6.7	6.5	6.1		
	16	6.7	9.5	7.7	5.3	5.4	4.1	2.7	1.5		
F	17	5.7	8.3	--	6.8	8.1	6.6	8.9	6.0	45	33
	18	6.7	8.5	6.8	6.1	6.1	7.0	6.2	6.0		
Mean standard growth		7.3	7.9	5.8	6.9	5.8	6.5	7.0	6.6		
Variance × $\frac{N}{N-1}$		1.18	0.91	1.26	0.65	1.10	1.15	1.53	0.96		

* Sack containing these fronds were lost, but was very close in size and weight to sack from plant F ,hence is estimated as around 45 lbs.

TABLE 63

Summary of Cutting Experiment H-4, Conducted at a Depth of 31 feet off La Jolla, California, During the Period 7 October to 17 December 1961. Cutting Took Place on 22 and 23 October at a Point 27 feet above the Holdfast. Underlined Values were Fronds Classed as Extremely Slow Growing and were Rejected as Abnormal when Computing Means. Differences Between the Means for Each Period were Tested for Significance by the † Test.

TABLE 63—Continued

Plant no.	Frond no.	Uncut Plants						
		Period over which growth was measured						
		10/16–10/21	10/21–10/31	10/31–11/7	11/7–11/15	11/15–11/24	11/24–12/2	12/2–12/17
		Standard Growth						
	19	7.8	7.6	6.3	6.6	7.4	8.8	5.4
G	20	5.1	7.8	8.2	6.7	6.6	8.4	5.7
	21	7.7	7.6	8.6	7.5	5.6	--	7.5
	22	11.4	7.0	8.3	6.2	6.6	7.8	4.9
H	23	$\underline{1.0}$	$\underline{3.8}$	$\underline{1.1}$	$\underline{0.5}$	$\underline{0.8}$	$\underline{1.3}$	$\underline{0.1}$
	24	5.6	8.4	7.8	8.5	6.4	9.7	11.2
	25	7.1	6.2	7.6	7.1	5.0	8.0	9.3
I	26	5.7	4.9	4.2	$\underline{2.7}$	$\underline{1.6}$	$\underline{3.0}$	4.3
	27	6.1	6.1	9.0	5.7	4.6	6.5	3.8
	28	5.2	6.2	7.8	6.3	4.9	6.2	4.7
J	29	5.1	5.8	7.8	6.7	5.2	5.2	7.2
	30	7.2	7.1	8.0	6.3	5.3	5.3	$\underline{3.9}$
	31	7.6	7.2	7.9	6.5	5.1	6.4	$\underline{3.7}$
K	32	7.4	6.4	8.4	4.8	5.1	6.3	5.7
	33	6.9	7.3	9.9	6.8	5.6	6.3	5.4
	34	7.1	7.9	7.8	5.2	4.2	6.6	5.7
L	35	8.0	8.0	9.6	5.5	$\underline{1.4}$	--	4.9
	36	5.7	5.6	7.8	5.9	--	5.0	5.2
	37	--	--	--	--	--	--	6.2
	38	--	--	--	--	--	--	7.0
Mean standard growth		6.9	6.9	7.9	6.4	5.5	6.6	5.6
Variance $\times \frac{N}{N-1}$		2.40	0.96	1.59	0.81	0.80	2.01	2.89
Standard error of the difference		0.44	0.36	0.36	0.33	0.36	0.48	0.48
"t"		2.27	3.06	2.78	1.82	2.78	0.21	1.04
Significance		<0.05	<0.005	0.01	>0.05	0.01	>0.05	>0.05

TABLE 63

Summary of Cutting Experiment H-4, Conducted at a Depth of 31 feet off La Jolla, California, During the Period 7 October to 17 December 1961. Cutting Took Place on 22 and 23 October at a Point 27 feet above the Holdfast. Underlined Values were Fronds Classed as Extremely Slow Growing and were Rejected as Abnormal when Computing Means. Differences Between the Means for Each Period were Tested for Significance by the † Test.

month, but H-4 differed from H-3 in the appearance of only two extremely slow growing fronds in the cut plants (although 6 of the 18 control fronds of H-4, under a dense canopy, exhibited abnormally slow growth at some time during the course of the experiment). Possibly elimination of the shading effects of the canopy in the cut area of H-4 helped prevent the appearance of these abnormal young fronds.

14.5.2.5. Study H-5, La Jolla, 31 feet

The last experiment was conducted at the same location as studies H-3 and H-4. The well-developed canopy persisted and was the densest to be found around La Jolla. Charles Martin, Kelco Company, surveyed the general region with us and stated that, except for the immediate vicinity of the study area, the La Jolla canopies were too poorly developed to justify commercial harvest. Continued use of this site, therefore, was judged desirable since it was the only easily accessible location where canopy conditions resembled those of a typical harvesting operation.

Study H-5 differed from the previous experiments in that the Kelco Company's harvesting vessel, *Elwood*, was used to perform the cutting operations. This prevented estimates of the proportion of material removed from each plant, but it allowed evaluation of the effects of a harvester on the growth rates of young fronds. From the theory and data discussed above, it is evident that a complex interplay of many variables governs the response by kelp plants to cutting, and direct interpolation from our small-scale experiments to a large harvesting operation might overlook important factors. Cutting by a harvester, for example, is not as uniform as our experiments (Figure 82) and this factor alone might introduce unexpected changes in the average values. It was necessary, therefore, to utilize a harvesting vessel for cutting, to check the applicability of the scientific studies to commercial operations.

The control and cut groups initially consisted of 28 and 27 plants respectively, with two short fronds per plant tagged for growth measurements. Numbers of fronds were, therefore, about three times greater than in any previous experiment and this enabled smaller changes to be classed as significant. The bed was cut by the *Elwood* on 27 November 1961 and during the following 7-day period the mean growth rate of the cut group did not change from values established during the two preceding 7-day periods (Table 64) . The control group, however, increased by 18 percent during the post-cutting week (from 6.2 to 7.3). The controls and cut plants study H-4 also exhibited increased growth rates at this time. Hence it was concluded that more favorable environmental conditions probably benefited all these kelp plants from 27 November to 4 December. The cut group of H-5 exhibited a retardation in the sense that the means standard growth did not increase proportionately to the increase displayed by other groups of plants in the area.

Variance-ratio tests did not indicate significant differences between the controls and the cut group for any of the periods of measurement. Differences in the means of the two groups were significant only for

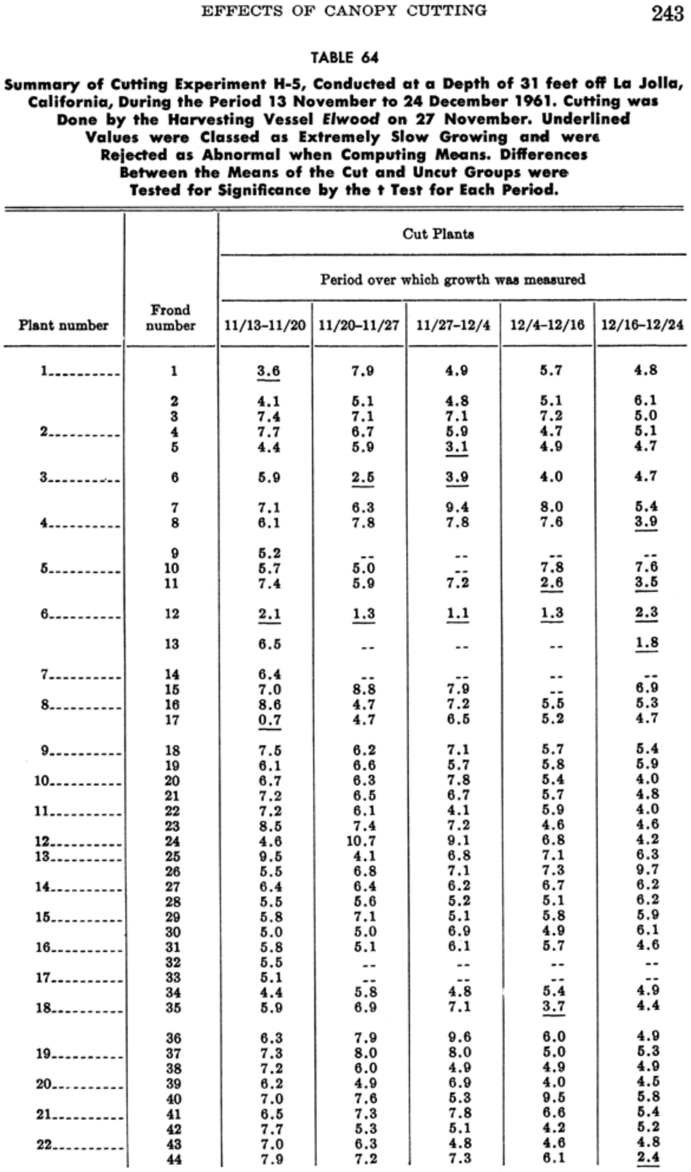

TABLE 64

Summary of Cutting Experiment H-5, Conducted at a Depth of 31 feet off La Jolla, California, During the Period 13 November to 24 December 1961. Cutting was Done by the Harvesting Vessel *Elwood* on 27 November. Underlined Values were Classed as Extremely Slow Growing and were Rejected as Abnormal when Computing Means. Differences Between the Means of the Cut and Uncut Groups were Tested for Significance by the † Test for Each Period.

Plant number	Frond number	Cut Plants				
		Period over which growth was measured				
		11/13–11/20	11/20–11/27	11/27–12/4	12/4–12/16	12/16–12/24
1	1	3.6	7.9	4.9	5.7	4.8
	2	4.1	5.1	4.8	5.1	6.1
	3	7.4	7.1	7.1	7.2	5.0
2	4	7.7	6.7	5.9	4.7	5.1
	5	4.4	5.9	3.1	4.9	4.7
3	6	5.9	2.5	3.9	4.0	4.7
	7	7.1	6.3	9.4	8.0	5.4
4	8	6.1	7.8	7.8	7.6	3.9
	9	5.2	--	--	--	--
5	10	5.7	5.0	--	7.8	7.6
	11	7.4	5.9	7.2	2.6	3.5
6	12	2.1	1.3	1.1	1.3	2.3
	13	6.5	--	--	--	1.8
7	14	6.4	--	--	--	--
	15	7.0	8.8	7.9	--	6.9
8	16	8.6	4.7	7.2	5.5	5.3
	17	0.7	4.7	6.5	5.2	4.7
9	18	7.5	6.2	7.1	5.7	5.4
	19	6.1	6.6	5.7	5.8	5.9
10	20	6.7	6.3	7.8	5.4	4.0
	21	7.2	6.5	6.7	5.7	4.8
11	22	7.2	6.1	4.1	5.9	4.0
	23	8.5	7.4	7.2	4.6	4.6
12	24	4.6	10.7	9.1	6.8	4.2
13	25	9.5	4.1	6.8	7.1	6.3
	26	5.5	6.8	7.1	7.3	9.7
14	27	6.4	6.4	6.2	6.7	6.2
	28	5.5	5.6	5.2	5.1	6.2
15	29	5.8	7.1	5.1	5.8	5.9
	30	5.0	5.0	6.9	4.9	6.1
16	31	5.8	5.1	6.1	5.7	4.6
	32	5.5	--	--	--	--
17	33	5.1	--	--	--	--
	34	4.4	5.8	4.8	5.4	4.9
18	35	5.9	6.9	7.1	3.7	4.4
	36	6.3	7.9	9.6	6.0	4.9
19	37	7.3	8.0	8.0	5.0	5.3
	38	7.2	6.0	4.9	4.9	4.9
20	39	6.2	4.9	6.9	4.0	4.5
	40	7.0	7.6	5.3	9.5	5.8
21	41	6.5	7.3	7.8	6.6	5.4
	42	7.7	5.3	5.1	4.2	5.2
22	43	7.0	6.3	4.8	4.6	4.8
	44	7.9	7.2	7.3	6.1	2.4

TABLE 64

Summary of Cutting Experiment H-5, Conducted at a Depth of 31 feet off La Jolla, California, During the Period 13 November to 24 December 1961. Cutting was Done by the Harvesting Vessel Elwood on 27 November. Underlined Values were Classed as Extremely Slow Growing and were Rejected as Abnormal when Computing Means. Differences Between the Means of the Cut and Uncut Groups were Tested for Significance by the † Test for Each Period.

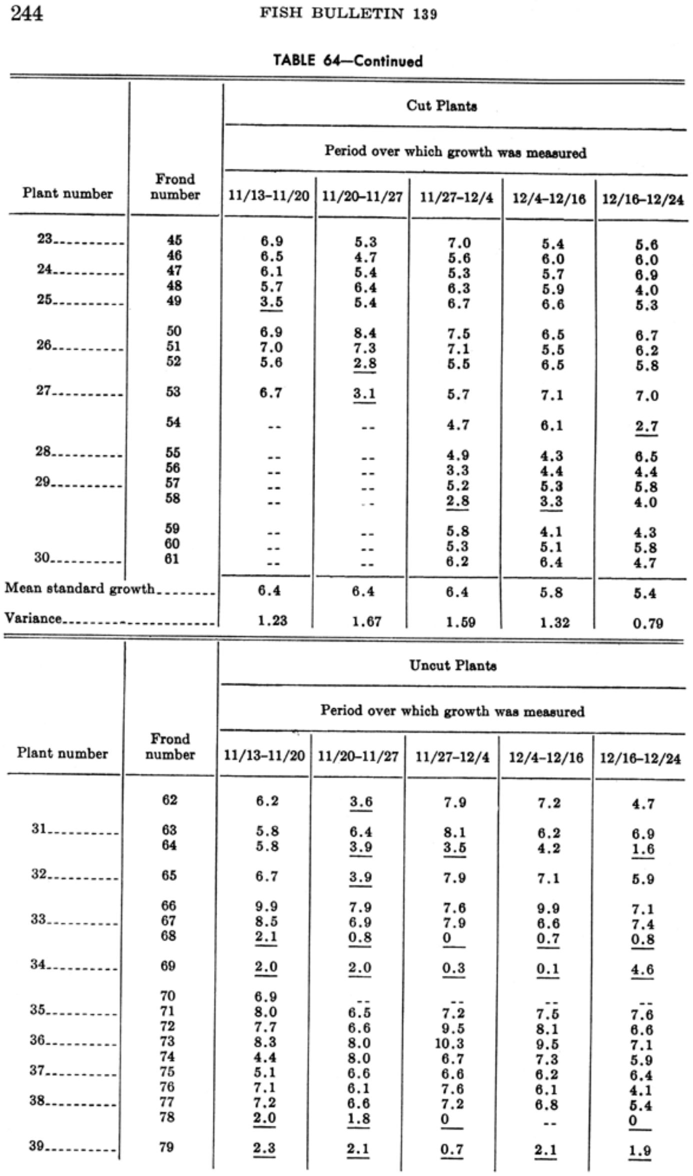

TABLE 64—Continued

Plant number	Frond number	Cut Plants: Period over which growth was measured: 11/13–11/20	11/20–11/27	11/27–12/4	12/4–12/16	12/16–12/24
23	45	6.9	5.3	7.0	5.4	5.6
	46	6.5	4.7	5.6	6.0	6.0
24	47	6.1	5.4	5.3	5.7	6.9
	48	5.7	6.4	6.3	5.9	4.0
25	49	3.5	5.4	6.7	6.6	5.3
	50	6.9	8.4	7.5	6.5	6.7
26	51	7.0	7.3	7.1	5.5	6.2
	52	5.6	2.8	5.5	6.5	5.8
27	53	6.7	3.1	5.7	7.1	7.0
	54	--	--	4.7	6.1	2.7
28	55	--	--	4.9	4.3	6.5
	56	--	--	3.3	4.4	4.4
29	57	--	--	5.2	5.3	5.8
	58	--	--	2.8	3.3	4.0
	59	--	--	5.8	4.1	4.3
	60	--	--	5.3	5.1	5.8
30	61	--	--	6.2	6.4	4.7
Mean standard growth		6.4	6.4	6.4	5.8	5.4
Variance		1.23	1.67	1.59	1.32	0.79

Plant number	Frond number	Uncut Plants: Period over which growth was measured: 11/13–11/20	11/20–11/27	11/27–12/4	12/4–12/16	12/16–12/24
	62	6.2	3.6	7.9	7.2	4.7
31	63	5.8	6.4	8.1	6.2	6.9
	64	5.8	3.9	3.5	4.2	1.6
32	65	6.7	3.9	7.9	7.1	5.9
	66	9.9	7.9	7.6	9.9	7.1
33	67	8.5	6.9	7.9	6.6	7.4
	68	2.1	0.8	0	0.7	0.8
34	69	2.0	2.0	0.3	0.1	4.6
	70	6.9	--	--	--	--
35	71	8.0	6.5	7.2	7.5	7.6
	72	7.7	6.6	9.5	8.1	6.6
36	73	8.3	8.0	10.3	9.5	7.1
	74	4.4	8.0	6.7	7.3	5.9
37	75	5.1	6.6	6.6	6.2	6.4
	76	7.1	6.1	7.6	6.1	4.1
38	77	7.2	6.6	7.2	6.8	5.4
	78	2.0	1.8	0	--	0
39	79	2.3	2.1	0.7	2.1	1.9

TABLE 64

Summary of Cutting Experiment H-5, Conducted at a Depth of 31 feet off La Jolla, California, During the Period 13 November to 24 December 1961. Cutting was Done by the Harvesting Vessel Elwood on 27 November. Underlined Values were Classed as Extremely Slow Growing and were Rejected as Abnormal when Computing Means. Differences Between the Means of the Cut and Uncut Groups were Tested for Significance by the † Test for Each Period.

TABLE 64—Continued

Plant number	Frond number	Uncut Plants				
		Period over which growth was measured				
		11/13–11/20	11/20–11/27	11/27–12/4	12/4–12/16	12/16–12/24
	80	4.9	5.3	5.1	7.2	7.0
40	81	4.0	6.2	9.0	6.8	8.3
	82	--	5.2	6.5	6.7	5.3
41	83	--	4.2	9.0	7.3	5.1
	84	6.4	6.9	8.4	8.2	5.8
42	85	7.6	7.6	8.6	8.3	4.7
	86	5.7	6.1	8.3	2.1	1.7
43	87	6.8	5.7	6.6	3.7	1.7
	88	5.3	5.0	6.1	5.4	4.7
44	89	7.1	6.8	6.6	4.7	4.3
	90	8.0	3.2	7.4	6.7	4.2
45	91	5.9	4.7	6.0	--	5.7
	92	7.4	3.8	3.1	2.2	--
46	93	7.1	7.9	7.1	6.7	1.8
	94	4.5	4.0	7.7	6.4	4.0
47	95	6.1	6.3	8.0	6.7	4.8
	96	7.4	6.9	10.1	6.9	5.2
48	97	7.8	7.7	8.8	5.7	6.3
	98	6.4	7.4	8.3	7.8	5.0
49	99	4.4	5.6	6.2	5.4	4.6
	100	6.5	8.0	9.3	7.1	4.4
50	101	4.6	5.5	7.4	7.3	4.4
	102	4.3	5.3	6.2	7.7	7.4
51	103	5.3	4.9	5.7	8.4	6.4
	104	7.2	4.7	7.2	7.0	6.4
52	105	2.7	3.9	3.0	3.8	4.3
	106	3.6	2.9	5.9	4.7	4.4
53	107	7.6	6.3	6.2	5.7	5.7
	108	7.2	6.7	7.8	5.1	4.7
54	109	7.6	5.9	8.3	8.6	--
	110	8.0	7.1	9.1	7.3	7.6
55	111	7.7	8.3	7.5	6.2	4.6
	112	4.5	4.2	0.8	2.2	3.1
56	113	7.6	4.2	4.4	4.2	4.1
57	114	7.6	5.5	6.2	5.2	3.6
58	115	8.0	--	--	--	--
	116	7.2	--	--	--	--
	117	--	5.8	8.8	--	--
59	118	--	--	8.7	5.7	5.8
	119	--	--	--	7.8	6.4
Mean standard growth		6.6	6.2	7.3	6.7	5.7
Variance		1.78	1.38	1.70	1.63	1.25
Standard error of the difference		0.254	0.273	0.266	0.250	0.209
"t"		0.79	0.73	3.48	3.60	1.43
Significance		>0.05	>0.05	0.001	<0.001	>0.05

TABLE 64

Summary of Cutting Experiment H-5, Conducted at a Depth of 31 feet off La Jolla, California, During the Period 13 November to 24 December 1961. Cutting was Done by the Harvesting Vessel Elwood on 27 November. Underlined Values were Classed as Extremely Slow Growing and were Rejected as Abnormal when Computing Means. Differences Between the Means of the Cut and Uncut Groups were Tested for Significance by the † Test for Each Period.

the two periods immediately following the cutting (11/27–12/4 and 12/4–12/16.) The results, therefore, confirm the findings of experiments H-3 and H-4: Cutting produces an initial retardation, which gradually disappears and any differences are not statistically significant within a month.

Comparison of the data for appearance of extremely slow-growing fronds showed that 15 fronds in the cut group fell into this classification during the month following cutting. Seven of these exhibited a previous history of abnormally slow growth, and three were not measured before cutting; hence only five could be considered as having any definable association with the cutting. Among the control group only 12 were classified as extremely slow-growing sometime during the month following the cutting and seven of these had a previous history of abnormally slow growth. Five control fronds thus changed to the extremely slow classification during the period 27 November to 24 December, the same number as in the cut plants. Thus there was no evidence of any major difference between the two groups leading to the same conclusion developed from study H-4: Removal of all the canopy from an area did not cause a significant increase in the appearance of extremely slow-growing fronds.

14.6. COMPARISON OF EMPIRICAL WITH PREDICTED VALUES

Sufficient data were collected during Studies H-2, H-3, and H-4 to allow using the mathematical model for predicting changes in total photosynthesis for each plant. If our basic premise was correct, any change in photosynthesis would be reflected in observed changes in growth rates of the young fronds. A comparison of predicted with observed changes should indicate the correctness of the model in its present state. Enough information was also gathered during study H-5 (even though the weight of the cut vegetation was not known) so that a rough estimate could be made as to expected changes so the predictions could again be compared with observed changes. In addition, the model could be used to explain some of our observations of factors governing the density of kelp plants in the bed. While the model still requires considerable refinement, it nonetheless is able to predict with fair accuracy.

14.6.1. Computation of Parameters

Values must first be assigned to the different variables involved. Since they themselves are often inconstant over periods of a week or more in a kelp bed, it was necessary to estimate average values for such parameters as light absorption by the water and percentage of the incident light transmitted by the canopy. Fortunately these parameters appeared to remain fairly constant during the periods between successive measurements in our experiments. For the comparison below only the period immediately following the cutting was used, as succeeding periods would tend more and more to include changes from influences unrelated to the cutting.

FIGURE 82. **Photograph taken in the cut area of Study H-5 on 28 November 1961, the day after the plants were trimmed of their canopy by the harvesting vessel *Elwood*. The picture illustrates the unevenness which cutting by this means produces, since one plant shows considerable canopy left on the surface, while an adjacent individual is cut at a depth of about three feet.**

FIGURE 82. ***Photograph taken in the cut area of Study H-5 on 28 November 1961, the day after the plants were trimmed of their canopy by the harvesting vessel Elwood. The picture illustrates the unevenness which cutting by this means produces, since one plant shows considerable canopy left on the surface, while an adjacent individual is cut at a depth of about three feet.***

14.6.1.1. Percent of the Plant Removed

In three of the cutting studies the weight of tissues cut from each plant was measured, as well as the numbers of stipes per plant (Tables 61, 62, and 63). The average weight of a frond was found to be about 3.3 lbs. (1500 gms) by weighing many plants, gathered without respect to size or amount of canopy. The total weight of an "average" plant can be estimated by multiplying this average weight per frond by the total numbers of fronds which such a plant displays. It is considered probable, however, that the plants with well-developed canopies, selected for the cutting studies, had heavier than average fronds.

For example, plant E in Study H-3 had 31 stipes and the upper portion, which was severed, weighed 113 pounds (Table 62). If the 3.3 value were used, the total weight would be 102 lbs., or less than the weight of the portion removed. At the time of cutting it was judged that roughly half of this plant was removed.

To overcome these difficulties, average weights were used that increased as the weight of the cut portion increased. A conversion weight of 3.3 lbs. (1.5 kg) per frond was used where the cut portion was less than 10 lbs., 4.4 lbs. (2 kg) when the cut portion weighed 10 to 20 lbs., and 5.5 lbs. (2.5 kg) when the cut portion weighed more than 20 lbs. The proportion of the plant removed was then computed on a percentage basis as one of the required parameters (Table 65).

14.6.1.2. Percent Light Transmitted by the Canopy

This factor was intended to account for self-shading and subsequent increase in submarine daylight after the canopy was removed. At the edge of a bed, where most of our plants were cut, one can treat the situation as if it were a sparse canopy, transmitting from 30 to 50 percent of the incident daylight. Theoretically a plant at the exact edge of a bed is shaded from three sides and exposed from the other direction. Under the dense canopies in our experiments, measurements indicated that 80 to 90 percent of the incident light was absorbed by the surface blades so that a plant which was 80 percent shaded on three sides was in an environment where about 40 percent of the total light was transmitted. If the plant extended somewhat out of the bed or was at a corner or projecting, the transmitted light would be greater until it reached about 90 percent for quite isolated plants in open water. Charts made during each experiment showed the location of all cut plants with respect to the edge of the bed.

The light transmitted parameter was not always constant. Currents may pull part or all of a kelp plant beneath the surface, altering very substantially the horizontal distribution of the blades so that the area of coverage varies. In strong currents where the stipe bundles converge and extend compactly downstream the overall light intensity on the bottom is increased. It is difficult to estimate how this might alter photosynthetic capacity of the plant. Substantial or variable water turbidity complicates the situation further. Accordingly, it was assumed that there were no appreciable currents during the periods of the study. This assumption was justified for the two shallow stations but was true perhaps only 80 percent of the time for station H-2. At this location, however, the water was quite clear during the time of the study, reducing the effect of this variable.

A plant well within the bed was regarded as being in an environment where only 10 percent of the incident light was transmitted by the canopy. A plant within 10 feet of the edge of the bed was considered to be in a 20 percent transmittance area. At the edge the transmittance was set at 30 to 50 percent, depending on the exact location, and values of 80 to 90 percent were used outside of the main bed, depending on the proximity of nearby plants (Table 65).

14.6.1.3. Light Absorbance by the Water

Water clarity can be a highly variable parameter, especially during times of plankton blooms. H-3 was conducted during such a season and values of 30 percent absorbance were common. Because the upper portions of plants adjacent to the cut individuals were left intact,

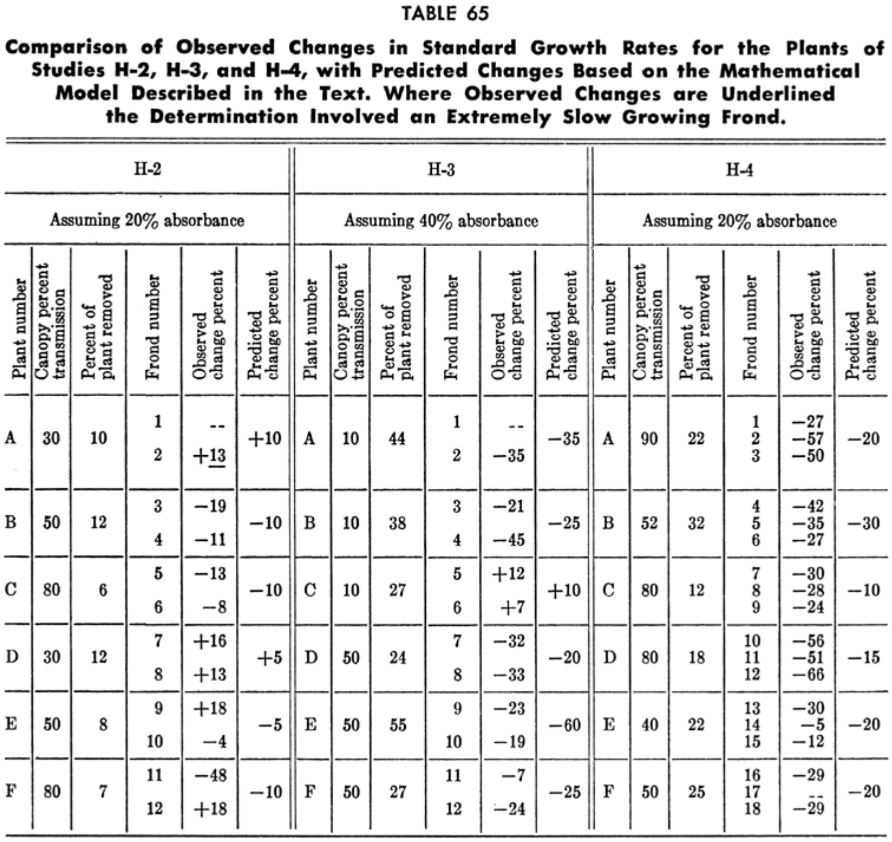

TABLE 65

Comparison of Observed Changes in Standard Growth Rates for the Plants of Studies H-2, H-3, and H-4, with Predicted Changes Based on the Mathematical Model Described in the Text. Where Observed Changes are Underlined the Determination Involved an Extremely Slow Growing Frond.

H-2					
Assuming 20% absorbance					
Plant number	Canopy percent transmission	Percent of plant removed	Frond number	Observed change percent	Predicted change percent
A	30	10	1	--	+10
			2	+13	
B	50	12	3	−19	−10
			4	−11	
C	80	6	5	−13	−10
			6	−8	
D	30	12	7	+16	+5
			8	+13	
E	50	8	9	+18	−5
			10	−4	
F	80	7	11	−48	−10
			12	+18	

H-3					
Assuming 40% absorbance					
Plant number	Canopy percent transmission	Percent of plant removed	Frond number	Observed change percent	Predicted change percent
A	10	44	1	--	−35
			2	−35	
B	10	38	3	−21	−25
			4	−45	
C	10	27	5	+12	+10
			6	+7	
D	50	24	7	−32	−20
			8	−33	
E	50	55	9	−23	−60
			10	−19	
F	50	27	11	−7	−25
			12	−24	

H-4					
Assuming 20% absorbance					
Plant number	Canopy percent transmission	Percent of plant removed	Frond number	Observed change percent	Predicted change percent
A	90	22	1	−27	−20
			2	−57	
			3	−50	
B	52	32	4	−42	−30
			5	−35	
			6	−27	
C	80	12	7	−30	−10
			8	−28	
			9	−24	
D	80	18	10	−56	−15
			11	−51	
			12	−66	
E	40	22	13	−30	−20
			14	−5	
			15	−12	
F	50	25	16	−29	−20
			17	--	
			18	−29	

TABLE 65

Comparison of Observed Changes in Standard Growth Rates for the Plants of Studies H-2, H-3, and H-4, with Predicted Changes Based on the Mathematical Model Described in the Text. Where Observed Changes are Underlined the Determination Involved an Extremely Slow Growing Frond.

the resulting shading was taken as equivalent to an increase in absorbance and a value of 40 percent was assumed (Table 65).

Studies H-2 and H-4 were conducted during seasons when plankton tended to be scarce and underwater visibility was always excellent. Measurements with an underwater photometer indicated that absorbancies of about 20 percent prevailed.

14.6.2. Testing the Model Against Cutting Experiments

Computing parameters as described above, the percent changes predicted from the mathematical model (Figures 80 and 81) were determined for each plant of studies H-2, H-3, and H-4 (Table 65). For the six plants of H-2, the model predicted only moderate changes. Except for frond 11, plant F, all observed changes were indeed relatively moderate. With regard to specific plants, the model appeared able to predict the sign (positive or negative) of the changes fairly well but it tended to underestimate positive changes slightly (plants A, D, and E). Overall there were no serious discrepancies between model predictions and the H-2 data.

In study H-3 the model again was entirely successful in predicting the sign of the change for each plant and was considered reasonably accurate for assessing the magnitude of the change except for plant

E. This plant had the greatest weight of tissue removed of any plant in the various cutting experiments, yet it was not a large individual, because it had only 31 stipes (Table 62). Possibly there were several large fronds in the canopy that had been almost or completely severed by grazing, adding substantially to the weight but contributing little to the nutrition of the plant and perhaps reducing it somewhat by shading.

As in H-2 and H-3, the model correctly predicted the negative signs for the changes in all the plants of study H-4 (Table 63). Where these changes were fairly large, however, (plants A, B, C, D, and G) the model tended to underestimate the magnitude. The causes for this underestimation are not known, but since this discrepancy was apparent in five of the six plants it appears that the model failed to account for some significant factor. H-4 was conducted at a season when days were quite short, hence there might be less total photosynthesis per day, and negative responses might be accentuated. The model could certainly be improved by including this as well as other variables. However, this comparison of predictions with the results of Studies H-2, H-3, and H-4 demonstrates that even in its present form the model is basically sound and useful.

The results from Study H-5 cannot be compared to model predictions in detail as for H-2, H-3, and H-4, because we do not know the proportion of tissues removed from each plant. One can, however, usefully estimate from the model what the overall results might be, since H-5 occurred during the latter part of H-4 and was located nearby in the same kelp bed. The plants of H-4 were selected for their heavy canopies while those of H-5 were tagged without regard to canopy. Hence one would expect that the average plant in H-5 would have a smaller percentage of its tissues removed. Approximately the same conditions of canopy density, absorbency, and depth prevailed during both experiments. Using the 20 percent absorbency graph (Figure 81) and decreasing the percent of the plant removed by cutting, the scale is shifted toward smaller negative changes on the ordinate or perhaps even positive changes. Discarding results from five extremely slow-growing fronds, the distribution of observed changes in the 41 fronds of H-5 do indeed substantiate this prediction compared to H-4 (Figure 83). The general validity of the model is thus confirmed.

The most important feature of the model, insofar as conservation of kelp resources is concerned, is the prediction that under certain conditions cutting of kelp stimulates photosynthesis. Under other circumstances, however, a net decrease in the photosynthetic capacity would be expected. This feature is amply confirmed by the cutting studies. In every experiment but one (H-4), both positive and negative net changes were recorded among the young fronds of cut plants, immediately following cutting.

In general, the model predicts that a stimulatory effect is most likely after a thick canopy is removed, especially for those plants with a small proportion of tissue at the surface. This tends to resemble conditions selected by commercial harvesters, as light canopies are uneconomical to cut. The stimulatory effect, however, also requires the

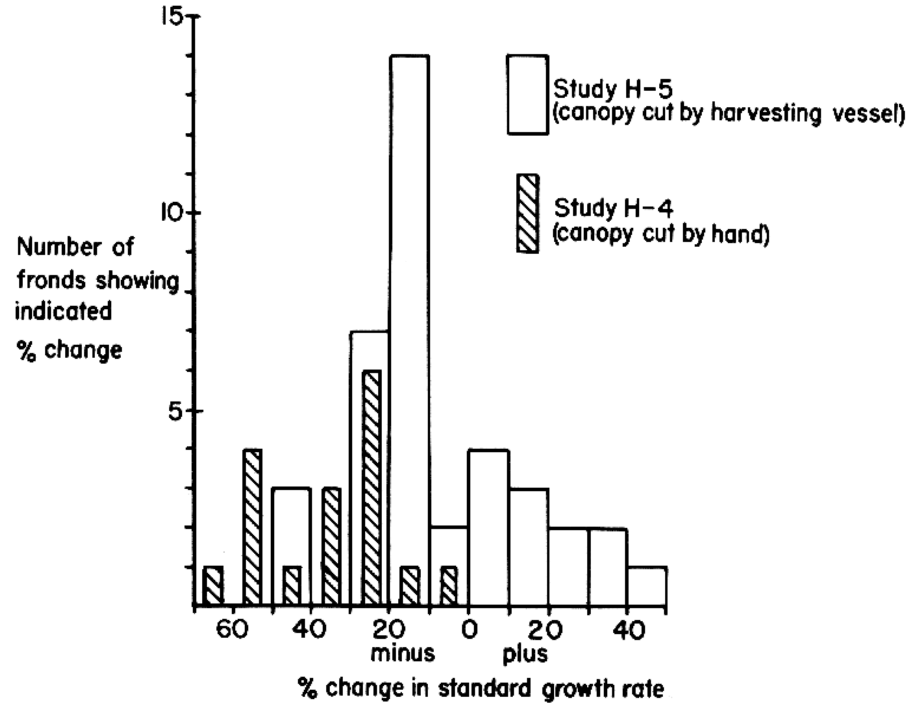

FIGURE 83. Graph showing the distribution of percent changes in standard growth rate for 41 fronds attached to cut plants in Study H-5. The changes were computed from the difference between the adjusted standard growth measured immediately before cutting (11/20–11/27) and the standard growth immediately after cutting (11/27–12/4). Both positive and negative changes occurred and this is in accord with predictions by the mathematical model.

FIGURE 83. ***Graph showing the distribution of percent changes in standard growth rate for 41 fronds attached to cut plants in Study H-5. The changes were computed from the difference between the adjusted standard growth measured immediately before cutting (11/20–11/27) and the standard growth immediately after cutting (11/27–12/4). Both positive and negative changes occurred and this is in accord with predictions by the mathematical model.***

correct combination of other factors. Certainly we still lack a complete understanding of the relationships among the complex of variables. It seems well worth the effort to increase our knowledge in this field, so that when we utilize the kelp beds we can be assured that we also benefit them.

One of the salient features demonstrated by the model is that as beds become denser, photosynthetic capacities are reduced not only from light absorption by canopies but also by the columns of kelp tissue in midwater. It would be expected, then, that denser beds could develop in shallow water since for equal canopies the shallower plants have proportionally less tissue in midwater. Taking concentration of stipes per unit area as an adequate measure of kelp density, the thickest beds do tend to develop in the lesser depths (Figure 84).

Some evidence of the effects of intense shading also appear in the data from Studies H-3 and H-4. In these experiments the cut plants were located near the edges of the bed but the control plants in both studies were well inside. All controls were from 50 to 100 feet from the edge, under a thick canopy and in a dense bed (nine stipes/yd^{2}). Two comparison periods were analyzed in H-3 before cutting, and one period in H-4 (4/20–5/2, 5/2–5/9 in H-3, and 10/14–10/21 in H-4). Growth rates near the edge can thus be compared with those in the interior (Tables 62 and 63). In each period the plants near the edges averaged higher values than the plants in the interior. The differences in these means were significant ($P < 0.05$) in two of the three periods. There are thus several lines of experimental evidence indicating the model predicts correctly that increasing the self-shading factor tends to reduce the photosynthetic capabilities of congregating plants.

In closing, it may help orient the reader by discussing the difficult question of the significance to a plant or a bed of a given loss in photosynthetic capacity. If, say, a 20 percent loss occurs when the canopy is removed, how deleterious is this effect? There is no absolute answer to such a question because each bed and perhaps each plant may be subjected to different degrees of environmental stress. A plant infested with many grazing animals, for example, would probably

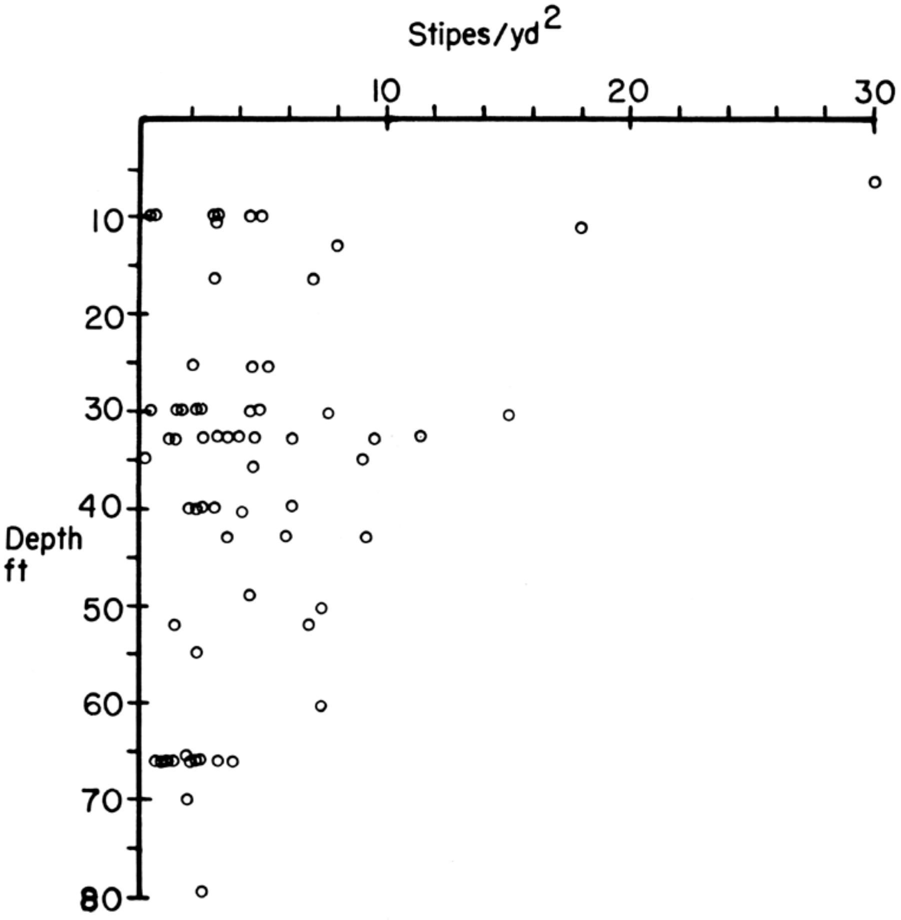

FIGURE 84. Graph showing the relationship between kelp density and water depth at a number of locations. It can be seen that although sparse stands of kelp do occur frequently in shallow water, dense stands also have been found. In deep water, however, dense stands are rare or absent, possibly because of increased shading when densities begin to get high. This agrees with expectations from the mathematical model.

FIGURE 84. ***Graph showing the relationship between kelp density and water depth at a number of locations. It can be seen that although sparse stands of kelp do occur frequently in shallow water, dense stands also have been found. In deep water, however, dense stands are rare or absent, possibly because of increased shading when densities begin to get high. This agrees with expectations from the mathematical model.***

not survive a loss of photosynthetic capacity that would be trifling to a plant free of grazing. The same reasoning applies to entire beds.

There does seem to be a rather wide margin in nature with regard to the amount of canopy that a plant may lose and still survive. Large quantities of surface tissue are torn away by winter storms or lost by sloughing during warm summers. Many plants and even entire beds do not survive if the loss is severe. Nonetheless, substantial losses must be tolerable under average conditions because they occur continuously and kelp beds are still present. The cutting experiments data make it appear that initial losses of at least 20 to 30 percent are tolerated and overcome in a few weeks. It must be remembered that the patches that were cut represent kelp in excellent condition. In the present state of our knowledge, it would be risky to predict that greater photosynthetic losses would not cause permanent damage in an average bed.

14.7. SUMMARY

1. The fronds of mature kelp plants become senile and deteriorate about 6 months after they are produced. It is vital that the plant continue to develop new replacement fronds. This study was concerned with the effects of canopy cutting on the growth rate of young fronds. While cutting might cause other effects, this particular aspect was chosen because of its fundamental importance to the welfare of individual plants and to the kelp beds. Since growth of young fronds is supported by nourishment translocated downwards from the older, long fronds, measurement of growth rates also provides a quantitative evaluation of the general condition of the entire plant and its overall response to cutting.

2. Growth depends on the total photosynthesis accomplished by a plant and this is affected by many variables. Kelp canopies under certain conditions nourish the underlying tissues more than they starve them by self-shading, whereas under other circumstances the shading factor predominates. It is not feasible to test all possible environmental conditions experimentally. Instead we developed a mathematical model which can be used to compute the effects of cutting on growth, over a wide range of conditions. Extensive laboratory and field data were used in developing the model.

3. The mathematical model formulated the photosynthetic capability of a kelp plant in terms of seven variables. It was then solved for two particular situations corresponding to the conditions prevailing for several canopy cutting experiments used to test the model.

4. In the first two canopy cutting experiments no significant effects were observed between the means of the standard growth rates of young fronds attached to cut plants vs. a control group of fronds. The amounts of material removed in the cutting operations were small.

5. In two subsequent experiments the amounts of tissue removed ranged up to an estimated 55 percent of the total weight of the plant and mean growth values were significantly retarded up to a month following cutting. Poor lighting conditions prevailed in one of the studies (where the canopy was left intact around the cut plants); the result was an unusually large number of extremely slow growing

fronds. This was considered to be abnormal. Slow-growing fronds did not appear in excessive numbers in the other experiment where all the canopy surrounding the cut plants was stripped away.

6. A fifth experiment utilized the harvesting vessel *Elwood* to cut the experimental patch. The results agreed with previous findings; there was an initial retardation in mean growth, but within a month the cut plants did not differ significantly from the controls. The numbers of extremely slow growing fronds was not excessive.

7. Comparison of predictions by the model with observed changes in the cutting studies were considered satisfactory for two of the experiments, but tended to underestimate retardation in a third study. The model appears basically sound and further improvements should make it useful for predicting the optimum conditions for harvesting. It is probably too complex for practical, on-the-spot-computations for deciding whether to harvest a particular bed. It should, however, be valuable in providing a basic understanding of what can happen when canopies are removed.

8. The model predicts, and experiments amply confirm, that canopy cutting can stimulate kelp growth or can retard it, depending on circumstances during and after cutting. Circumstances which render a bed attractive for harvesting are often those conditions where canopy removal favors kelp growth or at least does not have seriously adverse effects.

9. In a natural situation where plants with heavy canopies are shading plants with light canopies (such as a bed containing both young and old plants), harvesting will probably temporarily reduce growth of the large plants but should stimulate the smaller individuals. This "equalizing" effect would probably increase survival rates by lowering intraspecific competition.

15. 14. CONCLUDING DISCUSSION

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This fish Bulletin is one of two volumes summarizing investigations conducted principally by the University of California's Institute of Marine Resources.[1] The other publication is "An Investigation of the effects of Discharged Wastes on Kelp" (California Water Quality Control Board, 1964). Kelp investigations at the Institute of Marine Resources were grouped into a project called the IMR Kelp Program which lasted from 1956 to 1963. The overall program had several research objectives, corresponding in part to the interests of the different financing agencies. Over the years, 12 investigators in diverse fields pursued studies under the auspices of the Kelp Program. The voluminous results have been conveniently divided into two publications, as mentioned above. Some duplication of material has been necessary to provide coherence and a reasonable degree of completeness in each volume.

Readers with directed interests in kelp beds should find each volume sufficiently comprehensive. Broader understanding will require perusal of both volumes as well as the wealth of related literature.

The main objective of this bulletin is to assess the impact of man on the kelp environment. The text emphasizes hitherto unpublished studies conducted under the IMR Kelp Program, although the authors drew on all available information in preparing their discussions. Hopefully this new knowledge will bring increased understanding of the factors involved in many of the difficult problems connected with utilization of the kelp resources.

Chief emphasis has been given to problems concerning possible effects arising from kelp harvesting, particularly any effects on fish life. When kelp beds regress or disappear, both kelp harvesting and fishing suffer. It may be that areas of doubt concerning effects harvesting has had on kelp and fishlife will not be completely resolved by our discussions. Most assuredly, however, the ultimate answer to these problems lies not just in preserving what we have, but in increasing and expanding the kelp forests. Preliminary efforts along these lines have met with success. It seemed appropriate, therefore, to begin this bulletin with a short account of the life history of kelp and of methods for improving kelp areas and an assessment of the potentialities of such activities.

15.1. KELP-BED FISHES AND THEIR UTILIZATION

Seven chapters of this Bulletin define any known relationships existing between kelp and fishes and attempt to describe how harvesting might influence such relations. In this complex subject the search for

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[1] A third volume, "The Biology of the California Kelp Beds," is being published by J. Cramer, Germany.

possible relationships will probably never be complete; however, the extensive information that has been gathered provides a basis for drawing conclusions. The ecology of kelp fishes is treated exhaustively in five chapters by Jay C. Quast. He describes the kelp environment and gives detailed information on the diets of kelp fishes, their behavior, preferred habitats, abundances, and life histories. From this account it becomes clear that kelp plants benefit fishes in many ways. Some fishes eat kelp directly, others receive nourishment indirectly by preying on herbivores that consume kelp. Kelp furnishes extensive surfaces for colonization by sessile filter-feeders such as bryozoans, which subsist on microscopic plankton. Thus, phytoplankton-based food chains become available to certain fish species. Kelp furnishes a multitude of crevice environments that are beneficial. The kelp masses apparently attract into midwater many fishes that normally remain close to the bottom. This makes greater forage space available to them.

Although these relationships emphasize the importance of kelp, the plant does not appear to be an indispensable habitat requirement for any of the fish species studied. In fact, opaleye schools prefer moderate stands to dense groves. Blacksmith seem to avoid dense kelp, while the population densities of kelp bass are about the same in sparse and dense stands. Diversity of fish species is not altered significantly by presence or absence of kelp. A highly varied bottom topography appears to be important for extensive fishlife and to be of greater significance in this respect than kelp.

There is always room for further study in such a complex subject, but the reader will appreciate that Quast has based his statements and conclusions on a most intimate and extensive firsthand familiarity with this field. Certainly these five chapters constitute the most broad and detailed account of the biology of kelp fishes published to date.

In chapter 6 Quast summarizes his conclusions concerning possible influences harvesting might exert on relations between fishes and kelp. He opens with a brief review of conclusions reached by Limbaugh and by Davies, mainly to indicate how this chapter complements rather than duplicates their studies. He considered the possibility that harvesting adversely affects fish eggs and larvae as well as the possibility that harvesting operations frighten fishes. He concludes that such influences are so small as to be negligible, if indeed they exist at all. Perhaps the most important section of this chapter evaluates food losses suffered by fishes, arising from removal of kelp and invertebrates by harvesting. While some of the details are assumptive, the final estimates are sufficiently accurate to justify the conclusions. Quast calculates that a maximum of 10 percent food losses per year may occur in a heavily harvested bed. This amount, in his opinion, is not serious, in view of the food reserves he has observed. He cautions the reader that has conclusions assume cutting causes no harm to kelp plants. This reflects Quast's general belief that kelp contributes significantly to fishlife. The effects on kelp of cutting were studied by other investigators and are discussed in detail below.

Quast's painstaking surveys were complemented by a broad statistical approach by the late David H. Davies, utilizing sportfish catch and kelp harvest records compiled by the Department of Fish and

Game. This analysis covered a 10-year period (1947 to 1956) and embraced the entire southern California area. He sought correlations between the amounts of kelp harvested and the total fish catch, and between the kelp harvest and the fish catches per unit of effort. The only significant correlation was an inverse relationship between the barracuda catch and kelp harvesting (fishing was good when harvesting was light, fishing was poor when harvesting was heavy). Since barracuda are pelagic fish, presumably having a minimal relation to kelp compared to most other sport fishes, the inverse relation was more likely the result of an outside variable, such as temperature, rather than an indication that harvesting was adverse to the barracuda fishery.

Over the 10-year period the total tonnage of harvested kelp increased and the overall fish catch per unit effort also increased (from 4.51 in 1947 to 7.00 in 1956). Particular attention was paid to the kelp-bass fishery. This species is the most important to the sportfishery and is typically associated with kelp beds. While there were fluctuations in the statistics for kelp bass, these bore no evident relation to the amounts of kelp harvested. Comparisons were made for all of southern California as well as for a group of southern beds, a northern bed, and a group of island beds.

Additional analyses showed that the frequency of harvesting operations in a bed bore no apparent relation to sportfishing in general, or to kelp bass specifically. Fishing for kelp bass was better in harvested than in unharvested beds. A similar comparison for all sportfishing yielded no significant difference between harvested and unharvested areas.

Sportfish returns were examined for areas near San Diego and Los Angeles where continuous losses of kelp had occurred until very few plants remained. This study included the years 1947 to 1961. A deterioration of certain segments of the fishery occurred for long periods, particularly in the vicinity of the Palos Verdes peninsula. When catch per unit effort for one species declined, other species were sought until the more favored species returned in sufficient abundance. It was also apparent that large beds were not essential to support a kelp-bass fishery. Davies was unable to establish any significant effect on sportfishing ascribable to kelp harvesting.

The studies of Quast and of Davies failed to find general evidences of deterioration among the fish communities of southern California kelp beds. While it was not possible to compare present conditions with those of 40 or 50 years ago (when many of the beds were probably substantially larger), the two investigations found no indications of a recent drastic decline among kelp fishes.

15.2. HARVEST YIELDS AND THE EFFECTS OF CUTTING

The effects of kelp harvesting, both on individual plants and on populations, are assessed in three chapters. Kenneth A. Clendenning analyzed harvest returns compiled by the Department of Fish and Game for the period 1950 through 1960. He ranked the beds on the basis of total yields over the study period and selected for detailed study adjacent beds displaying a marked difference in rank. In this way it was possible to compare beds that had been intensely harvested with nearby beds that had been harvested only lightly. He found that beds which were not heavily harvested for several years did not increase their yield. The beds with the greatest yields were harvested every year, and tended to maintain their high yields throughout the 11-year study period. Clendenning was developing this analysis at the time of his death, so in some respects it is incomplete. Sufficient data are available, however, to establish that kelp harvesting, as currently practised, did not cause a significant decline in yield during the 11 years embraced by his investigation.

Clendenning includes a brief account of the intake of canopy invertebrates during harvesting in his next chapter. Agitation and drainage of cut fronds as they are brought aboard the harvesting vessel allows two thirds or more of the motile canopy invertebrates to escape. The invertebrates attached to canopy blades, however, are all removed from the kelp environment.

The chapter compares the advantages and disadvantages of harvesting kelp. Advantages include the deep-water habitat, permitting use of large vessels for cutting. Likewise, the morphology of kelp allows removal of the canopy, leaving the sites of vegetative and sexual reproduction undisturbed near the base. Cutting does not affect photosynthesis in adjacent parts of kelp fronds. Canopies can be regenerated in a matter of weeks or months because of rapid intercalary growth in the stipes. A final advantage is that the harvested material consists of almost pure Macrocystis without admixture of undesirable species.

Existence of kelp as a wild crop is one of the foremost disadvantages of kelp harvesting, since fluctuations are difficult to control. Beds near large cities have deteriorated in recent times and such losses may continue as metropolitan areas expand. Our kelp beds are subject to multiple uses, causing conflicts. Likewise the beds are publicly owned and are easily seen from shore. Harvesters may be blamed for kelp losses, beach litter, etc., simply because the public associates this activity with the beds.

Clendenning then discusses the effects of harvesting on different parts of the plant. The effect on juvenile fronds is variable (this aspect is covered in greater detail in Chapter 13 by North) and juvenile plants tend to profit by the increase in submarine light resulting from canopy removal. Harvesting removes mature and senescent fronds primarily, sparing young ones that soon reconstitute the canopy. A few fronds approaching maturity may have the tips removed but they continue to grow and photosynthesize. Bruce C. Parker (pers. commun.) has noted that a plugging mechanism helps reduce losses by exudation of translocated material from cut stipes.

The topic, effects of cutting, is concluded with a chapter by North, summarizing several experiments studying growth changes in juvenile fronds following canopy removal. Growth rates of juvenile fronds are believed to be a general measure of the health and well-being of kelp plants. The study included four experiments in which individual plants were cut by hand and a fifth in which a harvesting vessel severed the stipes. The growth of juvenile fronds was retarded on the average for about a month. Cutting did not necessarily cause retardation, however, either of an individual frond or of the entire population. Some juvenile fronds actually grew faster, presumably having benefitted from increased light. No significant differences were found between experiments in which plants were cut by hand and those in which they were harvested by a vessel.

The variability observed in effects on growth is considered a result of counteracting influences in the environment. Removal of the canopy caused a loss of photsynthetic tissue but at the same time increased the illumination of any kelp surfaces remaining. Under some conditions it was believed that the loss of photosynthetic tissue predominated and growth rates decreased. In other experiments growth was stimulated, probably because the increased submarine light enhanced photosynthesis in the remaining tissues. A mathematical model developed to explore the effects of different variables in this complex problem predicted that cutting under conditions usually sought by harvesters (dense beds with heavy canopies) tends to effect minimal retardation, or even stimulates growth. Predictions by the model showed fair agreement with results from the cutting experiments. Undoubtedly variables not taken into account influence growth and affect the precision of the predictions. Even so, it is believed that the model in its present form is sufficiently accurate to warrant the conslusions stated concerning the effects of harvesting.

In summary, predictions from the model, the cutting experiments, and physiological and ecological evidence combine to indicate that kelp harvesting as currently practiced causes very little damage to kelp beds and under certain circumstances may be beneficial. Such a conclusion is further supported by Clendenning's findings that the beds harvested most heavily showed no tendency to decrease their yields. It would also explain why no effects of harvesting on fish life were found by Quast or by Davies. Any one of these approaches may have shortcomings that leave individual results open to reasonable doubt. Taken together, however, they are extremely broad in scope and the fact that they are in general agreement strengthens the separate conclusions.

This does not mean that cutting cannot harm plants nor should harvesting operations be conducted without surveillance. Changing environmental influences may cause a decline in a given bed, altering effects of cutting. North's model predicts that under certain circumstances cutting may produce considerable losses in photosynthetic capacity. Instances have been studied in the field where cutting has probably been excessive and damaging. A strip of kelp, for example, continuously cut by small boat traffic at Paradise Cove displayed a smaller standing crop of kelp tissue than the surrounding bed (North, 1957). Beds harvested four times per year showed a decreasing yield in contrast to beds harvested less frequently (Brandt, 1923). These examples undoubtedly represent more severe cutting than is practised currently, but it is well to keep in mind that "overcutting" can occur.

15.3. A VIEW TOWARD THE FUTURE

All studies cited above indicate that a general equilibrium presently exists between man's withdrawal of resources from the kelp environment and replacement by natural productivity. It cannot be assumed that the various inputs and withdrawals will remain constant, and certainly natural and artificially induced changes in the environment will affect the overall system. It is reasonable to suppose that the future will bring greater demands for all kelp resources. If we are to maintain a stable equilibrium, increase in productivity of the resources is essential.

From historical evidence (Crandall, 1912) it appears that many of the kelp beds were substantially larger 50 years ago. Likewise, annual harvest yields were three to four times greater during World War I than in recent years. This suggests that the productivity of the beds may have been substantially greater. A promising first step toward increasing present productivity would be to expand existing coverage by kelp and to attempt to increase the density of sparse stands. Two chapters of this bulletin summarize present knowledge about the life cycle of kelp (Neushul and Haxo, Chapter 2, this bulletin), about culture techniques, and about methods of transplanting (North and Neushul, Chapter 3, this bulletin). This knowledge forms a logical starting point for any program aimed at increasing productivity of the kelp resources.

The life cycle of giant kelp involves two alternating phases. One phase produces the large familiar plant, the sporophyte, which liberates microscopic spores that give rise to the second phase, the microscopic gametophyte, which has been seen only in controlled laboratory cultures. The sporophyte is asexual, with no distinction between male and female, and no fertilization necessary for spore development. The gametophyte is sexual: the female plant produces an egg cell that must be fertilized by a motile "sperm" cell from a male plant. From this union, the sporophyte generation develops. If kelp is to remain in an area permanently, the environment must be suitable for both sporophytes and gametophytes.

The possibilities of improving kelp beds are enhanced because an adult kelp sporophyte has a tremendous reproductive capacity, typically liberating billions of spores annually. Transplanted adults should give rise to many offspring in an area where "seeding" by kelp is desired. Experimental transplants have frequently suffered heavily from grazing by animals and this factor often limits the success of such operations. Cultures of young plants on ropes can be started in the laboratory and then anchored at sea for development to adulthood.

The problems of grazer control are beyond the scope embraced by Neushul and North. Considerable success along these lines has been achieved recently in the Kelp Habitat Improvement Project (an outgrowth of the Kelp Program that began at the Institute of Marine Resources and was continued at the California Institute of Technology). This Project has also attempted to establish experimental kelp colonies using transplants. This phase of kelp research is treated in the reports issued by the sponsoring Universities (California Institute of Technology, 1965; Calif. Univ. IMR, 1963).

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The unmodified term "kelp" will henceforth indicate the genus Macrocystis.