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STATE OF CALIFORNIA
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Governor

AN INVESTIGATION OF THE EFFECTS OF DISCHARGED WASTES ON KELP

1964

THE RESOURCES AGENCY OF CALIFORNIA
STATE WATER QUALITY CONTROL BOARD

PUBLICATION NO. 26

THE RESOURCES AGENCY OF CALIFORNIA
HUGO FISHER
Administrator

STATE OF CALIFORNIA

STATE WATER QUALITY CONTROL BOARD

ROOM 316
1227 O STREET
SACRAMENTO, CALIFORNIA 95814

PAUL R. BONDERSON
Executive Officer

STATE OF CALIFORNIA
EDMUND G. BROWN
Governor

AN INVESTIGATION OF THE EFFECTS OF DISCHARGED WASTES ON KELP

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—February, 1963

FOREWORD

During the early years of the State Water Pollution Control Board (as named prior to September 20, 1963) its research program was devoted to problems affecting fresh water supplies. However, population and industry in California have tended to concentrate in coastal communities, with the result that approximately two-thirds of the municipal and industrial water-borne wastes are discharged to saline waters. The magnitude and complexity of waste disposal in the marine environment are intensified by the recreational and commercial beneficial uses of the receiving waters adjacent to metropolitan areas.

In 1954 the State Board sponsored an exploratory investigation of all aspects of the submarine outfall disposal of domestic wastes. The report on the investigation recommended various areas where oceanographic studies were needed.

On November 1, 1957, the State Board contracted with the University of California, Institute of Marine Resources, La Jolla, to conduct a program of research designed to (a) describe the effects of ocean outfall discharged wastes upon the survival, growth, and general condition of kelp, (b) measure the separate effects on kelp of such factors as turbidity, siltation, diseases, parasites, grazers, nutrients, and toxicity, and (c) reveal the concentrations of domestic sewage, industrial wastes, and components thereof in the sea water in kelp beds which are the maximum that the kelp can tolerate without being damaged. The study and preparation of the final report extended to March 1, 1963. The project was under the direction of Dr. Wheeler J. North, Assistant Research Biologist, Scripps Institution of Oceanography, who was the principal investigator.

The succeeding pages present the contractor's final project report dated April 1, 1963. Background information is given in the report transmittal letter, Preface and first chapter. The Abstract summarizes the report and the final chapter is a ''Concluding Discussion''.

Printing and distribution of the report as Publication No. 26 was authorized by the State Board on August 29, 1963.

The investigations reported herein were conducted under the sponsorship of the State Water Pollution Control Board (now the State Water Quality Control Board), which appointed a Research Consulting Board that met from time to time with the investigators to discuss results and to make suggestions. The investigations and their direction were under the sole responsibility of the University of California's Institute of Marine Resources. The conclusions and recommendations are, therefore, those of the research contractor, and do not necessarily reflect opinions or policies of the State Water Quality Control Board.

FINAL REPORT

AN INVESTIGATION OF THE EFFECTS OF DISCHARGED WASTES ON KELP

Standard Agreement 12C-16

April 1, 1963

UNIVERSITY OF CALIFORNIA

INSTITUTE OF MARINE RESOURCES
POST OFFICE BOX 109
LA JOLLA, CALIFORNIA

LETTER OF TRANSMITTAL

Submitted herewith is the final report, completing Standard Agreement 12C-16 between the State Water Pollution Control Board and the University of California, Institute of Marine Resources for an investigation of the effects of discharged wastes on kelp. The investigation was conducted from November, 1957, through June, 1962, and the final report was prepared in the ensuing nine months under an extension of the Standard Agreement. During this time a study of the biology of the kelp beds was conducted by the Institute of Marine Resources for the Department of Fish and Game and an investigation of food chain intermediates in the beds was supported by the National Science Foundation. Further, the Institute of Marine Resources provided special funds as salaries for additional investigators, equipment, and supplies in support of all these kelp studies. Close coordination was maintained between the various projects and each contributed substantially to the others. Work conducted on the effects of discharged wastes on kelp proved especially fruitful and has been continued under support from the Kelco Company of San Diego.

Respectfully submitted,

Wheeler J. North, *Project Officer*

Milner B. Schaefer, *Director, Institute of Marine Resources*

CONTRIBUTING INVESTIGATORS

Kenneth A. Clendenning, Physiology and Biochemistry
Lawrence G. Jones, Ecology and Physiology
James B. Lackey, Microbiology
David L. Leighton, Ecology and Physiology
Michael Neushul, Jr., Botany
Wheeler J. North, Ecology and Physiology
Marston C. Sargent, Plant Physiology
Harold L. Scotten, Microbiology

KELP ADVISORY PANEL

Kenneth A. Clendenning
Francis T. Haxo
Carl L. Hubbs
John D. Isaacs
Wheeler J. North
Milner B. Schaefer
John Tyler
Benjamin Volcani
Charles D. Wheelock
Claude E. ZoBell

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Frontispiece. Comparison of the off shore area of the southeast Palos Verdes peninsula in 1927 vs. 1958. Pt. Fermin is in the foreground and Los Angeles harbor lies at lower right. Note complete loss of kelp beds during this period. 1927 photo by Spence Air Photos.

PREFACE

During the decade of 1940-50, four productive kelp beds ringing the Palos Verdes peninsula deteriorated to the point where little or no harvesting was conducted in the area. From 1950 onwards it became obvious that two important beds off Point Loma were suffering the same fate, and concern was voiced by a number of interested groups that the declines were in some way connected with disposal of large quantities of wastes into marine waters. The kelp resources consist not only of the kelp itself, which is harvested and processed for fertilizer, animal foods, and chemicals, but also the associated animals, particularly fishes, lobster, and abalone, which find use commercially and for recreation. It is difficult to estimate the total direct value of the kelp resources of the two areas combined, but very likely it exceeds two million dollars annually. Indirect values are even more difficult to reckon but would raise the figure considerably and when added up over the years, the losses become indeed substantial.

In recognition of the urgent need for information on the kelp environment generally and the effects of discharged wastes in particular, a 5-year program of research, sponsored by the State Water Pollution Control Board, has been conducted by the University of California's Institute of Marine Resources. The need for a very broad approach was recognized from the start and many lines of investigation were pursued intensively, not because they gave promise of an early solution to the problem but because the information developed was required and indispensable. Outstanding in this category were the studies of toxicity to kelp of the many substances found in the various effluents discharged in southern California. No chemical or effluent was found which was sufficiently toxic to account for the widespread losses.

The explanation of kelp disappearance is based on subtle changes in the ecological balance of the kelp environment and was not apparent until an adequate understanding of normal conditions in these submarine jungles had been attained. A considerable portion of this report, accordingly, is concerned with general ecology of the nearshore region and with detailed accounts of life histories of certain critical organisms, their physiology, and their behavior.

The body of the report has been organized into three main groups, Background Information, Investigations, and Conclusions, References, Etc. Each of these general headings is subdivided into sections incorporating closely related material such as the Historical section, Microbiological section, etc. The policy has been to summarize the information in a fairly brief manner but including adequate data to substantiate the conclusions. Detailed accounts of the work will be published by the various investigators in appropriate journals.

ABSTRACT

Three major kelp areas exist near sites where wastes are discharged into the sea. The Pt. Loma beds, 10 or more miles from the discharge of the City of San Diego into San Diego Bay, the Palos Verdes beds which surround the outfall system of the Los Angeles County Sanitation Districts at Whites Pt., and the Santa Barbara bed which is immediately adjacent to the outfall of the City of Santa Barbara. The Pt. Loma and Palos Verdes beds have deteriorated badly since 1945, historical data indicating that those regions nearest the sources of waste were affected first and deterioration proceeded in either direction away from the regions nearest to the discharge. At Pt. Loma an additional complication may have been introduced by dredging in Mission Bay near the northern edge of the beds. The Santa Barbara bed, however, has remained in a good condition if allowance is made for the increase of other activities in the nearby harbor which may have contributed to kelp losses in the immediate vicinity.

Areas of investigation for possible harmful effects of discharged wastes on kelp included toxicity, sedimentation, turbidity, grazing, and disease. Toxicity thresholds were determined for six metallic ions (Hg, Cu, Cr, Zn, Ni, Pb, in order of decreasing toxicity), dilution of seawater with fresh water, many organics (toluene, benzene, n-hexane, phenol, ortho meta and para cresol, the detergents Santobrite, Zephiran chloride, SDS, and ABS), and a variety of complex mixtures (diesel oil, boiler fuel, chlorinated and unchlorinated San Diego sewage, sewage from Los Angeles County Sanitation Districts treatment plant, General Petroleum oil refinery wastes, and samples taken in Dominguez Channel near San Pedro). Insufficient toxicity was found to account for the widespread losses which have occurred. No evidence for toxicity effects was observed from transplantation experiments and field observations. San Diego sewage actually stimulated photosynthesis when diluted 100 to 1 with seawater in the laboratory. Sedimentation and disease were not observed to be significant factors in beds which were dwindling at Pt. Loma and Palos Verdes during the course of the study.

Turbidity proved to be such a complex question that effects of outfalls in changing water clarity in the kelp environment have not been resolved. Amount and character of plant distribution on the sea floor indicated that turbidity may be a significant factor. Grazing was definitely established as important in the destruction of vegetation at Pt. Loma and Palos Verdes; in particular the activities of two sea urchins (*Strongylocentrotus purpuratus* and *S. franciscanus*) appear to be extremely devastating. These animals can be starved to death in the laboratory in a few months but dense populations have persisted at Pt. Loma and Palos Verdes during the five years of the investigation, even in areas virtually devoid of vegetation. The environment has apparently altered in a way that favors survival of these two species. The explanation for the persistence of the Santa Barbara kelp bed follows from the grazing studies because this bed is located on a sedimentary bottom while these urchins are rocky substrate dwellers and are rare in the Santa Barabra bed.

When all the urchins were destroyed in a restricted area at Abalone Cove, Palos Verdes, vegetation including the giant kelp quickly returned but was eventually grazed away by other urchins migrating into the cleared area. A favorable method for treating large areas to control urchins appears to be the use of lumps of quicklime (calcium oxide) as a fairly specific poison for echinoderms.

BACKGROUND INFORMATION

INTRODUCTION

The Nearshore Areas of Southern California

The two main types of coastal environment found in the nearshore, open coasts of Southern California are rocky bottom and sandy areas. Silt or muddy patches occur in protected locations or in deeper zones, but sand and rock predominate at shallower levels. Probably less than half of the shallow bottom between the Mexican Border and Pt. Conception is rocky, but the rock areas are usually much more productive than the sandy areas in marine forms of economic value and, therefore, are probably of greater over-all importance. Historically, marine plants and animals have been the most important resource utilized by man in the nearshore regions, but within recent times the waters themselves have assumed significance as a dilution medium for sewage, and the water movement are utilized for dispersion of the waste materials.

A basic concept in ecology is that all animals derive their body substance from plants, either directly by grazing on vegetation or indirectly as when, for example, carnivores eat grazers. The abundance of animals in a large region must depend in some complex fashion upon the availability of plant material to supply food requirements. Plants are not uniform in their constituents or digestibility. Presumably, some types of plants are more desirable than others because for one reason or another they may represent better sources of nutrition for animals utilized by man. In the nearshore areas two groups of plants are generally found. Microscopic single celled algae—the phytoplankton—occur suspended in the water whereas seaweeds grow attached to the bottom at shallow depths. Both sandy and rocky areas often support seaweed growth, but this type of vegetation is usually much more abundant on rocks. Phytoplankton, on the other hand, is not known to exhibit any marked correlation with the bottom type. The presence of lush seaweed growth on the rock outcrops would be a further source of nutrition for grazers in addition to the phytoplankton in the water column. This may be a partial explanation why these environments are more productive of marine resources, but the crevices, caves, and similar irregularities are believed also to attract animals such as fishes and the lobster and are probably of survival value to them.

In assessing the nutritive role of plants, two concepts are generally accepted as being of fundamental importance: standing crop (the amount of plants present), and productivity (the amount of plant tissue produced in a given time). An excellent illustration that embodies the principles behind these concepts is provided by an individual's bank account. The bank balance represents, of course, the difference between the incoming and the outgoing funds and, although these figures are related, knowledge of these does not necessarily yield reliable information about the balance. The standing crop is increased by production of more plant tissue, but factors such as the activity of grazers and storm damage tend to reduce it.

Ecological interest has tended to center in computations of productivity since this is a measure of the amount of material becoming available as food for the animals of an area. The standing crop, however, may be an important consideration to coastal fauna. Returning again to the bank account analogy, the size of the balance does not serve as an indication of the amount of intake and outgo of money, but a large balance does provide a buffer against emergencies. Areas where large standing crops of seaweeds exist, therefore, may be expected to display greater stability in the composition of animal population. This might logically result in larger populations of long-lived animals since the faunal communities of seaweed-rich areas may not have to contend with the short-period fluctuations in food supply that may occur when phytoplankton forms the chief nutritive source. Among the marine animals utilized by man the long-lived varieties are by far the most important, although many of these forms apparently depend to a considerable extent on plankton for food sources.

In summary, the rocky sections nearshore are much more productive in animals of importance to man than the sandy sections. Three reasons have been listed: first, the rocks themselves with their irregular shapes are attractive to animals; second, the rocky areas often support much more seaweed growth than occurs on sandy areas and this increases the production of plant material that forms the basis of all animal food; third, the large standing crop of seaweed in the rocky areas may contribute to the stability of these environments, especially with regard to the longer-lived animals.

The Kelp Beds

One of the most prominent seaweeds of southern California waters is the giant kelp, *Macrocystis*. On exposed coasts it usually occurs only where secure attachment to the bottom can be obtained and, therefore, is largely restricted to rocky areas. In many protected locations, however, plants are able to maintain a fixed position on sandy or mud bottoms.

It is well known that plants depend on sunlight for the energy to synthesize the substance of their tissues. Light is absorbed and scattered by seawater so that surrounding light intensity becomes dimmer with increasing depth. In consequence, growth of seaweeds tends to diminish at greater depths, and below 100 ft. attached plants become quite sparse, even in clear water.

A most important feature in the growth of the giant kelp plant is the way the plant extends up toward the surface into the zones of bright illumina-

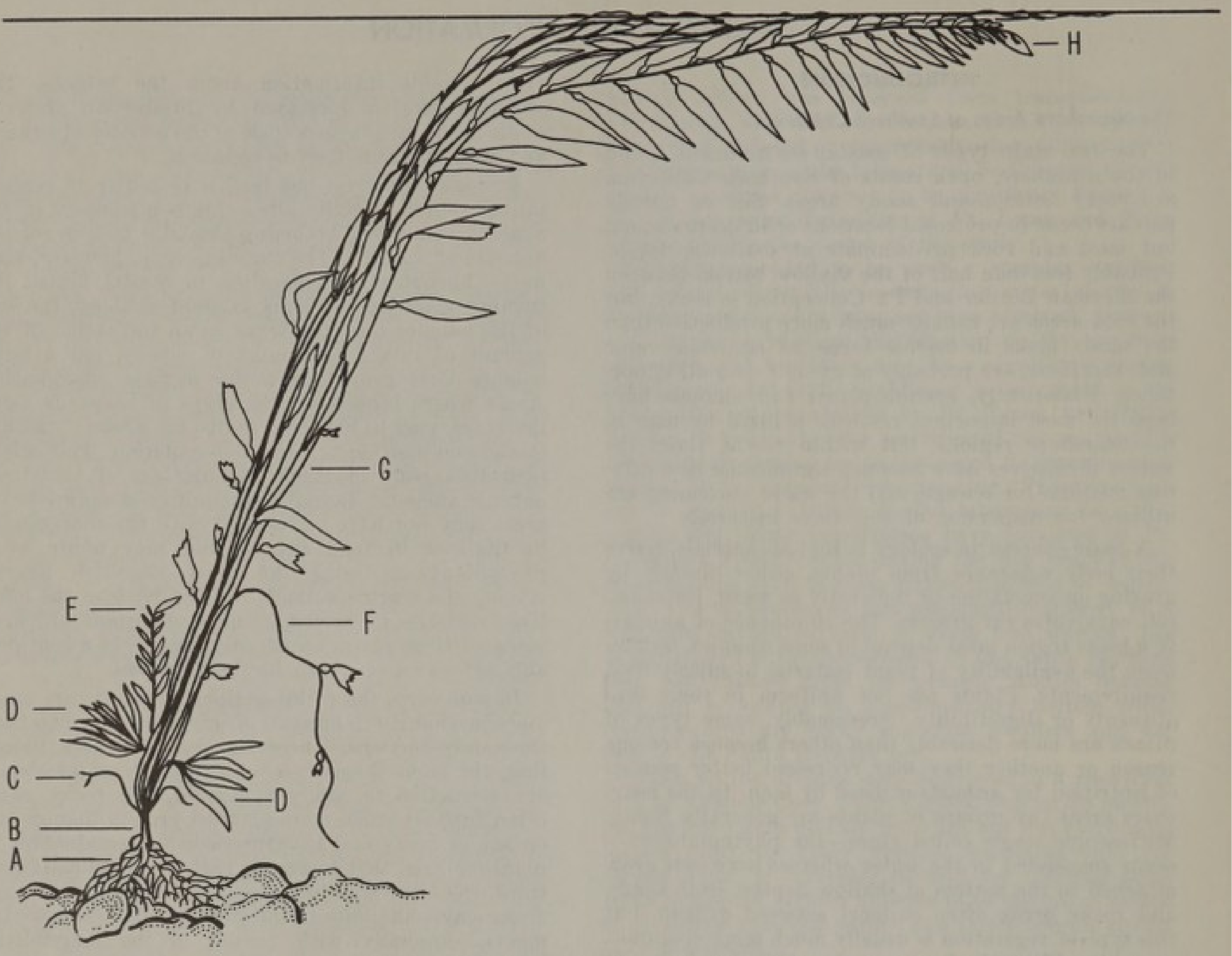


Figure 1. Diagrammatic representation of an adult giant kelp, Macrocystis pyrifera. A. Holdfast. B. Primary stipe. C. Remains of old stipes. D. Spore-bearing reproductive blades. E. Young frond. F. Senile frond. G. Main stipe bundle. H. Growing tip of a mature frond.

tion (Figure 1). This enables the plant to maintain a large portion of its photosynthetic tissue at the surface and creates, as it were, an intertidal zone of plant productivity in deep water. As might be expected, this produces a high standing crop. Our measurements of the approximate range of standing crops in kelp beds indicate that the values are indeed very high. From these considerations, then, we would expect that kelp beds should have a food potential which could result in much greater populations of animals than might ordinarily be able to subsist in the area if kelp were absent.

Many seaweeds can conceivably contribute to animal nutrition in areas where the plants do not grow. Wave action and other natural factors remove seaweeds from their attachment. Some of the drift is cast upon the beach, but probably of greater importance is the fact that drift has often been observed on the sea floor in areas much deeper than the kelp normally grows. Hence, it presumably moves seaward across the continental shelf. The extent to which drift seaweed is used by animals as food is not known, but many grazers eat the drift material. *Macrocystis* often comprises a substantial portion of drift and presumably is of importance in this form to many animals which do not inhabit the kelp beds.

Resources of the Beds

Two crops are gathered by man from the kelp areas: the plants themselves are harvested and processed for their chemical content and for use as food additives or fertilizer; many of the animals such as fish, lobster, and abalone are collected for food both commercially and for recreation. In years favorable to kelp growth the southern California beds formerly covered an area somewhat in excess of 100 sq. mi. or 200 sq. km. (Fig. 2). If we assume a modest value for the average density of plants in these beds, we arrive at a conservative estimate of the standing crop of kelp as about two million tons. It is known that kelp is able to produce new growth equal to two or three times its own weight annually so that the kelp tissue available on a yearly basis as food for animals very likely greatly exceeds two million tons. It was estimated that the Pt. Loma beds alone in good years produced resources valuing about 1 million dollars annually (San Diego Marine Consultants, 1959).

Natural Factors Causing Kelp Bed Deterioration

During this investigation we have observed both large and small scale disappearances and reappearances of kelp and there can be no doubt that nearly all the beds undergo profound fluctuations in size. Grazing animals, water movements, diseases, and unfavorable growing conditions are apparently all very important in their influence on kelp. Several changes resulting from operation of such factors have been well documented. Examples are furnished by the *Tampico* wreck study, and by the unfavorably high water temperatures. For our present discussion it is sufficient to note that these destructive forces exist and the amounts of kelp which they sometimes obliterate make the activities of man seem rather puny. From what we have been able to observe, however, it appears that over a period of several years in areas such as Baja California (where man's influence is much reduced) beds may fluctuate in size but they tend to return to what might be called an average value. In considering any changes in kelp areas near large cities it is important to remember that natural forces do cause large scale fluctuations, but losses tend eventually to be replaced.

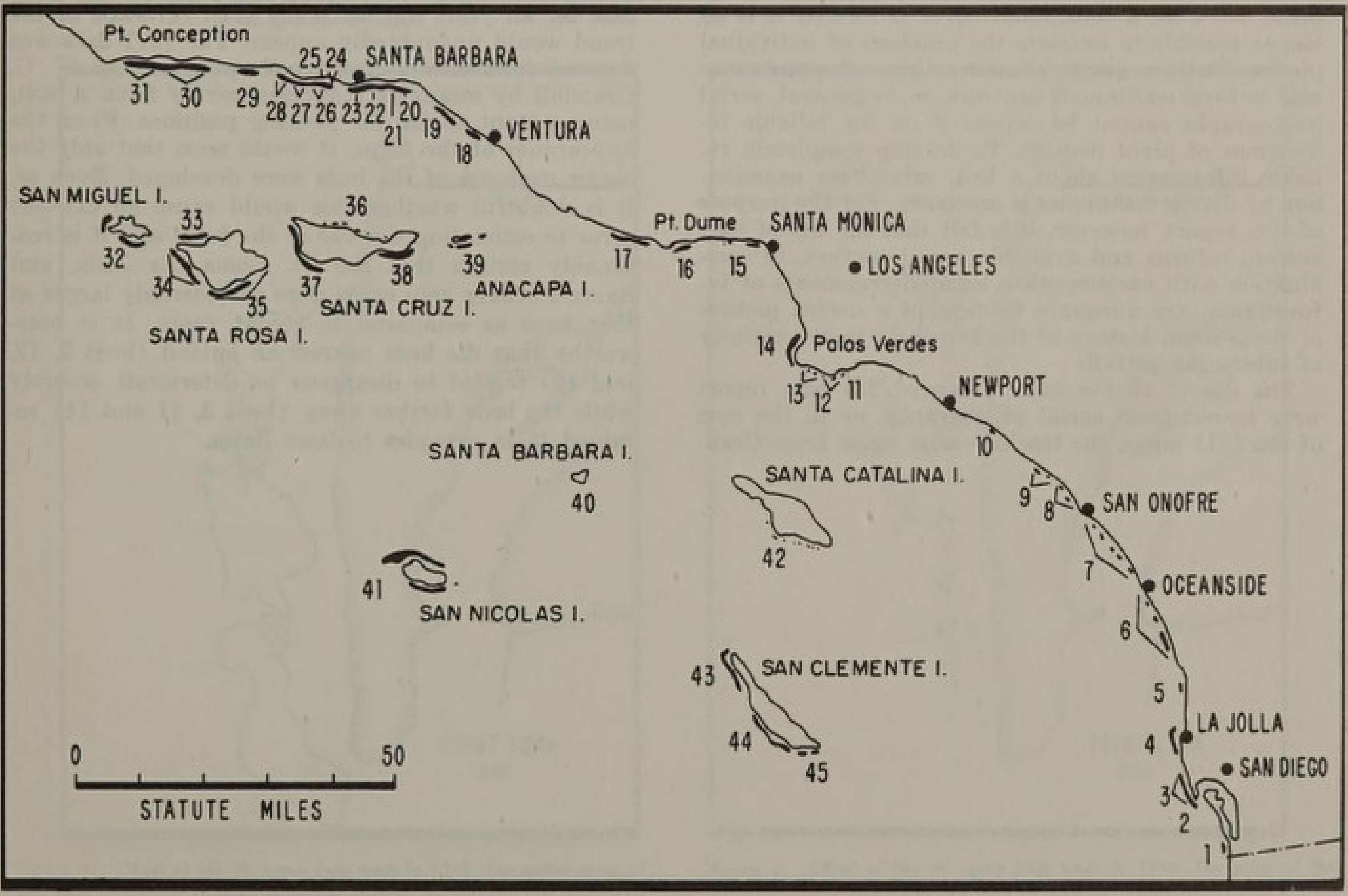
HISTORY OF SOUTHERN CALIFORNIA KELP BEDS

It has been well documented that even under undisturbed conditions the state of a kelp bed may be extremely inconstant. When historical trends are sought and the data at hand are not plentiful, it is necessary to be cautious in interpreting results, and only clearly defined patterns are here considered. This historical study is not intended to provide a detailed description of the State of a kelp bed at a given time, but rather to furnish a broad picture of sufficient accuracy to indicate long-term trends.

Methods

Two sources of information proved to be the most useful in supplying historical data on the state of the beds, but unfortunately both types have limitations which must be taken into consideration. Over the years the Department of Fish and Game has maintained records of the tons of kelp harvested from the different beds, and these statistics provide some measure of the health and productiveness of the kelp in a

Figure 2. Chart of the southern California region showing the official Department of Fish and Game numerical designations for the kelp beds of the area.



given location. Aerial photographs of the coast are also very useful in indicating the presence of kelp and, when the photographs are taken from a vertical position, maps showing the extent of the beds can be traced.

The beds with which this report is chiefly concerned are located near large cities where the processing plants of the harvesting companies are located. Because of their proximity these beds are the most economical to harvest and it is reasonable to assume that the harvesting statistics reflect the maximum utilization of the area's resources consistent with good business policy. Where the bed extends close to shore, however, boat operations can become hazardous and the area may never be subjected to cutting. Likewise a thin stand of kelp may not be considered worth the effort to gather and the absence of any harvesting returns from an area may not be indicative that plants have entirely disappeared. There is no practical way to convert harvesting yields into figures which would indicate the size of a bed or the density of the plants.

Aerial photographs can be misleading because strong currents can drag kelp beneath the surface, giving the appearance of a barren ocean. Waves, slicks, submerged rocks or reefs, and sun reflections can also render the interpretation of photographs difficult and the presence of other floating seaweeds such as *Egregia* and *Cystoseira* sometimes leads to confusion, although these forms are usually restricted to shallower water. Some indication of the density of plants may be gained if the kelp canopy is not too thick, but once a continuous cover is formed it is no longer possible to estimate the numbers of individual plants. Rather sparse concentrations of plants are able to form continuous canopies, so, in general, aerial photographs cannot be depended on for reliable indications of plant density. To develop completely reliable information about a bed, subsurface examination by diving techniques is necessary. For the purpose of this report, however, it is felt that the use of harvesting returns and available aerial surveys, in combination with various other isolated fragments of information, are adequate to develop a useful picture of the general history of the kelp beds in the vicinity of submarine outfalls.

The charts of the beds prepared for this report were traced from aerial photographs, or in the case of the 1911 maps, the tracings were made from Crandall's charts (W. C. Crandall, 1912). Reduction of the tracings to a standard page size was accomplished by use of a camera lucida and the accuracy was checked with a ruler by several measurements per chart. Computation of areas was made by placing the tracing over a grid and counting the squares contained within the kelp areas. In tracing the photographs, fine detail, such as convolutions in the edge of a bed caused by individual plants, was omitted since the effect on the total area was negligible. Major gaps or holes or isolated patches of significant size, however, were always taken into account.

Historical Charts

Charts for Santa Barbara, Palos Verdes, La Jolla (chosen as a control) and Pt. Loma are presented in figures 3 through 26. Where a kelp area amounting to less than 50% of the total for the chart was missing, owing to lack of a photograph, the corresponding area from the previous chart was traced onto the missing section. Such entries are denoted by dotted lines and occur in figures 16 through 19. With the exception of figures 17 and 19 (Palos Verdes 1945 and 1953) these areas were less than 20% of the total. In some years certain beds extended slightly beyond the limits shown on the figures, but the total extent of the beds was taken into account when computing areas (Figs. 3, 4, 9, 11 and 13).

In general, the trend for all beds studied indicated a shrinking in size (Table 1). There are upward fluctuations, however, and if adequate data were available for all years a great many such reversals of the trend would undoubtedly appear. The 1911 data was derived from charts of the beds prepared by W. C. Crandall by means of a surface survey from a boat, using sextant angles for plotting positions. From the appearance of the maps, it would seem that only the major contours of the beds were developed. Even so, it is doubtful whether this would cause an extreme error in estimating the size of the beds, and it is reasonably certain that the Pt. Loma, La Jolla, and Santa Barbara kelp areas were considerably larger at that time as compared to recent years. It is noteworthy that the beds nearest an outfall (beds 2, 12, and 13) tended to disappear or deteriorate severely while the beds farther away (beds 3, 11 and 14) retained their canopies to later dates.

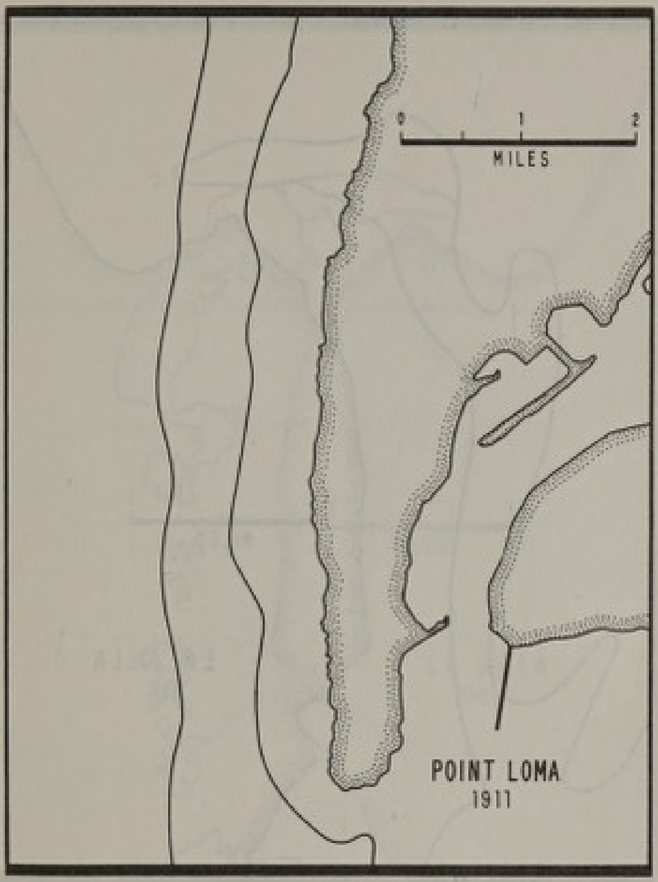


Figure 3. Chart of the Pt. Loma kelp beds in 1911. The entire area of the beds, including a small southern section not shown, was estimated as 5.95 square miles.

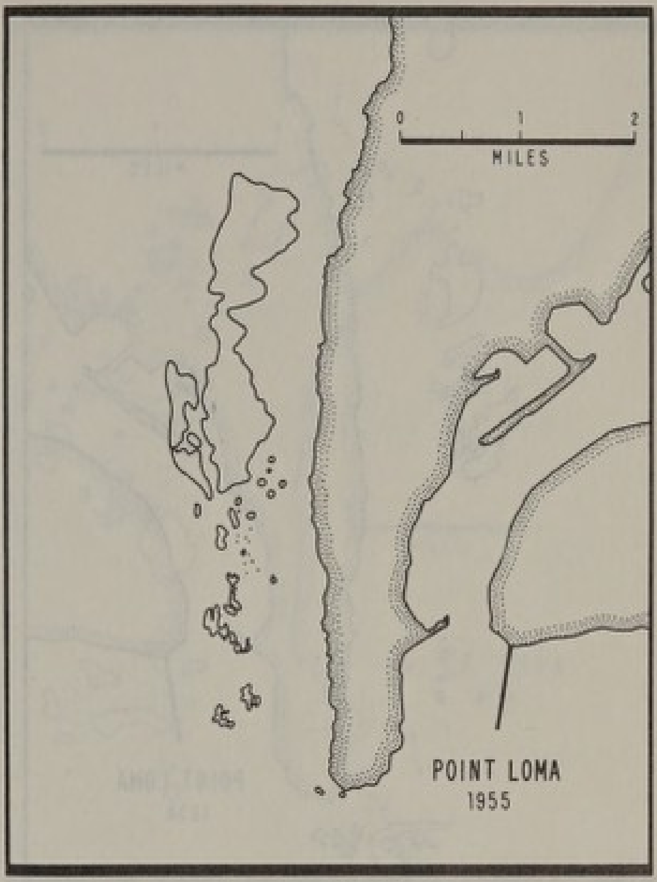


Figure 5. Chart of the Pt. Loma kelp beds in 1955. The area of the beds was estimated as 1.18 square miles.

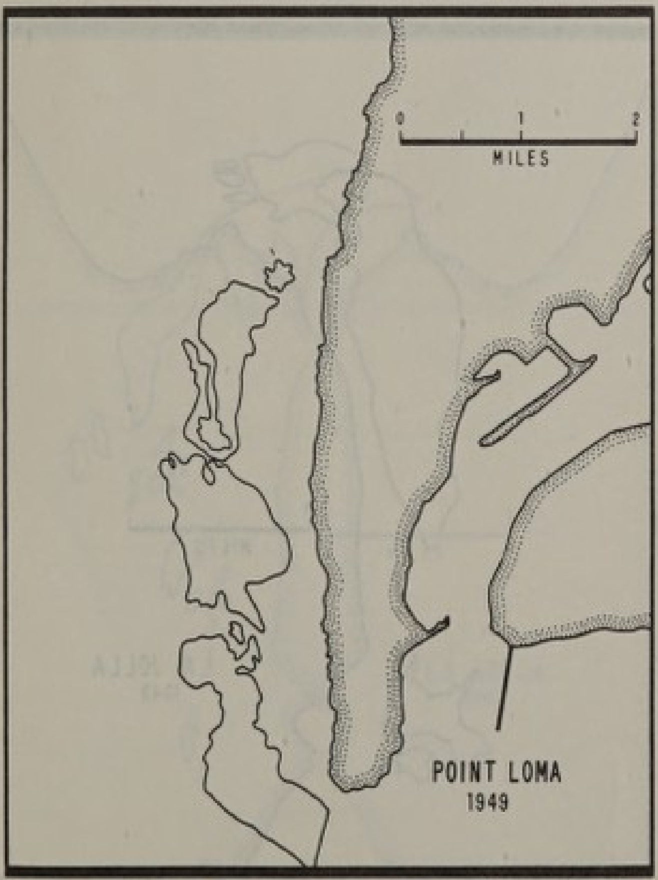


Figure 4. Chart of the Pt. Loma kelp beds in 1949. The entire area of the beds, including a small southern section not shown, was estimated as less than 2.11 square miles.

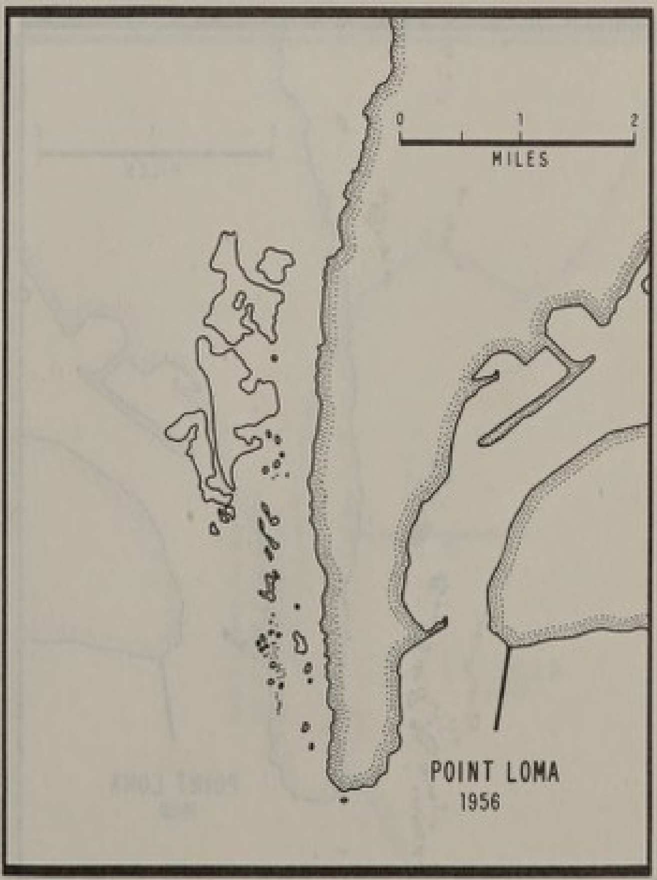


Figure 6. Chart of the Pt. Loma kelp beds in 1956. The area of the beds was estimated as 0.78 square mile.

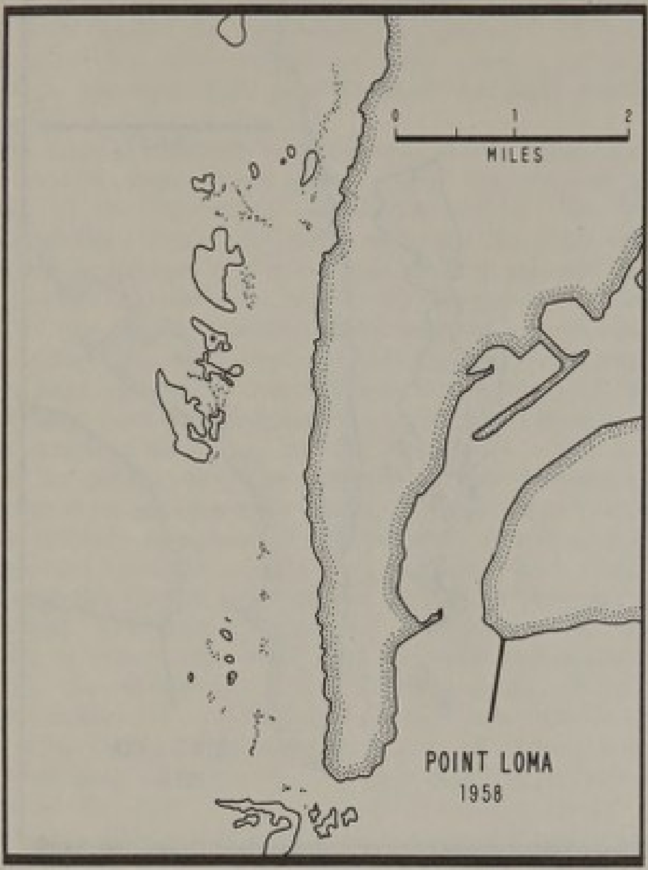


Figure 7. Chart of the Pt. Loma kelp beds in 1958. The area of the beds was estimated as 0.61 square mile.

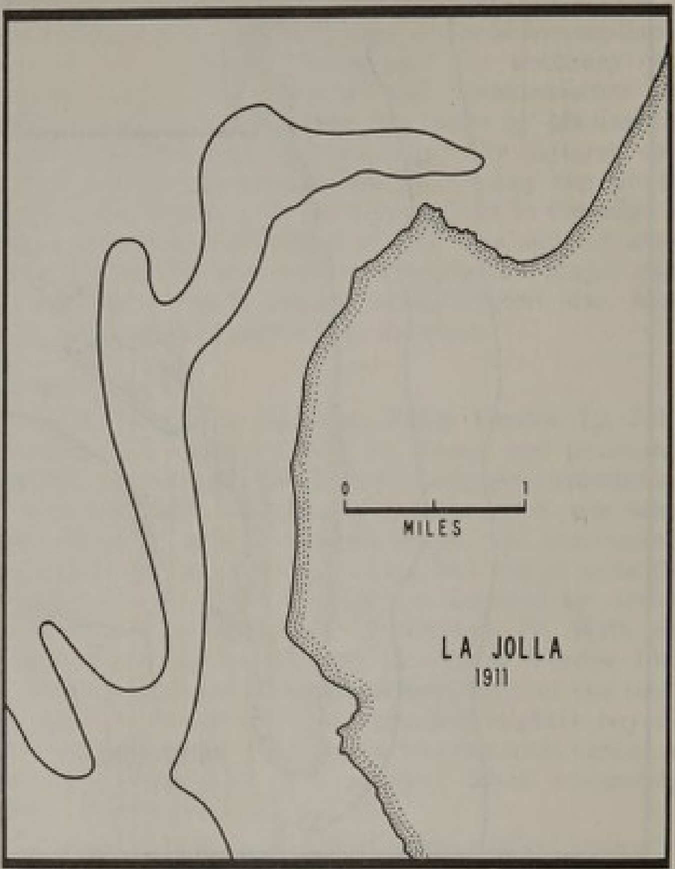


Figure 9. Chart of the La Jolla kelp bed in 1911. The area of the entire bed, including a small southern section not shown on the map, was estimated as 1.89 square miles.

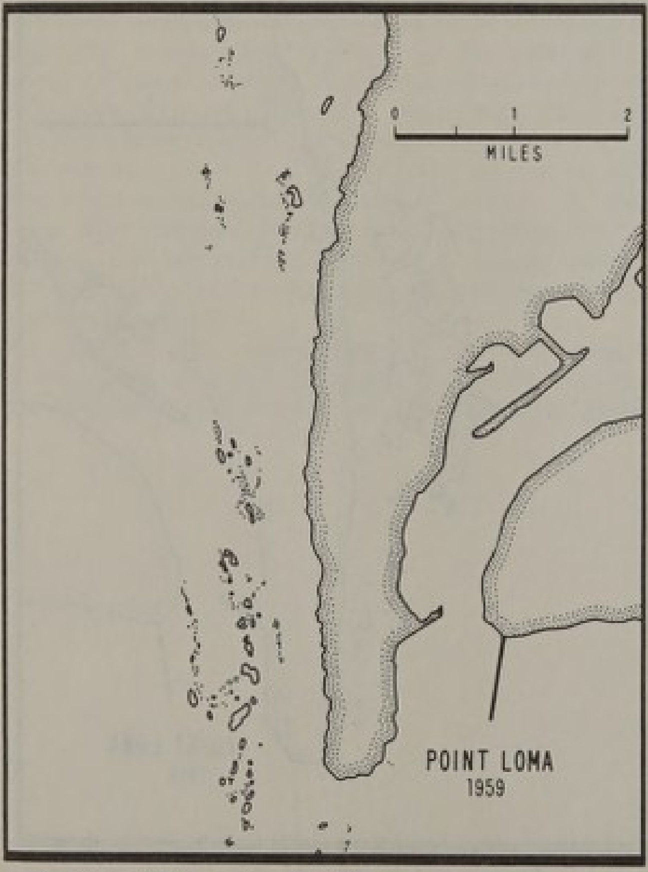


Figure 8. Chart of the Pt. Loma kelp beds in 1959. The area of the beds was estimated as 0.15 square mile.

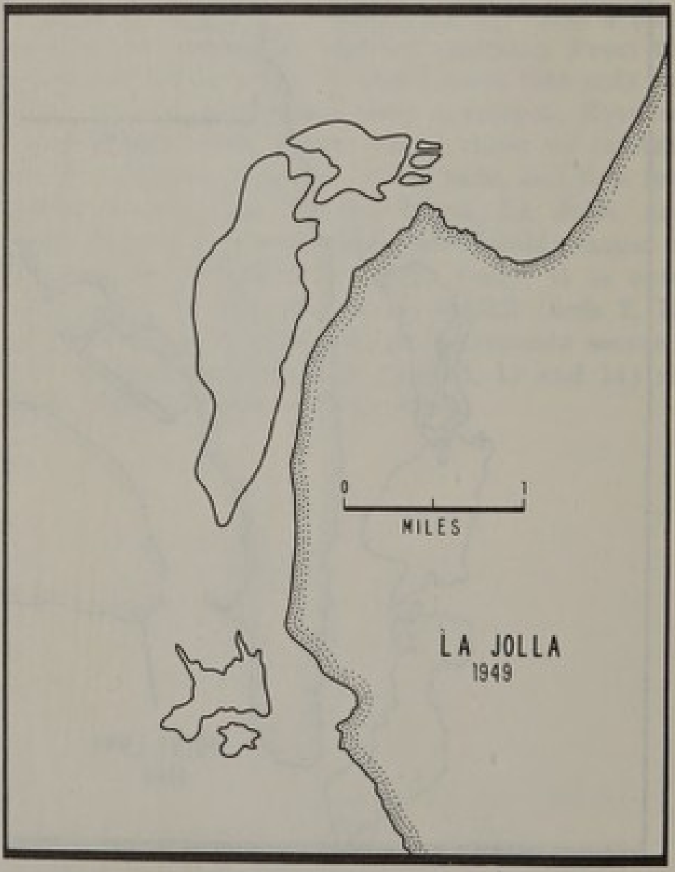


Figure 10. Chart of the La Jolla kelp bed in 1949. The area of the bed was estimated as 0.58 square mile.

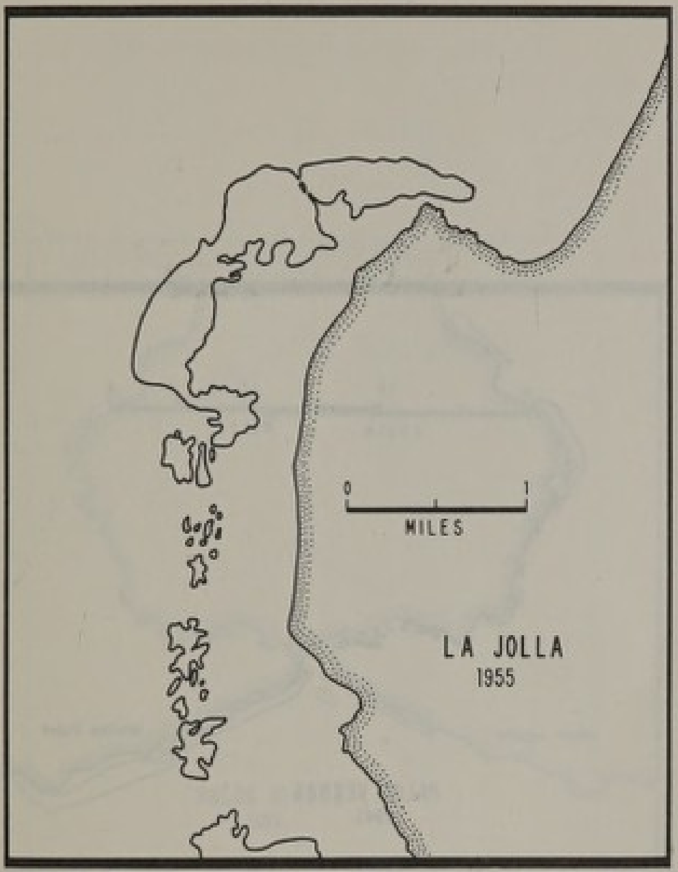


Figure 11. Chart of the La Jolla kelp bed in 1955. The area of the entire bed, including a small southern section not shown on the map, was estimated as 0.77 square mile.

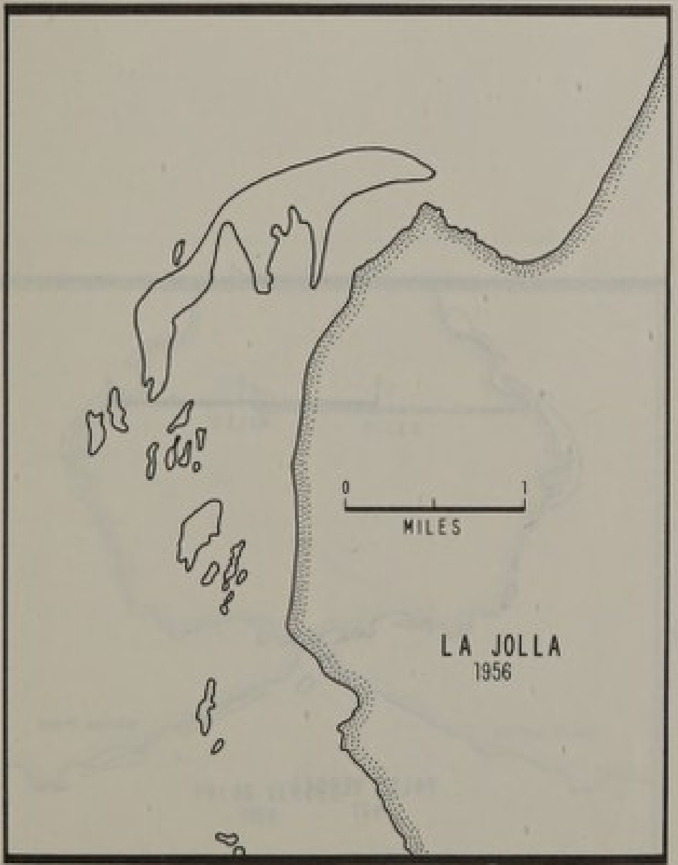


Figure 12. Chart of the La Jolla kelp bed in 1956. The area of the bed was estimated as 0.47 square mile.

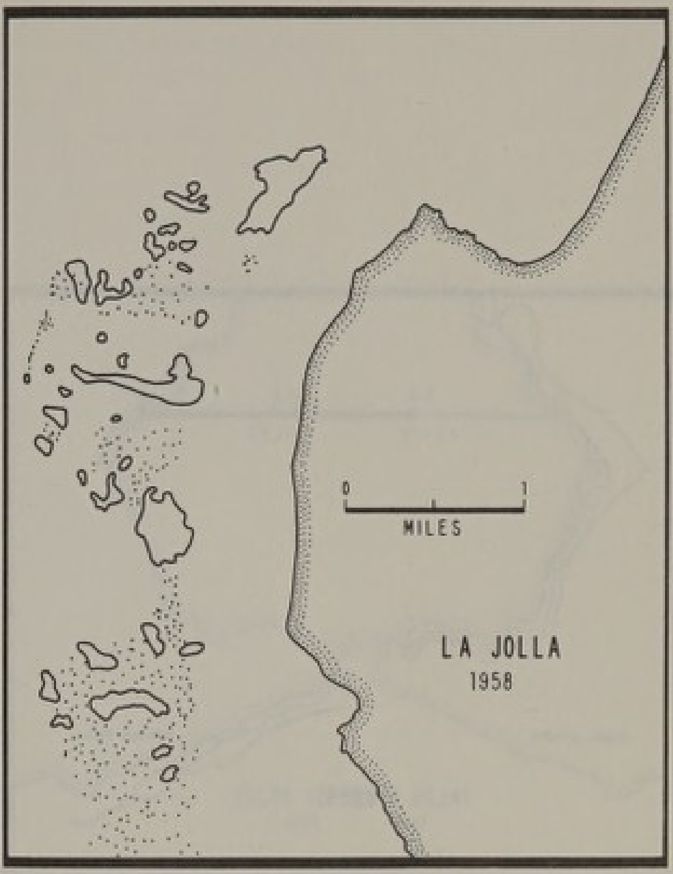


Figure 13. Chart of the La Jolla kelp bed in 1958. The area of the entire bed, including some isolated plants at the southern end of the bed, was estimated as 0.31 square mile.

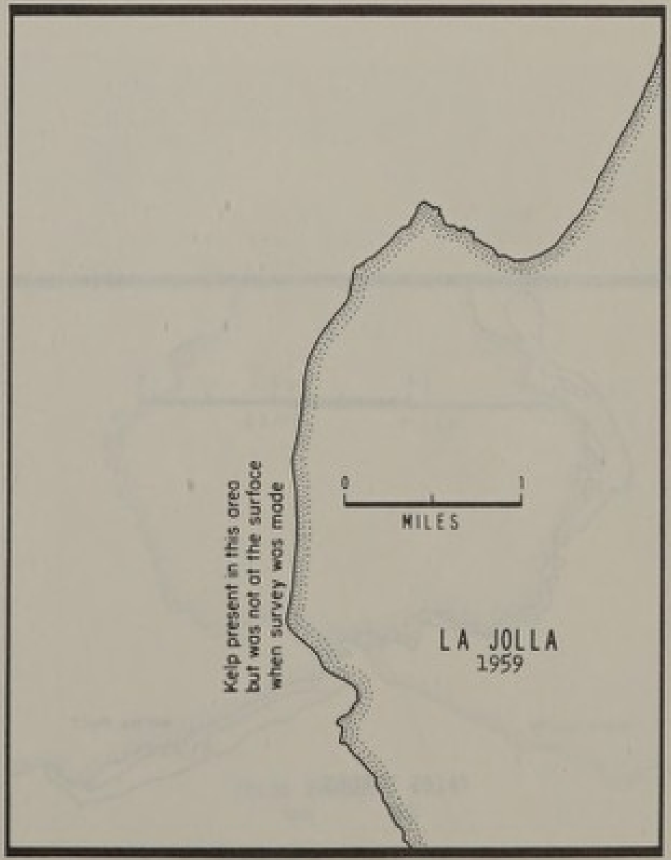


Figure 14. Chart of the La Jolla kelp bed in 1959. Map was taken from an aerial survey which failed to reveal any kelp. From surface and diving operations, however, it is known that a small amount of kelp was present in the area.

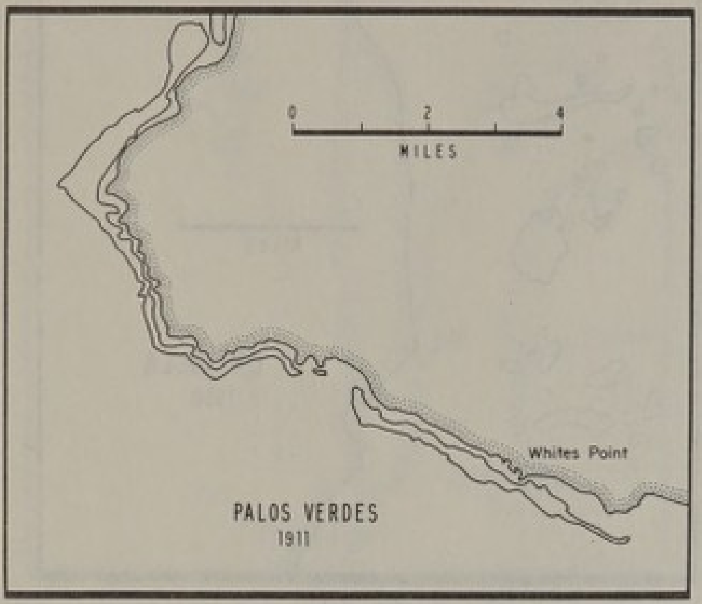


Figure 15. Chart of the Palos Verdes coast in 1911. The area of the kelp beds shown was estimated as 2.42 square miles.

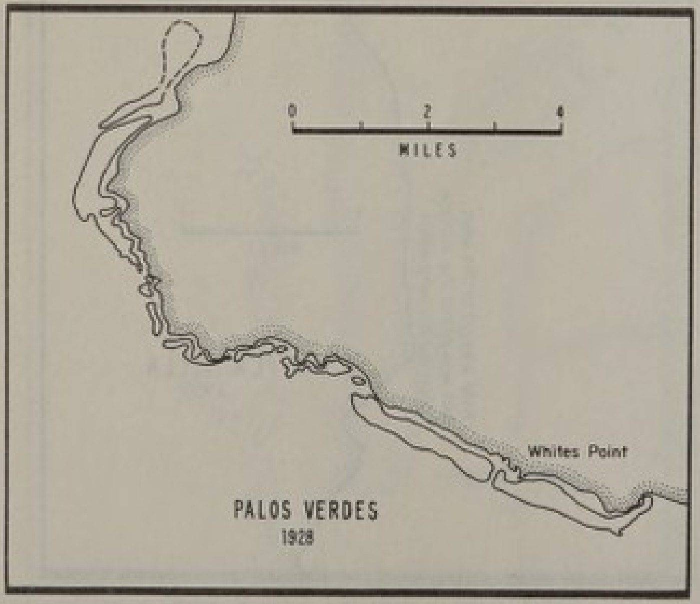


Figure 16. Chart of the Palos Verdes coast in 1928. The area of the kelp beds shown was estimated as less than 2.89 square miles.

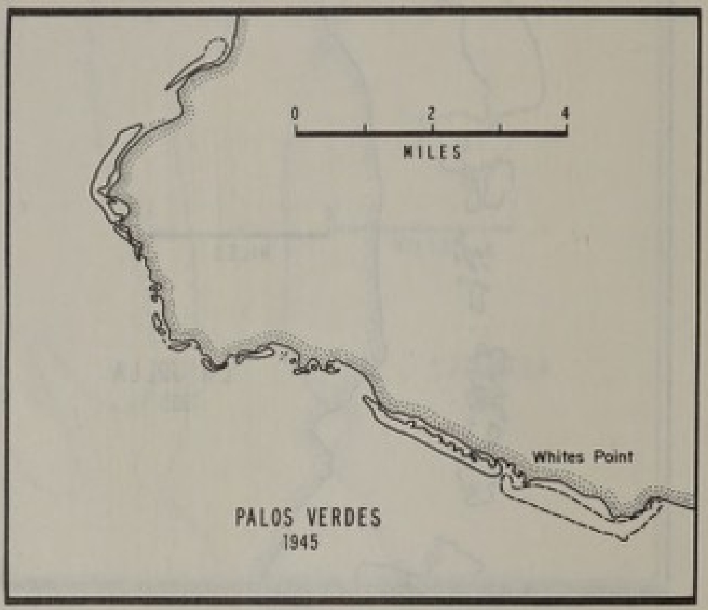


Figure 17. Chart of the Palos Verdes coast in 1945. The area of the kelp beds shown was estimated as less than 1.63 square miles.

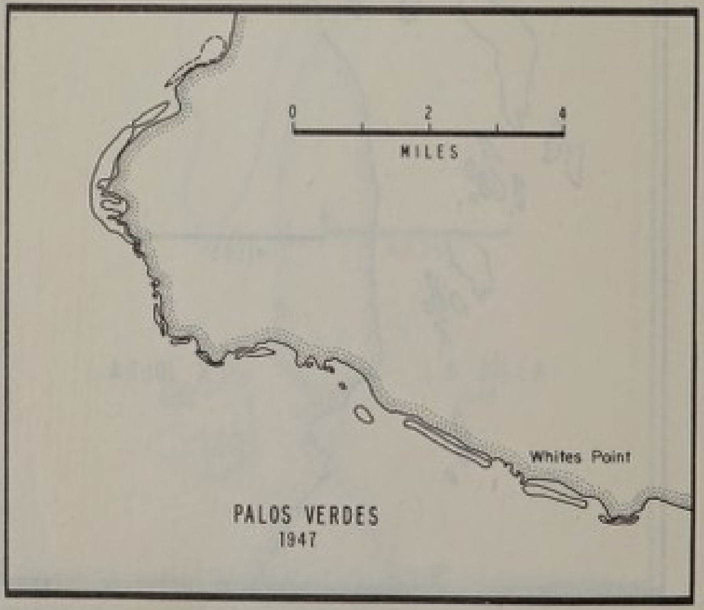


Figure 18. Chart of the Palos Verdes coast in 1947. The area of the kelp beds shown was estimated as less than 1.05 square miles.

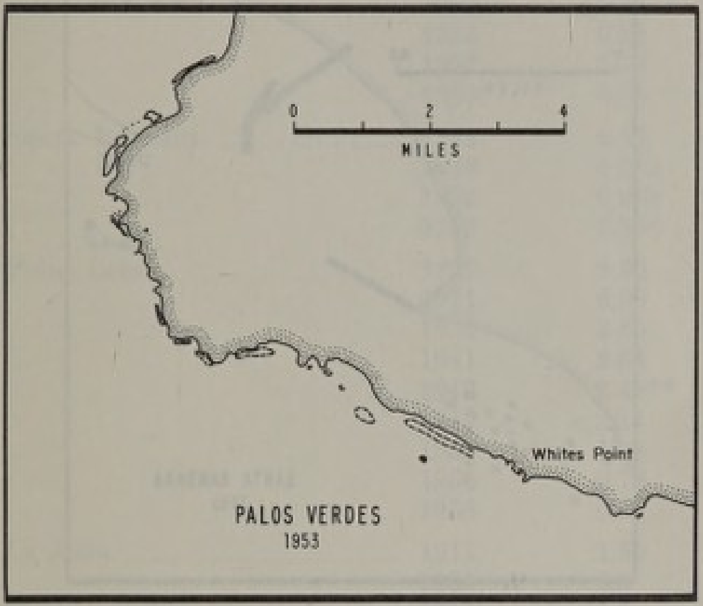


Figure 19. Chart of the Palos Verdes coast in 1953. The area of the kelp beds shown was estimated as greater than 0.44 square mile.

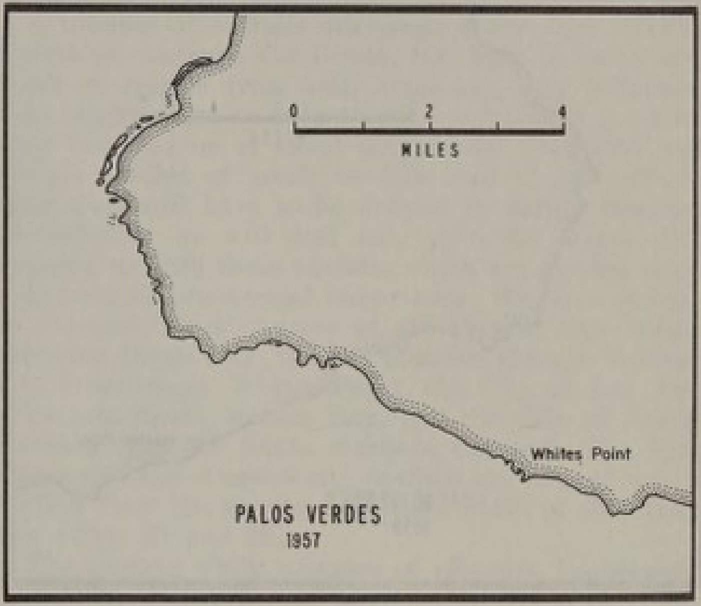


Figure 21. Chart of the Palos Verdes coast in 1957. The area of the kelp beds shown was estimated as 0.13 square mile.

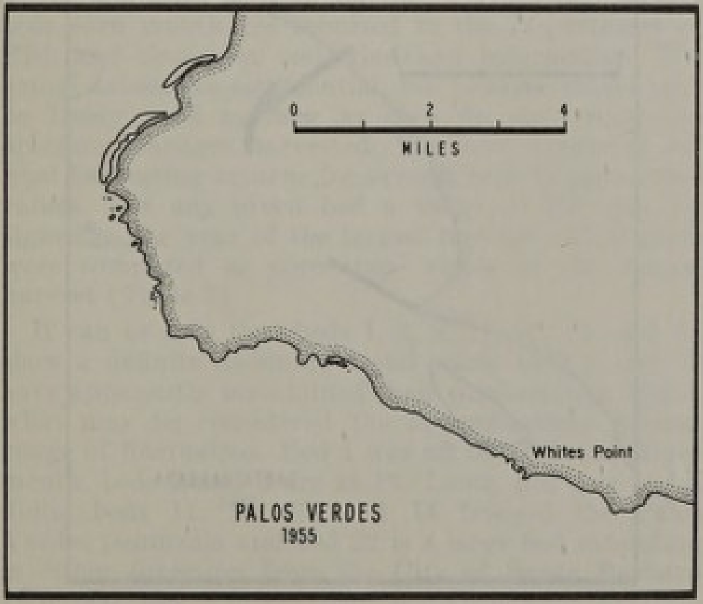


Figure 20. Chart of the Palos Verdes coast in 1955. The area of the kelp beds shown was estimated as 0.24 square mile.

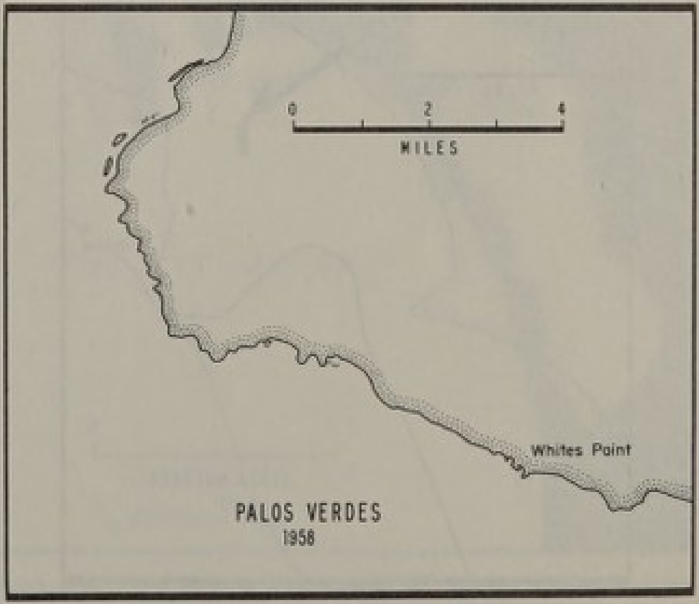


Figure 22. Chart of the Palos Verdes coast in 1958. The area of the kelp beds shown was estimated as 0.05 square mile.

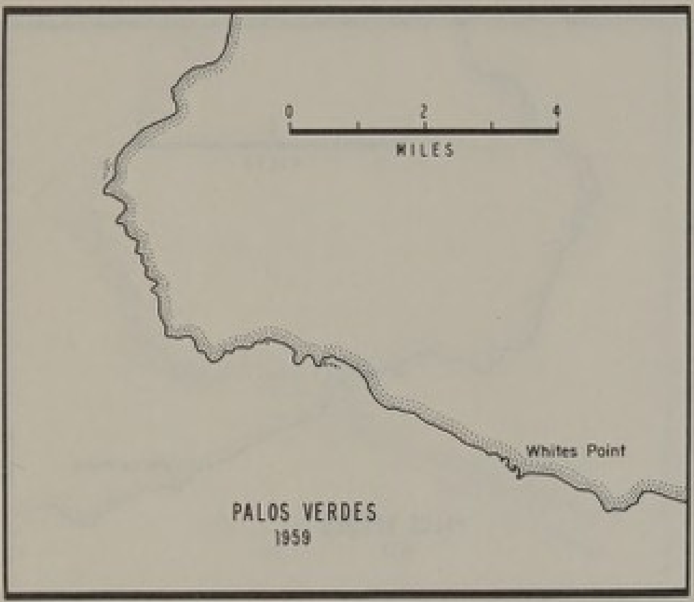


Figure 23. *Chart of the Palos Verdes coast in 1959. The area of the kelp beds shown was estimated as less than 0.01 square mile.*

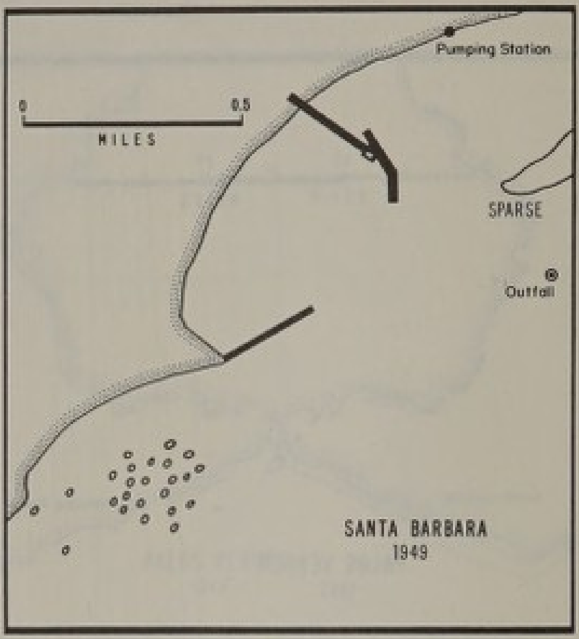


Figure 25. *Chart of the Santa Barbara coast in 1949. The area of the kelp bed shown was estimated as 0.013 square mile.*

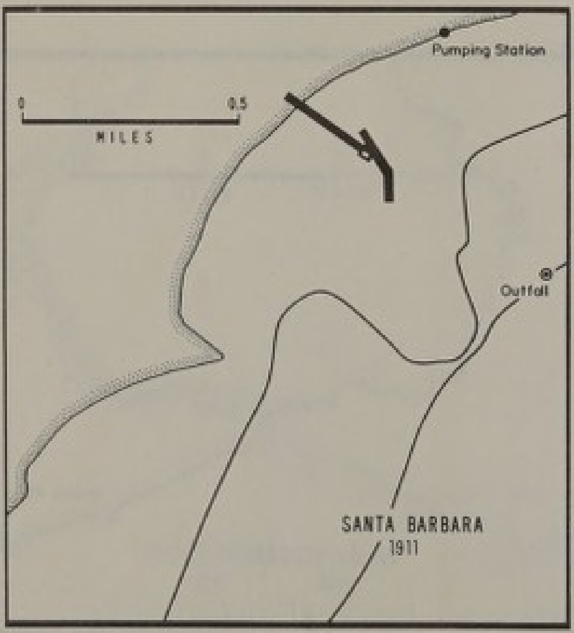


Figure 24. *Chart of the Santa Barbara coast in 1911. The area of the kelp bed shown was estimated as 0.32 square mile.*

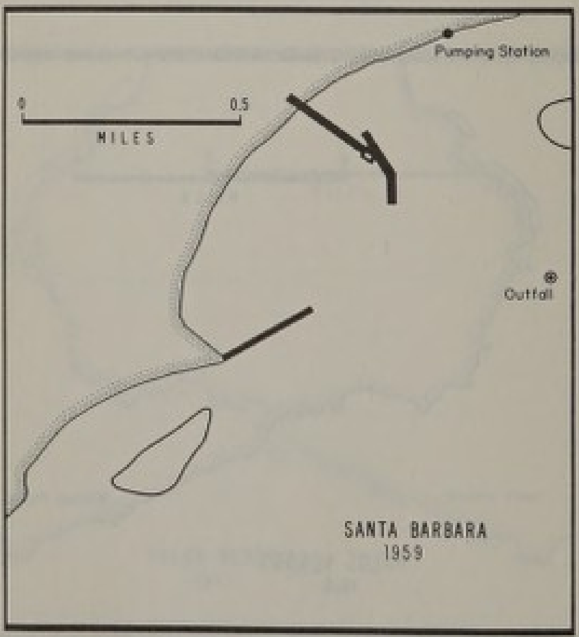


Figure 26. *Chart of the Santa Barbara coast in 1959. The area of the kelp bed shown was estimated as 0.032 square mile.*

Table 1

Historical variation in areas of certain kelp beds.

Location	*Year*	*Area in square miles*
Palos Verdes	1911	2.42
	1928	<2.89*
	1945	<1.63
	1947	<1.05
	1953	<0.44
	1955	0.24
	1957	0.13
	1958	0.05
Santa Barbara	1911	0.32
	1949	0.013
	1955	0.068
	1958	0.036
Point Loma	1857	5.95
	1911	5.95
	1934	3.65
	1941	2.64
	1942	3.49**
	1949	<2.11
	1955	1.18
	1956	0.78
	1958	0.61
La Jolla	1911	1.89
	1934	2.6
	1941	2.5
	1949	0.58
	1955	0.77
	1956	0.47
	1958	0.31

* Where "less than" (<) symbols are used, a portion of an area was missing from an aerial photograph and the kelp boundary from the previous chart was traced in and used for a real estimation. Since these instances occurred where kelp was in a disappearing trend (with the possible exception of Palos Verdes, 1928) it has been assumed that the "less than" symbol is justified.

** Wohnus, unpublished data.

Harvesting Returns

The tonnages of kelp harvested from the various beds each month are reported to the Department of Fish and Game for collection and information. The actual values are confidential, but relative values may be freely used as long as they do not reveal the absolute tonnages harvested. We have converted annual harvesting returns for several beds to percentage values. For any given bed a value of 100 was assigned to the year of the largest harvest; other years were computed as percentage ratios of the largest harvest (Table 2).

It can be seen that beds 1, 2, 3, 11, 12, 13, and 14 show a definite declining trend while beds 4 and 22 have apparently maintained their productivity within what may be considered the approximately normal range of fluctuation. Bed 1 was off the Tijuana River mouth, beds 2 and 3 are at Pt. Loma, bed 4 is at La Jolla, beds 11, 12, 13, and 14 fringed the Palos Verdes peninsula and bed 22 is a large bed extending in either direction from the City of Santa Barbara (Fig. 2).

A similar conclusion appears from these statistics as was found from the charts: beds 2, 12, and 13, nearest an outfall terminus, virtually ceased productivity before beds 3 and 14, farther away, were no longer harvested or declined seriously. Bed 11, near the mouth of Los Angeles harbor, was apparently not harvested heavily in recent times, although the charts show kelp to be present up to 1953.

The Submarine Outfalls

A number of outfalls discharge wastes into marine waters in southern California, but most of these are small or remote from kelp areas and any influence they might exert on kelp or its environment is probably localized or of small magnitude. Time did not permit studies of small outfalls and if any effects exist they will have to be defined in future studies. Accordingly we will deal only with the larger discharges, or with those outfalls which are located near kelp beds of commercial importance. We have chosen to describe the discharges of the City of San Diego into San Diego Bay, the Los Angeles County Sanitation Districts at Whites Point, the City of Los Angeles into Santa Monica Bay, and the City of Santa Barbara into the Santa Barbara Channel. The San Diego and Los Angeles city outfalls are located much farther from the nearest beds than either of the other two (Figs. 27 and 28).

The average daily volumes of effluents discharged, in millions of gallons per day, are presented in Table 3. The trend for all discharges has been in the direction of increase, although there were years when the average flow stayed constant or even decreased slightly.

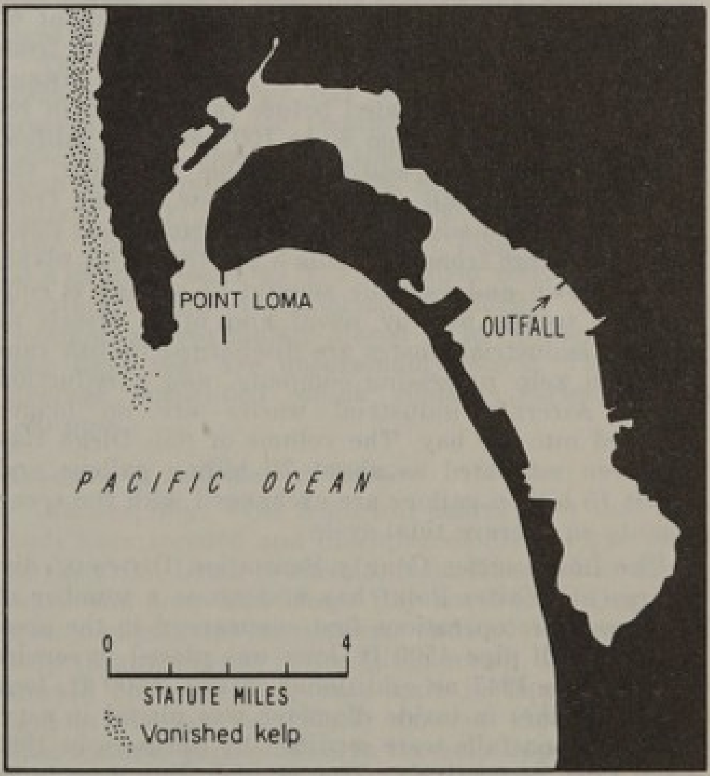


Figure 27. Chart showing the geographical relation of the Pt. Loma kelp beds to the City of San Diego's submarine outfall.

Table 2

Percentage yearly harvest from various beds. The year of maximum yield was taken as 100.

Year	Bed number								
	1	2	3	4	11	12	13	14	22
1916			43.4	47.1	100.0			100.0	
1917	29.7		100.0	45.7	69.9	100.0	100.0	61.4	
1918	100.0	100.0	54.5	100.0	45.0				36.9
1919									5.75
1920									46.2
1931			0.22						
1932		1.20	3.86	0.31	2.17	0.25	5.12	66.4	
1933	1.37	17.8	5.14	0.17	11.0	0.49	2.89	19.6	
1934	3.14	4.29	5.90	0.09	0.39	13.1	8.40	7.02	
1935	2.18	8.95	14.7	0.07		8.53	5.03	0.89	
1936	15.6	21.3	16.1	5.67		15.6	8.16	4.76	
1937	5.34	30.4	15.4	16.8		18.0	10.2	4.90	
1938	4.41	15.3	16.9	21.8		21.9	13.5	7.44	
1939	1.10	18.2	18.4	14.6		13.0	7.65	10.6	
1940		24.6	16.0	24.1				0.71	
1941		0.95	5.74	25.7			0.59	2.5	
1942		4.37	8.18	20.7	0.05	0.21	2.59	4.80	
1943		1.12	20.9	7.70		0.03		9.97	
1944		20.9	19.6	2.52				9.97	
1945		10.1	11.2	5.60	0.55	5.16	2.18	9.47	
1946		11.8	18.1	32.2	0.22	26.5	2.92	10.5	
1947		12.0	19.0	19.6	0.65	4.87	2.90	7.60	
1948		3.46	17.0	28.8	0.71	9.10	9.05	8.71	
1949		2.88	16.3	36.2		3.87	1.85	7.71	
1950			12.2	35.0				2.78	
1951		3.28	11.3	32.2					26.5
1952		3.51	14.1	34.4					13.7
1953		1.23	11.8	38.1					100.0
1954			7.10	27.1				0.29	28.0
1955			7.26	29.8					37.5
1956			7.15	32.7					44.5
1957		0.22	6.05	32.0					25.8
1958			2.71	15.3					26.2

The secondarily treated effluent from the plant of the City of San Diego is discharged into the bay from two open pipes at a depth of about 30 ft. The sewage is clarified and chlorinated before release, and in recent years averaged from 80 to 100 parts per million suspended solids. In addition to this discharge, the bay receives a small discharge of raw sewage from the City of Coronado and the Naval Amphibious Base, and a discharge from the Chula Vista treatment plant. An unknown and variable amount of sewage is contributed to the bay by naval and other vessels at anchor. Industrial wastes are discharged by fish canneries, a kelp processing company, and a reduction plant. Aircraft industrial wastes are no longer dumped into the bay. The volume of San Diego Bay has been estimated as about 70 billion gallons and about 15 billion gallons are exchanged with the ocean during an average tidal cycle.

The Los Angeles County Sanitation Districts' discharge at Whites Point has undergone a number of changes since operations first commenced in the area. A 60-in. i.d. pipe 4500 ft. long was placed in service in 1937. In 1947 an additional outfall, 6400 ft. long and 72 inches in inside diameter was placed in service. These outfalls were modified by diffusers in 1954 and 1953 respectively. The 60-inch line was bulkheaded at the terminus and holes were drilled in the pipe for 378 ft. along its length. The 72-inch line was fitted with a Y-shaped diffuser with legs 216 ft. long. The average depth of discharge of the 60-inch outfall was 108 ft., that of the 72-inch outfall, 155 ft. In 1956, a 90-inch pipe was placed in service, discharging through a Y diffuser with 1200-ft. legs at an average depth of 203 ft. The length of the outfall, excluding the diffuser, was 7900 ft. With diffusers it has been computed, from ammonia concentration measurements, that the average maximum sewage concentrations at the ocean surface over the point of discharge represent dilutions of 170 to 1 with the 60-inch line, 300 to 1 with the 72-inch and 400 to 1 with the 90-inch lines. Suspended solids average somewhat less than 300 ppm.

In addition to the outfalls at Whites Point, there are a number of discharges into nearby Los Angeles Harbor. Industrial wastes are derived from fish canneries, the oil industries, vegetable oil plants, creosoting and pile treating, metal working shops, and shipbuilding and repair facilities. Domestic wastes are discharged by small private sewage disposals, from ships and boats, and from the Terminal Island Sewage Treatment Plant serving San Pedro and Wilmington. The latter facility has an outfall discharging some 7 mgd on the average into the outer harbor. The effluent contains about 150 ppm suspended solids.

Table 3

Effluent volumes in millions of gallons per day.

Year	San Diego	L.A. County	L.A. City	Santa Barbara
1958	44	220	267	5.0
1957	43	195	256	4.7
1956	40	183	249	4.5
1955	39	180	244	4.3
1954	39	176	239	4.1
1953	38	154	230	3.9
1952	37	147	219	3.1
1951	32	125	204	
1950	28	114	194	
1949	25	104	199	
1948	23	82	184	
1947	21	59	178	
1946	23	53	161	
1945	22	52	160	
1944	9.7	52	162	
1943	5.2	47	148	
1942		35	143	
1941		34	144	
1940		29	133	
1939		25	130	
1938		23	131	
1937		20	131	
1936		19	114	
1935		18	113	
1934		17	107	
	↓		↓	↓
	1887		1894	1926

It is estimated that Los Angeles Harbor contains about 80 billion gallons of seawater and the average tidal cycle causes an exchange of about 16 billion gallons with the ocean.

The City of Los Angeles discharges wastes at the Hyperion Treatment Plant near El Segundo. In 1894, a 600-ft. long, 24-inch diameter cast iron pipe was installed. In 1904, a 940-ft. long, 30-inch diameter pipe was added to the facility. In 1908, a 940-ft. long, 34-inch diameter wooden stave pipe was put in, which was followed by a 54-inch diameter wooden stave pipe in 1918, laid on a trestle 2000 ft. long. In 1925, a 5000-ft. long, 7-ft. diameter concrete pipe was installed, and this remained in service until 1949. At this time a 1-mile long, 12-ft. diameter concrete pipe discharging at a depth of 60 ft. was put into use. In 1957 a sludge outfall was placed in use, discharging at a depth of about 320 feet. In 1960, effluent was diverted to a new pipe 12 feet in diameter, five miles long, with two diffuser legs each 4,000 feet long, discharging at about 200 feet depth. Treatment of the effluent was instituted in 1925 when fine screening was utilized to remove gross solids. Primary treatment was commenced in September, 1950, followed by secondary treatment in May, 1951, and high rate activated sludge treatment in 1952. It was estimated in 1952 that about 14% of the total flow was contributed by industrial sources. About 27% of the suspended solids, however, are contributed by industry and the final effluent averages about 70 to 80 ppm of this constituent.

Figure 28. Chart showing the geographical relation of the Palos Verdes kelp beds to adjacent submarine outfalls.

The Santa Barbara outfall was placed in service in 1926 and the sewage was screened. No flow meters were available in the treatment plant until August, 1951, when a new plant commenced operation. The connected population in 1926, however, was approximately 20,000 and it is roughly 50,000 at the present time. The outfall is about 3,000 ft. long and discharges at a depth of some 40 ft. The effluent receives primary treatment and is chlorinated during swimming weather, approximately March 15 to October 15, plus any days that are unseasonably warm. The yearly average suspended solids content varies around 100 ppm.

Dredging as an Ecological Factor

Mission Bay. The historical charts show that kelp beds have receded and disappeared along eight miles of the Point Loma peninsula, from Mission Bay southward and from San Diego Bay northward. One common denominator at opposite ends of the region of kelp disappearance is dredging, which has been conducted on a similarly vast scale in San Diego Bay and in Mission Bay. Early surveys (1851-57) show that natural gaps existed in the kelp opposite the entrances to Mission Bay and San Diego Bay before these estuaries were modified by man. Their subsequent modification for use as harbors is a factor that must be considered in any interpretation of the recession of the intervening kelp. Dredging in Mission Bay is by far the largest artificial change that has been made near the northern end of kelp bed No. 3.

Since World War II, twenty-seven million cubic yards or 5.45 billion gallons of mud have been dredged from Mission Bay (Table 4). This amount of dredging is equivalent to the uniform removal of a 6.6 ft. depth of mud from an area of four square miles. One result of this operation has been the conversion of four square miles of unnavigable mud flats into an attractive marine park with a water depth of about seven feet at low tide. This development has occurred almost entirely since World War II. Dredging plumes have been observed on occasion extending at least one mile seaward from the bay entrance, and these dredging plumes have been photographed from the air. As Table 4 shows, dredging in Mission Bay has been most intensive from 1957 onward. The dredging method has been improved meanwhile by conducting it within diked-off areas. The closed-cycle method reduces silt contamination and it has eliminated the visible dredging plumes outside the bay entrance. At equal distances within Mission Bay and San Diego Bay, year-round measurements of water transparency have revealed lower water transparency in Mission Bay (San Diego Marine Consultants, 1959). Closed-cycle dredging was being conducted in Mission Bay during June-August 1961, while the water was being routinely sampled at four stations as a part of this study. Although the water always had a turbid appearance, the suspended matter consisted of plankton rather than of soil particles—if silt particles were contributing to the turbidity, they were of sub-microscopic dimensions.

Table 4

Mission Bay dredging, 1946-1961
(from data provided by Messrs. F. S. Blankenship and L. D. Phillips, Resident Engineers, Mission Bay Aquatic Park).

Year	*Cubic yards of soil removed*
1946	531,300
1947	2,536,900
1948	2,573,600
1951	466,000
1952	1,273,900
1957	3,500,000
1959	3,893,600
1960	8,957,400
1961	3,357,200
Total, 1946-61	27,089,900

The finest silt in Mission Bay is located furthest from the entrance, in the lagoon separating Cabrillo Island from Highway 101 on the mainland side. There is silt in this region which never settles. The transition from the liquid to the solid state there involves a very gradual increase in solids, water depth in this section being difficult to define. The bottom of Mission Bay elsewhere consists of soft mud, and retention of the 7 foot water depth necessitates maintenance dredging.

Early topographical changes in this area were the diversion of the San Diego River from San Diego Bay to Mission Bay, and subsequently to the flood control channel, which is an artificial structure. The topographical changes within Mission Bay that have been effected by dredging and filling up to the present time are shown in Figs. 29, 30, and 31. The size and location of the basin has remained approximately the same. It was originally separated from the ocean by a sand bar projecting southward for two miles, Point Medanos, and this natural feature has been retained. Crown Point is also natural, and a few acres of tidal mud flat have remained undisturbed in the Scripps Wildlife Preserve, just west of De Anza Point. This mud flat is stabilized by marshy vegetation. Mission Bay otherwise is completely artificial (Fig. 31).

San Diego Bay. The area of San Diego Bay is 4.6 times greater than that of Mission Bay, and although the total dredging activity in San Diego Bay has been at least as large, the resulting topographical changes have been less conspicuous because of its greater area and depth. Dredging in San Diego Bay has been in progress for decades. San Diego Harbor was mainly developed before World War II, and subsequently, dredging there has been less extensive than in Mission Bay. The U. S. Navy, U. S. Corps of Engineers, San Diego Harbor Department, and the municipalities of Chula Vista, National City, and Coronado have all conducted dredging operations in San Diego Bay since *World War II*. It would be necessary to obtain data from all these sources in order to define the actual magnitude of this activity. For the purposes of this study, an approximation seemed adequate. Mr. John Lieberman, Chief Engineer, San Diego Harbor Department, has provided a rough estimate of 10-15 million cubic yards since World War II. One noteworthy development during 1960-62 has been the construction by dredging and filling of a new artificial island 8000 feet long, near Broadway Pier. It is not possible to define the relative importance of sewage disposal, dredging, and heavy ship traffic in San Diego Bay on kelp deterioration in bed No. 2 alongside the harbor entrance. Dredging has at least been a common denominator at opposite ends of the region of kelp disappearance. There is a suggestive similarity between the excessive rainfall and runoff during 1941 and the physical alteration of the neighboring estuaries by dredging.

Oceanographic and Meteorological Data

A wealth of data exists concerning the oceanography of southern California waters. It is, however, entirely beyond the scope of this report to attempt to present anything but an abstract of a small fraction of the available information. We are, therefore, selecting for presentation those factors which may be of greater importance in their influence on the well-being of kelp beds. These factors include temperature, rainfall, winds, and wave heights.

Temperatures much above 18°C may affect kelp adversely, the effect increasing with the length of time

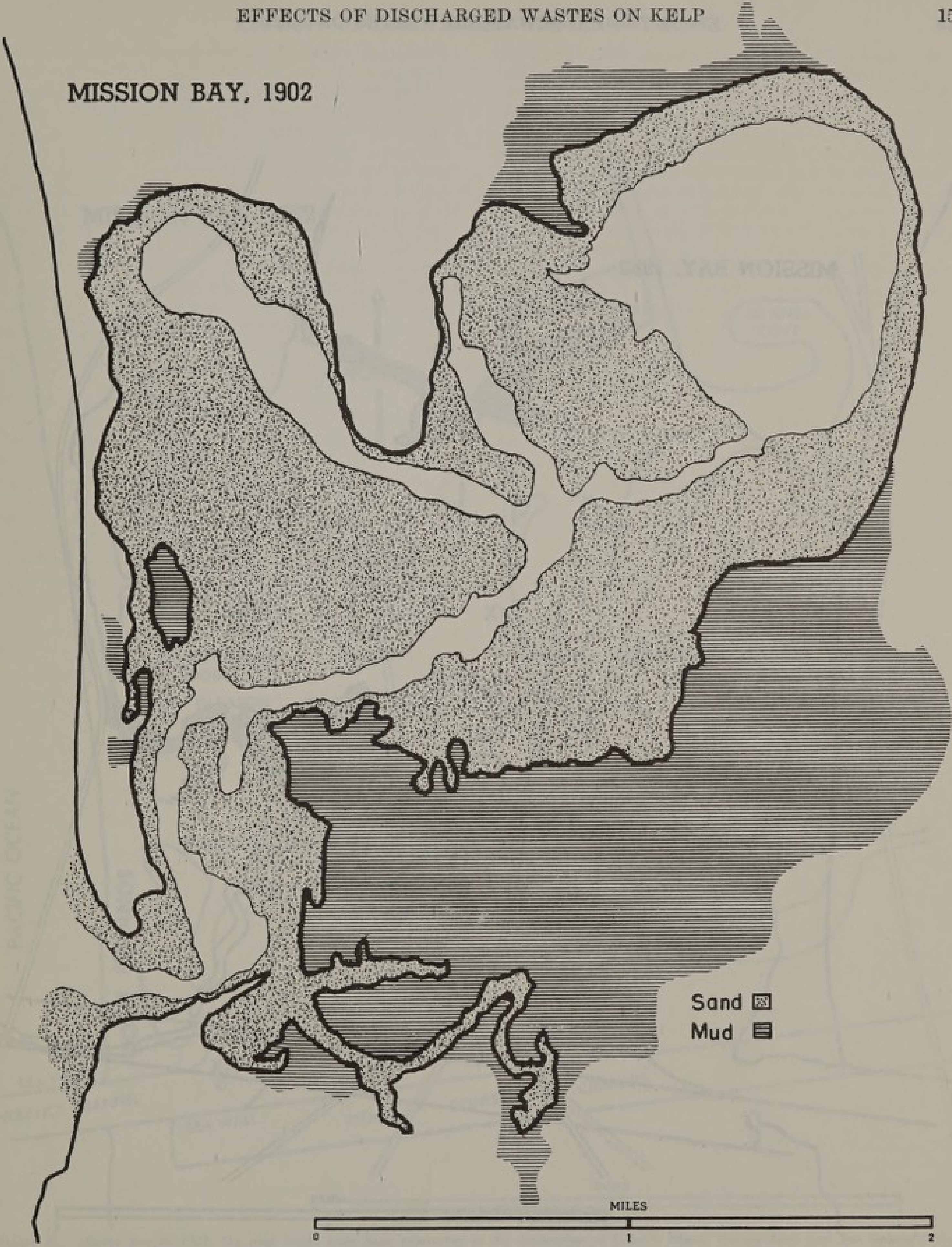


Figure 29. Mission Bay in its original state, according to the U. S. Coast and Geodetic Survey, 1902. The open area retained water to a depth of one foot or more at mean lower low water. Tidal flats are stippled and mud banks are heavily shaded.

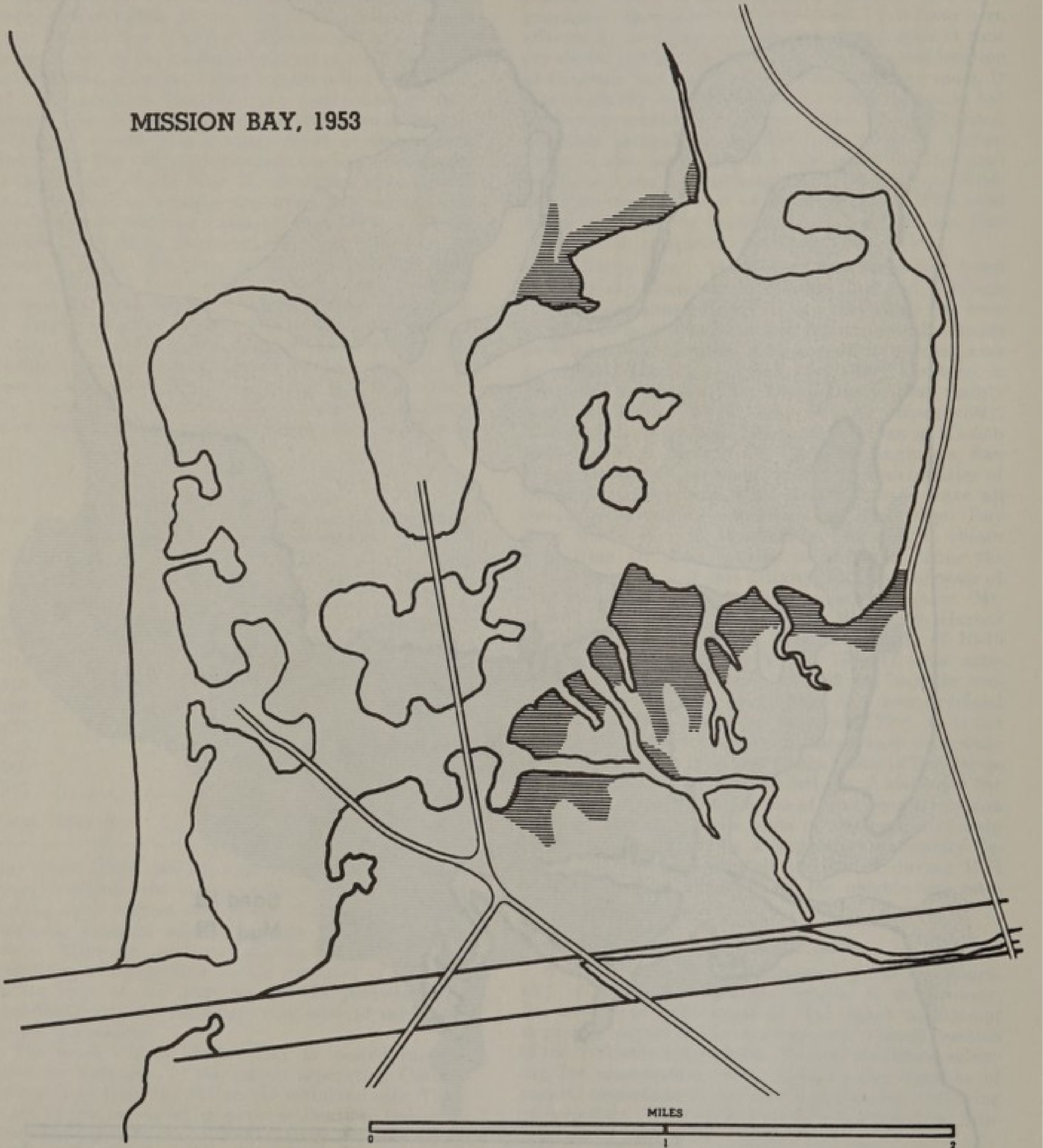


Figure 30. Mission Bay in 1953. Note absence of tidal flats, construction of Tierra del Fuego, De Anza Point, three small islands, four artificial peninsulas off Point Medanos, entrance channel, flood control channel and bridges.

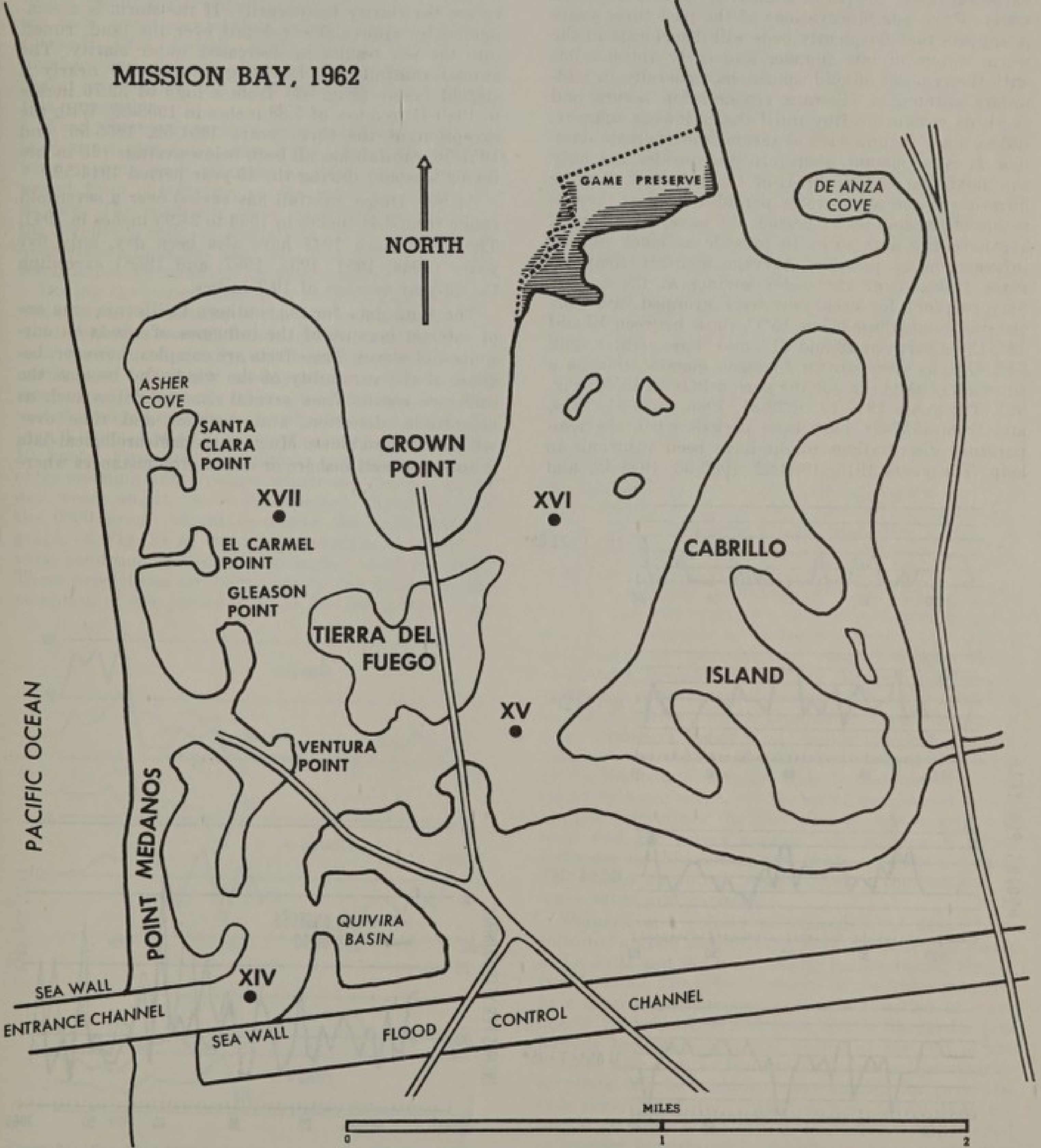


Figure 31. Mission Bay in 1962. The mud banks have been eliminated in the construction of Cabrillo Island, Quivira Basin and San Gabriel Cove have been constructed near the bay entrance, and the water depth is now maintained at seven feet or more. The stations routinely sampled through June-August, 1961 are shown as No. XIV-XVII.

the high temperature is maintained. The higher the temperature the shorter the time required for deterioration.

There also appears to be considerable geographic variation in the degree of sensitivity of kelp to warm water. From our observations of the past three years it appears that frequently beds will deteriorate in the warm waters of late summer and early autumn but with the renewal of cold conditions, generally in mid-to-late autumn, a vigorous regeneration occurs and the beds remain healthy until the following summer, unless other factors such as severe storms create damage. It is important, therefore, to consider not only the maximum temperatures of the year but also the duration of the warm-water period as well as the duration of the cold-water period. We have, accordingly, arranged the data so as to provide as much of this information as possible. Average monthly temperatures (taken near the water surface at the end of Scripps pier) for each year were grouped into four classifications, those below 15°C, those between 15 and 18°, those between 18 and 21°, and those greater than 21°. Graphs were drawn for each classification as a function of the year, for the period 1916 to 1959 (Fig. 32). The years 1917-19, 1929-31, 1936, 1939-41, 1954, and from 1957-59, have been periods when the temperature distributions might have been injurious to kelp. The years 1916, 1920-22, 1932-33, 1948-49, and 1953 were periods when temperatures were cold and prolonged.

Water clarity may be an important factor affecting the nearshore environment. Storms tend to stir up loosely compacted material from the bottom and decrease the clarity temporarily. If the storm is accompanied by appreciable rainfall over the land, runoff into the sea results in decreased water clarity. The annual rainfalls for Los Angeles vary by nearly a sixfold factor (Fig. 33) from a high of 32.76 inches in 1940-41 to a low of 5.58 inches in 1958-59. With the exception of the three years 1951-52, 1955-56, and 1957-58, rainfall has all been below average (15 inches for 82 seasons) during the 15-year period 1944-59.

At San Diego, rainfall has varied over a sevenfold range from 3.41 inches in 1953 to 24.93 inches in 1941. The years since 1943 have also been dry, only five years (1944, 1951, 1952, 1957, and 1958) exceeding the 53-year average of 10.7 inches.

The wind data for the southern California area are of interest because of the influence of winds on currents and waves. The effects are complex, however, because of the variability of the winds and because the influence results from several characteristics such as magnitude, direction, and distance and time over which the wind blows. Much of the meteorological data is collected well inshore or under circumstances where

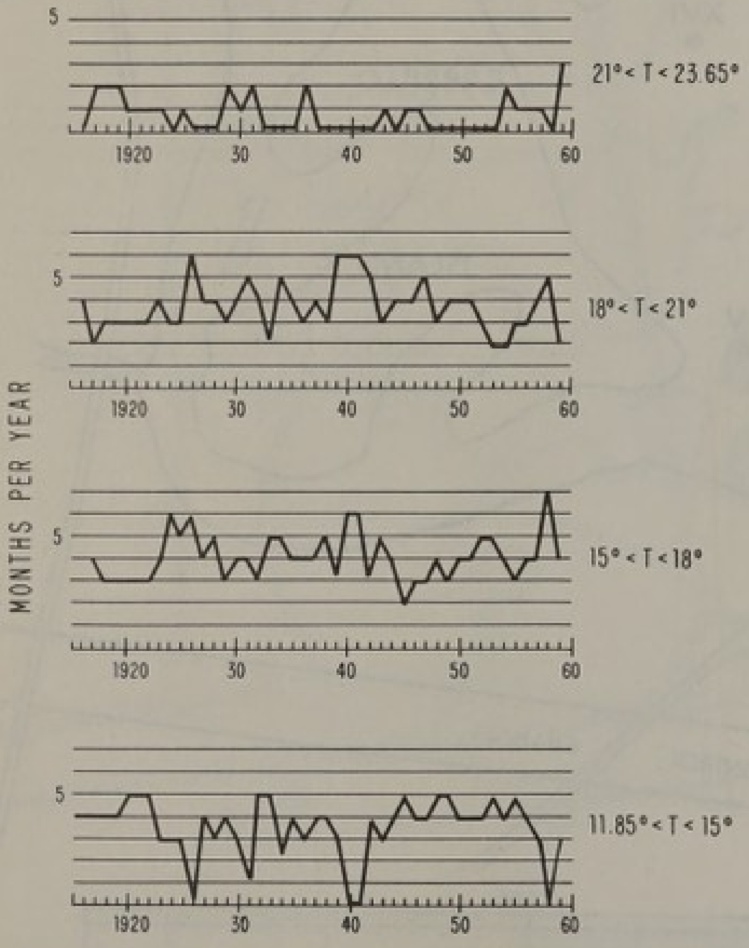


Figure 32. Graphs of average monthly sea surface temperatures at the end of Scripps pier, showing the yearly frequencies of selected ranges. Data furnished by the Scripps Institution Bathythermograph section.

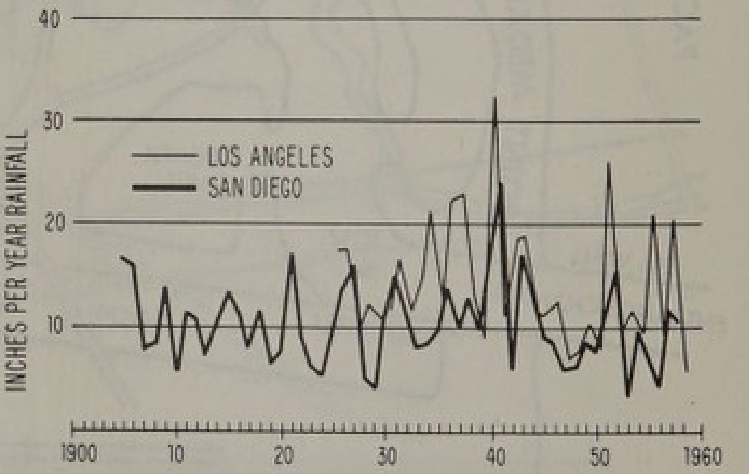


Figure 33. Yearly precipitation recorded by the U. S. Weather Bureau at the San Diego and Los Angeles stations.

land topography may modify some of the characteristics of the wind. It is likewise difficult to extract parameters from the mass of wind data which will typify with reasonable certainty natural factors which are known to influence the welfare of kelp beds. Storm conditions frequently remove much kelp from the beds, sometimes causing entire beds to disappear (Brandt, 1923; ZoBell, 1959). An indication of the numbers and violence of storms each year would be useful information and wind velocities are of value in this connection.

Wind observations have been made from the end of Scripps pier daily since 1925. Up until 1956 the wind velocity each morning at about 0800 was estimated from observation of the condition of the sea surface. The notations were converted by means of the Beaufort scale to numerical values. Since 1956, quantitative data has been obtained for the daily determination, by means of an anemometer.

During the period 1925-40 a recording anemometer was operated at the end of the pier and average daily wind velocities were determined. We have used these as a check on the daily 0800 measurement and the results are sufficiently satisfactory to allow several conclusions to be made (Fig. 34). The data are presented grouped into three classifications: velocities less than 4 knots, 4 to 10 knots, and velocities greater than 10 knots. Frequently conditions are calmest in the early morning and stronger winds may prevail as the day wears on. It would be expected, therefore, that the 0800 graph would lie above the daily average graph of Fig. 34 at the lower velocities, but the reverse condition should exist at higher wind velocities. These predictions are borne out by the data with the exception of the period 1925-31 for the greater than 10 knot velocity classification. This rather large variation resulted from an unusually high number of observations of winds greater than 16 knots recorded at 0800. Since these represent velocities which are well above 10 knots and therefore would be difficult to mistake, even by qualitative observations, it is likely that the period may have been anomalous in displaying forceful winds early in the morning.

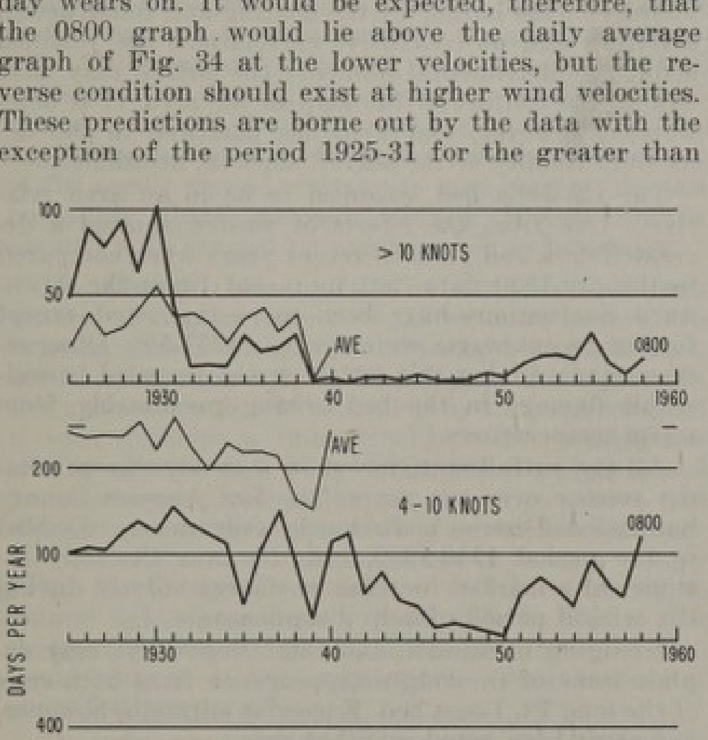


Figure 34. Graphs of 0800 and daily average wind velocities, showing the yearly frequency of selected ranges. Data from Jacobs and the Scripps Institution Bathythermograph section.

An additional test of the 0800 data may be attempted by noting whether fluctuations evidenced in the quantitative average measurements tend to correlate with the qualitative observations as well. Perfect correspondence could hardly be expected, but a fair degree of similarity is apparent except for the unusual period noted above in the greater than 10 knot graphs. The year 1935 is one of poor correspondence for both the less than 4 knot and the 4-10 knot graph, but otherwise the curves are in reasonable conformance. It seems safe to assume that the daily 0800 wind observations are reliable for limited conclusions.

The period from 1925 to 1940 appeared to be one characterized by a relatively large number of days of higher velocity winds. Starting at about 1940 the frequency of higher velocity winds declined or was extremely low until 1950-51. From this time till 1958 the higher velocities exhibited an upward trend or an irregularly increasing fluctuation which attained approximately the pre-1940 levels (excepting the unusually high values for the 1925-31 period). It would appear from the wind data, therefore, that the decade of the 1940's was increasingly favorable to kelp, up through 1950, at which time conditions were at their optimum.

Wave data are available for recent years, but like winds, waves have many characteristics and no information is available as to those aspects which are of importance in uprooting the plant holdfasts. Storm conditions, however, are known frequently to accompany the appearance of considerable drift seaweeds of many species. Storm-generated waves can travel great distances, hence it is possible that a storm may influence the welfare of a kelp bed without ever being in the immediate vicinity. Kelp is undoubtedly influenced by wave surge, yet the set of the current nearly always determines the direction in which kelp will tend and the waves appear only to have a minor influence in this connection. Quite possibly the damage caused by storms results from a combination of wave surge and currents.

Shepard and colleagues (unpublished data) have collected a great deal of information concerning waves at La Jolla and the surrounding region during the period 1945-55. The orbital velocity of the water particles in a deep water surface wave is a function of wave height, period, depth, and wave length. Shepard's data include breaker height and period at the end of the Scripps pier and the two characters do not necessarily correlate. We have chosen wave heights for presentation here, but future research may reveal that the period or some other characteristic may be of equal or greater importance in determining the destructive capacity of a wave. With the exception of 1947, the period 1945 through 1950 was relatively calm, but after that date there appears to be a tendency for the frequency of larger waves to increase (Fig. 35). The largest waves recorded averaged 15 feet in height and were observed on 5 December 1951.

Wave height and other characteristics will vary from one spot to another depending on the local bottom topography and the nature of the protection afforded by adjacent land masses. Consequently, the Scripps pier wave data cannot necessarily be said to be representative of other locations, but the year-to-year comparison of wave height frequencies probably has a more general application. This statement receives support from other unpublished measurements by Shepard and colleagues of wave heights observed intermittently during 1945 and 1946 at selected points from Pacific Beach to Oceanside, a distance of some 20 miles. Perfect correspondence of fluctuations was not obtained, but most of the major variations of wave heights were observed at the different stations. It is also of interest to note that the wave data bear some resemblance to the wind data from Scripps pier. Both indicate that the later 1940's were of more calm character than the early 1950's.

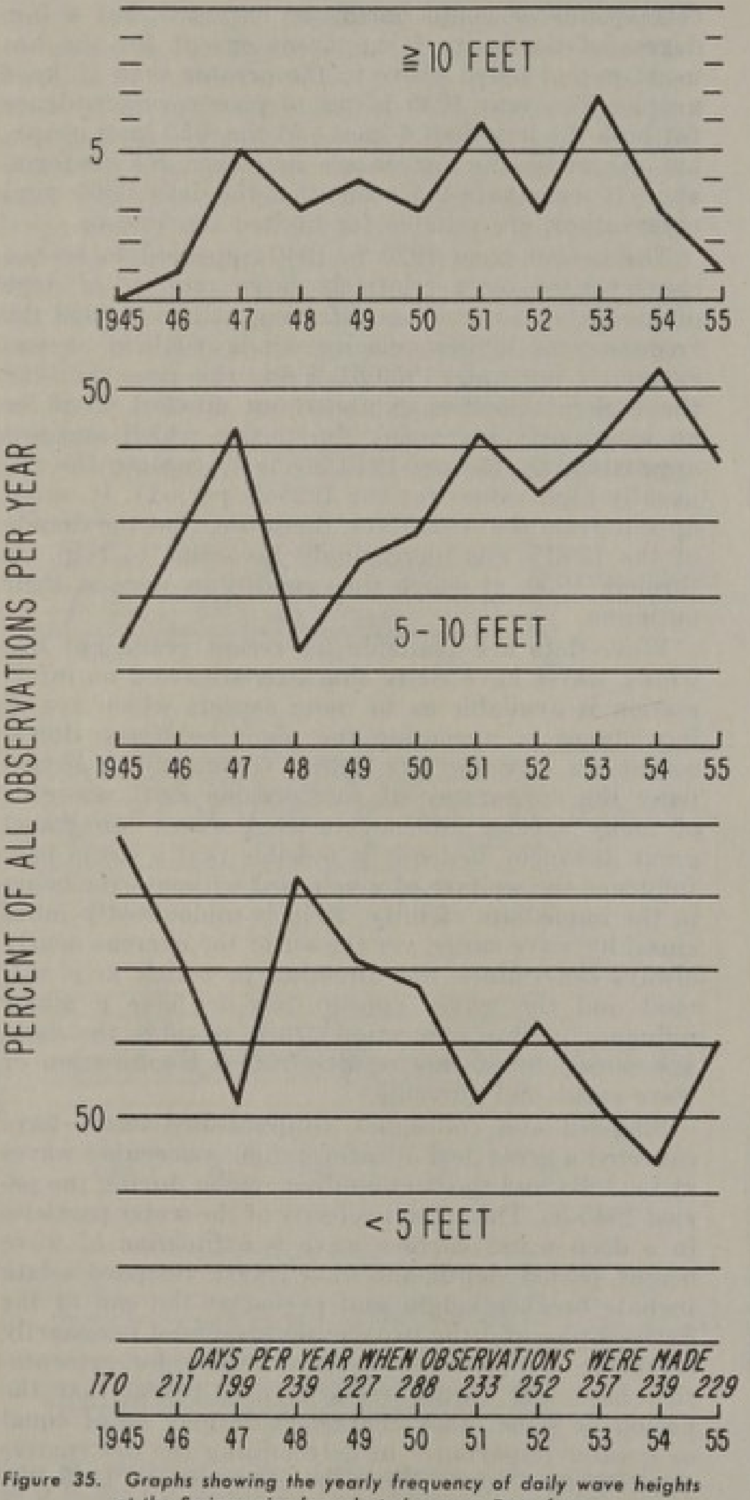


Figure 35. Graphs showing the yearly frequency of daily wave heights at the Scripps pier for selected ranges. Data from F. P. Shepard and associates.

Discussion

Both the charts and the harvesting returns show a drastic decline in the area and yield of the Pt. Loma and Palos Verdes beds before or around 1950; beds 2, 12, and 13, (nearest an outfall) tended to be affected seriously before beds 3 and 14 (lying farther from an outfall) deteriorated badly. Bed 3, the northern section of the Pt. Loma bed, maintained a decreasing yield through 1958. The charts of the Santa Barbara region show a decrease of kelp area within the last two decades in the vicinity of the outfall terminus, but the change is small compared with the large size of the whole bed of which this location forms a part. Consequently, the kelp losses are not reflected in the harvest statistics. There has undoubtedly been an influence on the kelp in the immediate vicinity of the harbor by the boating and construction activities and no conclusive correlations are justified about any detrimental influence the outfall may have had on the welfare of the kelp in the area. It is noteworthy, however, that kelp has persisted in the immediate vicinity of the outfall since its installation.

The La Jolla bed, assumed to be in an area relatively free from the effects of wastes, showed a decreased area and yield in recent years when compared to the pre-1920 data, but in recent times the downward fluctuations have been more restricted except for the recent warm water years (1957-59). Observations made during this latter period revealed considerable damage in the bed arising presumably from warm temperatures.

All the outfall statistics show a steady rise in effluent volume over the years. The Los Angeles County Sanitation District's discharge very nearly doubled in the period 1946-1949, but this was the only instance of a marked increase in effluent volume during the critical period of kelp disappearance.

Dredging in Mission and San Diego Bays may explain some of the kelp disappearance from both ends of the long Pt. Loma bed. Excessive siltation, however, has never been noted in either area.

The oceanographic and meteorological data offer little positive explanation of the long trend of kelp decline with the exception, noted above, of the unfavorable temperature conditions from 1957 to 1959. 1951-52 are possibly unfavorable years from the aspect of rainfall and runoff, and the decade of the 1950's has been poorer than the 1940's from the aspects of wind and limited wave data, as far as the welfare of kelp is concerned.

ECOLOGY OF THE KELP ENVIRONMENT

General Ecology of the Rocky Nearshore Environment in Southern California

Introduction. In terms of biomass of living matter, rocky surfaces are usually the richest substrates of nearshore environments. Barren rock surfaces are uncommon in shallow subtidal waters, and the presence of uncolonized stones or ledges usually indicates intensive grazing, frequent smothering or scouring action by sand, or unstable location of the rocks. Sessile animals compete with plants for attachment areas and the layer of living organisms on rocky bottoms may be six inches or more in thickness, with many species encrusted or otherwise superimposed upon each other. Under certain circumstances the attached communities are primarily plants, while in other circumstances sessile animals predominate. The availability of light is often of overriding importance in this connection and the highest standing crops of plants generally occur in shallow waters. Some well-illuminated habitats are, however, characteristically colonized by sessile animals to the virtual exclusion of plants, (intertidal mussel beds, for example) so that light does not necessarily preclude faunal colonization. Without light, however, attached plants soon disappear, and in caves or beneath overhanging surfaces animals are usually dominant.

Competition for light occurs among seaweeds, just as among terrestrial plants, and the species of greater stature are in a position to shade the shorter individuals. Taller plants, therefore, tend to achieve dominance and the familiar processes of ecological succession occur. As the bottom becomes densely shaded, the smaller plants tend to disappear and the composition of the sessile animal community may change; the last remaining short seaweeds usually become heavily covered with encrusting animals such as bryozoans.

The Climax Community. In southern California waters, at depths from 8 to 25 or more meters, the common climax community of rocky bottoms is dominated by the giant kelp, *Macrocystis*. As a juvenile, this species is subject to shading by its neighbors, but it soon develops a thin, vinelike stipe, bearing the leaflike blades and buoyed by gas bladders called pneumatocysts; elongation of the stipe allows the tissues to be carried upwards and on reaching the surface a horizontal extension occurs to form a canopy (Fig. 1). Canopies can achieve sufficient density to reduce light intensities a hundredfold. Figure 36b shows reduction of light by a canopy where the kelp tissue was at a relatively sparse concentration of about 2 stipes per m^2.

The influence exerted by *Macrocystis* on the biology of its surroundings may be seen in a quantitative study which was made on a small patch of kelp at Bird Rock, La Jolla, California, where a region under the dense *Macrocystis* canopy was compared to an adjacent area just outside of the shading influence. The canopy, about 100 x 300 meters in extent, had been under continuous observation since the time of its development, about a year prior to the study. Beneath the canopy vegetation was sparse (Fig. 36a) and many of the existing plants bore evidences of extensive grazing damage and were frequently heavily encrusted with animals. Immediately outside the sharply delimited canopy a luxurious crop of red and brown algae flourished (Fig. 37) and it was possible to select and sample two sites within 30 meters of each other. The more obvious grazers observed were common to both sites and included the abalone, *Haliotis fulgens*, the sea urchins, *Strongylocentrotus purpuratus* and *S. franciscanus*, the wavy top, *Astraea undosa*, the turban, *Norrisia norrisii*, and the opaleye, *Girella nigricans*. No quantitative attempt was made to determine if the concentrations of the various grazers was different within the two areas, but no obvious differences in concentration were observed. These herbivores possess sufficient mobility so that if one area were significantly more attractive, migration from one site to the other would have been entirely possible during the course of a year. Qualitative observations indicated that marked changes in vegetation and sessile animals coincided closely with the edge of the canopy throughout the bed and there is no strong reason to believe that causes other than the shading effect of *Macrocystis* and uniform grazing were responsible for the quantitative differences which were found in the algal standing crop.

The areas chosen for quantitative sampling were 20 x 20 m on a side and ten sample quadrats of one m^2, positioned randomly within each of the larger areas, were collected by the method described by North (1959) and described below (page 41). It should be emphasized that the location of each sample was determined by use of a table of random numbers and the results are therefore free from any bias or tendency for the divers to select a given type of environment when laying down the quadrat. Both of the sites displayed a similar bottom topography and were at approximately the same depth of 10 m.

The standing crop of seaweeds (excluding adult *Macrocystis*, and the closely encrusting *Lithothamnion*), was approximately seven times as great in the open area as under the kelp canopy (Table 5). All major components of the open water flora were reduced or absent in the shaded environment. If *Macrocystis* is included, however, the standing crop of plant material was three to four times as great in the bed as outside. In the open area the only seaweed of appreciable length was the feather-boa kelp, *Egregia*, the rest attaining heights of less than a meter. *Egregia* was not common in the area, however, hence the over-all effect of *Macrocystis* was to increase the standing crop of seaweed material and alter its distribution throughout the water column, causing a reduction near the bottom but increasing the quantities existing at higher levels, similar to terrestrial forests.

Different categories of seaweeds were not influenced in the same way by the *Macrocystis* canopy. The last column of Table 5 shows the ratio of the standing crops in the open area to those of the shaded area and was taken as an indication of the influence shading had had on the various categories. A series may be constructed going from little effect to severe effect, as follows:

Figure 36a. Photograph of sampling site under a Macrocystis canopy at Bird Rock. A healthy Macrocystis is at left center and a heavily grazed plant is at right center. Bare stipes of Pterygophora californica, about ½ m long, can be seen surrounding the healthy Macrocystis. The major portion of the bottom is covered with the encrusting bryozoan, Zoobotryon pellucida, usually attached to coralline algae.

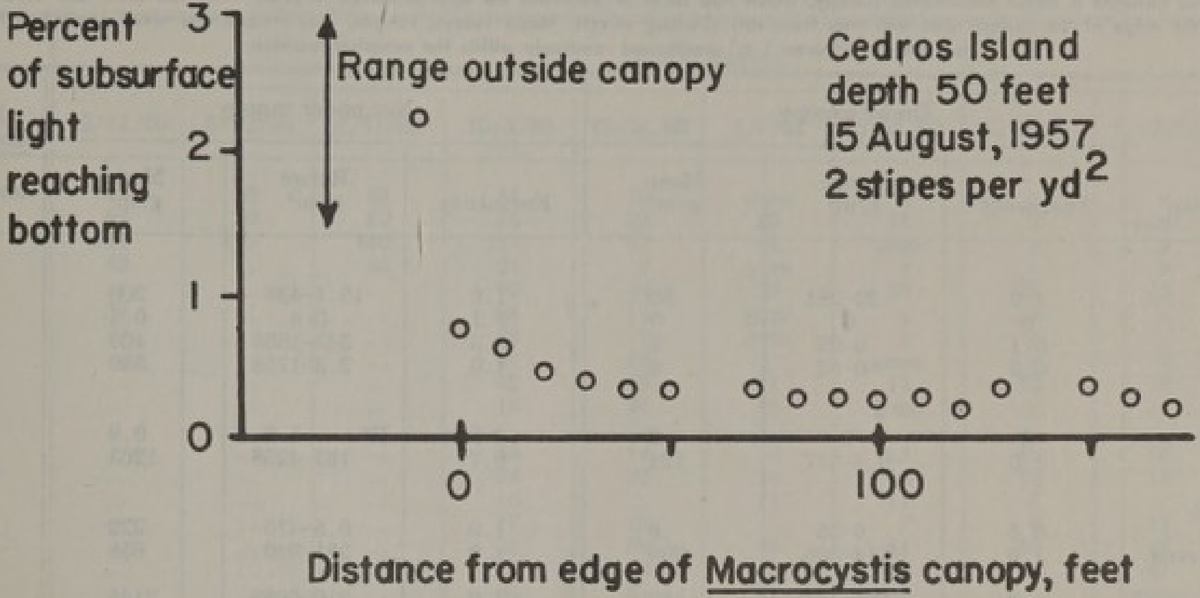


Figure 36b. *Light intensities under and outside of a very dense Macrocystis canopy on the west side of Cedros Island, Mexico, as a function of distance from the edge of the canopy. Light data by Michael Neushul.*

Figure 37. *Photograph of sampling site just outside of a Macrocystis canopy at Bird Rock and separated from the location of figure 36 by about 30 m. At the right side there is almost complete coverage by brown seaweeds, thinning out as one moves to the left, revealing a rich understory of red algae. The principal brown algae shown are Pterygophora californica, Cystoseira osmundaceae, and Laminaria farlowii. The principal red algae are Corallina officinalis and Bossiella orbigniana.*

Table 5

Comparison of the standing crops of the chief attached plants and sessile animals from two locations separated by about 30 m from each other. One site was well beneath a dense *Macrocystis* canopy, which had been in existence for approximately a year, while the other site extended out from the edge of the canopy and was free from any shading effects. Mean values, ranges, and frequencies were computed from ten samples of area 1 m^2, positioned randomly within the sampled location.

Classification	Under canopy			Not under canopy			Mean not under canopy / Mean under canopy
	Frequency	Range g/m^2	Mean g/m^2	Frequency	Range g/m^2	Mean g/m^2	
Phaeophyceae							
Cystoseira	1.0	22–281	90	1.0	18.1–436	200	2
Egregia	0	0	0	0.1	0–4	0.4	----
Eisenia	0.1	0–22	2	0.3	343–1865	405	200
Laminaria	0.2	0–52	6	1.0	2.3–1758	539	90
Juvenile							
Macrocystis	0	0	0	0.8	P* –5.8	0.9	----
Pterygophora	1.0	0.4–517	124	0.7	163–4258	1263	10
Rhodophyceae							
Fleshy reds	0.6	0–25	6	1.0	0.5–476	222	37
Calcareous reds	1.0	114–366	209	1.0	281–940	658	3
All algae**	1.0	285–1058	469	1.0	810–6688	3145	7
Sessile animals	1.0	193–923	508	1.0	129–999	506	1

* P—present but less than 0.1 g.
** Does not include adult *Macrocystis* or *Lithothamnion.*

Cystoseira—*Pterygophora*—Fleshy Reds—
Laminaria—*Eisenia*—Calcareous Reds

With the exception of *Eisenia* (which was sufficiently infrequent so that its position in this series may be inaccurate), the series corresponds satisfactorily with the results of Leighton's laboratory studies of algal preferences shown by 11 common grazers; *Cystoseira* and the calcareous reds such as *Corallina* and *Bossiella* were low on the scale of algal preference while *Laminaria* and *Gigartina* (a typical fleshy red) were high, and they indicate a general decrease in algal growth rate due to shading, combined with a preference by marine herbivores for certain species. All of the major components of the flora collected at the two sites are common seaward from the location, out to depths of 30 m or more, hence it is believed that shading was probably not the sole factor responsible for altering the bottom vegetation. (Photometer readings at the two sites indicated that the canopy reduced bottom light intensities from two- to three-fold in the region 450-500 $m\mu$, compared with the open location.)

Differences were also found in the character of the sessile and encrusting animals at the two sites. No outstanding variation was found when comparing total weights of these animals in the two sets of samples, but marked differences appeared when considering individual species. The chief encrusting animal beneath the canopy was the bryozoan, *Zoobotryon pellucida*, averaging 44% by weight of all animals in this category (frequency = 1.0); this species, however, only averaged 2% by weight of the encrustations occurring in the samples taken outside the canopy (frequency = 1.0). A tunicate, *Cystodytes* sp., was second in importance beneath the canopy (19% by weight with a frequency of 0.8) but accounted for 1% of the weight of encrustations recovered from outside the canopy (frequency = 0.3). No such clearly dominating species were found in the samples from the open location. The causes of these effects on the encrusting forms are not understood. Qualitative observations indicated that *Zoobotryon* and *Cystodytes* were indeed very abundantly distributed everywhere beneath the canopy, but were much less common in the open, hence the results are not thought to have arisen from sampling error.

Five of the open water samples were from positions displaying a heavy cover of the shorter brown algae. There was no clear-cut indication of a reduction of the short red algae in these five samples, suggesting that any shading by the shorter brown algae does not have the considerable influence demonstrated by the *Macrocystis* canopy with its continuous cover at the water surface. Kitching (1941), however, working with *Laminaria* associations, reported a light limiting effect of this bottom community.

Deterioration of the Climax Community. A number of natural factors are known to affect *Macrocystis* adversely. Elevated temperatures, storms, and grazing animals have all been observed to cause extensive and sometimes fatal damage to individual plants and indeed to entire beds. Light screen capable of altering bottom vegetation can, however, be maintained by the canopy from only a sparse scattering of large plants; (2 stipes per sq. m being the minimum density thus far encountered for thick cover). Eventually, however, plants inevitably die so that, where openings in the canopy develop and sufficient light penetrates to the bottom to affect the growth of other seaweeds as well as juveniles of *Macrocystis*, the cycle of succession starts once more. During a 2 year surveillance period of a La Jolla deep water bed the latter portion of such a cycle was observed to occur. Out of 45 plants tagged

Table 6

Mortality and variations in size among 45 tagged adult *Macrocystis* plants at La Jolla, California, observed for approximately two years. Depth of site was 20 m. Values are the numbers of stipes per plant.

	Date of Survey									
Plant No.	12/11/59	5/26/60	8/31/60	10/3/60	12/26/60	4/7/61	5/31/61	7/21/61	9/13/61	11/11/61
1	68	59	43	31	15	gone	x	x	x	x
2	64	59	52	54	23	29	15	7	gone	x
3	121	143	140	113	87	61	gone	x	x	x
4	42	--	35	21	2	gone	x	x	x	x
5	--	--	--	62	34	25	29	37	65	44
6	34	--	--	24	13	gone	x	x	x	x
7	70	--	--	26	9	gone	x	x	x	x
8	--	--	--	48	14	--	gone	x	x	x
9	--	--	--	49	19	11	13	12	8	11
10	--	--	--	16	24	18	gone	x	x	x
11	--	--	--	16	14	9	13	15	16	12
12	--	--	--	24	22	14	14	16	11	11
13	--	--	--	16	--	11	11	7	--	gone
14	--	--	--	17	13	--	7	8	13	8
15	--	--	--	46	39	49	41	39	28	15
16	--	--	--	71	60	43	40	53	47	37
17	--	--	--	66	37	32	5	--	gone	x
18	--	--	--	72	--	11	10	18	gone	x
19	--	--	--	36	23	8	5	7	8	6
20	--	--	--	15	10	3	gone	x	x	x
21	--	--	--	4	1	gone	x	x	x	x
22	--	--	--	13	13	gone	x	x	x	x
23	--	--	--	23	34	5	gone	x	x	x
24	--	--	--	86	32	gone	x	x	x	x
25	--	--	--	19	gone	x	x	x	x	x
26	--	--	--	27	4	3	gone	x	x	x
27	--	--	--	84	56	25	29	gone	x	x
28	--	--	--	45	24	13	gone	x	x	x
29	--	--	80	70	50	27	29	gone	x	x
30	--	--	--	39	27	5	16	18	16	20
31	--	--	--	13	4	9	gone	x	x	x
32	--	--	--	14	2	--	gone	x	x	x
33	--	--	55	36	18	--	14	20	19	18
34	--	--	41	26	17	12	--	--	16	6
35	--	--	15	9	5	--	--	--	gone	x
36	--	--	8	8	9	tag lost	--	--	--	--
37	--	--	--	26	17	17	14	--	13	8
38	--	--	--	18	8	13	tag lost	--	--	--
39	--	--	--	--	10	tag lost	--	--	--	--
40	--	--	--	--	12	tag lost	--	--	--	--
41	66	34	--	27	33	20	3	--	5	3
42	34	--	--	33	28	27	28	--	26	10
43	40	--	--	20	14	20	20	--	24	13
44	85	86	--	69	52	42	32	--	gone	x
45	26	28	--	28	18	16	17	--	gone	x
No. of Plants Remaining	45	45	45	45	44	37–33	28–24	26–22	20–16	19–15
Avg. stipes per plant	59	47	38	36	23	20	19	20	20	16

during this time only 15 remain (Table 6); the others have succumbed to grazers (principally *Astrala undosa* and *Strongylocentrotus franciscanus*) or were torn loose by storms. Since the summer of 1961, juvenile *Macrocystis* plants have been observed developing in profusion in this bed, principally in the areas where the greatest mortality of adults occurred.

Such a transition from a typical climax community to a bottom supporting luxurious growths of short seaweeds does not always occur directly. It is not uncommon to find beds disappearing apparently due to the activities of much larger and more extensive concentrations of grazers than noted in the La Jolla study above. The sea urchins, *Strongylocentrotus franciscanus* and *S. purpuratus* sometimes become tremendously abundant, and after the kelp has gone, these grazers apparently prevent other plant species from developing and the substrate remains quite barren. If sufficient detritus is brought in by currents so that the herbivore population is saved from complete starvation, an algal-free substrate may persist for many years. Such a population has been under continuous

Table 7

Plant mortalities observed at different locations and times. Half lives were computed by assuming a uniform logarithmic mortality rate and are given only to facilitate comparison of the different sites.

Location of bed	Depth m	Period of observations	Duration of observations, months	No. of tagged plants		Half life months
				Start	Finish	
Turtle Bay, Mexico	15	Mar.–Oct., 1961	6½	11	6	7
Punta Cabras, Mexico	3	Nov.–Dec., 1961	1½	100	77	4
Pt. Loma	15	Dec.–Jan., 1959-60	1	53	46	8
La Jolla	9	Jan.–May, 1961	4½	12	9	10
La Jolla	9	Sept.–Dec., 1961	3	100	77	8
La Jolla	20	Dec., 1959–Nov., 1961	23	41	15	16
Santa Barbara–Gaviota area	10	Sept., 1960–Jan., 1961	3½	29	28	80
Santa Barbara	10	Sept.–Dec., 1961	2½	100	98	100

observation for six years at Papalote Bay, Baja California.

The time required for completion of the cycle of succession varies from one bed to another and appears to depend on environmental circumstances. A short cycle of about 2 years has been found in a bed at Papalote Bay, Mexico; the kelp in this area has been observed to vanish and reappear three times since 1957. The area is exposed to strong southern swell and in addition the plants appear to be especially sensitive to warm water. Characteristically, clear water, as well as extensive upwelling, may favor rapid recolonization of the area by juveniles, once the adults have disappeared.

At the other extreme, kelp beds in the vicinity of Santa Barbara, California, appear to have a long period cycle. The area is well protected from weather and the heaviest seas we have ever observed there consisted of waves 2 to 3 feet in height and a period estimated at less than 5 seconds. The plants develop large holdfasts, up to several meters in diameter, and these serve to anchor the bed securely in a muddy bottom. Juvenile plants usually start by attaching to worm tubes or shell fragments. The usual benthic kelp grazers, sea urchins, wavy top snails, and other gastropods, which are typically found in rocky habitats, are missing or rare in the Santa Barbara bed. Freedom from losses to grazers and to storms, therefore, may explain the low plant mortality rates observed in this region (Table 7). The bed, for this reason, evidently has a long period cycle of disappearance and reappearance. It has dwindled in area but in recent times has apparently become stabilized at a reduced size (Table 1) and the only recorded instance of a total disappearance was an extensive loss in 1917 due to high water temperatures, described by Brandt (1923).

The Macrocystis Plant

Life Cycle. The giant kelp, *Macrocystis pyrifera*, ordinarily grows in 20 to 80 feet of water along the southern California coast, but the vertical range is greater in certain places. The adult plant consists of several distinct portions (Fig. 1). It clings to the substrate by means of a tangle of rootlike structures known as a holdfast. Rising from the holdfast are a number of stalks called stipes, which bear the leaves or blades of the plant. The blades are attached to the stipe by means of gas-filled bladders called pneumatocysts. Kelp tissue is denser than seawater and the pneumatocysts are needed to give the fronds buoyancy (a frond is an entire stipe plus its attached pneumatocysts and blades). The number of blades attached to a given stipe may be as many as 250 in a mature frond. The tip of the stipe bears the apical blade which is the chief growing area of the frond. If the distal part of the frond bearing the apical blade be cut off or otherwise destroyed, it is thought that no more blades can be produced on the fronds. In such circumstances it is known that elongation of the stipe can continue. The reproductive structures of the adult plant (called the sporophyte) are blades known as sporophylls and they usually occur just above the holdfast. The sporophylls liberate tremendous numbers of microscopic spores, apparently throughout the year, some of which eventually settle down and develop into microscopic plants called gametophytes (Fig. 38). The gametophytes consist of only a few cells and are sexually dioecious, that is, either a male or a female. The female gametophyte produces an egg which is fertilized by a sperm from the male and the fertilized egg develops into the sporophyte, which at maturity, is the large form that we think of as "kelp." Almost no information exists as to the conditions necessary for the success of this complicated reproductive cycle in nature. About half a year elapses from the time of liberation of the spores to the development of a sporophyte about 18 inches high (Brandt, 1923; Neushul, 1963).

The life span of an adult sporophyte is variable; under favorable conditions they are perennial. The growth habits may vary considerably and a significant shift in growth habit appears to occur somewhere between La Jolla and San Clemente so that at Palos Verdes we are dealing with a different variety or race of *Macrocystis* than exists at Point Loma.

The growing points which give rise to new fronds appear at the base of the plant. A given plant may produce hundreds of fronds during its existence; apparently the stipes become senescent and deteriorate but are continually being replaced by young growth from below. This vegetative reproduction is rapid in contrast to the slow sexual reproduction.

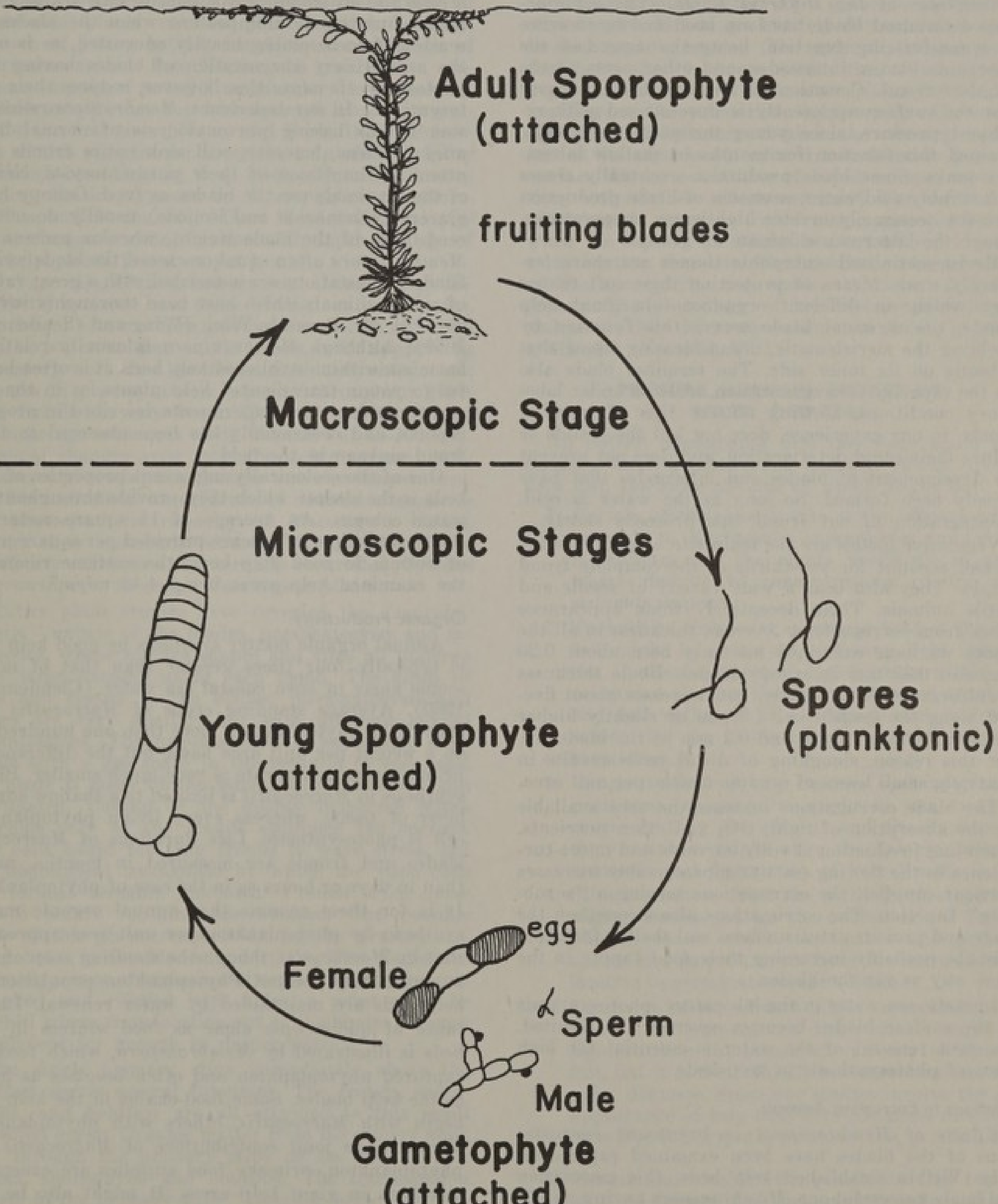


Figure 38. Life history of the giant kelp, Macrocystis pyrifera.

There is evidence (Clendenning and Sargent, 1958a, Parker, personal communication) that organic matter synthesized in one part of the plant can be transported many yards to another section to provide the necessary material for growth.

Functions of the Different Parts. The scimitar-shaped terminal blade has long been known to serve an organ-forming function, being the source of the embryonic blades, internodes, and other parts of the complete frond. Cessation of terminal blade activity near the surface apparently is unconnected with rereduced pressure, since young terminal blades have retained this function for months in shallow laboratory tanks. Since blade production eventually ceases in favorably cold water, cessation of blade production does not necessarily involve high water temperatures, though the latter can eliminate all growth.

Meristematic and embryonic tissues are characteristically weak. Means of protecting these soft tissues vary widely in different organisms—in giant kelp fronds, the terminal blade serves this function by shielding the meristematic, organ-forming tissue that is borne on its inner side. The terminal blade also has the capacity for regeneration, at least under laboratory conditions. Cutting off the tips of growing fronds, in our experience, does not kill the fronds or induce their rapid deterioration, and does not prevent the development of blades and internodes that have already been formed. So long as the water is cold, disintegration of cut frond tips proceeds slowly.

Vegetative blades are the main site of photosynthesis and account for two-thirds of the complete frond weight. They also bear a wide variety of sessile and motile animals. Their deceptively thick appearance arises from corrugations. Average thickness in all the blades we have examined has only been about 0.30 mm, and 0.35 mm in canopy blades. Blade thickness is uniform across the blade, but decreases about five-fold along the length, i.e., 1.0 mm or slightly higher in the attachment zone, and 0.2 mm at the blade tip. For this reason, sloughing of distal parts results in relatively small losses of organic matter per unit area.

The blade corrugations increase the area available for the absorption of light, CO_2 and other nutrients. Attending production of eddy currents and micro-turbulence in the flowing sea water presumably increases nutrient supplies, the corrugations serving a ''scrubbing'' function. The corrugations also strengthen the blade and provide extra surfaces and shelter for blade animals, probably increasing their food supply in the same way as for the blades.

In static sea water in the laboratory, photosynthesis in the surface blades becomes severely CO_2 limited. Constant renewal of the water is essential for high rates of photosynthesis in kelp beds.

Relations to Encrusting Animals

Effects of *Membranipora* (a bryozoan) encrustations of the blades have been examined experimentally. Within established kelp beds, this association is a fairly successful one, *Membranipora* having mildly favorable as well as harmful effects. Shading effects seem to be of little consequence because of the open lattice-structure of the colonies, at least in well-lighted surface water. Protection against canopy grazers (gammarids and isopods) seems to be afforded by *Membranipora.* By its respiration, *Membranipora* contributes extra CO_2 for the blades. The protoplasm of the *Membranipora* colonies can impede CO_2 traffic to the blades but this is unimportant when the blades are senile before becoming heavily encrusted, as is often the case. Heavy encrustation of blades having high photosynthetic capacities, however, reduces their photosynthesis. In our experience, *Membranipora* does not sink fronds having pneumatocysts of normal buoyancy. Pectens, however, will sink entire fronds with attending implosion of their pneumatocysts. Neither of these animals use the blades as food. Canopy blade grazers (gammarids and isopods) usually do not exceed 0.1% of the blade weight, whereas pectens and *Membranipora* often equal or exceed the blade weight. Blade encrustations are associated with a great variety of motile animals which have been thoroughly investigated by Mr. Bruce L. Wing (Wing and Clendenning, 1959). Although *Membranipora* is usually relatively harmless within established kelp beds, it is often harmful to young transplanted kelp plants, as in the raft and transplantation experiments described in progress reports, and occasionally has been observed to cause frond sinkage in the field.

One of the ecologically important properties of kelp beds is the shelter which they provide throughout the water column. An average of 15 square meters of sheltering kelp surfaces are provided per square meter of bottom in good kelp beds, the extreme range for the examined kelp areas being 4-40 m^2/m^2.

Organic Productivity

Annual organic matter synthesis by good kelp beds is typically four times greater than that of microscopic algae in open coastal sea water (Clendenning, 1960). Average standing crops of *Macrocystis* may exceed the phytoplankton more than one hundredfold on a weight per unit area basis, but the difference in primary production rate is very much smaller. Photosynthesis in *Macrocystis* is limited to a shallow surface layer of tissue, whereas every living phytoplankton cell is photosynthetic. Life durations of *Macrocystis* blades and fronds are measured in months, rather than in days or hours as in the case of phytoplankton. It is for these reasons that annual organic matter synthesis by phytoplankton per unit area approaches that by *Macrocystis,* though the standing crop of kelp is enormously greater. Phytoplankton populations in kelp beds are maintained by water renewal. Importance of microscopic algae as food sources in kelp beds is illustrated by *Membranipora,* which feeds on captured phytoplankton and often becomes as heavy as the kelp blades. Some food-chains in the kelp beds begin with *Macrocystis,* others with phytoplankton. Through the joint contributions of *Macrocystis* and phytoplankton, primary food supplies are exceptionally high in giant kelp areas. It might also be said that internal food chains operate within giant kelp plants, one part feeding another by translocation.

Field photosynthesis measurements on bottom kelp blades showed that young fronds attached to the base of large plants can grow when there is insufficient light for their own net synthesis of organic matter. Submarine light requirements, therefore, are different for new vegetative fronds developing at the base of established plants vs. new plants arising sexually. Growth of young bottom fronds by translocation of nutrients explains how *Macrocystis* maintains a continuous supply of young fronds under dense canopies.

Chlorophyll c has now been isolated from *Macrocystis* for the first time (Haxo, and Fork, 1959). Possession of this pigment increases the kelp plant's ability to absorb blue light in deep water. The other known photosynthetic pigments in *Macrocystis* are chlorophyll a and fucoxanthin. How these individual pigments change in concentration with depth and age of the kelp plants is not as yet known.

Ontogenetic, diurnal and seasonal changes in photosynthetic activity have been studied in kelp blades, and their photosynthesis has been measured throughout the water column in the ocean, with supporting laboratory work. In a spatial sense at least, ontogenetic changes in photosynthetic capacity throughout giant kelp fronds are very large. The blades are arranged in linear age-sequences along distances of 60-100 feet. Seasonal changes arise from damaging summer temperatures plus adaptive changes to water temperature. We have obtained no evidence of diurnal changes in the photosynthetic capacity of *Macrocystis* blades, though these commonly occur in phytoplankton. The possibility still exists of internally controlled rhythms of growth, etc., in entire *Macrocystis* plants.

Entire plant studies have revealed the "morphoplastic" nature of the blades, pneumatocysts and internodes, whose mature shapes and sizes all undergo very large changes along each frond. The kinds of cells and tissues in the blades, pneumatocysts and stipes are very similar, but with different spatial organizations. The pneumatocyst is essentially stipe tissue with a gas space in the medulla or core, and the blade is made of the same tissues, flattened and corrugated. Coiling of the deeply immersed stipes develops only as the fronds approach the surface. The coils adapt the long fronds to wave stress, but the histological mechanism by which the stipe coils are formed remains unknown. Fronds often cease growth before reaching the surface. One possible cause of this phenomenon is damage by grazing creating holes in the blades and stipes. The blades are the main source of organic matter, and as they become sloughed and riddled with holes, a point must be reached where translocation out of the blades becomes insufficient for growth in deeper parts.

The single primary stipe immediately above the holdfast serves several functions. The fronds, sporophylls, and holdfast are all attached to this small perennial organ. Organic matter from the canopy must flow through the primary stipe on its way to new fronds, sporophylls and holdfast. The translocation system in the primary stipe "clearing house" has yet to be studied. Analyses of large, completely dissected *Macrocystis* holdfasts allowed us to relate their organic matter contents to the number of vegetative fronds they had borne. Purple and yellow holdfast haptera that have been examined were found incapable of photosynthesis, but rates which are at or above the compensating level have been observed in brown haptera from shallow water. As a general rule, primary stipes and holdfasts are entirely dependent on translocated organic matter. The sporophylls and young fronds attached to them subsist either on translocated organic matter or on their own photosynthesis, depending on the submarine light supply. Harvesting should increase photosynthesis in the submerged parts, but at the expense of reduced translocation from the surface. Under conditions of rapid canopy regeneration, both of these effects are brief. The holdfast regions remain supplied with fruiting sporophylls even when the tops of the plants are cut off continuously as in boating channels. Photosynthetic characteristics of the sporophylls are similar to those of bottom fronds. The physiology of kelp zoospores is largely unknown; they do, however, show an ability to photosynthesize (Neushul, 1959).

POSSIBLE HARMFUL EFFECTS OF WASTE DISPOSAL

An outfall discharging into the ocean could conceivably have a number of harmful effects upon a kelp bed, the more obvious of which might be:

1. Certain of the constituents of the effluent might be toxic to *Macrocystis* sporophytes and/or gametophytes and the plants would die in areas where destructive concentrations of the constituents appear.
2. Turbidities within the discharge field of the outfall might be increased, reducing light intensities or altering spectral distributions within the ocean and altering the balance between synthesis and destruction of kelp tissue to such a drastic extent that the plants could no longer maintain themselves.
3. Concentrations of kelp enemies such as grazers, pathogens, or parasites might in some way be encouraged by the effluent and the increase in their numbers might alter the balance between synthesis and destruction of kelp tissue.
4. Siltation effects from the settling of suspended matter discharged by the outfall might reduce photosynthesis within the leaves and prevent spores and gametophytes from finding a suitable location to germinate on the bottom.
5. Discharge of the effluent might cause changes in salinity or temperature. Such effects might be significant in the immediate vicinity of an outfall, but it is doubtful if they would extend any great distance. Since our studies involve the disappearance of kelp beds over distances measured in miles, this hypothesis seems less promising.

One must also consider the possibility that two or more of these factors may concurrently influence kelp distributions. Further complications are introduced by changes in the outfalls themselves; new construction may be installed, leaks may occur and then be repaired, the quantity and composition of the discharged wastes may change both seasonally and from year to year. There is even the possibility that transient fluctuations in the concentrations of certain substances might occur in the effluent owing to their sudden introduction in considerable quantity into the sewage system. In addition, it is important to bear in mind that natural factors cause deterioration of the beds and they must be taken into consideration. It can be seen that the situation at any given location may be the result of a complicated interaction of influences and a thorough analysis is necessary before attempting to draw conclusions.

The first four hypothetical influences listed above might be expected to alter kelp and the nearshore marine environment in the following ways:

A. If harmful substances in the effluent are being liberated more or less continuously in concentrations which are toxic in the vicinity of the outfall, one would suppose that with increasing distance from the terminus the probability should become higher that non-toxic concentrations prevail, simply because of dilution effects. Plants and animals affected by these harmful substances should be missing from the outfall area in this case, but they might be expected to appear at some distance to either side of the outfall.

B. Increased turbidities might have a very complex effect, but in general one would expect that the amount of attached seaweeds would become greatly reduced as the depth increased. The nearshore zone supporting plant growth in the region of an outfall, therefore, should be much narrower than one might expect for a given substrate, grazing population, etc.

C. The encouragement of grazers, pathogens, and parasites by sewage is difficult to establish if one does not have at hand reliable data of previously existing conditions. Existing populations can be studied for several outfall areas and compared with unaffected areas. Likewise causes of kelp loss can be investigated in the field at the time beds or patches are deteriorating and any abnormal conditions noted.

D. The degree of silt deposition on blades of kelp can be estimated by frequent observations. We have been unable to find appreciable siltation on the leaves of plants in any of the outfall areas studied. Siltation on the bottom in sufficient amount to affect adult plants and the settling of spores can also be determined by observation.

It should also be noted that outfalls could conceivably have beneficial effects upon kelp. It will be shown below, in another section of this report, that dilute sewage effluent can stimulate photosynthesis in the laboratory.

INVESTIGATIONS OF CAUSES OF KELP REGRESSION

SURVEYS

A number of surveys and observations were made during the investigation; these included continuous inspection of kelp areas adjacent to submarine outfalls, as well as inspection of control sites in southern California and areas well removed from any major human influence in Baja California.

Observations were made of the Pt. Loma, Palos Verdes, and Santa Barbara areas to establish conditions at the start of the investigation (winter and spring of 1957-58). This initial period coincided with three years of unusually warm ocean temperatures and nearly all kelp beds in southern California deteriorated, especially in the summer of 1958. In July, August, and September, 1958, one of the most intense red tides ever witnessed in southern California, developed throughout the coastal zones and was composed primarily of the dinoflagellate *Gonyaulax polyedra*. The more normal cold water regime returned at the end of 1959 and considerable regeneration of kelp beds has since been observed. No major restoration of kelp, however, occurred either at Pt. Loma or Palos Verdes, but the bed at Santa Barbara has improved substantially.

During the latter portion of the investigation, quantitative studies on features such as growth rates of kelp plants and mortalities of populations were conducted in the beds near outfalls. Many of the techniques involved were developed as a part of this program and the concurrent Kelp Investigations Program sponsored by the Department of Fish and Game.

The initial surveys suggested the importance of physical factors such as light intensity and biological influences such as grazing on plants in the study areas. Accordingly further work was done collecting some data on light intensities and attenuation coefficients as a function of geographical location. Characterization of the populations of the chief grazers, the sea urchins, was undertaken at various locations at Pt. Loma and Palos Verdes. Work on these latter aspects is still being conducted under a grant from the Kelco Company of San Diego. Quantitative and descriptive surveys of algal biomass as a function of depth were also performed to determine the status of attached vegetation at Pt. Loma and Palos Verdes.

Point Loma in 1957-58

The Point Loma-San Diego Bay region is shown in Fig. 39 which depicts the situation at the inception of our study. Wastes are discharged into the bay at a number of locations and consist almost entirely of domestic sewage and industrial organic waste. Prior to our investigation, heavy metal ions were discharged into the bay from industrial processes; since 1957 this type of waste is disposed of elsewhere. The principal source of domestic sewage is a short outfall at the City's treatment plant (F in Fig. 39) which at present has an average daily output of about 50 million gallons.

The large kelp bed offshore from Point Loma is subdivided into two parts, designated by the Department of Fish and Game as beds 2 and 3. The relative tonnages harvested from two beds, expressed as a percentage of the 1933 harvest, are shown in Fig. 40. The last cutting from bed 2 was a small amount gathered in 1957 and the annual yields from this bed have shown decreasing tendencies since the middle 40s. Aerial photographs of the area have been taken since 1950 by the Kelco Company of San Diego and have been made available for our inspection. The greatest disappearance in surface canopy appears to have occurred around 1954 and to have extended north to the New Hope Rock region, a distance of some three miles. Harvesting returns dropped substantially at this time.

In order to document initial conditions, surveys were conducted along line transects located at the stations indicated in Fig. 39. The results are presented in Table 8. Stations 1 and 2 were in bed 2 while stations 3-7 were in bed 3. Stations 1 through 4 were located in the area where kelp had disappeared; stations 5 and 6 were placed in bed 3 where kelp yields had diminished but were still continuing; station 7 was in an isolated patch to the north which disappeared at about the same time as bed 2, but returned and has since vanished.

It can be seen from Table 8 that the character of the beds changed between stations 4 and 5, which corresponded to the change from an area of deterioration to a less affected area. Stations 1 to 4 had relatively high concentrations of adult plants per m ^{2}, but the sizes were small, averaging around 10 stipes per plant. Stations 5, 6, and 7 had lower concentrations, but the plants averaged considerably larger in size. It is apparent that the southern portion of the Point Loma bed consisted of relatively young kelp, if we accept size as a measure of age. It is believed that this is a safe assumption in this case since examination of the holdfast regions of the southerly young plants did not reveal an excessive number of deteriorated stipes or stubs at the bottom of the plants and it is not likely that they were severely shaded in their juvenile stages. Figure 41 shows ogives for the populations sampled at stations 1 and 5, representing the extremes.

Parasites and pathogens were not present in the kelp of beds 2 and 3 to such an extent that they were detected by casual inspection. Deterioration similar to temperature damage was noted during the latter part of June and heavy encrustation with the bryozoan *Membranipora* became common at the same time in the upper portion of the plants. Clendenning (1957) has noted, however, that photosynthesis at saturating light intensities does not appear to be influenced by this organism.

Appreciable siltation has never been observed in beds 2 or 3 either on the fronds or on the holdfasts of the plants. Wave surge and currents are apparently sufficient to prevent fine suspensoids from settling and sand which does exist in low pockets among the rocks is usually rather coarse.

Inspection surveys were made of the barren areas lying immediately south of the southernmost patches of kelp in this area. The bottom consists of low rock ridges and outcrops interspersed with coarse sand and cobble fills. A few lobsters and abalone were present, as well as *Astraea* and *Murex*, and the chief alga was an occasional clump of *Grateloupia*. By far the most abundant organisms, however, were the sea urchins *Strongylocentrotus franciscanus* and *S. purpuratus*, which were present in heavy concentrations estimated at up to 50 or more per square meter. The area was somewhat reminiscent of certain other locations where kelp beds had disappeared in recent times (New Hope Rock, South Coronado Island).

The Palos Verdes Peninsula in 1958

The Palos Verdes Peninsula (Fig. 42) was formerly ringed by an almost continuous thick band of kelp, designated as beds 11, 12, 13, and 14. The beds yielded kelp for commercial purposes until around 1950 (Figs. 43 and 44).

At the start of the program, *Macrocystis* existed in only four areas of the peninsula (Fig. 42); a patch

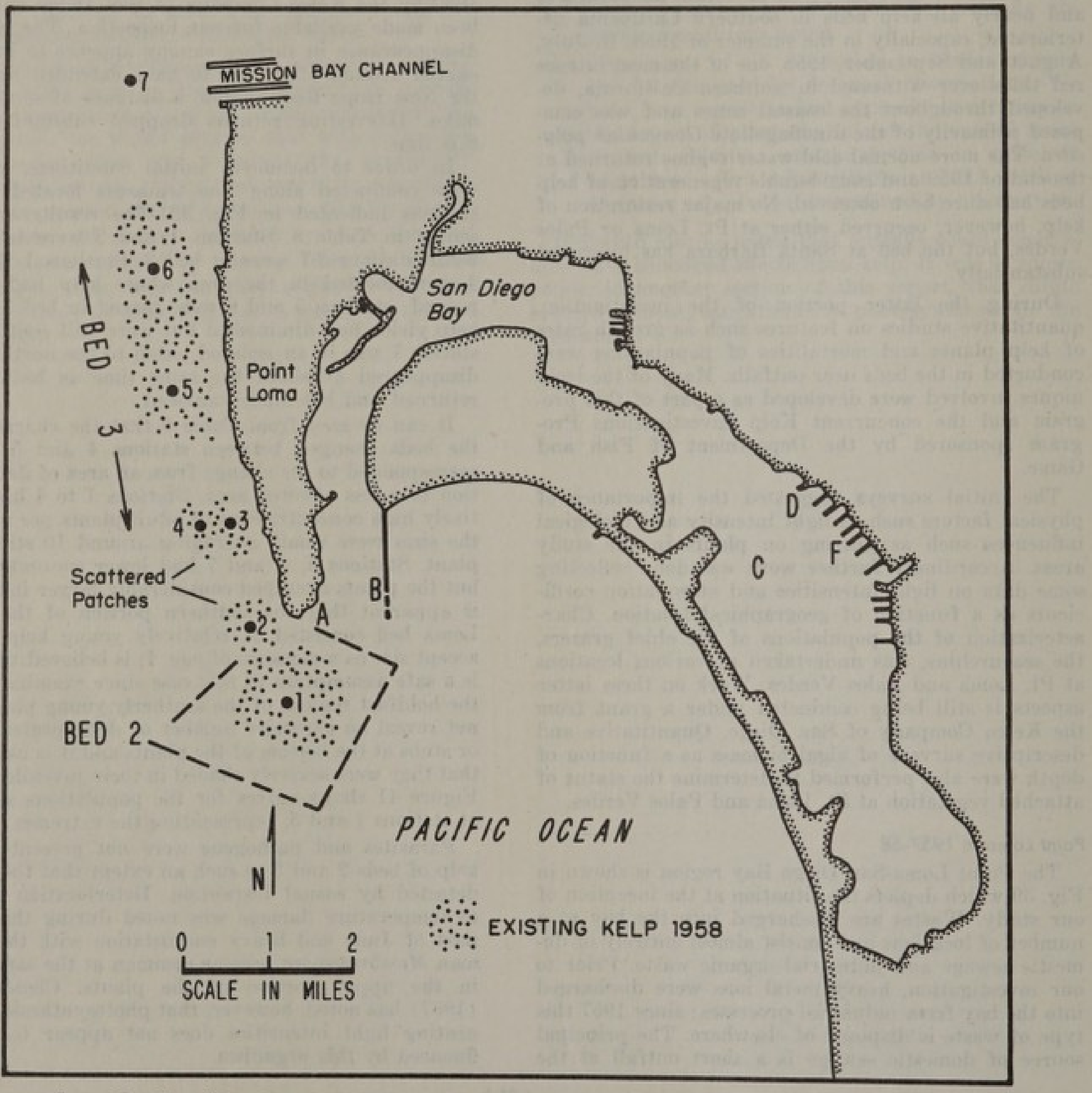


Figure 39. Chart of San Diego Bay-Point Loma area showing location of experimental stations described in the text.

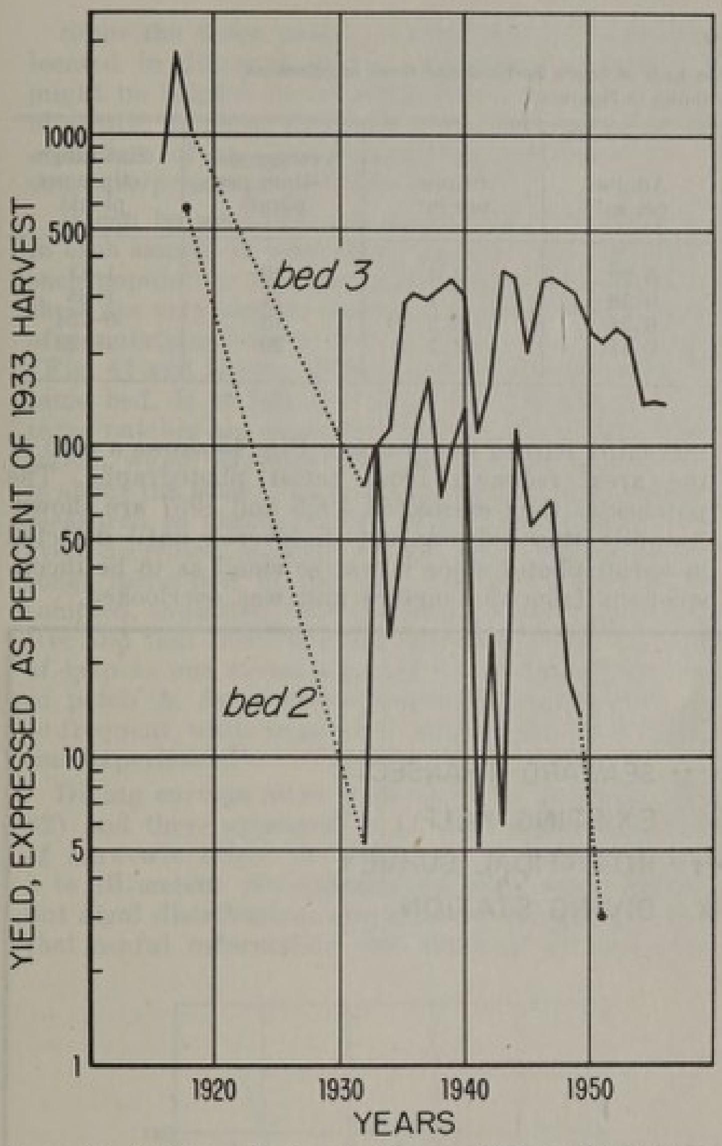


Figure 40. Relative yields harvested from beds 2 and 3 (Point Loma bed). Data furnished by the California Department of Fish and Game. Dotted lines indicate that no tonnages were recorded during those years and points indicate a reported yield for a year with no harvesting recorded for the previous or the subsequent years.

reported to have existed between Cabrillo Beach and Point Fermin in 1954 (Limbaugh, personal communication) and some patches which were in the coves near Rocky Point Vicente in early 1955 had vanished.

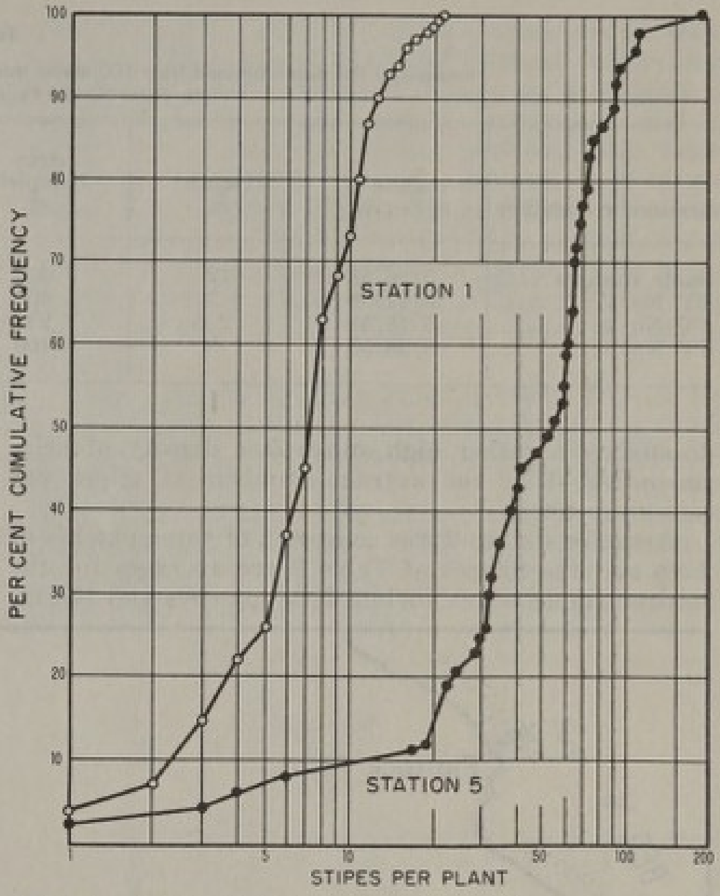


Figure 41. Ogives of two kelp populations which were sampled at stations 1 and 5 in Figure 39. The southern sample indicates the population consisted of much smaller and therefore presumably younger plants than the northern population.

Table 9 shows the results obtained for the Palos Verdes kelp at the three stations indicated in Fig. 42, as well as data obtained from a bed at Santa Barbara which will be discussed later. Kelp is not shown at station 1 in Crandall's map of the area in 1911, but the beds at stations 2 and 3 were present then. There were no juveniles found in any of the beds. The statistics are entirely within the normal range of what had been found in other beds (North, 1957b), although the average size of the plants in the Portuguese Bend bed (station 1) was small for a northern bed. It is of interest that a bed such as that at station 2, apparently within the influence of an outfall, is able

Table 8

Summary of results obtained for seven stations in kelp along Point Loma.

Station number	Date	Depth m	Area sampled m²	Adults per m²	Juveniles per m²	Stipes per m²	Average size (stipes per plant)	Size range (stipes per plant)
1	1/ 2/58	12	400	0.37	0.04	3.0	8	1–22
2	3/ 3/58	12	400	0.20	0.01	2.4	11	1–33
3	3/24/58	20	120	0.20	0	2.3	12	2–33
4	3/24/58	11	194	0.45	0.03	4.5	10	2–22
5	9/17/57	16	400	0.13	0	6.9	52	1–199
6	3/31/58	21	400	0.07	0.1	1.9	27	1–115
7	3/ 5/58	24	400	0.09	0	2.5	30	1–53

Table 9

Analysis of the data obtained from 100 meter transects in beds at Santa Barbara and three locations on the Palos Verdes Peninsula, shown in Figure 42.

Station or Location	Date of Survey	Depth m	Area Sampled m	Adults per m²	Stipes per m²	Average size (stipes per plant)	Size range (stipes per plant)
Santa Barbara	3/26/58	12	400	0.22	2.3	10	1–41
PV No. 1	3/14/58	3	400	0.28	3.1	11	1–85
PV No. 2	5/15/58	2–5	234	0.28	6.5	18	0–134
PV No. 3	3/28/58	8	400	0.11	2.1	20	1–129

to sustain a rather high subsurface density of kelp, as indicated by the average numbers of stipes per square meter.

Actually station 2 was composed of three patches of kelp and the figures of Table 9 are averages for the entire sample which included the patches and the intervening barren sandy areas. Fig. 45 shows a map of the area, redrawn from aerial photographs. The patches as they existed in 1955 and 1957 are shown. Actually this bed was not discovered until detected in aerial photos since it was so small as to be inconspicuous from the surface and was overlooked.

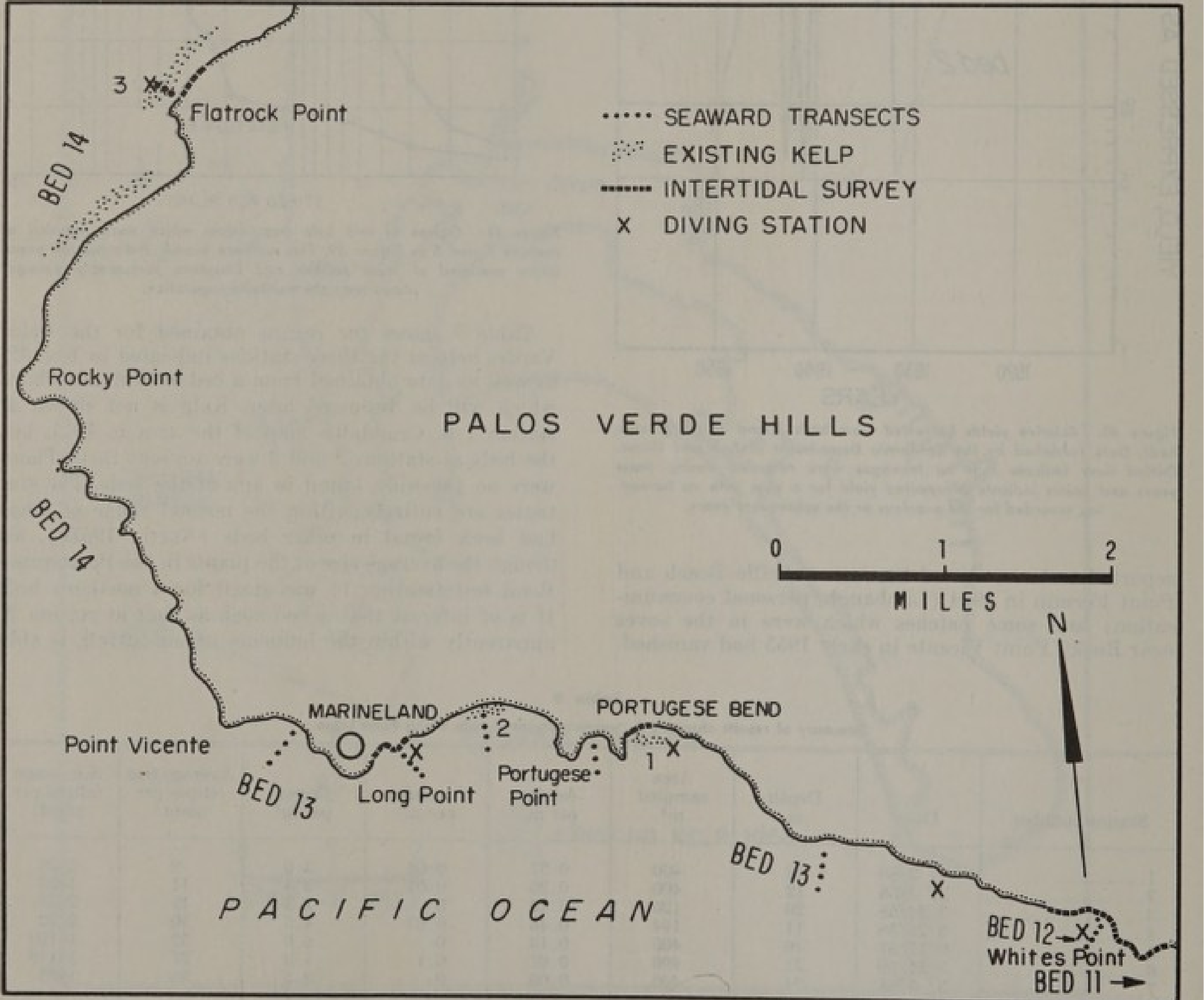


Figure 42. Chart of the Palos Verdes Peninsula showing the location of the 1958 field operations described in the text.

Since the three patches comprising station 2 were located in different depths, information about each might be helpful in revealing facts about the effects of depth. A more thorough study was made of this area than of any bed hitherto analyzed and the results are presented in Table 10.

It can be seen that the average size of the plants in each sample is very close. The size distributions of each population are represented as ogives in Fig. 46; these are very similar curves as compared with ogives of populations known to be different from each other (Fig. 41 and North, 1958a), and yet coming from the same bed. It is felt that Fig. 46 indicates that the three patches are separated islands of the same population, which explains why the average size of each is about the same. The concentration of kelp, whether measured as plants per m² or as stipes per m², however, decreased steadily as the water deepened. Personal inspection of the three patches, in areas not sampled, indicated that the samples were representative and that there is a real decrease in the thickness of kelp as one swims seaward (it is difficult to swim in patch A, for example, because entanglement was so frequent, while in patch C, little if any such trouble was experienced).

Diving surveys were made at other locations (Fig. 42) and there appeared to be only sparse quantities of seaweeds below the relatively shallow depths of 3 to 10 meters. No quantitative data were obtained, but algal distributions are often so sharply delimited that useful information was obtained by inspection.

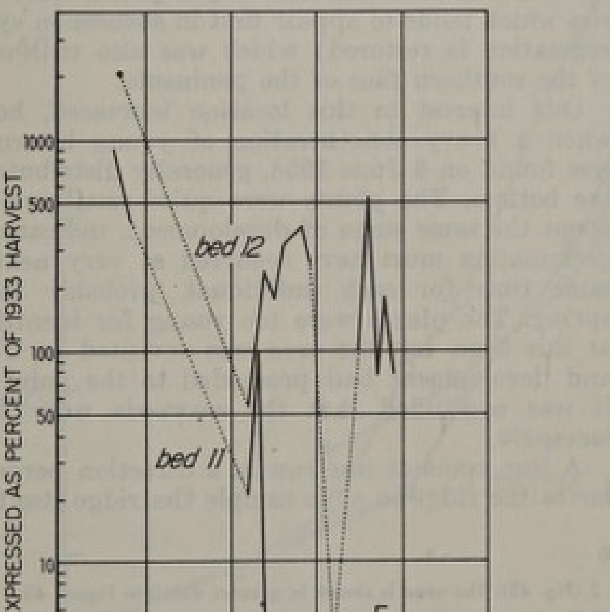


Figure 43. Relative yields of harvested kelp from beds 11 and 12, near Whites Pt. Dotted lines denote years of no recorded harvest for the beds. Data furnished by the Department of Fish and Game.

In swimming from the shore out to sea at these locations (Fig. 42), it was usually found that at shallow depths, down to about 3 meters, an abundance of attached seaweeds was present. Between 3 and 10 meters the quantity decreased markedly and below about the 10-meter level only occasional tufts of material were encountered. In Puget Sound, where waters are characteristically turbid from natural causes, plant cover commonly extends to depths of 20 m, according to the dredging results of Seagel (1957) and the diving observations of Neushul (personal communication).

When considering large areas of rocky bottom, the environmental parameter that often limits the depth to which algal growth extends is light intensity. If this is the limiting factor at Palos Verdes it suggests that on the average, light attenuation in the coastal waters must be unusually high since 10 meters is quite shallow for plant growth to thin out. At La Jolla, and at northern Point Loma, for example, 25

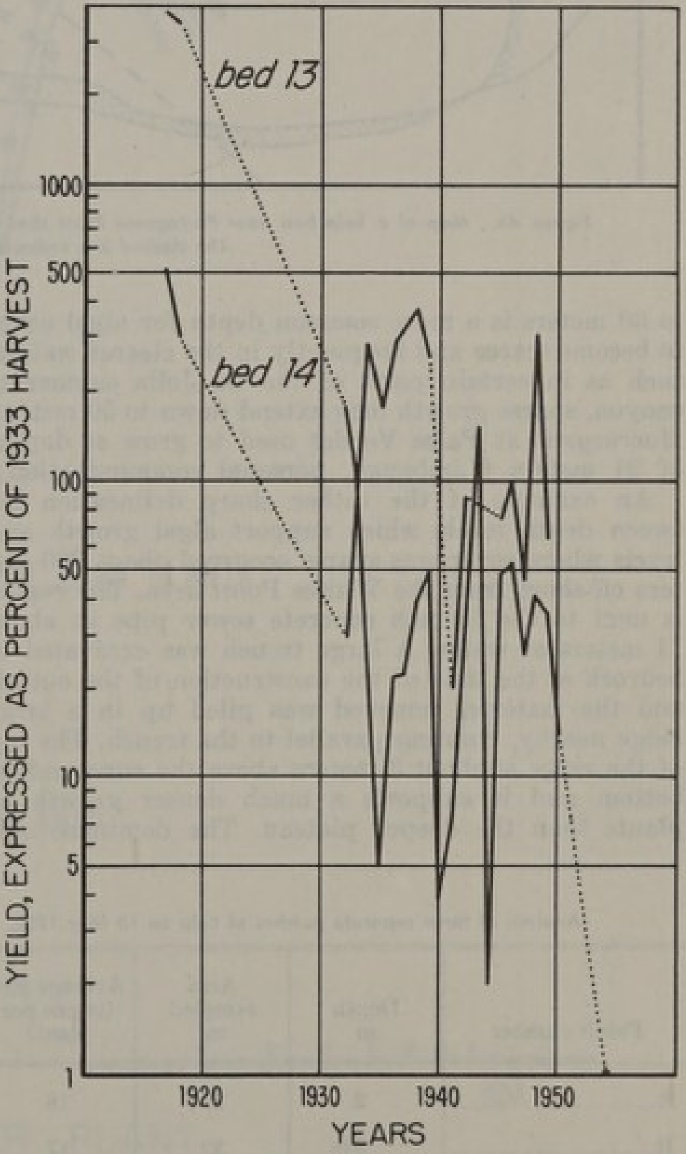


Figure 44. Relative yields of harvested kelp from beds 13 and 14, fringing the Palos Verdes Peninsula. Dotted lines denote years of no recorded harvest for the beds. Data furnished by the Department of Fish and Game.

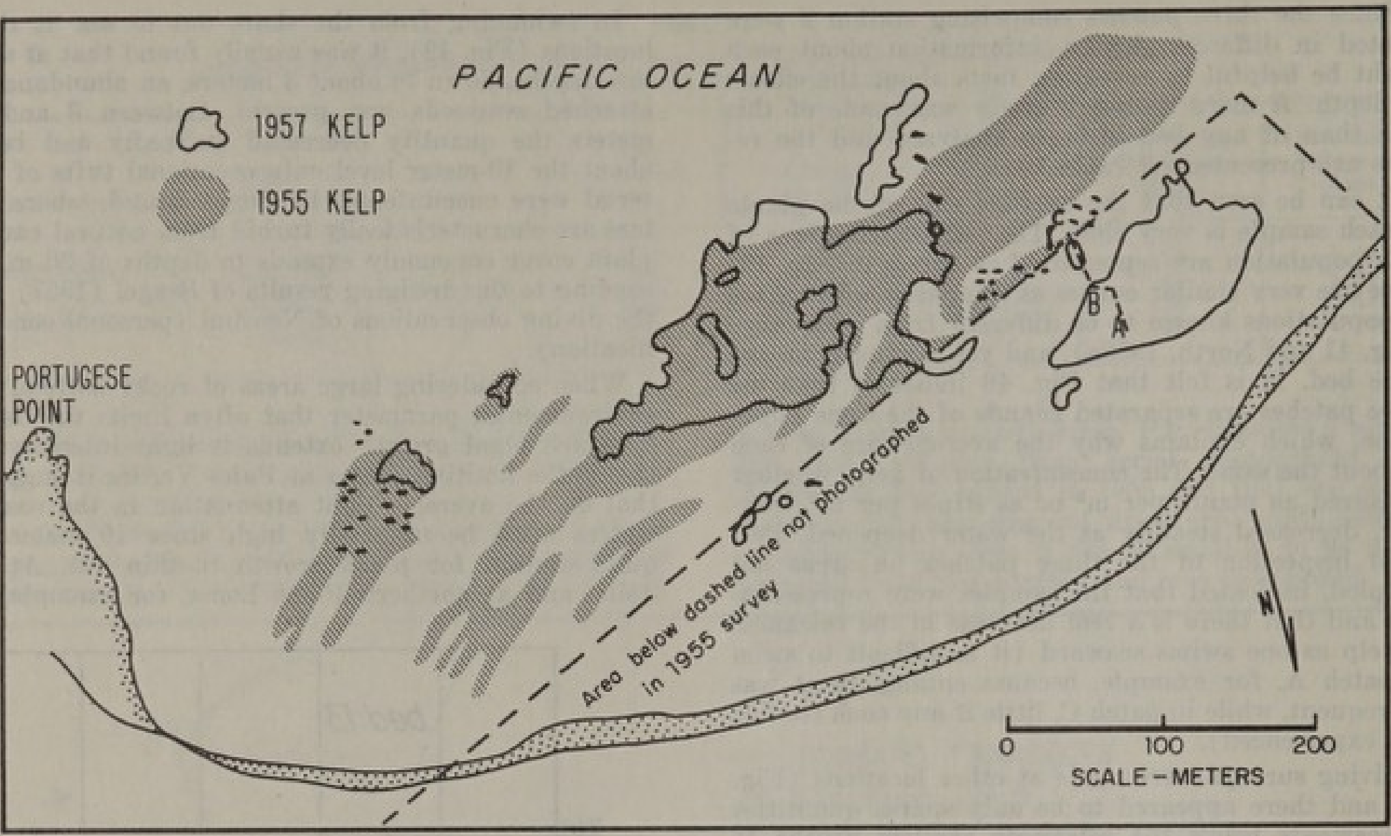


Figure 45. Map of a kelp bed near Portuguese Point showing approximate positions of the kelp patches described in the text. The dashed line indicates the location of our line transect.

to 30 meters is a more common depth for algal cover to become scarce and frequently in the clearer waters, such as in certain parts of the La Jolla submarine canyon, sparse growth may extend down to 50 meters. *Macrocystis* at Palos Verdes used to grow at depths of 21 meters (Limbaugh, personal communication).

An example of the rather sharp delineation between depth levels which support algal growth and levels where cover was sparse occurred about 300 meters off-short from the Whites Point area. The region is next to the 90-inch concrete sewer pipe in about 11 meters of water. A large trench was excavated in bedrock at the time of the construction of the outfall and the material removed was piled up in a large ridge nearby, running parallel to the trench. The top of the ridge is about 3 meters above the surrounding bottom and it supports a much denser growth of plants than the deeper plateau. The dominant seaweed in this area was *Ectocarpus granulosus*, (a species which tends to appear first in succession cycles as vegetation is restored) which was also true of most of the southern face of the peninsula.

Our interest in this location increased, however, when a heavy concentration of young brown algae was found on 6 June 1958, generally distributed over the bottom. The plants were quite small and all at about the same stage of development, indicating that germination must have occurred at very nearly the same time for each individual, probably in early spring. The plants were too young for identification at this time, but the area was revisited on 27 June and development had proceeded to the point where it was concluded that the seaweeds were *Egregia laevigata*.

A line transect was run in a direction perpendicular to the ridge so as to sample the ridge itself and a

Table 10

Analysis of three separate patches of kelp on 15 May 1958, at station 2 (Fig. 42). The area is shown in greater detail in Figure 45.

Patch number	Depth m	Area sampled m^2	Average size (stipes per plant)	Plants per m^2	Stipes per m^2	Stubs / Stipes	Total number of stipes	Total number of stubs
A	2	22	18	1.7	30	0.08	656	51
B	3½	22	17	1.0	18	0.05	386	18
C	5	69	19	0.4	7	0.20	481	91

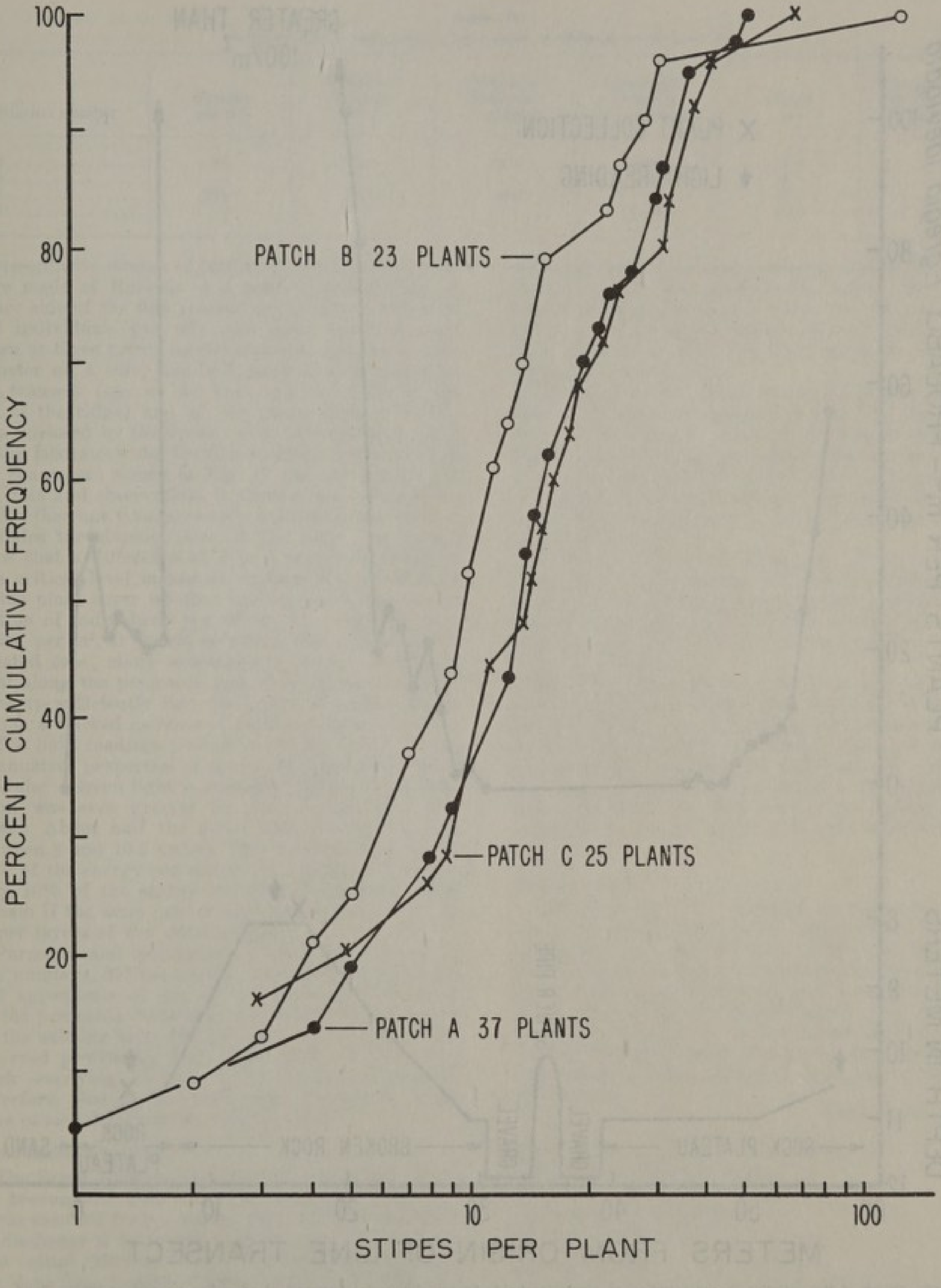


Figure 46. Ogives of three kelp patches located in the bed near Portuguese Point.

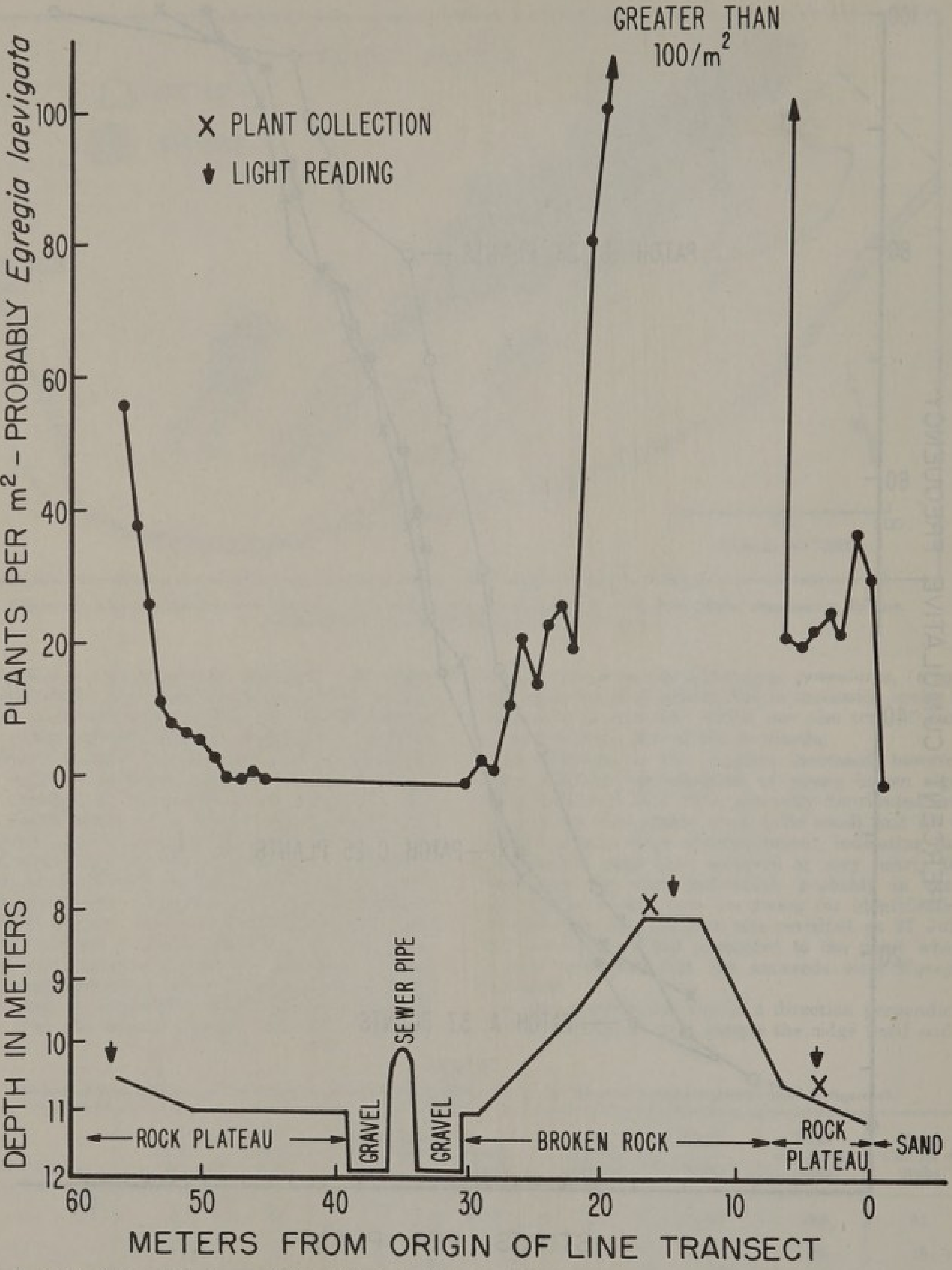


Figure 47. Graph of the variation in concentration of plants (probably Egregia laevigata) observed along a line transect at Whites Point on 27 June, 1958. A topographical cross section along the transect is shown to indicate the variations in bottom depth which were encountered (vertical scale exaggerated 5 times).

Table 11

Summary of data taken along a line transect at Whites Point, 27 June 1958.

Station number	*Egregia* per m²	Weight of *Egregia* g/m²	Weight of *Ectocarpus* g/m²	Green light intensity ergs/cm²/sec	Depth m	Average weight per specimen of *Egregia*, g
4	38	82	14.6	25,000	10.5	2.2
15	—	—	—	45,000	8	—
16	214	740	302	—	8	3.5
57	—	—	—	21,000	10.5	—

representative stretch of bottom on either side. Counts were made of *Egregia* in a patch 1 meter wide on either side of the line (except where counts exceeded 100 individuals per m²) and light readings were taken at three points on the transect. A brass square, 1 meter on a side, was laid down at two points on the transect (one at the base and the other at the top of the ridge) and all the plants growing in the area enclosed by the square were gathered and taken to the laboratory for further analysis. The results of the counts are shown in Fig. 47 and the analysis of the data and observations is summarized in Table 11.

Whether one compares only horizontal surfaces, or includes the sloping sides of the ridge, the results show that a difference of 2 to 3 meters in depth at this critical level makes an extraordinary difference in the plant cover whether one considers the concentration of individuals per m² or the weight of vegetation per m². It should be added that this is not an isolated case; many submarine pinnacles or hillocks exist along the peninsula and where the top or crest rises up sufficiently into the layers of higher illumination a marked increase in algal growth is noted.

The light readings provide a rough estimate of the attenuative properties of the water mass observed on 27 June. (Green light is considered here; the attenuation was even greater for red, orange, and blue light.) About half the green light energy was lost between 8 and 10.5 meters. This amounts to a loss of 25% of the energy per meter. At a depth of 8 meters only 10% of the energy entering the surface would remain if the same rate or attenuation persists in the upper layers of the water column.

Parasites and pathogens, if they are present in any numbers, did not seem to have affected the health and appearance of any of the *Macrocystis* observed on the peninsula. Siltation was not causing any effect on the existing kelp, but old *Macrocystis* plants were observed protruding from sand patches a foot or so thick overlying bedrock. It is considered possible, therefore, that in the past, sand movements might have caused deterioration of kelp plants.

Santa Barbara in 1958

The Santa Barbara region is of considerable interest because the City's outfall terminates about 100 yards seaward from a rather thick bed and the depth of discharge is relatively shallow (about 40 feet) so that initial dilutions must be substantially less than the deep Los Angeles County outfall at Whites Pt. The field of the discharge has been observed to extend back into the canopy of the bed and the water in the outer edge of the bed was extremely turbid on the one occasion a dive was made in the region. The ocean bottom at Santa Barbara is rather fine silt and this is apt to create profound changes of the faunal populations in this bed compared with fauna on the rocky bottoms described above.

The *Macrocystis* plants were attached to the old dead holdfasts which apparently etxended deep down into the mud bottom. Much of the kelp in the Santa Barbara area rests on a muddy substrate and conditions were quite normal for the region in this respect. No sludge was found and an excavation about six inches deep into the mud failed to reveal any sulfide-blackened sediment.

A transect was swum along the bottom from the outer edge of the canopy for 150 feet towards the outfall. A few straggly plants on old holdfasts were observed near the area where the canopy began, then only old holdfasts with no growth, and finally even these disappeared.

The *Macrocystis* plants in the main part of the bed looked healthy except that they appeared to be damaged by intense grazing. Stipes are concentrated in dense masses although the plants themselves may be separated by considerable distances. No juvenile plants were observed. Analysis of a 100-meter transect swum from the outer edge of the canopy northeasterly into the bed yielded the data summarized in Table 9.

Kelp Regression

The years 1957-59 witnessed an influx of warm water. Unusually high water temperatures persisted throughout the year and most of the canopies in the kelp beds of southern California deteriorated and many beds virtually disappeared. In a letter dated 5 November 1958, Mr. Lee D. Pratt, vice president of the Kelco Company (a San Diego-based kelp harvesting concern) outlined some of the observations made by the members of his company on the condition of the beds.

November 5, 1958

Dr. Wheeler J. North, Project Officer
Kelp Investigations Program
Institute of Marine Resources
University of California
La Jolla, California

Dear Dr. North:

It is my understanding that it would be helpful to your kelp study group to have information regarding our observations of the current condition of the kelp beds in Southern California waters.

Since the beds are, and have been for some time, in poor condition from the standpoint of very sparse or no canopy, the effect of this on sportfishing should be checked very closely. If there is any relationship between the kelp canopy and fishing, certainly such would be most evident at this time.

At present, there is less *Macrocystis pyrifera* on the surface throughout all the kelp beds in Southern California than ever before in our experience.

We have been constantly checking the beds and last week we made an aerial survey of all beds in which we operate supplemented by surface observations. Beds at Point Loma and La Jolla (Nos. 3 and 4), which are normally very productive, have no harvestable kelp and have shown little growth in the past two years. Harvesting this past year in these beds has been about twenty percent of normal and there has been no appreciable harvesting for five months in these beds. There is practically no kelp in Bed No. 5 (Del Mar) and Bed No. 6 (Encinitas to Carlsbad) has less than ten percent of normal surface cover though neither bed has been harvested in over five months.

Bed No. 8 (off the City of San Clemente) has some kelp although less than normal and there is very little kelp in Bed No. 9 (Dana Point). These beds have not been touched in over eight months.

Beds in the Santa Barbara area (Nos. 20, 21 and 22), which are normally very productive and usually have their best growth in the fall months, are showing practically no growth. We harvested a small amount in Bed No. 20 and Bed No. 21 six months ago and in Bed No. 22 nine months ago and they have not been harvested since. At present, there are only occasional strands of kelp on the surface to show where very healthy, productive kelp beds were two years ago.

Bed Nos. 24, 25 and 28 show no new growth. The last appreciable quantities of kelp from Bed Nos. 24 and 25 were six months ago, and Bed No. 25 yielded twenty percent of normal for the past year. Bed No. 28 has been near normal this year but has no kelp now and no indications of growth.

Bed No. 30 has shown no significant growth since being harvested five months ago. Bed No. 31 which is being harvested now, shows no new growth and the bulbs show signs of losing their buoyancy.

Bed No. 33 (North Santa Rosa Island) is one exception in that it has done well this year, but it is only a small bed. No kelp is available in Beds 34, 35 and 37 now and no apparent growth. Small quantities were harvested from these beds recently. Previous to this, Beds 34 and 35 had not been harvested for nine years and No. 37 for fifteen years.

There is practically no kelp and no growth at San Nicolas Island (Bed No. 41) which normally thrives even when warm water affects coastal beds. There has been very little harvesting in five months and the total yield this past year was half of normal. San Clemente Island (Bed Nos. 43, 44 and 45) has no harvestable kelp now and shows no growth although Beds 43 and 44 have been harvested recently. Bed No. 45 has been completely nonproductive all year.

A kelp bed that we have been observing north of Point Conception that has never been harvested had a considerable quantity of kelp last month but now has no canopy. In almost all of the kelp beds there is either no canopy or a very thin canopy. In most of the beds, the canopy is much thinner than that left after harvesting.

Thus, in the twenty-three kelp beds in which we usually harvest, only seven have any appreciable surface canopy, and that is far below normal. While we have in past years observed one or two beds go below normal for a year or two (while some others are unusually productive), we have never experienced such an over-all lack of growth. Observation from the air of the beds leased to other companies indicates a similar condition.

As you know, in 1957 we had unusually warm ocean water temperatures, and the coastal kelp beds did not grow well although the island beds were normal. This year all of the beds are even less productive.

We hope the above information will be of help to your group in its study of kelp, its environment and its relationship to fishing. You may have questions regarding some of the observations and I know our men will be glad to discuss them with you.

Very truly yours,

KELCO COMPANY
L. D. Pratt
Vice President

Anomalies in the pattern of kelp regression did exist, however. Bed 2 at the southern tip of Point Loma and that kelp south of the Coronados Islands developed luxuriously. A new patch of kelp appeared just south of the Mexican border, below the area once occupied by Bed 1.

Above the Palos Verdes Peninsula the small patches of *Macrocystis* at Portuguese Bend and Abalone Cove dwindled somewhat, especially at Portuguese Bend. The main body of kelp on the Peninsula, however, was located between Malaga Cove and Rocky Point on the northerly side. This bed deteriorated badly and finally disappeared in the fall of 1958. Examination of the plants in the area as it was deteriorating showed that the remains consisted mainly of stipes and pneumatocysts. Nearly all the blades, growing points, and sporophylls had been stripped from the plants, suggesting that excessive grazing may have occurred. We were unable, however, to find any extraordinary condition such as excessive turbidities or evidence of toxic action, which might implicate nearby sewer outfalls (the area has always been characteristically turbid, however).

Examination of beds at Lo Jolla, Point Loma, and the Coronados Islands in the fall of 1958 showed that the tissues of most of the plants were in good condition. Traces of black rot were observed among the growing points and juvenile blades of plants at the Coronados Islands, but on the whole, the kelp appeared to be quite healthy. At La Jolla, all adult plants observed were fruiting and had an abundance of sporophylls. These plants all seemed unusually short so that their entire length was held beneath the surface by even a moderate current.

Some of the plants had an excessively grazed appearance, especially in the region of the holdfast. Within a square 10 feet on a side, surrounding one plant at La Jolla, 83 wavy top snails *(Astraea undosa)* were counted. Many of these were touching or feeding on the holdfast of the plant.

During the earlier, warmer part of the autumn of 1958 much kelp was observed adrift or up on the beach at La Jolla. In addition, 12 plants were observed strewn in disorder along the bottom at a depth of 150 feet in a small tributary at the head of the La Jolla submarine canyon. Debris of seaweed origin is common along the bottom of the canyons and this observation suggests that perhaps an appreciable quantity of non-floating *Macrocystis*, which never was observed on the beach, found its way out to sea in this manner. No spectacular deposits of *Macrosystis* beach litter were observed at La Jolla this year, and yet the quantity of material which, judging from aerial estimates, must have disappeared from the La Jolla bed was enormous. Poor growth rates, grazing damage, and removal to seaward would appear to be the most likely means of accounting for the lost kelp.

Measurements of Algal Distributions

Quantitative measurements were made of the standing crop of attached algae at a number of locations, at depths of 3 m, 8 m, and 12 m. These values were chosen because qualitative observations in the vicinity of the Whites Point outfall indicated that profuse growth could often be found at 3 m; the growth often became quite thin at 8 m; it usually became virtually nonexistent at 12 m.

It was decided to adopt the southern edge of the Palos Verdes peninsula as a typical area where kelp had disappeared and possible effects of waste discharges existed. Studies of a control area at La Jolla which would supposedly be free from effects of outfalls were also accomplished. La Jolla was selected as a matter of convenience, and although there is some septic tank drainage to the sea, this is almost certainly a negligible factor.

It was also considered desirable for a fair assessment in a study of this kind, to include control areas which, because of their remoteness, could be assumed to be free from the effects of outfalls, but which qualitatively appeared barren because of the presence of excessive numbers of grazers. One such area chosen for study was Papalote Bay on the southwest face of Punta Banda in Baja California. This was an area containing several acres of rocky bottom habitually dominated by sea urchins, as well as kelp patches in other sections of the bay. Prime attention was paid to the urchin territory to compare the algal standing crop with similar urchin dominated environments near outfalls. The kelp patches were not sampled quantitatively, but observations from time to time on the canopies have indicated they flourish, disappear, and return, apparently undergoing natural succession cycles (see page 21).

Preliminary diving observations were conducted in an area, and a region fairly free from sand patches was found (the attached algae do not ordinarily grow on sand or mud bottoms, and the above process is designed to eliminate sampling of areas lacking in plants). Once a rocky bottom of at least 50 x 50 meters in area was found, the boat was anchored at one edge, and divers descended carrying written instructions derived from a table of random numbers as to the locations within the 50-meter square which were to be sampled. An example of such an instruction sheet is given in Table 12.

In addition to the instruction card, the divers carried a 100-meter length of cord wound on a reel. The cord was marked with a numbered tape at each meter of its length, and the divers tied the free end of the cord to the anchor and swam out the measured distance indicated in the "distance out" column for the first sample (29 meters in this case). They then turned 90° to the right or left as indicated in the "left or right" column and then swam in a direction perpendicular to the line already established. Proceeding a measured distance according to the instructions given in the "distance sideways" column and, at the point where the sample is to be taken, the number on the tape attached to the line is given in the "total length of line out" column. A square formed of thin brass rods 1 meter long was then placed on the bottom, in a position such that one corner lay on the marked tape and an extension of the line would coincide with a diagonal of the square. Figure 48 shows how a square 50 meters on a side would be sampled by the instructions contained in Table 12.

After the brass square was placed on the sea floor, the divers collected all the attached algae within the contained area by hand and scraper and placed it in a plastic bag with an identification tag. The fresh weight of the contents was measured upon arrival at shore, and the material was either preserved for fu-

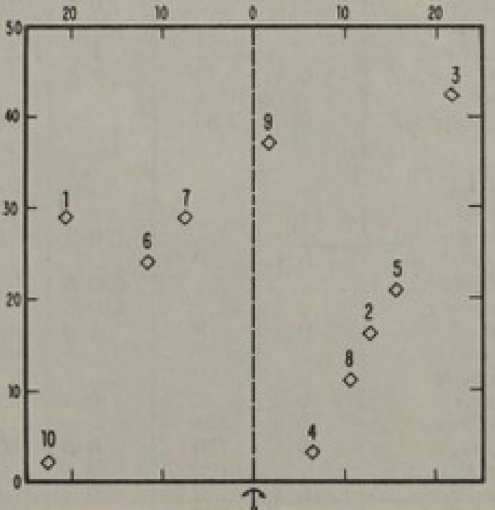


Figure 48. Example of a square, 50 meters on a side, sampled randomly at 10 different locations by a method described in the text.

Table 12

Example of a set of instructions describing sample locations to a diver. Numbers are obtained from a table of random numbers, and the order of right-left instructions by flipping a coin.

Sample No.	*Distance out (m)*	*Left or right (m)*	*Distance sideways (m)*	*Total length of line out (m)*
1	29	L	20	49
2	16	R	12	28
3	42	R	22	64
4	3	R	6	9
5	21	R	15	36
6	24	L	11	35
7	29	L	7	36
8	11	R	10	21
9	37	L	1	38
10	2	L	22	24

ture sorting or sorted as to species and the quantities thereof while fresh; weights of each species were also recorded. Ecologically it was also important to lump the different species into higher taxonomic categories such as greens, browns, reds, and spermatophytes. As noted above, these broad groups have characteristic modes of participation in succession cycles. The red algae were divided into two groups: the fleshy reds, comprising a great variety of species; and the calcareous reds, of which *Corallina*, *Bossiella*, and *Lithothamnium* were the principal components. The fleshy reds frequently dominated the red algae at 3 meters, but were usually in the minority at 8 meters, and were rare at 12 meters. Among the calcareous reds, *Lithothamnium* was not collected. It is an encrusting form, covering the rock surface with a smoothish layer of hard growth, and no satisfactory way has been devised for obtaining estimates of the amount of this genus when present.

All our surveys along the entire Palos Verdes coastline have revealed that the bottom at depths greater than 3 meters is uncommonly barren of seaweeds; large populations of 2 herbivores, the sea urchins *Strongylocentrotus purpuratus* and *S. franciscanus*, and a scattering of other grazers are usually present (Fig. 49). Quantitative sampling showed at 3 depths the standing crop of seaweeds at Whites Point averaged roughly an order of magnitude less than a control area in La Jolla Bay, presumably unaffected by discharged wastes (Fig. 50). The slopes of the standing crop curves down to the 8 m depth are also quite different for the 2 areas; the entire curve for Whites

Table 13

Comparison of the standing crops and frequencies of seaweeds at 3 depths determined by random sampling within rocky areas 50 x 50 m at Whites Pt. and La Jolla Bay. Each mean value represents the average of ten samples of 1 m² each.

Depth	3 m				8 m				13 m			
	Whites Point		La Jolla		Whites Point		La Jolla		Whites Point		La Jolla	
Category	freq.	mean g/m²	freq.	mean g/m²	freq.	mean g/m²	freq.	mean g/m²	freq.	mean g/m²	freq.	mean g/m²
Spermatophytes												
Phyllospadix	--------	--------	0.7	1824	--------	--------	0.6	740	--------	--------	--------	--------
Chlorophyceae	0.1	P*	--------	--------	--------	--------	0.2	0.4	--------	--------	--------	--------
Phaeophyceae												
Cystoseira	--------	--------	--------	--------	--------	--------	0.7	711	--------	--------	0.6	179
Dictyopteris	--------	--------	0.3	113	--------	--------	--------	--------	--------	--------	--------	--------
Dictyota	--------	--------	0.2	20	--------	--------	0.3	0.8	--------	--------	0.2	0.7
Egregia	0.2	58	--------	--------	0.4	165	0.3	752	0.1	40	--------	--------
Eisenia	--------	--------	0.4	1216	--------	--------	0.6	884	--------	--------	0.1	57
Laminaria	--------	--------	--------	--------	--------	--------	0.4	40	--------	--------	0.4	105
Pterygophora	--------	--------	--------	--------	--------	--------	0.2	23	--------	--------	0.3	258
Others	0.1	25	0.1	2	--------	--------	0.2	3	0.1	0.2	0.3	0.4
Total Browns	--------	83	--------	1341	--------	165	--------	3154	--------	40	--------	600
Fleshy Rhodophyceae												
Gelidium	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	0.4	113
Gigartina	--------	--------	0.3	12	--------	--------	0.2	23	--------	--------	--------	--------
Laurencia	0.1	P	--------	--------	0.4	0.6	--------	--------	--------	--------	--------	--------
Pterocladia	--------	--------	0.8	285	--------	--------	0.3	84	--------	--------	--------	--------
Rhodymenia	--------	--------	0.8	50	--------	--------	0.3	69	--------	--------	0.1	0.6
Others	0.1	P	1.0	324	--------	--------	0.6	107	--------	--------	0.3	17
Calcareous Rhodophyceae												
Bossiella	0.2	47	0.4	16	0.4	1.4	0.8	72	0.5	3.4	0.8	135
Calliarthron	0.6	151	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
Corallina	0.6	180	0.8	509	0.5	0.2	0.8	280	0.3	P	0.8	213
Lithotrix	--------	--------	0.8	0.2	--------	--------	0.5	3	--------	--------	0.5	2
Others	0.1	2	0.3	P	0.1	0.4	--------	--------	--------	--------	0.2	1
Total Reds	--------	380	--------	1196	--------	2.6	--------	638	--------	3.4	--------	482
Total algae	--------	463	--------	4361	--------	168	--------	4532	--------	44	--------	1082

* P = <0.1 gm.

Point has a slope more nearly comparable to the La Jolla area for depths greater than 8 meters. Assuming that the average values represent equilibrium conditions for each station, the standing crops are the amount of plant tissue which exists under given conditions of productivity and of destructive agencies. Productivity and destruction are themselves complexly related to the size of the standing crop, as well as to depth, and the observed differences in slopes of the curves suggest that the dynamic action of ecological forces is not the same in the two areas. Although the shallowest station at Whites Point resembles most nearly the deepest station at La Jolla, considering both slope and standing crop, even these are not entirely similar.

Analysis of the samples (Table 13) showed that with one minor exception (total Chlorophyceae at the 3 m depth), all the principal categories of vegetation were sparse at Whites Point when compared to La Jolla. The greatest algal deficiencies appeared in the category of the fleshy reds. The calcareous reds or corallines were likewise very deficient at depths of

Figure 49. Photograph of the sea floor at Whites Point at the 3 m depth station described in the text. Four species of herbivores common to most southern California rocky bottoms are shown and include the sea urchins, Strongylocentrotus franciscanus and S. purpuratus, the wavy top, Astraea undosa, and the abalone, Haliotis cracherodii (the latter well below its usual depth range). Light patches are the only alga in the photograph, the encrusting calcareous red alga, Lithothamnion sp. Scene is typical of a major portion of the Palos Verdes Peninsula at this depth.

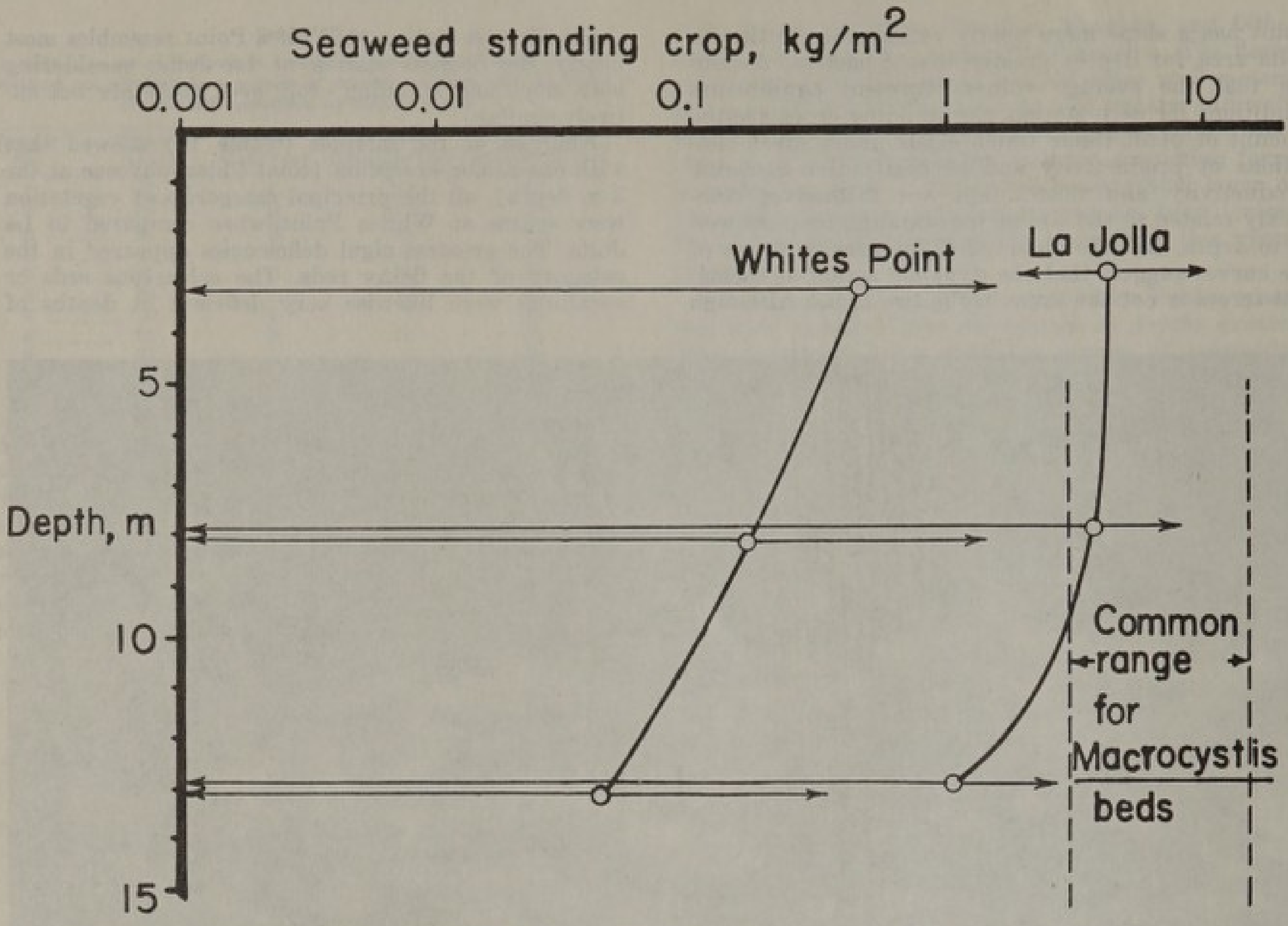


Figure 50. Comparison of total standing crops of seaweeds as a function of depth for Whites Pt. vs. La Jolla. The common range of standing crop for Macrocystis beds is also indicated.

8 and 13 m, but became nearly comparable to La Jolla at the 3 m station. The Phaeophyceae or brown algae were the least deficient, as a group of any category, principally because of a stand of *Egregia* which existed at Whites Point at the time the sampling program was begun. This species has all but disappeared from the whole region for the past 3 years, however, and a repetition of the survey would undoubtedly find this group much more seriously depleted than indicated by Table 13. The spermatophyte, *Phyllospadix* is completely absent from all but a few intertidal spots at Whites Point.

The comparison of the seaweed crops of these two locations is somewhat reminiscent of our comparison, above, of the algae under and outside of a *Macrocystis* canopy at Bird Rock. Herbivore populations appear to be much greater at Whites Point than anywhere off La Jolla, but this may be due in part to the general lack of concealing vegetation along the Palos Verdes peninsula, causing the larger grazers to be more obvious to the observer.

Sampling of seaweeds at other stations along the Palos Verdes coast substantiates the qualitative observations; the total floral standing crop is impoverished wherever it has been studied.

At the present time, only one small patch of *Macrocystis* is left at Palos Verdes, but it is healthy in appearance. The plants are located at Abalone Cove, about 7 km west of the outfall terminus, in depths of 3 to 6 m. The area is protected against severe weather from all quarters and the plants apparently are able to grow and reproduce sufficiently to maintain the colony in spite of losses to a large population of sea urchins. *Macrocystis* has disappeared from areas much farther removed from the outfall than Abalone Cove, but the losses have occurred in deeper locations which are exposed to severe wave action.

No quantitative collections of bottom vegetation have been made at Point Loma, but qualitative observations indicate that even near the entrance to San Diego Bay the rocky substratum is not as barren as was found at Palos Verdes. Small patches of *Macrocystis* likewise occur and nearly always consist of small plants, as measured by the numbers of stipes. The area is exposed to severe weather and large populations of herbivores are present. No patch appears to be able to maintain itself, but new growth springs up in another location after one colony of plants succumbs, so there has always been some *Macrocystis* in the area. Juvenile plants in various stages of development can usually be found, especially in the vicinity of a newly-formed canopy. Mortality in the area can, however, be quite high (Table 7), and may explain why extensive colonization has not occurred.

The Santa Barbara kelp bed showed some decline during the warm water years but recently has expanded (Table 14). Although the Santa Barbara discharge is small, being approximately a tenth of the San Diego volume and a sixtieth of the volume handled by the Los Angeles County Sanitation Districts' system, the proximity of the kelp bed to the terminus raises reasonable doubt as to whether a discharge can have an appreciable influence on this form of *Macrocystis*. It was noted above, however, that the mortality rate of plants in the Santa Barbara bed appears to be relatively low. Mature plants are known to support their lower structures by translocation of nutrients synthesized in the brightly illuminated canopy, down the long stipes, to the dimly lit underlying regions (Parker, personal communication). Adult plants, therefore, would not be as vulnerable to changes in water transparency as juveniles or other attached algae of short stature, and the translocation mechanism, combined with a low mortality rate, may enable the *Macrocystis* at Santa Barbara to persist in the immediate vicinity of a submarine outfall.

Table 14

Fluctuations in extent of the portion of the entire bed 22 lying east of the Santa Barbara outfall and presumably, therefore, not greatly influenced by harbor activities. The areas considered in Table 1 were only those portions of the bed immediately adjacent to the outfall and harbor.

Year	Type of Survey	Area km^2
1911	Boat & sextant	1.82
1949	Aerial Photo	1.42
1955	" "	1.13
1958	" "	0.55
1959	" "	0.58
1960	" "	0.35
1961	" "	0.74

The Punta Banda peninsula, just south of Ensenada (Fig. 51), was sampled in August, 1958. This area is noted for cold, clear water, presumably the result of upwelling. It faces about the same direction as the southwest aspect of the Palos Verdes peninsula, and like that area, supports an abundant intertidal population of the black abalone, *Haliotis cracherodii*. It is of further interest in that there are several areas of the ocean bottom which are apparently quite barren of algal growth, presumably because of the presence of hordes of the sea urchins, *Strongylocentrotus purpuratus* and *S. franciscanus*, which are omnivorous in habit and frequently are observed eating plant material. A survey was conducted of one such area, located in Papalote Bay (Fig. 51). The results are shown in Table 15.

The rocks contained within the sample area were again covered with *Lithothamnium*, and no attempt was made to estimate the amount. It can be seen that the quantity and character of the algal cover is quite different from that of La Jolla. *Calliarthron* is a hard, long, dichotomously branched, articulated shaped, calcareous, red alga, and it was found necessary to use a steel chisel to remove it effectively from the rocks. It probably is able to withstand the grazing activities of sea urchins as well as, or better than, most species of algae.

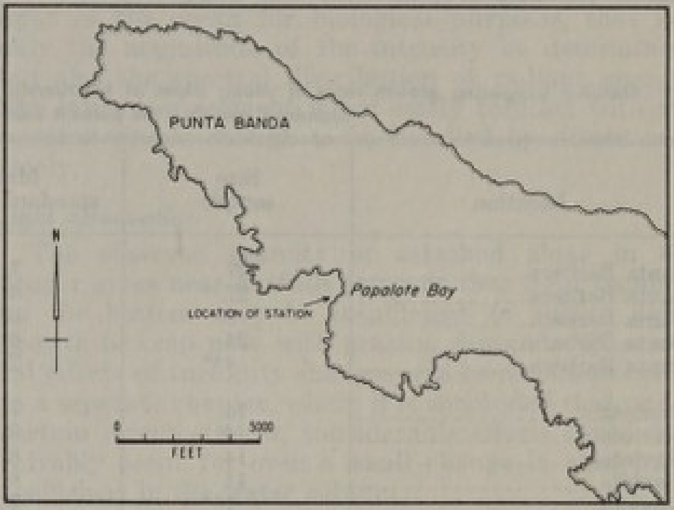


Figure 51. Chart of Punta Banda, showing Papalote Bay and the location of a barren area sampled for seaweeds.

Regularity of Growth. From several hundred elongation measurements, conducted over a 900 km geographical range from Gaviota to Turtle Bay, we have gathered sufficient evidence to indicate that the developing *Macrocystis* frond tends to elongate in a prescribed pattern which can be described by the equation $E = G - (2\log_e L)$ where E is daily elongation expressed as a percent of the total length L, and G is the normalized daily elongation when the frond was of unit length. Because of the uniformity with which growth of young stipes occurs, the rates of elongation can be used as a field method for determining the state of health of a plant. In particular, it has enabled us to study conditions presumably within the influence of an outfall and compare them with a control area free from the effects of discharged wastes.

Table 15

Weights of algae (all *Calliarthron*) collected from sample areas of 1 m^2 at Papalote Bay, and urchin (*Strongylocentrotus purpuratus*) concentrations observed.

Sample no.	Date collected	Depth m	Urchins/m^2	kg of *Calliarthron*/m^2
1	8/13/58	5.7	85	0.8
2	8/14/58	5	143	0.3
3	"	6	177	0.07
4	"	6	69	0.1

Santa Barbara Growth Studies. During the years 1960-61, the Santa Barbara kelp bed recovered from its warm water regression and extended to within about a thousand feet of the Santa Barbara outfall; growth studies were undertaken at this time to compare rates of elongation of juvenile fronds attached to those adult plants closest to the outfall with comparable controls some 25 miles west at Gaviota. No significant differences were noted, although the Santa Barbara area characteristically had much more turbid water (Tables 16 and 19). The explanation for this apparent independence from light energy arises from the fact that nutrients synthesized in the mature fronds in the surface canopy can be translocated down the stipes to nurture growth of the dimly illuminated juvenile fronds. This was suggested by Clendenning and Sargent (1958b) who demonstrated that respiration exceeded photosynthesis at the base of kelp plants under thick canopies. Further confirmation has come from studies wherein removal of mature stipes nearest a juvenile frond on the holdfast attach-

Table 16

Statistics comparing growth rates of young stipes of *Macrocystis* at an outfall site near Santa Barbara and at a control station at Gaviota. Standard growth is the percent daily elongation normalized to a one meter length.

Location	Size sample	Mean standard growth	Standard deviation	Coefficient of variation	Dates (1960-61)
Santa Barbara	27	7.5	2.30	31	9/14 to 9/29
Santa Barbara	27	6.3	1.72	27	9/29 to 10/12
Santa Barbara	5*	6.5	0.53	8	10/12 to 10/27
Santa Barbara	24	6.2	1.42	23	10/27 to 11/17
Santa Barbara	4**	2.0	0.46	23	11/17 to 1/11
Gaviota	14	7.0	1.50	22	9/15 to 9/30
Gaviota	14	8.6	1.23	14	9/30 to 10/13
Gaviota	14	8.2	1.04	13	10/13 to 10/28
Gavoita	11	6.3	0.69	11	10/28 to 11/18
Gaviota	1**	2.8			11/18 to 1/12

* Poor visibility hindered operations severely.
** Most of the experimental fronds were senile and decaying.

Table 17

Summary of an experiment testing the effects on young growth of cutting away the mature fronds attached near the young test frond. The results presented are standard growth rates. Cutting was done on 9/28/60 (1 mature frond removed per young frond) and on 10/6/60 (3 to 4 mature fronds removed).

Plant no.	Frond no.	9/10–9/21	9/21–9/28	9/28–10/5	10/5–10/14	10/14–10/20	10/20–11/2	11/2–11/13	11/13–11/20	Remarks
1	A	6.4	8.6	8.0	6.7	7.8	6.6	5.3		Control
	B	7.4	8.3	10.1	8.5	7.8	6.9	7.0		Control
	C	7.6	8.6	7.6	6.7	3.4	4.1	2.5	1.9	Cut
	D	8.1	7.4							Cut
2*	E	7.4	7.9	4.7	2.8	2.0	3.2	2.3	2.0	Control
	F	9.3	9.6	6.0	5.8	4.2	4.9	4.9	2.7	Cut
3*	G	4.6	8.5	7.3	4.0	1.7	1.7	1.5	0.8	Cut
	H	3.0	2.6	1.1		1.4	1.6	0.4		Control
4	I	8.0	8.6	9.2	3.6	4.1	2.0	2.2	0.2	Cut
	J	7.3	7.8	7.6	5.5	4.7	8.4	1.1		Control
	K	2.4	0.6	0.4						Control
	L	9.8	10.2	8.4	2.7	2.6	3.4	1.1	2.3	Cut
5*	M	5.2	6.0	6.8	6.4	6.0				Control
	N	5.3	5.3	1.4	0.6	1.2	0.5	0.4	0	Cut
6	O	5.5	5.4	6.3	4.8	7.2	9.7	5.3	4.9	Control
	P		3.7	2.7	2.2	3.2	1.3	0.8	0.6	Control
	Q	6.6	5.7	6.3	3.3	1.6	0.5	0.9	0.6	Cut
	R	7.0	6.5	8.8	5.9	7.5	6.6	7.1	7.0	Cut**
7*	S	6.5	3.2	0.7	1.2	1.3	2.2	1.1	2.1	Cut
	T	6.3	5.7	1.3	0.3	0.8	2.5	0.7	1.7	Control
8*	U	6.7	8.7	6.5	8.2	7.3	7.2	2.9	2.6	Control
	V	10.0	10.8	7.0	8.0	5.7	4.1	2.4	2.6	Cut
9*	W	2.8	1.2	1.0	0.6	3.2	0	0.5	0.8	Control
	X	4.0	6.9	3.7	4.0	3.7	1.4	2.8	1.1	Cut
Averages		7.1	7.8	6.0	4.1	3.4	2.8	2.4	1.9	Cut
		5.5	5.5	4.7	4.2	4.3	4.7	2.6	2.1	Control

* Small plants where the cutting may have influenced both test fronds.
** Although several mature fronds were removed, young frond was still located near other intact mature fronds.

ment was found to cause a drastic decrease in the elongation rate of the young frond (Table 17). Translocation has recently been followed by the use of radioactive tracers and dyes (Parker, personal communication).

It is apparent, then, why no difference in elongation rates was found between the Santa Barbara bed and Gaviota areas. Although the outfall affected the water clarity in the Santa Barbara bed, there were no toxic influences from this primarily domestic type of waste discharge.

Light Measurements

Sunlight is a factor of paramount importance to kelp because it is the source of energy for the photosynthetic processes whereby the plant manufactures its food. The action spectrum for photosynthesis in *Macrocystis* is probably similar to that of *Coilodesme* (Haxo, personal communication), which was studied by Haxo and Blinks (1950). In the latter brown alga, light absorbed by chlorophyll and carotenoids in the region 400 to 500 mμ was found to be photosynthetically active as well as light of wavelengths 500 to 560 mμ where absorption is by a carotenoid-protein complex involving fucoxanthin. Minimum activity in this seaweed occurred in the region 560 to 640 mμ.

It is important, therefore, when measuring ambient light in the ocean for biological purposes, that not only the magnitude of the intensity be determined, but also the spectral distribution of radiant energy. The latter requirement is not easily fulfilled with apparatus simple enough to be handled by divers routinely.

Light Attenuation

The observed scarcity of attached algae in the deeper areas near outfalls suggests that light incident on the bottom may be insufficient to enable plant growth to keep pace with grazing demands. Theoretical effects of turbidity changes will be discussed below in a separate chapter, where it is concluded that under certain circumstances, considerable effects could conceivably occur for even a small change in absorption coefficient in the water column.

Table 18

Monochromatic values of attenuation obtained at various locations.

Date	Location	Depth m	Distance from nearest outfall km	Color	Attenuation Percent	Remarks
6/27/58	Whites Point	10.5	0	Blue	25	
6/27/58	Whites Point	10.5	0	Green	25	North, IMR Ref. 58-11
6/27/58	Whites Point	10.5	0	Orange	25	
6/27/58	Whites Point	10.5	0	Red	35	
12/22/58	Point Vicente	20	8.7	Blue	>25	
12/22/58	Point Vicente	20	8.7	Green	>25	
12/22/58	Point Vicente	20	8.7	Orange	29	
12/22/58	Abalone Cove	6	6.4	Blue	26	
12/22/58	Abalone Cove	6	6.4	Green	26	
12/22/58	Abalone Cove	6	6.4	Orange	34	
12/23/58	Long Point	17.3	7	Blue	20	
12/23/58	Long Point	17.3	7	Green	19	
12/23/58	Long Point	17.3	7	Orange	24	
12/23/58	SE. Portugese Bend Bay	11	3.2	Blue	52	
12/23/58	SE. Portugese Bend Bay	11	3.2	Green	36	
12/23/58	SE. Portugese Bend Bay	11	3.2	Orange	42	
12/23/58	Whites Point	10.5	0	Blue	72	Very poor underwater visibility
12/23/58	Whites Point	10.5	0	Green	40	
12/23/58	Whites Point	10.5	0	Orange	46	
12/30/58	La Jolla Kelp Bed	11.5	---	Blue	15	
12/30/58	La Jolla Kelp Bed	11.5	---	Green	12	
12/30/58	La Jolla Kelp Bed	11.5	---	Orange	13	
12/31/58	La Jolla Submarine Canyon	18.5	---	Blue	11	Good visibility
12/31/58	La Jolla Submarine Canyon	18.5	---	Green	15	
12/31/58	La Jolla Submarine Canyon	18.5	---	Orange	24	
9/60-1/61	Santa Barbara	10	0.3	Red	52	Average values, See Table 19
9/60-1/61	Santa Barbara	10	0.3	Orange	42	Average values, See Table 19
9/60-1/61	Santa Barbara	10	0.3	Green	32	Average values, See Table 19
9/60-1/61	Santa Barbara	10	0.3	Blue	38	Average values, See Table 19
9/60-1/61	Gaviota	10	---	Red	40	Average values, See Table 19
9/60-1/61	Gaviota	10	---	Orange	27	Average values, See Table 19
9/60-1/61	Gaviota	10	---	Green	17	Average values, See Table 19
9/60-1/61	Gaviota	10	---	Blue	21	Average values, See Table 19

Table 19

Light attenuation measurements at Santa Barbara (about 1,000 feet from the outfall terminus) and at a control station at Gaviota. Values represent the fraction of the surface light reaching a horizontally oriented photocell at the bottom. Depths were 10 m at both stations.

Location	Red	Orange	Green	Blue	Date (1960-61)
Santa Barbara	0.00062	0.0018	0.011	0.0031	9/14
Santa Barbara	<0.0015	0.0041	0.0064	0.0022	9/29
Santa Barbara	<0.0013	0.0074	0.062	0.020	10/12
Santa Barbara	<0.0042	<0.00029	<0.0071	<0.0051	10/27
Santa Barbara	<0.0055	0.0081	<0.013	<0.013	11/17
Santa Barbara	<0.0013	0.00049	0.0015	<0.0030	1/11
Average*	0.00062	0.0044	0.020	0.008	-----
Gaviota	0.0091	0.055	0.16	0.087	9/15
Gaviota	0.0064	0.14	0.20	0.11	9/30
Gaviota	0.0052	0.031	0.073	0.076	10/13
Gaviota	0.0032	0.0109	0.069	0.036	10/28
Gaviota	0.0088	0.0050	0.33	0.270	11/18
Gaviota	0.0013	0.0040	0.048	0.018	1/12
Average	0.0057	0.04	0.15	0.10	-----

* Excluding all values where water opacity was so great that no bottom reading was obtained (i.e., "less than" symbols have had to be used).

A large scale program of submarine light determinations was beyond the scope of this program. A few surveys were made, however, to establish some basis for estimating ambient intensities in different locations, and to gain some idea of spectral distributions and attenuation coefficients. Measurements of light intensity are made just beneath the surface, using plexiglas color filters (red, orange, green, and blue) in an underwater photometer, and the same measurements are repeated on the bottom. The depth at the location is measured with a depth gauge or sounding line and the total attenuation throughout the water column is then computed. From this information the average attenuation coefficient (the percent of radiant energy lost because of absorption and scattering per meter of transit) was calculated, as well as light lost, spectral distribution, and radiant energy striking the bottom.

It can be seen from Table 18 that the Palos Verdes measurements tended to yield considerably higher values of attenuation coefficients than were found for La Jolla. We believe that restraint must be exercised

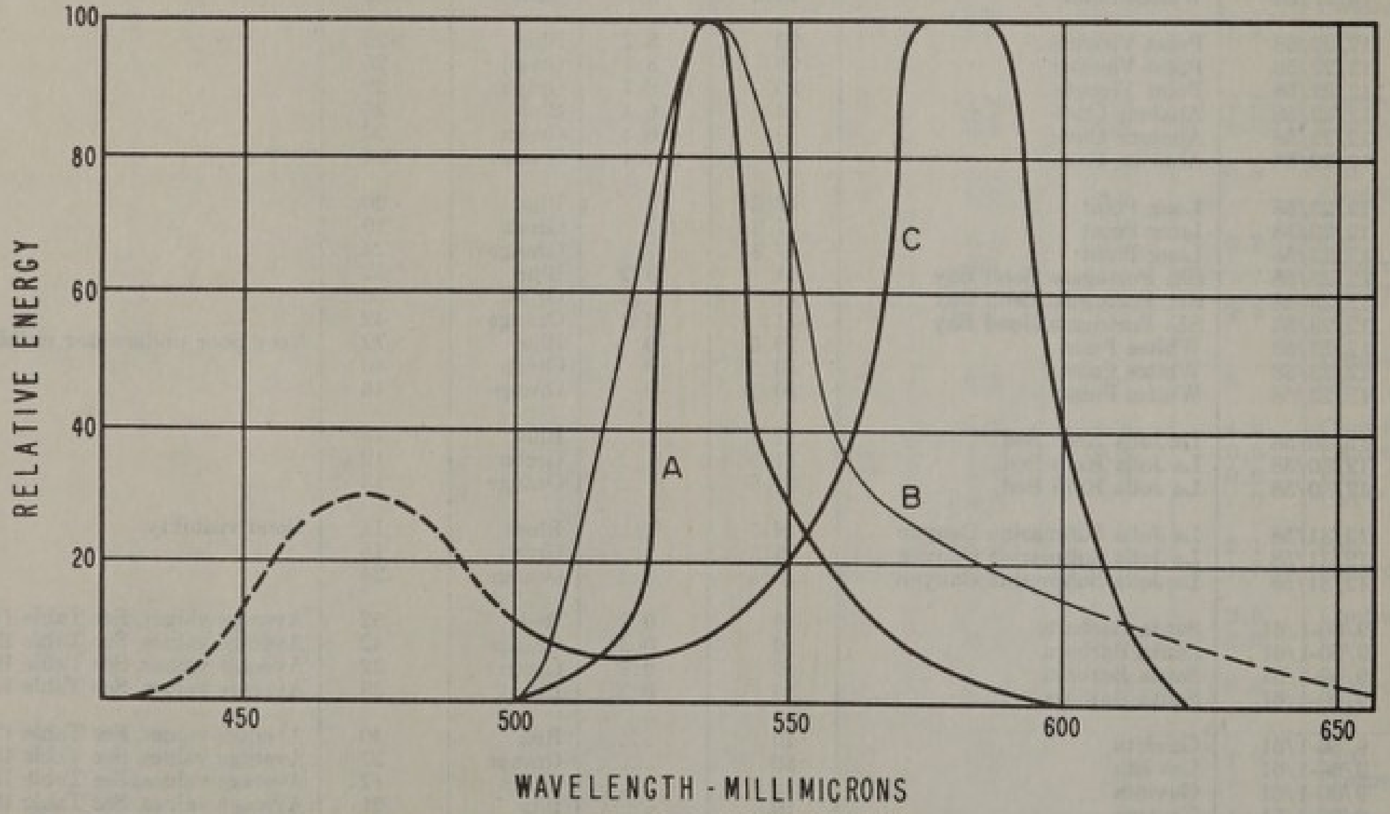


Figure 52. Relative spectral distribution of radiant energies measured in three kelp beds. Curve A is for Station 4 at Pt. Loma shown in Figure 39, curve B is for Station 3 in Figure 39, and curve C is for the Santa Barbara bed described in the text.

in interpreting these values, however, until a considerably greater number are available for comparison. If, for example, the measurements had been made a month earlier, the differences would probably not have been nearly as striking. In fact, there were probably times during the summer when red tide conditions at La Jolla caused far more attenuation of light energy in the water column than even the highest values listed in Table 18 for Whites Point.

Total light loss was determined on 6 separate visits to Santa Barbara outfall and this was compared with a control area at Gaviota (Table 19). Average attenuation coefficients were computed from this data (Table 18).

Fig. 52 shows the calculated relative spectral distribution of radiant energy measured on the sea floor under kelp canopies at three different locations. Curves A and B represent readings in beds at Point Loma which presumably were not in sea water containing appreciable sewage at the time of the measurement because of the extreme clarity of the water. Curve C shows the spectral distribution for the corner of the Santa Barbara kelp bed nearest to the city's outfall, taken at a time when the current direction was such as to carry the effluent into the bed. Because of the broad bandwidths of the colored filters employed, certain segments of the curves of Figure 52 may not be entirely accurate and accordingly, these sections of the curves are represented by dotted lines. Mathematically, more than one solution is possible under the conditions of the determination for the dotted-line regions, and that solution which would appear to be the most logical is represented; where the curve is depicted by a full line, however, confidence may be placed in the interpretation. The ordinate is taken as relative energy to enable spectral comparison. If absolute values were plotted, curve C would be quite small in height while A would be intermediate between B and C.

Curves A and B show that both distribution patterns found off Point Loma had the major portion of the energy concentrated in a narrow band centering around 530 to 540 mμ. The deep pattern, A, (70 ft. depth) was somewhat more narrow than the shallow distribution, B (36 ft. depth). It is noteworthy that this radiant energy could be utilized by the brown algal pigment fucoxanthin or the photosynthetic pigment phycoerythrin of red algae.

Curve C shows a distribution of an entirely different character. The main concentration of energy shifted towards the red end of the spectrum with the new peak at about 580 mμ. Proportionately, more energy also appeared at wavelengths shorter than 500 mμ than was found at Pt. Loma, but the exact character of its distribution is in doubt because of the broad transmission characteristics of the blue filter employed. The significance of curve C is that the radiant energy is probably less effective in promoting photosynthesis since the greater part of the energy occurs at wavelengths where photosynthetic pigments display reduced absorption.

Absolute values of light intensity measurements are listed in Table 20 for various locations. The readings were all made with the use of a green filter whose maximum transmission was in the region of 530 to 540 mμ with 50% or more of the energy within 10 to 15 mμ to either side; the values therefore represent radiant energy in a region of high absorption by phycoerythrin and fucoxanthin. In order to enable a basis for comparison, the depths, times of day, and sky conditions are given.

Several conclusions are evident. Light intensity of this spectral character within the water column is strongly reduced by the kelp canopy lying on the surface. In the instance where this factor was measured at Pt. Loma, a reduction of fourfold was encountered.

Turbidity can be very effective in reducing light intensity, as shown by the readings taken at San Diego Bay, La Jolla, and Santa Barbara. It is of interest that a fairly high intensity was found at Whites Point on 27, Mar., 1958, but at other times it was low.

Table 20

Values of green radiant energy measured at various locations during the final week of March 1958.

Date	Location	Time	Sky condition	Depth (ft.)	Green radiant energy Ergs/cm²/sec	Remarks
3/24/58	Central Point Loma	Midmorning	Clear	66	1600	Under kelp canopy
3/24/58	Central Point Loma	Noon	Clear	36	2000	Under kelp canopy
3/24/58	Central Point Loma	Noon	Clear	36	8700	Same location as previous reading but not under canopy
3/24/58	Entrance to San Diego Bay	Midafternoon	Clear	27	2400	
3/25/58	1 mile N. of SIO	Midafternoon	Cloudy	70	6300	Sandy bottom
3/25/58	La Jolla Kelp Bed	Midafternoon	Cloudy	60	0	Very turbid water
3/26/58	Santa Barbara Kelp Bed near Outfall	Midafternoon	Scattered clouds	40	700	Very turbid water
3/27/58	Whites Point	Midafternoon	Scattered clouds	25	7800	
3/28/58	Palos Verdes Flat Rock Point	Noon	Clear	25	3500	Under canopy
3/31/58	North Point Loma	Midmorning	Scattered clouds	70	2300	Under canopy

TOXICITY

Information on toxicity effects was sought from historical data, field observations, and laboratory studies. We have seen in the historical section that permanent kelp deterioration and disappearance at Palos Verdes and southern Pt. Loma initially began in the sections closest to the outfalls and receded northward (Pt. Loma) or to either side (Palos Verdes) away from the focal point of waste discharge. While causes other than toxicity could explain the patterns of disappearance, it was generally agreed that questions involving toxic thresholds must be answered in any investigation of the effects of discharged wastes on kelp, and a considerable portion of the program was related to this type of study.

Field Studies on Toxicity

Several approaches were taken in attempts to delineate toxicity effects in the field. Juvenile and adult plants were transplanted to various locations where kelp had been known to exist formerly; their survival or eventual loss was followed and causes for any unhealthiness or deterioration were analyzed. The general regions of outfalls were kept under continuous surveillance for any development of kelp and those beds nearest outfalls were studied, often during the course of many disappearances which occurred while the project was underway.

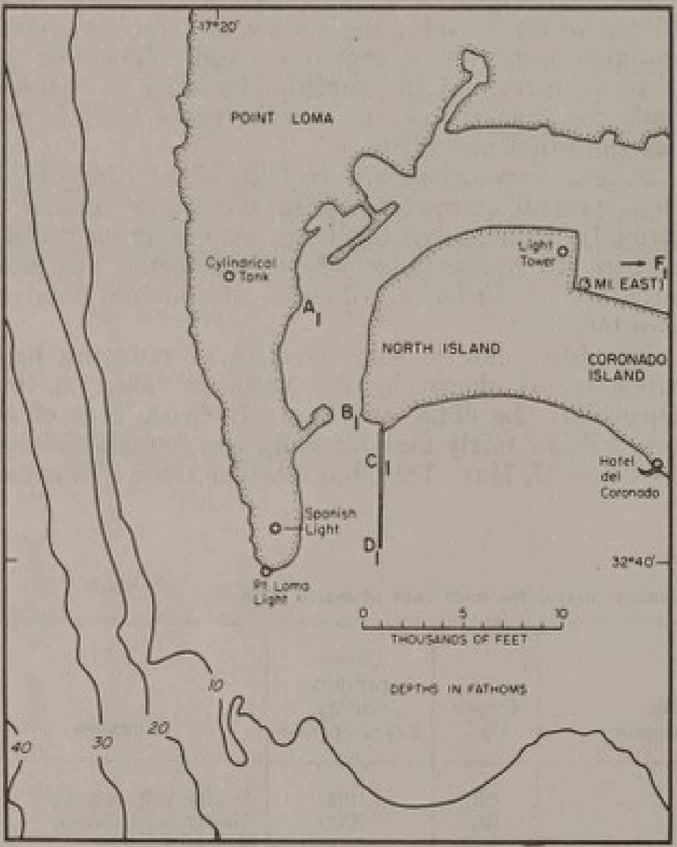


Figure 53. Chart of the San Diego Bay region, showing the locations of four stations marked A_1, B_1, C_1, and D_1 where isolated specimens of Macrocystis were found growing naturally (A_1 and C_1) or laboratory-cultured plants were set out in the field (B_1 and D_1) in March, 1957. The experiment was an attempt to ascertain whether pollution from the San Diego outfall (located approximately three miles to the east of point F) could be responsible for limiting the growth of kelp in the Bay. The main Point Loma bed stopped just east of the Point Loma light in about four fathoms of water. Specimen A was a small plant found growing attached to the rudder of a buoy boat which had last been used in early February, 1957. The jetty at the entrance to the harbor had a thick algal covering, but only one Macrocystis plant was found.

Plants and animals remaining in areas where kelp had disappeared were scrutinized for signs of unhealthiness or other symptoms which might be caused by toxic substances. Distributions of different organisms were determined to see if any unusual patterns indicated either tolerance or susceptibility to the presence of a discharge.

Transplantation Studies in San Diego Bay

Preliminary transplantation experiments were made in the spring of 1957 in the San Diego Harbor region (Fig. 53). Stations A_1, B_1, C_1, and D_1 on the map denote the locations either of young individual plants settled and developing naturally or of points where laboratory-cultured plants were set out in the field in early March. About a dozen young plants placed at Station D_1 failed to grow, but the remainder of the dozen or so plants at each of the other stations did very well until they were either removed or suddenly deteriorated when the bay water began to approach a temperature of 20° C. Fig. 54 shows plants from Station B_1 after nearly three months in the field. The location of the main discharge from the city of San Diego is shown in Fig. 55. Because the dozen or so plants at each of Stations A_2, B_2, and C_2, grew successfully and because abundant stands of brown algae grow on the jetty near Station D_2, it was concluded that the plants at this station probably did not perish because of pollution effects.

On 20 November 1957, seven adult plants of *Macrocystis pyrifera* were gathered from a small bed located in about 10 feet of water near the Point Loma light house at Station A_2 (Fig. 55). The holdfasts of

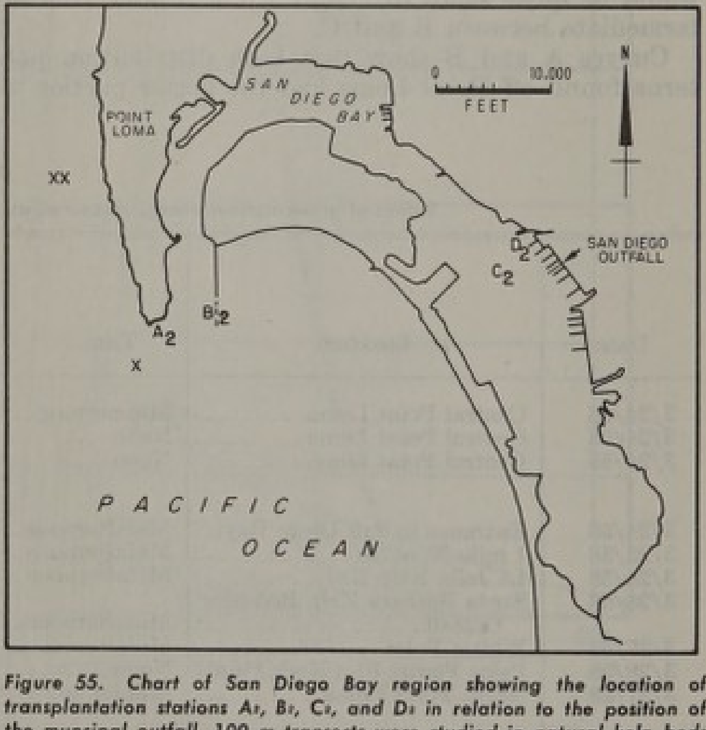


Figure 55. Chart of San Diego Bay region showing the location of transplantation stations A_2, B_2, C_2, and D_2 in relation to the position of the muncipal outfall. 100 m transects were studied in natural kelp beds at X and XX.

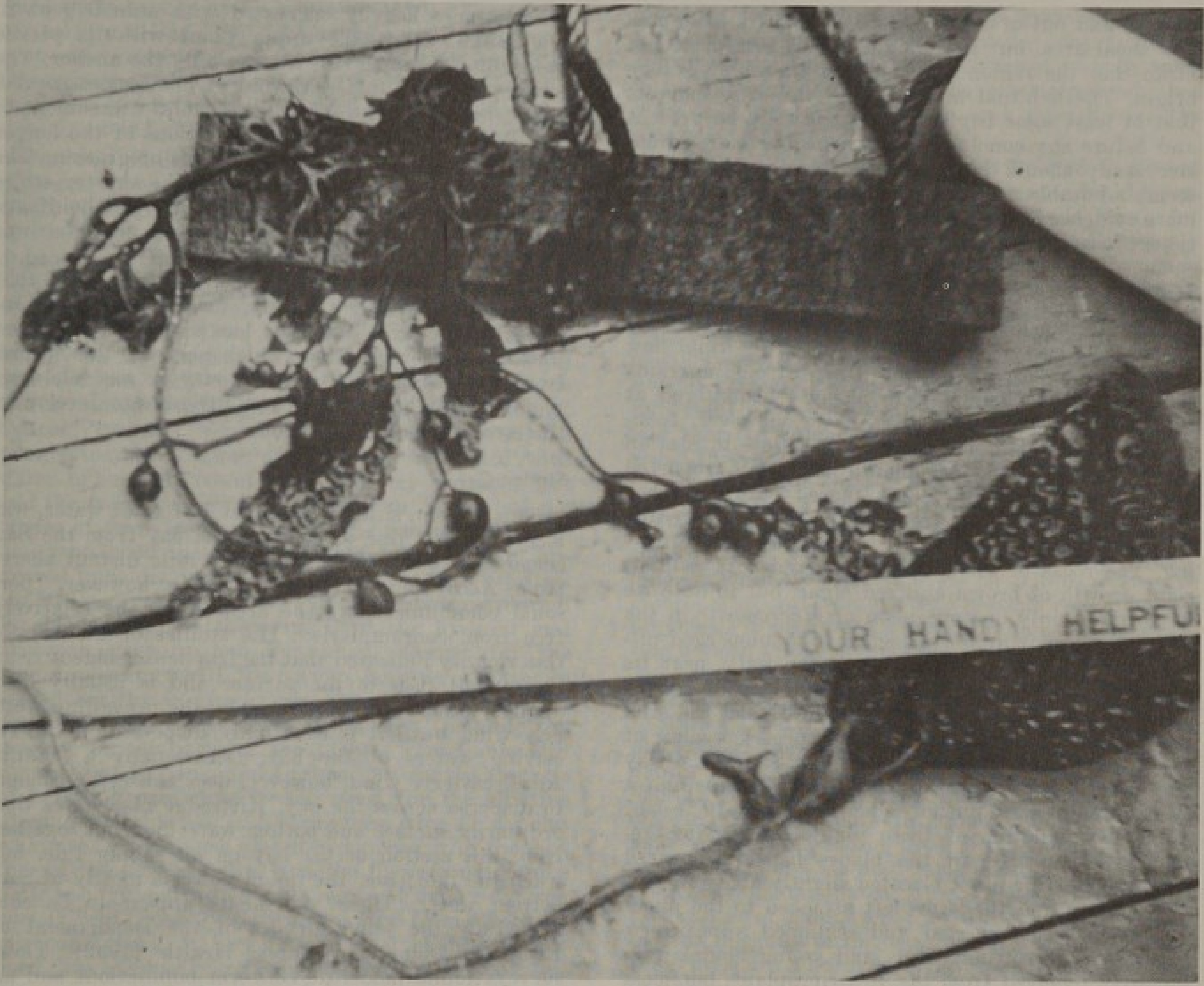


Figure 54. Young kelp plants which were germinated in the laboratory and then transplanted into San Diego Bay at Station B_1 (Fig. 53). There are seven plants shown in the picture, the largest of which was about a yard long. It can be seen that severe grazing of the blades had occurred.

the plants were held against plastic surfaces by securing them with nylon cord and the arrangement was then anchored at selected stations in San Diego Bay (B_2, C_2, and D_2, Fig. 55). During the time required to journey from the collecting point to the various stations (about an hour and a half to the last station at D_2), the plants were kept covered with damp burlap sacks on the deck of the boat.

On 25 Nov., 1957, two more plants were removed from the bottom at Station A_2 and these were then fastened to plastic surfaces as above and anchored back in the same bed from which they were taken, to serve as controls. Summaries of our subsequent observations on these plants are given below, grouped according to station.

Station A_2

Control plants of 10 and 4 stipes each were installed on 25 Nov., 1957. When examined on 13 Dec., 1957, both still had the same number of stipes and were normal and healthy in appearance. On 20 December, a dive in the area was made but visibility was less than one foot and we were unable to locate the specimens. On 2 Jan., 1958, the station was revisited and again we were unsuccessful in our searches for these two specimens. At this time the visibilty had improved to about 5 feet and the entire area was thoroughly searched. The bearings used in locating this station were excellent so presumably the plants were lost. It should be mentioned, however, that other plants in this bed, during the period covered by this report, remained entirely normal and healthy in appearance and a great number of flourishing juvenile plants were observed on the bottom at all times. Station A_2 was visited four times during this study and at all times the currents at this location were slight and different in direction from the strong velocities found out in the main channel. The main tidal flow in and out of San Diego Bay appears to bypass this shoal area, but this should not be interpreted to mean that the region does not contain water of bay origin. The habitual murkiness of the area suggests that at least some bay water may usually be present and before any conclusions are drawn, a more intensive study should be made. At the present time it seems advisable to defer such studies until there is more evidence on the influences of different concentrations of sewage-seawater mixtures on kelp.

Station B_2

This station, located across the main channel from Station A_2, was in the main stream of the tidal flow into and out of San Diego Bay. Strong currents parallel to the channel were always encountered at this location (the station was never, however, occupied at slack tide). The location was close to Station D_1 of the previous transplantation study, reported above, where juvenile plants placed on the harbor jetty (about 100 yards from Station B_2) quickly disappeared from the boards on which they were growing. The rocks of the jetty are covered with a luxuriant growth of brown and red algae, but to date we have found only one specimen of *Macrocystis* in the vicinity. This plant was attached to a submerged piling, located about 50 feet west of the jetty, near its inner end. It was decided to transplant adult *Macrocystis* to the jetty to test the hypothesis that the area was generally unfavorable to this species because of exposure to contaminated water from San Diego Bay on ebbing tides. On 20 Nov., 1957, an 18-stipe and a 17-stipe plant were anchored here in about 10 feet of water. Examination of these plants on 25 Nov. revealed that nearly all the blades had disappeared from the 17-stipe plant (located slightly above the 18-stipe plant) and the stubs left attached to the pneumatocysts had a chewed and scalloped appearance. Likewise the growing points and young blades were similarly removed from the 18-stripe plant, but most of the large blades were still intact. Except for the condition noted above, the plants were healthy in appearance and no excessive growth of encrusting organisms was noted. On 6 Dec., 1957, the station was visited, but a heavy wave surge, strong current, and murky water prevented any effective observations and the dive was terminated because of dangerous conditions after one plant with no blades was located. On 13 Dec., both plants were devoid of blades except for a few badly chewed sporophylls. The numbers of stipes were 16 and 20. Some water was noted within a few of the pneumatocysts but the fronds were still buoyant. Some hydroid- or bryozoan-like growth was noted on the stipes and pneumatocysts that extended up near the surface, but otherwise the tissues of the plants appeared to be healthy and clean. On 20 Dec., 1957, the plants had much the same appearance except that the numbers of stipes were now 10 and 17. The 10-stipe plant (lower) was attaching itself firmly to the plastic surface by means of its holdfast, and extensive young hapteral growth was noted on both holdfasts. The portions of the fronds that extended up near the surface were beginning to darken and become more heavily encrusted with animal growth. On 2 Jan., 1958, the upper plant with its plastic holder had disappeared, leaving only the anchor. The lower plant was totally devoid of blades, possessed 8 stipes, and was continuing its hapteral attachment to the plastic surface. The upper portions of the longer stipes showed an appearance of disintegration. The lower portions of these stipes and the shorter stipes and their pneumatocysts, as well as the holdfasts, seemed to be normal and healthy and no water was noted in any of the pneumatocysts.

In view of these observations, it would seem that there is intensive grazing, preferentially on *Macrocystis*, in this area and it is less likely that polluted water is the major factor which prevents this species from establishing itself on the jetty or was solely responsible for the failure of our juveniles to develop in this area a few months prior.

Station C_2

This station, situated in about 12 feet of water, was located almost due west across the bay from the San Diego sewer outfall, and about a mile distant therefrom. According to James Kittredge, however, (personal communication) the area should be relatively free from contamination. His studies of the bay in this vicinity indicated that the less dense effluent from the outfall rises to the surface and is usually held against the northeastern shore by the prevailing westerly wind until it is eventually dispersed in the receiving waters of the bay. Occasionally a "Santa Ana" easterly wind, however, does cause the effluent to disperse across the bay. Kittredge also states that ordinarily surface and bottom water flow out together from this section of the bay on an ebbing tide, but when the tide rises, the inflow consists mostly of cold bottom water. These statements appear to be confirmed by the joint surveys of the Department of Fish and Game and Public Health (1952). These surveys found moderate coliform populations and an absence of sludge in the vicinity of Station C_2. It seemed, therefore, that this location might afford an opportunity to expose plants to the environment of the inner bay without coming in contact with an excessive concentration of effluent. Unfortunately, easterly winds occur commonly in the fall along this part of the coast and, indeed, strong Santa Ana wind conditions prevailed on at least three occasions during the course of our study. One such occasion coincided with one of our visits to Station C_2 on 13 Dec., 1957, and considerable particulate matter was observed in the upper part of the water column and much scummy material floated in patches on the surface.

Even so, there was never an appreciable amount of sludge on the fine sandy bottom in this area, and a wealth of invertebrate life existed on a nearby piling and on the bottom. In addition, a red alga, *Laurencia*, grows in profusion near the surface attached to the pilings in the area and other unidentified drifting masses of algae occur unattached on the bottom. Tidal currents are strong and the two *Macrocystis* plants placed at Station C_2 were never observed to reach the surface, but were always extended downcurrent from their anchor at an angle of 45° or less to the bottom. On 6 Dec., 1957, the surface and bottom currents were measured at about 10:30 A.M. and both had velocities of about 50 feet/minute due north. A high tide of 6.8 feet had occurred at 8:00 A.M. and a low of —0.9 feet occurred at 3:11 P.M. on this day.

The two plants initially had 11 and 6 stipes each and were anchored at Station C_2 on 20 Nov., 1957. On 25 Nov., 1957, the 6-stipe plant was missing many of its blades and the remaining stubs had a chewed appearance. On 6 Dec., 1957, the plants appeared much the same except that stipe counts gave figures of 10 and 7 stipes each. Some bryozoan encrustation was noted. On 13 Dec., 1957, the plants were not as healthy in appearance as previously. They had 10 and 4 stipes each and there had been considerable sedimentation deposits on the blades. Bryozoan and hydroid growths were becoming abundant and the pneumatocysts of some of the stipes had filled with water to such an extent that buoyancy had been lost and the frond was lying on the bottom. Several of the blades of such fronds were observed to have a mold-like growth on them and the tissue of the plant appeared to be disintegrating underneath these growths. On 20 Dec., young tunicate colonies were apparent on the blades for the first time and the hydroid and bryozoan growths had continued. Except for the blades in contact with the bottom, however, the tissues looked healthy in appearance although there was extensive evidence of physical damage, possibly by grazers, on all parts of the plants. The plants still consisted of 10 stipes and 4 stipes, but the slight stress of handling proved to be too much for the 10 stipe plant and it parted at the primary stipe at a point where the nylon cord caused a depression in the surface of the primary stipe and the tissue proved to be quite spongy and soft in this region. Further damage was evident, possibly from grazers or from attack by microorganisms. It was not felt that chafing by the cord was primarily responsible for the loss of this plant since other plants which have been transplanted to oceanic locations where water movements and consequent chafing must be much greater, have shown little or no deterioration of tissue beneath the cord. Neushul and Haxo (personal communication) experienced difficulties from cord securings when transplanting juvenile plants, but large holdfasts of adults do not seem to be affected. The pneumatocysts on the plants at Station C_2 had, if anything, regained some of their buoyancy. New hapteral growth was noted in the holdfasts of both plants. On 2 Jan., 1958, the area was visited and the remaining plant had only one stipe left. The other severed stipes were entangled in it, however, so the tissues of the plant were all available for examination. The animal growth on the plants was more abundant and several nudibranchs were crawling over the surface of the kelp. Deterioration of several of the blades still buoyed up by pneumatocysts was evident and loss of carotenoid and other pigments had occurred as portions of these blades were greenish or transparent in appearance. Most of the tissues, however, even underneath the extensive animal growth, appeared healthy except where physical damage, presumably by grazers, had occurred. Sedimentation on the blades was moderate and new hapteral growth was observed in both holdfasts, although it could not be ascertained whether there had been an increase in such growth over the previous observation.

It is opined that observations at Station C_2 do not constitute evidence that the bay water in this region is toxic to *Macrocystis*. There is need for further investigation as to the responsible agents causing softening of the primary stipe (a phenomenon also observed at Station D_2) as well as those causing pigment loss in some of the blades, but it is felt that failure of the plants to maintain themselves at this location may be explained by the unfavorable activities of grazers or of microorganisms. It is, of course, important not to overdraw conclusions, but it is certain that the animal populations of the regions surveyed in inner San Diego Bay are radically different in composition from those normally encountered in kelp beds. While the preponderance of the animals in the bay are filter feeders, observations of this study suggest that there is nonetheless a sufficient abundance of animals that will graze on kelp to render the environment unfavorable. The possible role of microorganisms in producing some of the signs of deterioration noticed in our plants should not be overlooked.

Station D_2

Station D_2, located in 30 feet of water, was the only place where the experimental plants were placed at a depth appreciably different from their original habitat. Three plants were anchored about 10 feet offshore from the southern corner of the 28th Street mole, an area described by the 1952 surveys of the Departments of Fish and Game and of Public Health as grossly contaminated. We always encountered a few inches of sludge on the bottom at this station, but the thickness of the deposit varied somewhat from time to time. The area is approximately one mile northwest of the San Diego outfall, and is directly downcurrent on an ebbing tide. Strong currents were likewise encountered at Station D_2, and velocities of 50 ft./minute at the bottom and 65 ft./minute at the surface were measured here at 11:00 A.M. on 6 Dec., 1957, by timing dye marker for a known distance. At this rate of movement, therefore, effluent from the outfall would require about an hour and a half to reach Station D_2, assuming that it followed a straightline course.

The fate of the plants anchored at this station was remarkably similar to that of the plants at Station C_2. It may be noteworthy that a nearby wooden piling had a nearly identical community of filter-feeding organisms growing on it as were found on the concrete piling near Station C_2. The red alga, *Laurencia*, was likewise found in abundance on the piling at Station D_2 near the surface. Three specimens of *Macrocystis* were anchored at this station on 20 Nov. and had 7, 4 and 4 stipes each. No changes were apparent on 25 Nov., but on 6 Dec. the 7-stipe plant and one of the 4-stipers had only a single stipe left, while the remaining plant had none. The stump left on the holdfast of the latter had a chewed, uneven appearance. As at Station C_2, most of the tissues of the former two plants were still present since the severed stipes were thoroughly entwined in the single remaining intact stipe. The blades and stipes looked healthy except where there was physical damage, but grazing on the blades was somewhat less than at Station C_2. Some bryozoan encrustation was noted. On 13 Dec., the plants had only 2, 2, and no remaining stipes and the first and only fish we have observed in the inner bay was noted (a flatfish). The pneumatocysts contained some water but were still quite buoyant. Bryozoan growth had increased but, as before, the plant tissues appeared healthy. On 20 Dec., the plant which had originally possessed 7 stipes broke loose as it was being examined and the tangle of stipes and blades was carefully lifted aboard our boat and placed in a bucket of seawater to be taken to Dr. Clendenning at Scripps for further analysis by laboratory methods (see below under Kelp Plants after 1 month in San Diego Bay).

The holdfast of this plant was likewise raised and photographed. The remaining plant now supported tunicate and hydroid growth in addition to bryozoan encrustation. New hapteral growth was noted on all the holdfasts and spirontocarid shrimps were found in fair numbers in the holdfast on the boat deck. On 2 Jan., 1958, neither of the remaining plants had any intact stipes left. The holdfast of the plant which had been stipeless since 6 Dec. was beginning to darken considerably, but the other holdfast continued to show new hapteral growth.

Conclusions about the suitability of Station D_2 to support kelp growth are very much the same as those inferred for Station C_2. The water itself appears to be non-toxic, but the biological community is definitely unfavorable.

Nowhere in the regions surveyed by us within the bay was there a complete absence of animals and usually they occurred in abundance. The sparsest area we observed was at the San Diego outfall itself, but tunicates and crabs (*Hemigrapsus*) were quite common in this area. Where sludge occurs, it seems to inhibit the presence of burrowing forms such as clams, worms, and anemones, but it does not appear to affect bottom organisms such as crabs, tunicates, nudibranchs, and sponges, which can rest lightly on the oxidized yellowish surface crust. Whenever a rock or piece of debris protrudes up through the sludge, it is apt to be covered with a multitude of animals.

No transplantation was attempted to areas outside the Bay, off Point Loma because healthy, although sometimes sparse, *Macrocystis* was always present someplaces in this area throughout the duration of the study. It was felt that this constituted evidence that toxicity was not affecting the waters off Pt. Loma.

Transplantation Studies at Palos Verdes

First efforts at transplanting kelp were unsuccessful. Adult plants from the small bed at Portuguese Bend were transplanted about 2 miles east into the immediate vicinity of the outfall at Whites Point. The specimens were placed in large cages to protect against grazing, but the installation was presumably carried away by heavy seas as it was never located again although good bearings were used.

On 27 Feb., 1959, eight young *Macrocystis* plants from the Pt. Loma bed were attached to an iron framework anchored on a sandy bottom at a depth of 35 feet off of the Marineland pier at Long Point on the Palos peninsula. The location was about five statute miles from the outfall at Whites Point and natural beds of *Macrocystis* had persisted in the region at least until 1955.

As originally designed, the transplantation experiment was intended to distinguish between a number of influences which might have caused kelp to disappear from the area. Two plants were placed within cages to protect against grazing and kept under continuous illumination supplied by four photospot bulbs at a depth of 35 feet. Two other plants were kept in cages at the same depth, but not subject to continuous illumination. A plant was attached to the outside of each of the two groups of cages. Two more plants were placed in cages and were maintained by means of buoys and a rope at a depth of 10 feet, some 25 feet above the iron framework. These plants at 10 feet were not subject to continuous illumination.

The cages were made of ½-in. mesh hardware cloth and would not deter microorganisms but would prevent large grazers from attacking the plants. The two plants attached outside of the cages served to indicate whether intensive grazing existed in the area. Excessive light reduction from turbidity would be detected by failure of the deep unilluminated plants to develop, while the illuminated and the shallow plants might exhibit growth. Unfortunately, the photospot bulbs proved unreliable in operation and any turbidity effects could not be assessed. Toxicity effects would be suspected if the entire group of plants failed to develop.

All ungrazed plant tissues always appeared healthy, hence toxicity influences did not appear to have been acting adversely on the plants.

The two plants attached outside of the cages were last observed in good condition on 13 Mar., 1959; a moderate amount of grazing loss was apparent on the blades. When the installation was next visited on 3 April, 1959, one cage had vanished and the outside plants had disappeared. Some corrosion of the cages themselves was apparent.

The two caged plants at the 10 foot depth showed a good deal of animal growth, such as small hydroids, attached, which appeared to be considerably reduced in the deep plants. Extensive epiphytic growth of *Ectocarpus* likewise was troublesome nearer the surface.

On 8 April, 1959, only two deep cages remained of the original four. Both 35 feet and 10 feet deep plants appeared healthy and had exhibited growth. By May, 1959, the shallow plants had vanished and the deep ones had grown to such an enormous size that the cages were completely filled, so the experiment was abandoned.

The transplantation studies at Palos Verdes, therefore, although indicating damage from grazers, did not reveal evidences of toxic action. When large areas were cleared of sea urchins (see end of Grazing Section) young kelp plants soon appeared, indicating absence of toxicity for the gametophytic stages.

Field Observations

A great many field trips to beds at Pt. Loma, Palos Verdes, and Santa Barbara, failed to produce clear-cut evidences of toxic damage. Although plants were frequently found in an unhealthy state, causes other than toxicity could account for the circumstances. Grazing, for example, even if the grazer is motile (such as a fish) and has left the area, is detectable by the chewed appearance of the damaged kelp tissues and the healthy appearance of the unaffected tissues. Temperature damage causes general loss of pigment, brittleness of the tissues, and irregular growth of the haptera in the holdfast. Black rot causes sloughing of certain areas, but if the plant is examined at an early stage, much healthy tissue remains and usually nearly unaffected plants can be found. More detailed accounts of certain of these field studies are given in the section on surveys and further on in the section on grazing. Symptoms of toxicity damage are described in the laboratory section, below, and include blistering, browning, exudation of "yellow substance," and development of green necrotic spots.

During the project, young kelp was observed on two occasions to develop on ship's hulls at the NEL dock in San Diego Bay. The vessels had both been exposed to possible colonization by spores during journeys to waters off Pt. Loma, prior to being anchored semipermanently in the Bay. This suggests that the shallow regions of this area were not toxic to kelp sporophytes and probably the gametophytic stages as well.

Laboratory Determinations of Toxicity

A wide variety of inorganic and organic ions and compounds were tested in the laboratory with respect to their toxic thresholds for *Macrocystis*. Complex mixtures such as various oils, which conceivably may come in contact with kelp from time to time, were included. Likewise the effect of dilution by freshwater was determined, and a number of effluents and water samples from areas receiving wastes were studied. One naturally occurring potential toxicant, the red tide dinoflagellates, was also included in the investigation during the intense blooms of the summer of 1958.

Physiological Test for Toxicity

The test procedure used was as follows: Gallon glass jars were employed in two sets of six each. After preliminary washing, the jars were immersed overnight under flowing sea water; they were then rinsed and filled with the test sea water solutions, tightly covered, and re-immersed in flowing sea water for temperature equilibration. The temperature was not allowed to rise above 17°C during the test period, which normally extended for 7-10 days. The light intensity was kept moderately low to avoid CO_2 exhaustion effects, the jars were gently shaken a few times each day, and the liquid/sample ratio was high.

The test kelp blades were ⅓ to ½ of mature size from near the apical meristem of short young fronds freshly collected at 50 to 60 ft. depths by divers. The young kelp blades were placed in pairs in each of the prepared jars, the blades being held vertically upright by their floats. A sample disc was cut from one of each pair of blades beforehand, and was used in establishing the initial photosynthetic capacity. Further sample discs were taken successively from the same blades during the exposure period. The intact blades in each jar served as "uncut" controls. Sea water from the Scripps Institution pumping system was filtered and used as the control medium and in preparing the test solutions. The concentrations of suspected toxic agents were varied by factors of 10 in exploratory experiments, after which the indicated critical range was examined at smaller concentration intervals.

Reduction in photosynthetic capacity has been the most sensitive symptom of injury found as yet, and it could be measured quantitatively in advance of the qualitative or visible symptoms of injury which were also under observation. Grossly damaged blades were physically weakened and had a faded or greenish color, the capacity for photosynthesis being eliminated before these changes occur. Other symptoms of injury included (a) the production of a coumarin-like odor (b) exudation of "yellow substance" (c) browning discoloration of the spines and pneumatocysts.

Toxic Effects of Metallic Ions

Six metallic ions were tested in the laboratory (Cu, Cr, Zn, Ni, Pb, Hg). Mercury proved most poisonous but was included only for reference purposes, not as a suspected toxic agent near ocean outfalls.

$CuSO_4$ to give concentrations of 10.0, 1.0, 0.1, and 0.01 ppm Cu^{++} was first supplied to the young kelp blades. With one ppm Cu^{++} or more, photosynthesis was rapidly eliminated, the blades exuded yellow substance and also developed a "coumarin" or "new mown hay" odor, and the spines and bulbs developed a brown discoloration. The "toxicity syndrome" associated with copper poisoning is thus a very broad one. Excess copper was precipitated as basic carbonate (Harvey, 1955). The precipitated copper carried down the exuded "yellow substance" from kelp to form a brown sediment which was decomposed by acidification. The latter events may provide a simple laboratory model of what happens to copper in the sea, i.e., copper deposition in sediments from which it may be gradually released by the microbial production of acids. The copper precipitating agent in fresh sea water was shown to be the bicarbonate-carbonate buffer with the aid of "decarbonated" sea water. When the bicarbonate-carbonate was removed beforehand, copper remained in solution even at 6000 ppm (0.1M), at the natural salinity and pH of sea water.

The lowest copper concentration which had toxic effects on kelp was 0.1 ppm (Table 21 and 22) and the threshold is considered to lie between 0.01 and 0.1 ppm. Several days are required for injury at this "threshold concentration"; there have recently been instances in which kelp photosynthesis was not reduced significantly during four days exposure to 0.1

Table 21

Effects of copper and chromate upon the photosynthetic capacities of half-grown kelp blades (nine-day incubation at 17° ± 1° C).

Incubation Medium	40-45 hrs	Exposure Time in Hours 114-119 hrs	 170-174 hrs	 216-220 hrs
	(Photosynthesis as % of initial activity)			
Natural sea water	92	97	107	104
0.01 ppm Cu++	99	93	---	---
0.1 ppm Cu++	84 52	36 46 42	36 45	27 29
1 ppm Cu++	−2. +1.	−6.5 +2.	---	---
10 ppm Cu++	−7	−6	---	---
0.001 ppm Cr as chromate	109	-----	---	---
0.01 ppm Cr as chromate	100	87	---	---
0.1 ppm Cr as chromate	109	110	101	110
1 ppm Cr as chromate	98	89	82	76
10 ppm Cr as chromate	37	−7	---	---

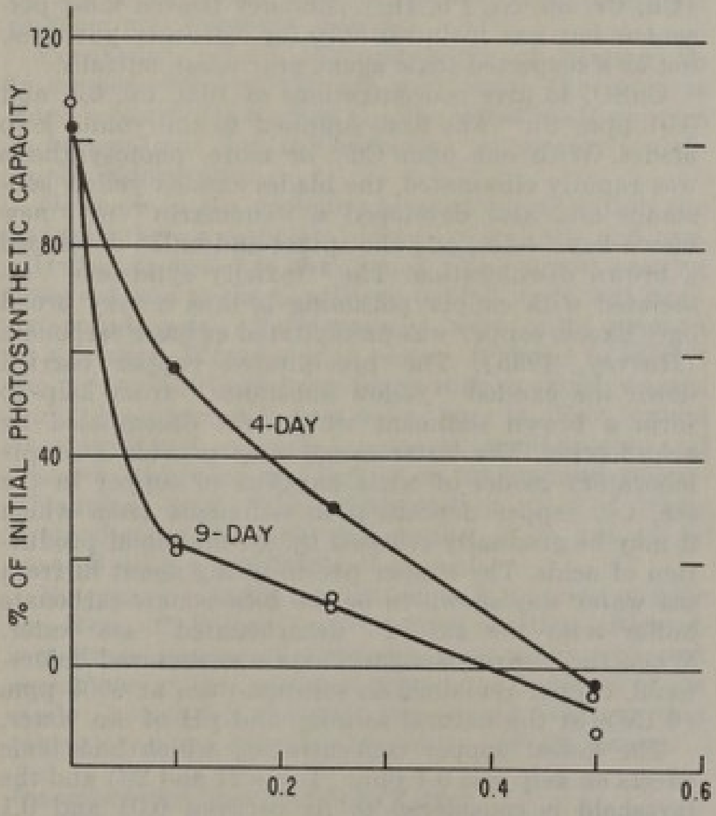


Figure 56. Inactivation of photosynthesis in half-grown kelp blades following 4-day and 9-day exposures to 0.1-0.5 ppm Cu++ in sea water at 15° C.

Table 22

Effects of copper in trace amounts upon the photosynthetic capacity of young kelp blades.

Incubation Medium	Incubation Time 23 hours	 42 hours	 118-140 hours
	(Percent of initial activity)		
Control sea water	95	113	124
0.1 ppm Cu	94	84	42
0.5 ppm Cu	39	--	−1.
1.0 ppm Cu	0	--	−2.

ppm copper. Large inactivations during the first day of exposure have always been observed with copper concentrations of 0.5 ppm upward. Since copper has a high affinity for dissolved organic matter and organic suspensoids, its action on kelp is apt to be modified in their presence. Definition of its action in marine sediments will necessitate research on the latter.

Fig. 56 reports additional data defining more precisely the toxicity of copper for kelp. After 90-hour exposures, photosynthesis was eliminated by 0.5 ppm Cu^{++}, was inhibited 70% by 0.25 ppm, and was reduced nearly 50% by 0.1 ppm. These effects became greater with increasing time of exposure. Visible injury of the kelp by 0.1 ppm Cu^{++} appeared within ten days, and after six weeks the blades were bleached white and they fell to pieces when handled. The control samples retained a healthy brown appearance during these six-week experiments. Intermittent exposures, reversibility studies, toxicity threshold concentrations for indefinitely long exposures of kelp blades and for microscopic stages of the sexual reproductive cycle, heavy metal concentrations in sea water near outfalls and in the kelp are some of the topics awaiting attention.

A logarithmic series of five hexavalent chromium concentrations (prepared from $Na_2Cr_2O_7$) between 0.001 and 10 ppm showed that chromate is strongly toxic to young kelp blades at 10 ppm but not at one ppm and lower concentrations (Table 21). During nine-day exposures, 0.1 ppm was without effect, 1.0 ppm caused a very gradual reduction in photosynthesis which only amounted to 25% in the nine days, and 10 ppm chromium eliminated photosynthesis in five days (Table 21). Young kelp blades were then exposed for equally long periods to hexavalent chromium concentrations of up to five ppm, which colors the sea water distinctly yellow. After four- and nine-day exposures, no physiological response to 2 and 5 ppm chromium was observed, and there was no apparent visible damage after ten days of continuous exposure to these high concentrations of chromium. The chromium concentration required for 50% inactivation in four days has not been defined precisely, but the available evidence indicated that it is between 5 ppm and 10 ppm. To produce equivalent injury, 50-100 times more chromium is required than copper.

Table 23

Effects of heavy metals upon the photosynthetic capacities of half-grown kelp blades.

	Metal concentrate as ppm	Incubation Time	
		One day	Four days
		Percent of initial activity	
Natural sea water		115	113
Mercury as $HgCl_2$			
$1 \times 10^{-6}M$ (0.2 ppm)	0.2	—7.7*	--
$5 \times 10^{-7}M$ (0.1 ppm)	0.1	85	—4*
Copper as $CuSO_4$			
$2 \times 10^{-5}M$ (1.3 ppm)	1.27	58	—7*
$2 \times 10^{-6}M$ (0.1 ppm)	0.127	95	100
Zinc as $ZnSO_4$			
$2 \times 10^{-4}M$ (13 ppm)	13.1	84	50* (damaged at blade tips)
$2 \times 10^{-5}M$ (1.3 ppm)	1.31	95	94
Nickel as $NiSO_4$			
$2 \times 10^{-4}M$ (12 ppm)	11.7	106	13
$2 \times 10^{-5}M$ (1 ppm)	1.17	107	56
$2 \times 10^{-6}M$ (0.1 ppm)	0.12	140	92
Lead as $PbNO_3$			
$2 \times 10^{-5}M$ (ppte) (4.1 ppm)	4.1	96	100
$2 \times 10^{-6}M$ (0.4 ppm)	0.41	103	118

* Tissue disintegrating or visibly damaged.

Table 23 reports effects of five metallic ions upon young kelp blades. Mercury was more toxic than copper. Visible damage of the distal parts of the blades occurred during four days in $2 \times 10^{-4}M$ (13 ppm) zinc. The photosynthetic capacities were reduced by four-day exposures to 2×10^{-4} and $2 \times 10^{-5}M$ nickel sulfate (12 to 1.2 ppm), but there was no outward evidence of injury to the blades by these concentrations of nickel ions. Lead was the least toxic of the metals investigated. When supplied at $2 \times 10^{-5}M$ (4.1 ppm), part of the lead was precipitated on the kelp blades. Photosynthesis was unaffected by this saturating concentration of lead, and the blades showed no visible evidence of injury. Lead, like copper, was shown to be affected by the bicarbonate-carbonate buffer in sea water.

On the basis of our studies, the relative toxicities of the tested metallic ions towards kelp are Hg^{++} Cu^{++} Cr^6 Zn^{++} Ni^{++} Pb^{++}.

In order to obtain some idea of the amount of toxic material required, consider one of the most active substances thus far investigated, copper, and estimate the amount required to cause severe damage to bed 2, at the southern tip of Pt. Loma.

According to the official map of the kelp beds of the Department of Fish and Game, the area of bed 2 was 1.85 square miles. The average depth of the bed was about 50 feet, judging from W. C. Crandall's map of the bed (Crandall, 1912) plotted in the summer of 1911. It can be calculated from these figures that bed 2 encompasses about 2.5 billion cubic feet of sea water weighing some 160 billion pounds. 0.1 part per million of copper ion inhibits net photosynthesis 50% in 2-5 days and 70% inhibition was noted in 7-9 days. A concentration of 0.1 ppm of this metal would require about 8 tons of the ion distributed evenly over bed 2. The total amount of copper which has gone into the ocean from San Diego Bay is not known. C. Gunnerson (personal communication) states that the average daily weight of copper discharged into the sea at the Hyperion outfall is 400 pounds, hence it may be somewhat unlikely to suppose that 40 times this amount was put into San Diego Bay for about a week and found its way into the Point Loma area.

If, however, we consider the possibility of small parts of the bed being destroyed from time to time, lesser amounts of toxic substance would be required, provided it be supplied regularly. If an ion were incorporated into sediments through precipitation mechanisms at times of higher concentrations and then liberated slowly at a later time, a means of maintaining a low but fairly continuous concentration might be established.

Copper could be concentrated in sediments inorganically as the sulfide, basic carbonate, etc., as well as in organic combinations. Copper sulfide formation is to be expected prior to discharge, and copper in this form should be precipitated quantitatively in widely dispersed sediments. Because of the extreme insolubility of copper sulfide, one might regard it as biologically inert, but this is apparently not the case. There is evidence of bacterial decomposition of copper sulfide (Bryner *et al.*, 1954). Porphyrins occur in all living cells, and their affinity for copper is so great that they "pull it out" of copper sulfide in *vitro* (Corwin, 1950).

Heavy metals are judged unimportant at present in the San Diego Bay area for the following reasons: No detrimental effects on kelp have been observed in tests on San Diego Bay water collected one mile or more from the municipal outfall; healthy young *Macrocystis* plants developed within the Bay at the NEL dock, which would involve exposures to the north bay water for months at different stages of development from the microscopic zoospores onward; a good local source of young kelp sporophytes during the entire study was in bed 2 at Pt. Loma, near the entrance to San Diego harbor.

Salinity

Preliminary studies utilized mature kelp blades from the surface canopy. No detrimental effects on photosynthetic capacity were observed following 18-hour exposures to salinities 25% higher or lower than natural sea water. We have also compared the responses to salinity changes of young blades from the surface canopy and from young fronds collected in the holdfast region (Table 24). After 5-day incubations at 20° C, the photosynthetic capacities were lower in the samples that had been exposed to sea water diluted 10% and 25% with distilled water. Larger responses were observed on the young bottom fronds than on young blades from the surface canopy. These kelp samples retained a healthy appearance, however, as was also the case when corresponding samples were maintained in sea water diluted 1:1 with distilled water. "Blistering" occurred only with very drastic reductions of salinity, as when sodium chloride was withheld from otherwise complete Lyman-Fleming artificial sea water. Prominent water blisters which developed on kelp blades in 10% sewage therefore were possibly not caused by the accompanying reduction in salinity.

Table 24

Effects of reduced salinities upon the photosynthetic capacities of half-grown kelp blades. (Five-day incubations at 20 ± 0.5° C).

Sample	Incubation medium	Photosynthetic capacity (% of initial activity)
Young bottom frond..	Natural sea water.....	80.
Young bottom frond..	90 parts sea water 10 parts distilled water	44.
Young bottom frond..	75 parts sea water 25 parts distilled water	45.
Young surface frond..	Natural sea water.....	124.
Surface frond........	75 parts sea water 25 parts distilled water	96.

Chlorine

No detrimental effects of chlorine on kelp were observed during 5 days' exposure to sea water provided with initial concentrations of 1.0 ppm (see Table 40). Chlorine odor was quite strong over sea water provided with 5 and 10 ppm chlorine, and at these concentrations, there was only 10-15% reductions in photosynthetic capacity following 2 days' exposure, and 50-70% after 5 and 7 days' exposure. The kelp blades retained an outwardly healthy appearance during 7 days of exposure to the latter chlorine concentrations. The effects of chlorine differed strikingly from those of sewage effluents, indicating that chlorine is not responsible for the toxic action of the latter on kelp.

Results are presented in detail below in the section treating studies of chlorinated and unchlorinated effluent from the City of San Diego Sewage Treatment Plant.

Simple Aromatic Compounds

The toxicity of toluene, benzene and n-hexane was determined at 10 ppm in sea water (Table 25). Toluene was the most toxic of these three compounds. The response to toluene was rather sluggish, but there were large reductions in photosynthetic capacity after four days' exposure to 10 ppm toluene accompanied by visible injuries. Benzene seemed to exert a small inhibiting effect between the second and fourth day of exposure, but the photosynthetic response to 10 ppm benzene was small, and the three kelp samples exposed to it retained normal appearance. There was still smaller response to 10 ppm n-hexane.

Phenolic Compounds

This important group of water-soluble compounds includes phenol (monohydroxybenzene), three isomers of cresol (methyl phenol), six isomers of xylenol (dimethyl phenol), and other related compounds and derivatives. When phenolic wastes are chlorinated in dilute solution, derivatives are apt to be formed whose toxicity, taste, and odor thresholds greatly exceed those of the parent compounds. Chlorinated phenols accordingly have been included in this study.

Table 25

Percentage of initial photosynthetic capacity retained by bottom kelp blades following exposure to 10 ppm toluene, benzene, and n-hexane.

Test solution	*Test no.*	*Exposure time* *48 hours*	 *96 hours*
Natural sea water	(a)	99	98
	(b)	125	126,132
10 ppm toluene	(a)	101	20
	(b)	102	32
10 ppm benzene	(a)	108	80
	(b)	120	106
10 ppm n-hexane	(a)	111	101
	(b)	134	119

Phenol ordinarily means monohydroxy-benzene (carbolic acid), but the term is also used as a group name for phenolic compounds, i.e., any mono- or polycyclic aromatic compound having one or more hydroxyl groups attached to ring carbon atoms. Thus phenolic wastes include phenol, cresols, xylenols, and many higher homologs. In our toxicity measurements, however, phenol refers only to the simple phenol, C_6H_5OH, which was included mainly for comparison with its chlorinated derivatives.

In preliminary experiments, young kelp fronds about one meter long were collected by divers at a depth of 50-60 feet and brought to the laboratory in buckets of sea water. They were held overnight in flowing refrigerated sea water at 14-15°C. Individual blades were removed with their bulbs and separated into two size-groups, one from each group being exposed to the various test media. Under these conditions, the photosynthetic capacity of the blades in control sea water subsequently rises with time. We have yet to show whether this increase results from normal maturation or from recovery from the harvesting operation, but it provides an extra basis for observing toxic effects. When young bottom kelp blades in the refrigerated sea water show equivalent gains in photosynthetic capacity when exposed to suspected toxic agents, the latter are judged harmless.

Equivalent gains in photosynthetic capacity were observed in control sea water and in 10^{-5}M (0.9 ppm) phenol (Table 26). The photosynthetic capacities remained unchanged in the presence of 10^{-4}M (9.4 ppm) phenol but were reduced 30% below the initial values by 10^{-3}M (94 ppm) phenol. All of the kelp blades exposed to phenol showed higher respiration rates than the controls. There was no visible evidence of injury during seven days' exposure to 94 ppm and less of phenol. Phenol oxidases are usually abundant in plants, the standard source of this group of enzymes. Detoxification of phenol by chemical combination with ascorbic acid has been reported (Leibowitz and Guggenheim, 1938; Ekman, 1942). Vitamin C, or ascorbic acid, is regularly present in marine algae (Lunde and Lie, 1938; Black and Woodward, 1957). These and possibly other detoxifying agents presumably account for the rather low sensitivity of giant kelp to phenol. A possibly damaging effect of phenol on red algae "farms" in shallow Japanese water has been indicated by Yamasaki (1955). Phenol and urea were both found to inhibit catalase in *Porphyra tenera* and *Amphiroa ephedraea*. Under intense illumination, hydrogen peroxide formed in photoxidations would be removed by catalase; if the catalase were blocked by phenol, harmful peroxide concentrations might develop in strong light, promoting solarization injury. This possibility has not been explored in surface kelp exposed to full sunlight.

On the basis of the preceding work, concentration ranges selected for further study were 10^{-4}-10^{-5}M cresols (1 to 11 ppm) and 10^{-2}-10^{-4}M phenol (9.4 to 940 ppm). Each test solution received three samples (large and small blade samples plus an apical growing point), practically all parts of the kelp fronds being represented. Several control samples were included in each experiment, and the experiments were repeated three times. The changes in photosynthetic capacity were measured after 48, 96 and 192 hour exposures.

Table 26

Photosynthetic capacities of bottom kelp blades following three-day exposures to 10^{-3} to 10^{-5}M. phenol in sea water.

Treatment	Sample	Photosynthesis as percent of initial activity
Control sea water	Large blade	135
	Small blade	120
10^{-5}M. phenol	Large blade	127
0.94 ppm	Small blade	144
10^{-4}M. phenol	Large blade	106
9.4 ppm	Small blade	99
10^{-3}M. phenol	Large blade	70
94. ppm	Small blade	72

Visibile injuries also were recorded following 8 days' exposure. The 96-hour photosynthetic data are the most useful and are summarized in Table 27.

10^{-3}M phenol caused complete or nearly complete inactivation of photosynthesis in 96 hours, and visible injuries were apparent after one week. 5 × 10^{-5}M phenol also caused over 50% inactivation in two experiments, and visible injuries also developed at this concentration. The photosynthetic and visible responses to 10^{-4}M phenol varied widely; half the samples showed less than 50% inactivation, and half showed 90% or greater reductions in photosynthetic capacity.

The responses to 10^{-4}M o-cresol shown by six samples are in satisfactory agreement, the small blades being appreciably more sensitive to this compound. Every kelp sample exposed to 10^{-4}M o-cresol developed visible injuries within one week. In four tests with 5 × 10^{-5}M o-cresol, photosynthesis was reduced 60-85%. With 1 × 10^{-5}M o-cresol, half the samples showed over 50% and half showed under 50% inactivation in four days. Visible damage to the blades and growing points developed during one week's exposure to 10^{-5}M o-cresol, so its threshold concentration for toxicity is below 1.0 ppm (and above 0.1 ppm judging from earlier work).

In four experiments with 10^{-4}M m-cresol, 80-90% inactivation of photosynthesis occurred in four days. In four experiments with 5 × 10^{-5}M m-cresol, there was an average inactivation of 50%. With 1 × 10^{-5}M m-cresol, half the samples showed over 50% and half showed under 50% inactivation. Visible damage developed consistently in the nine samples which were exposed to 1 × 10^{-5}M m-cresol for one week, so its toxicity threshold concentration is also in the range 0.1–1.0 ppm.

In six experiments with 10^{-4}M p-cresol, there was an average reduction of 40% in photosynthetic capacity in four days, two of the six samples showing 70% inactivation. In six experiments with 10^{-5}M p-cresol, there was an average reduction of 20% in photosynthetic capacity, only one sample showing over 50% inactivation. P-cresol was the only cresol isomer which did not cause visible damage to the kelp samples dur-

Table 27

Photosynthetic capacities of bottom kelp blades following 96 hour exposures to phenol and cresols.

Medium	Percent of initial photosynthetic capacity						
	Large blades			Small blades			Average
Control	118	112 123	87	115	106 88	97	106
1 × 10^{-3}M phenol (94 ppm)	0	0	12	0	--	0	2
5 × 10^{-4}M phenol (47 ppm)	--	10	--	--	36	--	23
1 × 10^{-4}M phenol (9.4 ppm)	7	52	70	7	0	93	38
10^{-4}M o-cresol (11 ppm)	47	44	48	10	2	14	28
5 × 10^{-5}M o-cresol (5.4 ppm)	47	41	--	38	15	--	35
1 × 10^{-5}M o-cresol (1.1 ppm)	40	65	80	20	35	84	54
10^{-4}M m-cresol (11 ppm)	20	--	11	20	--	11	16
5 × 10^{-5}M m-cresol (5.4 ppm)	12	94	--	38	56	--	50
1 × 10^{-5}M m-cresol (1.1 ppm)	11	99	60	13	116	21	54
10^{-4}M p-cresol (11 ppm)	74	70	29	59	92	29	59
5 × 10^{-5}M p-cresol (5.4 ppm)	55	95	--	82	73	--	76
1 × 10^{-5}M p-cresol (1.1 ppm)	70	117	81	97	96	34	83

ing one week at 1 × 10^{-5}M and apparently is the least toxic of the three cresols toward kelp. The differences between o- and m-cresols in this respect are small. Phenol is less toxic to kelp than o- and m-cresols but not less toxic than p-cresol.

In practice, phenolic wastes include phenol, cresols, xylenols, etc., which are commonly reported together as "ppm phenol". Even when o- and m- cresols predominate, 10 ppm solutions should be rendered harmless to kelp when diluted one hundred fold with natural seawater. Chlorination can increase the toxicity markedly, depending on the extent that chlorinated phenols and cresols are formed; if fully chlorinated, the toxicity could be vastly increased. Phenolic compounds are highly reactive and can be concentrated in sludges by polymerization and other condensation reactions. Phenol and cresols form clear solutions in sea water, but on standing for a week or more, polymerized material is deposited, especially from o-cresol solutions.

Chlorinated Phenols

The chemicals used in this study follow:

1. Pentachlorophenol (Eastman, reagent grade, M.W. 266.35, white crystals).
2. Sodium pentachlorophenate (Monsanto "Santobrite", technical grade, M.W. 288.34, purity above 90%, a light tan powder).
3. Pentachlorobenzenethiol (duPont, technical grade, M.W. 282.7, purity 96.5%, steel-grey granules).
4. p-Chlorothiophenol (Evans, M.W. 144.7 gm, purity 99.4%, coarse white crystals).

Past work has indicated very similar toxic effects of pentachlorophenol and its sodium salt. Both of these compounds dissolved readily in sea water at the concentrations reported in Table 28. In weighing out the chlorinated phenols with a conscious effort to avoid exposure, nausea was experienced almost at once, and two persons developed heavy colds after handling these compounds. A sickening odor was provided by only a few ppm of pentachlorophenol and Santobrite in sea water. The pentachlorobenzenethiol and p-chlorothiophenol were essentially insoluble in sea water; these were ground in a mortar with successive lots of sea water. The two resulting mixtures were at least "saturated", but part of the 10 ppm of supplies chemicals remained suspended.

Table 28

Photosynthetic capacities of bottom kelp blades following four-day exposures to chlorinated phenols.

Treatment	Sample	Photosynthesis as percent of initial value
Control sea water	Large blade	106
	Small blade	114
p-chlorothiophenol 10 ppm	Large blade	24
	Small blade	23
Pentachlorobenzenethiol, 10 ppm	Large blade	0 (photoxidation)
	Small blade	0 (photoxidation)
Sodium pentachlorophenate (Santobrite) 3 × 10^{-5}M. 10 ppm	Large blade	0 (photoxidation)
	Small blade	0 (photoxidation)
Pentachlorophenol 10^{-4}M. (26.6 ppm)	Large blade	0 (photoxidation)
	Small blade	0 (photoxidation)
Pentachlorophenol 10^{-5}M. (2.66 ppm)	Large blade	0 (photoxidation)
	Small blade	0 (photoxidation)

All of the treatments with chlorinated phenols listed in Table 28 caused large reductions in photosynthetic capacity of the kelp blades. The 10 ppm solution-suspension of p-chlorothiophenol caused 75% inhibition during four days' exposure, and photosynthesis was eliminated by the treatments with 10 ppm pentachlorobenzenethiol and Santobrite, as well as with 2.7 ppm pentachlorophenol. All of the treated blades of Table 28 were visibly injured after five days: The treated blades became green and flaccid except with 2.7 ppm (10^{-5}M) pentachlorophenol. In the latter instance, the blades became weak or flaccid, emanated "new-mown hay" odor, but retained a normal brown color.

The effect of Santobrite was also determined on a pair of kelp blades at a concentration of one ppm, (Table 29). After 48 hours' exposure, the photosynthetic capacity of the kelp was eliminated in the presence of this trace of Santobrite, whereas a gain in photosynthetic capacity occurred in the controls. The appearance of the blades following this exposure to Santobrite was the same as was observed with 2.66 ppm (10^{-5}M.) pentachlorophenol. The blades remained brown but were flaccid and also emanated "new-mown hay" or "grassy" odor.

In further duplicate experiments with 1.0 and 0.50-0.58 ppm of Santobrite, photosynthesis in kelp was eliminated during two and four day exposures, including two-day exposures to 0.58 ppm (2×10^{-6}M). The concentration required for 50% inactivation of kelp photosynthesis in four days is therefore below 0.5 ppm. A single test at 0.28 ppm showed partial inactivation in two days and complete inactivation in four days. A single test at 0.1 ppm showed no inactivation during two-, four-, and eight-day exposures. The critical concentration range is therefore 0.1–0.5 ppm for Santobrite, and presumably for pentachlorophenol as well. By interpolation, the concentration required for 50% inactivation in 96 hours (four days) is 0.2–0.3 ppm, or about 1×10^{-6}M.

Table 29

Photosynthetic capacities and respiration of bottom kelp blades before and after 48-hour exposure to one ppm sodium pentachlorophenate (Santobrite).

Treatment and sample	Net photosynthetic capacity (mm^3 O_2/sample/hour)		Photosynthesis as percent of initial value
	Before	After	
Control sea water			
large blade	50	57	113
small blade	57	74	130
Sodium pentachlorophenate, one ppm			
large blade	44	—5.5	0 (photoxidation)
small blade	46	—4.8	0 (photoxidation)

Sodium pentachlorophenate is the strongest organic poison of kelp tissue that has been encountered thus far. Its toxicity is vastly greater than that of its chlorine and phenol components, when supplied as free chlorine and free phenol. The hydroxyl or "phenol" substituent apparently does not affect the toxicity of pentachlorophenol except by promoting water solubility. The hydrogen and oxygen atoms of this hydroxyl group can both be replaced without loss of toxicity (Clendenning, 1959a). Replacing the hydroxyl hydrogen with sodium increases water solubility without reducing the toxicity; replacing the hydroxyl oxygen with sulfur (pentachlorobenzenethiol) almost eliminated solubility in water, but toxicity toward kelp is retained (Clendenning, 1959a). For these reasons, the toxicity of pentachlorophenol is based on its chlorinated benzene ring, and its water solubility is determined by the hydroxyl substituent. The intracellular effects of chlorinated phenols, cresols, and benzene are apt to be closely related, since they all possess a chlorinated benzene ring, but their different solubilities should affect penetrability and possibly other properties.

These studies could be extended along numerous lines, but they have already shown that chlorinated phenols are potent algicides with reference to young *Macrocystis* plants. The phenol or hydroxy group itself seems to contribute little to the toxicity; sodium pentachlorophenate is strongly toxic, as well as pentachlorobenzenethiol, in which the phenolic group is replaced with a sulfhydryl group. The phenol group increases solubility in water, but the algicidal action of chlorinated hydrocarbons noted by D. W. Hood, *et al.* (1958) may be basically similar to that of chlorinated phenols. It has long been known that when phenolic wastes are chlorinated during sewage treatment, chlorinated phenols are formed, imparting an objectionable odor and taste. The reported taste threshold for phenol after chlorination is 0.1 part per billion (McKee, 1956).

Pentachlorophenol is less soluble in water than its sodium salt, but as would be expected their toxicities toward kelp are very similar since both are ionized when in solution. In studying the literature on these compounds, the authors were impressed by the range of organisms poisoned by them. The Monsanto Bulletin No. 0-23 (Santobrite) discusses toxicity to fungi, bacteria, algae, protozoa, yeasts, fish, higher animals, and human beings (it is also highly toxic to insects, molluscs, and weeds).

Santobrite is used to eliminate algae and molds from industrial cooling water. It has often been used as a weed-killer, both alone and mixed with other herbicides. The Monsanto bulletin states that 0.5 ppm of Santobrite will kill most fish. LD_{50} (oral dosage for a 50% kill) for a variety of laboratory animals ranges from 50 to 500 mg/kg. Reported effects on humans include injury to the eyes, and irritation of the nose, throat, and skin. Pentachlorophenol and its sodium salt therefore should be regarded as general poisons. The basis of this general poisonous effect is not completely understood, but one "common denominator" in its effects on living cells is the uncoupling of the phosphorylation mechanism, which plays a central role in cellular metabolism (E. C. Weinbach and M. O. Nolan, 1956).

Synthetic Detergents

Synthetic detergents are compounds of relatively large molecular weight in which part of the molecule is lyophilic, having an affinity for greases and other organic substances, and part is hydrophilic, having an affinity for water. They are divided into three major groups: those which the lyophilic part of the molecule forms an anion, those in which the lyophilic part forms a cation, and those that remain un-ionized.

Among the anionic group are the alkyl benzene sulfonates, or ABS, constituting about 75% of the synthetic detergent fraction of non-soap household detergents. Most of the ABS on the market uses a polymer of propylene, principally tetrapropylene, for the alkyl group. This is a 12-carbon branched structure containing quaternary carbon atoms that block biological oxidation of the molecule; hence detergents of this type remain in the effluents of secondary sewage treatment plants. ABS can be manufactured with a straight-chain 12-carbon or dodecyl radical, and this form is attacked biologically.

Another form of anionic detergent is sodium alkyl sulfate, as for example sodium dodecyl sulfate (SDS). This type is biologically degradable, and is second in importance among the household synthetic detergents.

Cationic detergents are quaternary ammonium compounds, of quite limited household uses. They are not expected in sewage effluents because of their precipitation by the anionics.

The principal uses of nonionic detergents are industrial. Little is known about their concentrations in sewage.

Raw sewage typically contains 5 to 10 mg/l of anionic detergents. Effluents of biological oxidation plants are typically in the range of 3 to 4 mg/l.

Table 30 reports the effects of the cationic detergent "zephiran chloride" and of the anionic detergent sodium dodecyl sulfate (SDS) upon the photosynthetic capacities of young kelp blades following one-day and five-day exposures. Both of these detergents were rapidly injurious at and above 10 ppm. With 10 ppm of the cationic detergent, photosynthesis was eliminated and the blades turned green and flaccid during the first day. With one ppm of this detergent, photosynthesis was eliminated by five days' exposure. The anionic detergent was not so strongly toxic, but photosynthesis was strongly inhibited by 10 ppm SDS during the first day of exposure. A significant response to one ppm SDS was not observed. The 25% loss in photosynthetic capacity during five days in the control sea water is attributed to the high sea water temperature (20°–21°) prevailing in the laboratory at the time.

Effects on plant life near ocean outfalls are difficult to predict since certain types of detergents are rapidly decomposed by bacteria, and the resistant types which enter the receiving water are probably bound to a considerable extent on colloidal and larger particles.

According to C. N. Sawyer and D. W. Ryckman (1957), alkyl benzene sulfonates (ABS) of the polypropylene type account for half or more of the synthetic detergents in use, and they are extremely resistant to biological oxidation. Locus of this resistance apparently is the quaternary carbon atom attached to the benzene ring. Primary and secondary ABS detergents are oxidized by acclimatized bacterial cultures, but they are unimportant commercially. Tertiary ABS detergents in general are resistant to biological oxidation, but it is the branched polypropylene type which predominates in commercial detergents. These petrochemical detergents include di-, tri-, tetra- and pentapropylene benzene sulfonates, of which the tetramer is adequately representative. Sodium tetrapropylene benzene sulfonate accordingly was obtained for study from the Research Department, Procter and Gamble Co. (Table 31). Sodium dodecyl benzene sulfonate was also supplied by Procter and Gamble as a representative secondary ABS detergent.

Practically nothing was known concerning ABS detergents in marine environments, and some interesting facts emerged. Their solubility in sea water was slightly below 0.01% (100 ppm). While this was much lower than in distilled water it is high enough so that it cannot be expected to precipitate under conditions of normal waste discharge. The sea water constituents responsible for this solubility proved to be $MgCl_2$, $CaCl_2$ and NaCl, with which the precipitating action of complete sea water was duplicated. Supplied singly at their concentrations in Lyman-Fleming sea water, their relative effectiveness as ABS-precipitants was Mg, Ca, Na. Increasing the concentrations of $MgCl_2$ and $CaCl_2$ above those in sea water caused further decreases in ABS solubility; in molar $CaCl_2$ and molar $MgCl_2$, ABS solubility was reduced to 2 to 5 ppm. The ABS-detergent fraction in the Whites Point effluent was removed by the froth flotation method of McGauhey and Klein (1959), filtered, then mixed 1:1 with clear saturated $CaCl_2$ solution. This treatment caused development of turbidity, but the ABS concentration was insufficient for spontaneous sedimentation.

Kelp blades and growing points were rapidly injured by 5 and 2 ppm of the ABS detergent (Table

Table 30

Effects of trace amounts of an anionic (SDS) and a cationic (Zephiran chloride) detergent upon the photosynthetic capacity of young kelp blades.

Incubation fluid	Incubation Time	
	One day	Five days
Control sea water	105 ± 10	80
SDS one ppm	116	73
SDS 10 ppm	24	9
Zephiran chloride one ppm (cationic)	93	—2
Zephiran chloride 10 ppm	—12.5	blades disintegrating

31), but a significant photosynthetic response was not shown at 0.5 ppm. The concentration range in need of further study is 0.5 to 1.5 ppm, within which 50% inactivation of kelp photosynthesis in four days is to be expected. The toxicity of the pure tertiary ABS detergent to kelp is similar to that of cationic detergents of the quaternary ammonium type, one having a quaternary carbon and the other a quaternary nitrogen atom. The solubility of petroleum compounds in water is increased by either of these types of detergents, so synergistic effects having this basis are possible when oil substances and detergents are supplied simultaneously in very low concentrations. Monomolecular films containing ABS detergents and other petroleum compounds could conceivably develop on rocks near outfalls, denying these surfaces to attached plants, a possibility which has yet to be explored.

Fuel Oils

Some Properties of Fuel Oil Emulsions. Certain field studies under this program were concerned with the changes in the fauna and flora of a small bay which became grossly contaminated with diesel oil after the *Tampico* wreck (North, 1957a, 1957b, 1958b, 1958c; Neushul, 1958). How could diesel oil remove benthic animals as much as 20 feet below the water surface? Are the toxic effects of fuel oils on kelp and kelp grazers sufficiently different to allow oils to be used in kelp beds as a means of suppressing sea urchins and other kelp predators? In investigating these and other questions, three fuel oils were used: dark diesel and boiler fuel oils supplied by the U.S. Navy fueling station at Point Loma, and a dark diesel oil matching the *Tampico* cargo, which was supplied by the Union Oil Company, Brea, California.

Table 31

Percentage of initial photosynthetic capacity retained by bottom kelp blades following exposure to 0.5-5.0 ppm ABS detergent.

		Exposure time	
Test solution		*48 hours*	*96 hours*
5 ppm ABS detergent *	(a)	0	0
	(b)	0	0
2 ppm ABS detergent	(a)	0	0
	(b)	0	0
0.5 ppm ABS detergent	(a)	104	94
	(b)	114	99
Natural sea water	(b)	99	98
	(b)	125	126,132

* Sodium tetrapropylene benzene sulfonate, Procter and Gamble Co.

It was reasoned that the oil released by the *Tampico* probably became emulsified in the surf and subsequently spread as an emulsion to the deeply submerged animals on the bottom. To test this interpretation, a film of diesel oil was provided on a dish of sea water, which was then poured through a height of three to four feet into a second vessel. An emulsion formed at once. This test showed that oil emulsification could occur rapidly in the surf. For the routine production of seawater-fuel oil emulsions, a one-minute treatment in the Waring blendor was adopted. Oil emulsification was not dependent on sea water constituents or stabilizing impurities since it occurred readily in distilled water. These emulsions were not broken by 40 minutes centrifuging in a clinical centrifuge, and they also remained cloudy on standing for days; the sea water-oil emulsions cleared on standing for a week or more.

Sea water-diesel oil emulsions were then examined with a calibrated measuring microscope. The turbid sea water was teeming with tiny oil globules in vigorous Brownian motion. The smallest globules showed the largest random movements, but Brownian motion was still perceptible in oil globules up to about 5 μ in diameter. The freshly prepared emulsions contained a few oil globules larger than 5 μ, plus tiny air bubbles which were removed by centrifuging, the size of the oil globules extended from 0.3 μ to 6.5 μ. The oil globules often collided during their spontaneous Brownian movements, but they were not observed to coalesce on contact.

A one-quarter sample of oil-contaminated sea water had been collected by North from a high tide-pool at the *Tampico* wreck site, and this "*Tampico* water" was provided for laboratory study. After it had stood for weeks in a clear glass jar, four zones were evident: (a) a voluminous bottom sludge (b) relatively clear water occupying ⅔ of the sample bottom (c) a voluminous top sludge and (d) a surface oil film. Most of the oil was located in the sludge fractions, which were loosely flocculent. Uncovered drops of the bottom and top sludges were examined microscopically. Both contained oil globules of widely different sizes bound in clumps of detritus. The size of the oil globules trapped in these aggregates ranged up to 120 μ in diameter, which was much larger than had been observed in sea water-oil emulsions containing negligible suspended solids. The intermediate clear water contained no oil globules after long standing. Upon shaking the sample thoroughly and centrifuging, the "clear" water now contained tiny oil globules with a maximum diameter of 2 μ. Larger globules were presumably screened out by detritus on the centrifuge.

To isolate oil from the *Tampico* water, a 250 ml aliquot was extracted in separatory funnels for two days with petroleum ether. Microscopic examination of the sludge aggregates revealed that oil globules remained within these masses after this treatment. The ether extract was filtered, evaporated at room temperature and then at 62°C. The recovered oil was darker and more viscous than the Navy diesel oil, but closely resembled the "*Tampico*" oil later supplied by the Union Oil Company.

The foregoing studies show that fuel oil is rapidly emulsified under simulated surf conditions. In the absence of suspended solids, small oil globules (<5 μ) are stabilized by Brownian motion and by unidentified factors (electric charges, surface components?) which resist coalescence when the globules collide. In the presence of suspended solids, oil globules associate with them to form oily sludges. The sludge fractions in the *Tampico* water sample have retained emulsified oil for 2½ years without preservative, so oil in this form can be very persistent. The bottom sludge in this sample could bring oil into selective contact with benthic animals.

Effects of Fuel Oil on Kelp. Large, small, and apical meristematic blades from bottom kelp fronds were first subjected for two days to 1% Navy diesel and boiler fuels which had been blended in sea water (Table 32). The four control samples all showed increases in photosynthetic capacity. Photosynthesis was eliminated in the apical meristematic and half-grown blades exposed to both oils. The large blades were inactivated by the 1% boiler fuel and their photosynthesis was reduced 85-90% by the 1% diesel oil. The kelp blades retained a normal brown color during these two-day exposures and their pneumatocysts remained functional. The blades were noticeably flaccid, however.

In the next experiment (Fig. 57 and Table 33), young blades from the surface canopy and from bottom fronds were exposed continuously to a range of emulsified diesel oil concentrations and also to surface oil films. The changes in photosynthetic capacity were measured after one, three, and seven days of continuous exposure. This experiment revealed that oil injury develops rather slowly in the kelp blades, more than one day being required for an appreciable inactivation of photosynthesis by sever oil treatments (the required time of exposure for oil injury actually is a matter of hours, but several days are required for its manifestation). After three days' continuous exposure to these diesel oil emulsions, there were large reductions in photosynthetic capacity, which increased with the oil concentration (Fig. 57). After seven days' exposure, photosynthesis was reduced to zero by 0.01% and higher diesel oil concentrations (Table 33). Damaging effects of surface oil films were observed on both surface and bottom kelp blades, the latter showing the larger response (Table 33).

In the next set of experiments (Figs. 58 and 59, Table 34), bottom kelp blades were exposed to fuel oil-sea water emulsions for 3, 6, 12, 24, and 48 hours, then washed and maintained in natural seawater for up to one week. In this way, the effects of exposure time could be distinguished from the rather long time that is required for the development of oil injury.

Figure 58 shows the large reductions in photosynthetic capacity which occurred when young bottom kelp blades were exposed to 0.01%-0.1% *Tampico* diesel oil for 3, 6, 24, and 48 hours and subsequently maintained in sea water. Photosynthetic responses to the oil were apparent following three hour exposures; 50% inactivation by 0.01% (100 ppm) of this oil occurred following one-day exposures. These changes in

Table 32

Photosynthetic capacities of bottom kelp fronds following two-day exposures to 1% Navy diesel and boiler fuel oils in sea water.

Sample	*Treatment*	*Photosynthetic capacity, % of initial value*
Large blades	Control sea water	135,114
	1% diesel fuel	11,15
	1% boiler fuel	0
Small blades	Control sea water	119
	1% diesel fuel	0
	1% boiler fuel	0
Apical meristematic blades (growing points)	Control sea water	130
	1% diesel fuel	0
	1% boiler fuel	0

Table 33

Photosynthetic capacities of surface and bottom kelp blades (from 60 feet) following one-, three-, and seven-day continuous exposures to Navy diesel oil-sea water mixtures.

		Exposure time		
Sample	*Medium*	*one day*	*three days*	*seven days*
Surface kelp blades	Control sea water	--	134	157
	1% oil in sea water	--	0	0
	0.1% oil in sea water	--	20	0
	0.01% oil in sea water	--	77.5	0
	Surface oil film (one ml on 527 cm²)	--	33	--
Bottom kelp blades	Control sea water	135	142	236
	1% oil in sea water	99	0	--
	0.1% oil in sea water	110	7	0
	0.01% oil in sea water	130	38	0
	Surface oil film (one ml on 527 cm²)	147	0	--

Table 34

Photosynthetic capacities of young bottom kelp blades following brief exposures to 0.1% *Tampico* diesel oil emulsions. (Examined on third day).

Exposure time hours	*0.1% Tampico oil emulsion (% of initial activity)*	*0.01% Tampico oil emulsion (% of initial activity)*
0 (Control)	133	132
3	107	97
6	31.1	90.6
24	27.8	65.8
24	25.0	65.0
48	1.0	39.0

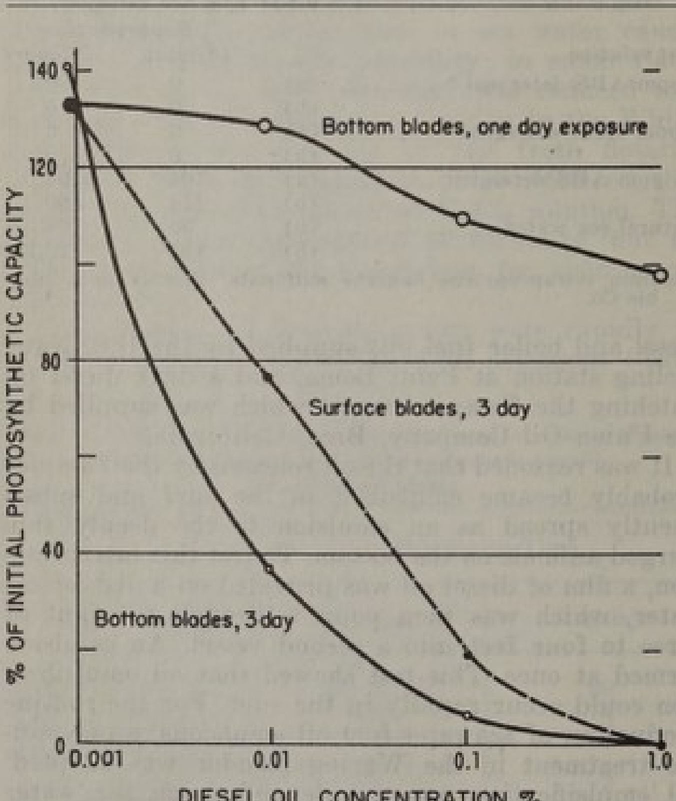


Figure 57. Inactivation of kelp photosynthesis during lengthy continuous exposures to diesel oil-sea water emulsions (0.01% is 100 mg/l of diesel oil in sea water).

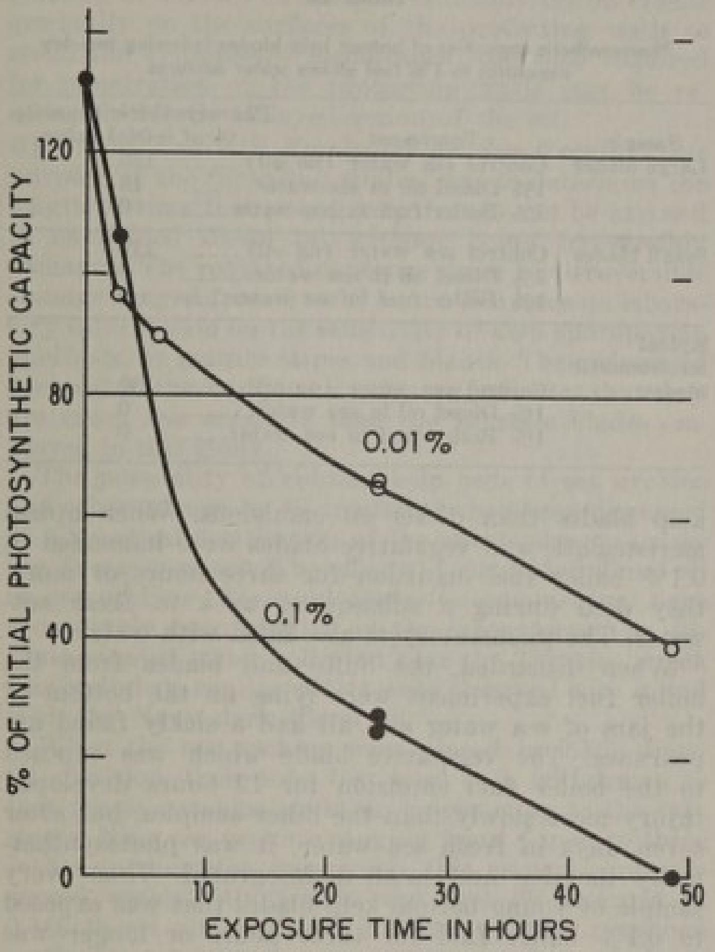


Figure 58. Inactivation of photosynthesis in half-grown bottom kelp blades following brief exposures to Tampico diesel oil-sea water emulsions.

photosynthetic capacity preceded the visible evidences of injury, which developed more slowly. After five days in sea water, practically all of the blades which had been briefly exposed to these oil emulsions were visibly damaged. (The only exceptions were the blades exposed to 0.01% *Tampico* oil for three hours, which retained the same healthy appearance as the controls.) All of the blades that had been exposed to the 0.1 emulsion for three hours or more turned green and were decomposing within one week. With the 0.01 *Tampico* oil emulsions, green necrotic spots developed on all young kelp blades exposed for six hours or longer, and the severity of this injury increased with the exposure time.

Although injury of surface and bottom kelp blades was observed following three-day exposures to a surface oil film, additional work is needed on this aspect under improved conditions. A device for supporting and rocking the blades at the surface would be superior to the crude method used thus far. To preserve a surface oil film over a period of days, losses by creeping and evaporation need to be prevented; when a very thin continuous oil film is provided in a glass aquarium, it soon breaks into patches which decrease in size. At least in the laboratory, the same amount of diesel oil supplied as emulsified droplets is more persistent than when supplied as a surface film.

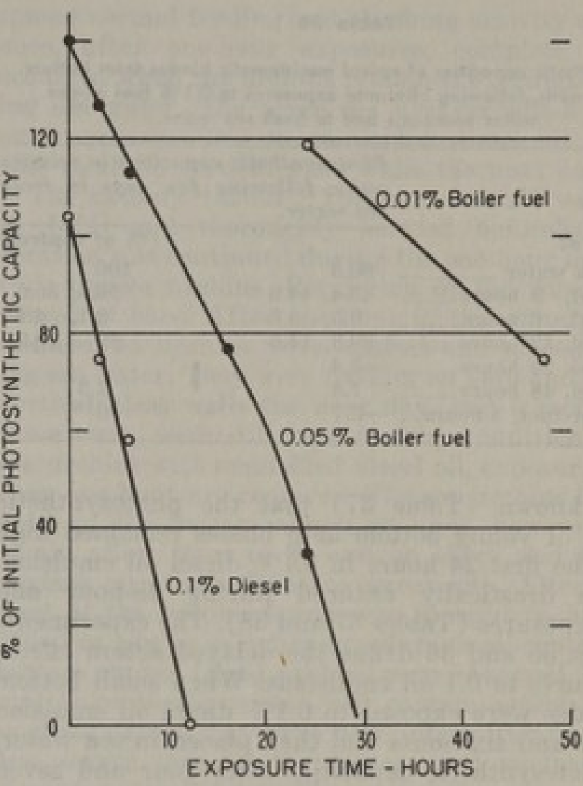


Figure 59. Inactivation of photosynthesis in half-grown bottom kelp blades following brief exposure to Navy diesel and boiler fuel emulsions.

The next set of experiments (Tables 35 and 36) involved exposure of bottom kelp blades to 0.1% diesel and boiler fuel emulsions for relatively brief periods, after which the kelp samples were washed carefully in flowing sea water and then maintained for up to one week in 4-gallon jars of sea water, which was changed daily. These experiments allowed reversible effects to be distinguished from irreversible effects, and also demonstrated that although relatively brief exposures to the dilute oil emulsions can be injurious, days are required for the development of injuries which can be detected or measured. The "delayed action" effect of oils revealed in this study has not previously been studied.

Table 35

Photosynthetic capacities of bottom kelp fronds following alternate exposures to 0.1% diesel oil in sea water and to fresh sea water.

	Time in fresh sea water	
	4 days	*7 days*
Treatment	*% of initial photosynthetic capacity*	
Control sea water	105	104
0.1% diesel, 3 hours	75.5	75.5, 74
0.1% diesel, 6 hours	68	61.5, 55
0.1% diesel, 12 hours	0	0, 0
0.1% diesel, 24 hours	38	0, 0
0.1% diesel, 48 hours	6	0, 0
	4 days	*6 days*
Control sea water	137	--
0.1% boiler fuel, 3 hours	0	0
0.1% boiler fuel, 6 hours	0	0
0.1% boiler fuel, 12 hours	75	0
0.1% boiler fuel, 24 hours	0	0
0.1% boiler fuel, 48 hours	1.8	0

Table 36

Photosynthetic capacities of apical meristematic blades from bottom kelp fronds, following alternate exposures to 0.1% fuel oil-sea water emulsions and to fresh sea water.

	Photosynthetic capacities in relative units, following five days in fresh sea water.	
Treatment		*(% of control)*
Control sea water	80.3	100
0.1% diesel, 3 hours	45.4, 44.6	56.6, 55.6
0.1% diesel, 6 hours	6.5, 3.5	8.1, 4.4
0.1% diesel, 12 hours	39.3, 14.6	49 18.2
0.1% diesel, 24 hours	—3.4	0
0.1% diesel, 48 hours	1.4	1.3
0.1% boiler fuel, 3 hours	—3.7	0

Table 38

Photosynthetic capacities of bottom kelp blades following two-day exposures to 1% fuel oil-sea water mixtures.

Sample	*Treatment*	*Photosynthetic capacity, % of initial value*
Large blades	Control sea water (no oil)	135
	1% Diesel oil in sea water	13
	1% Boiler fuel in sea water	0
Small blades	Control sea water (no oil)	119
	1% Diesel oil in sea water	0
	1% Boiler fuel in sea water	0
Apical meristematic blades	Control sea water (no oil)	130
	1% Diesel oil in sea water	0
	1% Boiler fuel in sea water	0

It is known (Table 37) that the photosynthetic capacity of young bottom kelp blades remained high during the first 24 hours in 0.1% diesel oil emulsion, but was drastically reduced during 48-hour and longer exposures (Tables 37 and 38). The experiments of Tables 35 and 36 define the delayed action effects of exposures to 0.1 oil emulsions. When small bottom kelp blades were exposed to 0.1% diesel oil emulsion for three and six hours and then placed in sea water, their photosynthetic capacities after four and seven days were reduced significantly but the blades retained a healthy appearance and did not lose turgor. A larger response, was shown by the apical meristematic blades following three and six hours' exposure to 0.1% diesel oil emulsion (Table 36). There was some irregularity in the data for 12-hour and longer exposures to the 0.1 diesel oil emulsion. Photosynthetic activity was retained in the vegetative blade exposed for 24 hours and tested after four days, but photosynthesis in the vegetative blades was eliminated following 12-, 24-, and 48-hour exposures after one week in fresh sea water (Table 35). Photosynthesis was eliminated from the apical meristematic blades (within 1%) following 24- and 48-hour exposures to the 0.1% diesel oil emulsion; inhibitions of 50-85% were observed following 12-hour exposures.

Sea water emulsions prepared with the black viscous boiler fuel proved to be far more toxic to young kelp blades than diesel oil emulsions. When apical meristematic and vegetative blades were immersed in 0.1% boiler fuel emulsion for three hours or more, they died during a subsequent week in fresh seawater. The pneumatocysts also filled with water.

Table 37

Photosynthetic capacities of kelp fronds collected at 60 feet and from the surface following exposures to diesel oil-sea water mixtures.

Sample	*Medium*	*Exposure time* *1 day*	*3 days*	*7 days*
		% of initial photosynthetic capacity		
Bottom kelp blades	Control sea water	135	142	236
	1% oil in sea water	99	0	-
	0.1% oil in sea water	110	7	0
	0.01% oil in sea water	130	38	0
	Surface oil film	147	0	-
Surface kelp blades	Control sea water	-	134	157
	1% oil in sea water	-	0	0
	0.1% oil in sea water	-	20	0
	0.01% oil in sea water	-	77.5	0
	Surface oil film	-	33	-

When discarded, the bulbs and blades from the boiler fuel experiment were lying on the bottom of the jars of sea water and all had a sickly faded appearance. The vegetative blade which was exposed to the boiler fuel emulsion for 12 hours developed injury more slowly than the other samples, but after seven days in fresh sea water, it was photosynthetically inactive and later disintegrated. Thus every sample of young bottom kelp blades that was exposed to 0.1% boiler fuel for three hours or longer was irreversibly damaged. The strikingly greater toxicity of the black boiler vs. diesel fuel toward kelp supports van Overbeek's conclusion that the phytotoxicity of oils increases with their content of dark aromatic compounds.

Bacteria are able to oxidize and assimilate hydrocarbons (ZoBell, 1946), which raises the question, did the observed toxic effects of oil on kelp arise indirectly via oxygen deficit? We have not compared the effects of oil emulsions under different conditions of aeration, but several lines of evidence indicate that oxygen deficit was not involved. Visible appearance of the injured blades was quite unlike that of the blades which had been exposed to water of high BOD in earlier experiments. The "delayed action" effect of the oil allowed the kelp to be maintained in fresh sea water that was changed daily as injury developed. Microbial activity in general increases with decreasing size of the container, but it seemed to make no difference whether half-gallon or 4-gallon glass jars were employed (the latter were used in most of this work).

How oils supplied as tiny globules or as a surface film gain access to living kelp cells remains unknown. According to van Overbeek and Blondeau (1954), oils act first on the fatty constituents of the cytoplasmic membrane. This interpretation conforms with our observation that loss of turgor is an early sympton of injury to kelp blades. The cytoplasmic membranes, however, are protected by relatively thick walls of hydrated polysaccharides so that the living protoplasts of kelp cannot come directly into contact with oil globules or surface oil films. Presumably the oil creeps gradually on the surfaces of the protecting walls to reach the cytoplasmic membranes; the time required for penetration of the protecting walls may be responsible for the delayed action of the oil.

Effects of Fuel Oil Emulsions on Sea Urchins. One purpose of the foregoing studies was to determine the length of time that young kelp fronds can be exposed to emulsified diesel oil without being irreversibly damaged. The required exposure times for irreversible damage ranged from 6 to 12 hours. We have no laboratory information on the sensitivity of kelp sporophylls, holdfasts, or mature stipes and blades. Their observed survival in the *Tampico* wreck area indicates that they are much less sensitive than the juvenile blades employed in this study.

The possibility of ridding kelp beds of sea urchins and other grazers by oil treatments had been discussed as a practical application of the effects observed near the *Tampico* wreck. The effects of emulsified diesel oil on sea urchins *(Strongylocentrotus purpuratus)* have accordingly been studied in the laboratory. The oil-contaminated water collected near the *Tampico* wreck was included; similar effects were observed with it and with the Navy dark diesel oil.

When the sea urchins were placed in 0.1% diesel oil emulsion, their tube feet were soon withdrawn so that the sea urchins could no longer cling to the substrate. Nine sea urchins ranging from ½ inch to three inches in diameter were used; this response was observed consistently within the first 20 minutes in 0.1% diesel oil emulsion. The sea urchins remained motionless during longer exposures, but shed no spines. After 20, 40, and 60 minutes' exposures, the sea urchins were washed in fresh sea water, then placed in large jars of flowing sea water for observation. The recovery time increased with the time of exposure; after 20-minute exposures, the sea urchins resumed normal feeding and climbing activity almost at once, after one-hour exposures, complete recovery occurred when the urchins remained overnight in flowing sea water. The seven sea urchins which received one-hour exposures to emulsified diesel oil were all able to climb vertical glass walls the next day.

The densely turbid "*Tampico* water" was cooled to 15°C and thoroughly aerated beforehand, and aeration was continued during the one-hour immersion tests on sea urchins. Retraction of the tube feet occurred at once. After one hour in this water, the motionless sea urchins were washed and placed in flowing sea water. They were feeding on kelp and climbing vertical glass walls the next day, and a month after these tests, were still in a healthy condition. To kill sea urchins with emulsified diesel oil, exposures longer than one hour are required. The sea urchins lose their hold on the bottom almost at once, however, which would allow them to be cast on shore and killed by surface oil at the *Tampico* wreck site. Alternatively, part of the bottom fauna was thought to have been killed *in situ* by selective exposure to oil-contaminated bottom sludge (dead urchins were observed in cracks and holes in the rocks). Oil contamination at intermediate depths may have been intermittent and much less severe than at the bottom and surface in the *Tampico* wreck area. The sensitivity of young kelp fronds to emulsified diesel oil observed in this study, however, indicates that their profuse development was separated in time from the destruction of bottom grazers.

Toxicity Tests on San Diego Bay Water

Young fronds of 1 to 2 meter lengths were adopted as test material because we had previously found them to be more sensitive to environmental factors (light and temperature) than fronds of greater age and length. Large water samples were collected for this

Table 39

Relative photosynthetic capacities of young kelp frond samples following three-day incubations in San Diego Bay water and fresh sea water (mm³ O₂/disc/hour at 15° C).

Sample	Incubation fluid			
	Natural sea water (pH 8.2)	San Diego Bay water (28th St. Mole) (pH 8.0)	San Diego Bay water (over municipal outfall) (pH 7.45)	Average percent inactivation (outfall water)
Apical Blade	59.6 60.0 65.5 61.4	85.2 87.6 82.0	11.2 26.8 12.9 —6.5 —8.8	88.5
Blade No. 10	71.3	105.7	20.4	71.4
Blade No. 25 ±1	102.2 108.8	101.0 106.0	—2.1 —2.1 +4.0 —8.2 —13.7	100.0
Oldest blade on *ca.* one-meter frond	56.7	64.7	—11.4	100.0

purpose by Wheeler North and James Stewart (a) over the San Diego municipal outfall and (b) one mile northward off the 28th Street mole. The latter was also the site of transplanted kelp plants. The photosynthetic capacity of kelp blades per unit area regularly increases with increasing size of the blades and later declines, as shown by the control data of Table 39 for different parts of young kelp fronds.

Agreement between replicates was within 5% for the kelp samples that were maintained in control sea water and in the water from the 28th Street mole. The latter water sample showed no toxic effects on kelp; following incubation in this water, the photosynthetic capacities were in most cases significantly higher than the controls. The outfall water soon caused visible damage to all tested parts of the kelp fronds, which disintegrated within one week. The most rapid and uniform inactivation of photosynthesis by the outfall water was observed on *ca.* halfgrown blades.

The pH of the outfall water was below that of natural sea water, but adjusting the latter to pH 7.45 did not result in physiological damage. The markedly damaging effect of the cloudy outfall water persisted when it was rendered water-clear by centrifugation.

Effects of Diluted Sewage and of Chlorine

Composite samples of sewage effluent, before and after chlorination, were obtained from the San Diego Municipal Sewage Treatment Plant. These consisted of hourly samples collected for 24 hours. The 24-hour composites were diluted with 9 and 99 volumes of fresh sea water. The young kelp blades were incubated in the 1% sewage and control sea water for 15 days, and the 10% mixtures until disintegration occurred.

Table 40

Percentage of initial photosynthetic capacity shown by young kelp fronds following lengthy incubations in diluted sewage effluents and chlorinated sea water.

Incubation fluid	Exposure Time		
	42 hours	120 hours	360 hours
	Percent of initial photosynthesis		
Natural sea water	113	130	115
1 percent chlorinated sewage effluent in sea water	114	142	140
1 percent unchlorinated sewage effluent in sea water	120	162	151
10 percent chlorinated sewage effluent in sea water	20.5	disintegrated	disintegrated
10 percent unchlorinated sewage effluent in sea water	0 (disintegrating)	disintegrated	disintegrated
0.5 ppm chlorine in sea water	105.5	116	---
1.0 ppm chlorine in sea water	105.5	131	---
5.0 ppm chlorine in sea water	82.5	29.5	---
10.0 ppm chlorine in sea water	91.0	61.0	---

Under conditions suitable for growth, the photosynthetic capacity per unit area will increase above the initial value, as was observed repeatedly in the experiments reported in Table 40. Instead of physiological injury by the 1% sewage during 15-day exposures, a significant stimulatory effect was observed. With the 10% sewage effluents, however, the blades were damaged in the same drastic manner as with water collected over the San Diego municipal outfall.

According to Fair and Geyer (1954), it is seldom necessary to provide over one ppm chlorine to prevent the growth of phytoplankton. We observed no detrimental effects of chlorine on young kelp blades during 5-day exposures to initial concentrations of one ppm and less. Partial inactivations of photosynthesis were observed only following lengthy exposures to 5 to 10 ppm chlorine, which provided a rather strong chlorine odor.

Studies of Kelp Plants After One Month off the 28th Street Mole in San Diego Bay

Portions of these damaged plants were brought to the laboratory for study. About half of the blades were missing, some of the remaining blades were afflicted with black rot, and there were also blade areas which had faded or had turned green and flaccid. Some of the pneumatocysts were filled with water. The stipes (stems) appeared to be the healthiest parts of these plants, being deep brown and free of encrusting organisms. The blades which had remained intact were covered almost completely with a variety of marine invertebrates. The most prominent of these was the tunicate *Acidia*, which covered the kelp with white tubular outgrowths to depths of 0.5 to 1.5 cm, often on both sides. Pink tufts of the hydroid *Tubularia* were frequently attached at junctures of the pneumatocysts and blades, and the nudibranch *Polycera* was observed feeding on this hydroid. There were heavy encrustations of the bryozoan *Membranipora tuberculata*. The littoral copepod *Tisbe* and unidentified protozoans were also abundant on this kelp. (Identification of these animals was kindly provided by the Division of Marine Invertebrates, SIO.)

To allow comparisons with kelp freshly harvested from the local bed, and to determine the effects of the covering layers of marine invertebrates upon photosynthesis in saturating light, photosynthesis and respiration measurements were conducted on 12 subsamples of the foregoing kelp plants. The general level of the photosynthetic capacities in intact blade tissue from these plants was 60-80 percent of that in corresponding parts of kelp in prime condition from the La Jolla kelp bed. The photosynthetic capacities of kelp blade samples which were very heavily coated with tunicates and bryozoans were compared with adjoining blade areas which either were free of these organisms or which were carefully freed of them mechanically.

When provided with a saturating light intensity and CO_2 supply, the photosynthetic capacities of the underlying blade tissues were unaffected by *Membranipora*, and were not reduced more than 20 percent by the bulkiest covering of tunicates that could be found. The effects of these attached filter-feeders upon photosynthesis in kelp should therefore be small in strongly illuminated surface waters. Under oblique illumination at limiting light intensities, as in deep, turbid water, their effects may be much greater, but no measurements have yet been made under these conditions.

The naked cylindrical stipes showed almost as high photosynthetic capacities per unit of surface area as intact blades; their healthy state after one month in San Diego Bay was probably due in part to their ability to manufacture food independently.

The Palos Verdes Wastes

The following Los Angeles County waste waters were selected for study:

(a) Composite domestic and industrial wastes as released at the Whites Point outfalls.

(b) General Petroleum Co. waste water from several refineries in the Wilmington area, also released off Whites Point.

(c) Composite oil field brines before and after treatment by Oil Operators Inc.; these brines are from several oil fields and presently amount to 95,000 barrels per day.

(d) Dominguez Channel water—an industrial stream serving various industries which flows into Los Angeles harbor near Terminal Island.

Arrangements for sampling the brines at Oil Operators Inc. were made for us by Mr. William Graham, Superintendent of Waste Water Disposal, Richfield Oil Corporation, who also provided helpful advice and information. Composite samples of General Petroleum waste water and of Los Angeles County sewage effluent were provided by Mr. Carl Nagel, Plant Superintendent, Los Angeles County Sanitation Districts. On the basis of our earlier work, all these waste waters should be severely injurious to kelp when diluted only tenfold with sea water, so dilutions of this order were omitted. Demonstrable effects are judged unlikely after 1000-fold dilutions, also on the basis of earlier experience, hence 50-fold, 100-fold, and 200-fold dilutions with fresh sea water were used, a range which should reveal toxic effects that have practical significance. The standard photosynthetic procedure was employed for exploratory purposes, with 48-, 96- and 144-hour exposures, two blades and an apical growing point from young bottom kelp fronds being exposed to each dilution.

Table 41 reports the results obtained with the initial set of waste water samples collected in late 1959. Oil field brines were omitted in this instance, but they were included in the next collections. No adverse effects of the 24-hour composite sample of Whites Point effluent were observed after it had been diluted 50-fold, 100-fold, and 200-fold with sea water. The nine kelp samples which were exposed to these mixtures for one week all retained a completely healthy appearance, and the photosynthetic capacities appeared to be slightly stimulated by the 50-fold dilution.

Table 41

Percentage of initial photosynthetic capacity retained by bottom *Macrocystis* blades following exposures to Los Angeles County waste waters.

Test solution			*Exposure time, hours*		
			48	*96*	*144*
Natural sea water (Control)		(a)	104	116	122
		(b)	94	91	97, 97
Whites Point effluent	2%	(a)	128	116	122
		(b)	129	135	141
	1%	(a)	106	108	116
		(b)	115	138	130
	0.5%	(a)	98	110	108
		(b)	111	108	120
Oil refinery waste (General Petroleum)	2%	(a)	69	42	40
		(b)	65	57	52
	1%	(a)	44	66	67
		(b)	110	105	124
	0.5%	(a)	99	90	101
		(b)	98	80	103
Dominguez Channel water	2%	(a)	133	143	168
		(b)	117	128	120
	1%	(a)	107	84	80
		(b)	124	129	135
	0.5%	(a)	101	93	101
		(b)	108	117	116

The General Petroleum refinery waste water accounted for only 1/175th of the Whites Point effluent at the time (late December, 1959), and when tested separately, it proved strongly toxic to *Macrocystis* after 50-fold dilution with fresh sea water (Table 41). The apical growing point and kelp blades exposed to this 2% oil refinery waste all showed visible injuries within the first week. When diluted 100-fold, this refinery waste caused a reduction in photosynthetic capacity of one of the two blade samples, both of which retained a healthy appearance. There was a visible fading of the apical growing point at 100-fold dilution. When diluted 200-fold, this oil refinery waste water had no detectable effect.

The Dominguez channel sample in this instance was collected off Wilmington Bridge, and it showed no evidence of toxicity toward kelp after 50-fold dilution with sea water (Table 41). The small decrease observed in one of the six samples (sample a at 1%) was probably insignificant in view of the negligible response to the 50-fold dilution.

28-Day Exposures to Los Angeles County Waste Waters

After one month's continuous exposure, the kelp samples in 0.5, 1.0, and 2.0% of Whites Point sewage retained the same healthy appearance as the controls (growing points and blades). Simultaneously, the kelp samples were visibly damaged by the 1% and 2% petroleum refinery waste water. The kelp samples which had shown no evidence of injury by 0.5-2.0% Dominguez Channel water during the first week developed a mildly unhealthy appearance after one month's continuous exposure.

Two additional collections of General Petroleum refinery waste water, of Los Angeles County treated municipal sewage, and of Dominguez Channel water were analyzed in the spring of 1960. Research was also initiated on oil field brines, sampled before and after their purification in the treatment plant of Oil

Operators Inc., Long Beach. The composite samples of petroleum refinery waste water and of Los Angeles County treated sewage were based on 24 hourly collections on three days and on five hourly collections on a fourth day. The samples of oil field brines were provided by Mr. Robert House, Manager, Oil Operators, Inc., Long Beach.

Table 42 reports the photosynthetic responses which were observed with February 1960 collections of Los Angeles County waste waters. There were slight decreases in photosynthetic capacity of the samples exposed to 2% Whites Point effluent but not to 1%.

Table 42

Retention of photosynthetic capacity in bottom *Macrocystis* blades during 96-hour exposures to Los Angeles County wastes diluted with fresh sea water, February, 1960. Photosynthetic capacities are expressed as % of the initial value.

	Young blades	*Mature blades*
Control	64	85
2% Whites Point effluent	87	92
1% Whites Point effluent	103	112
2% General Petroleum refinery waste water	0	66
1% General Petroleum refinery waste water	86	67
2% Oil field brine, crude *	0	17
1% Oil field brine, crude *	0	43
2% Oil field brine, purified *	2	63
1% Oil field brine, purified	63	40
2% Dominguez Channel, mid-stream	81	77
1% Dominguez Channel, mid-stream	79	79
1% Dominguez Channel, near shore	114	72

* Treatment plant of Oil Operators Inc.

There was also a minor effect of the 1% and 2% Dominguez Channel water which was collected off Henry Ford Avenue Bridge from the middle and side of the stream. Severe injuries were produced in the young blades by 2% purified oil field brine. The mature blades were much less sensitive than the young blades to the oil refinery waste water and oil field brine. In this experiment, larger responses were observed with the crude than with the purified oil field brine, but phytotoxic constituents nonetheless were still present in the latter.

Table 43 reports the most extensive toxicity study of Los Angeles County waste waters that the authors conducted. Quadruplicate control samples were used, several of the composite wastes were collected separately on two days, and the photosynthetic capacity measurements were all made in duplicate or triplicate after ten days exposures (photosynthesis and respiration were measured in 96 kelp samples in this experiment). The young blades showed larger responses than the mature blades. When diluted 100-fold with sea water, the Whites Point effluent was still non-injurious. Severe injury of the young blades was produced by the 1% General Petroleum refinery water, with much smaller responses by the mature blades. Diluted 100-fold the oil field brines were about equally toxic before and after passage through the treatment plant of Oil Operators Inc. The toxicity of the purified oil field brine was severe when diluted 50-fold, but no response to this waste was observed during 10-day exposures when it was diluted 200-fold. Dominguez Channel receives very large amounts of petroleum industry wastes, but when diluted 100-fold with fresh sea water, the examined samples of Dominguez Channel water have not been measurably toxic to kelp during 10-day exposures.

Table 43

Retention of photosynthetic capacity in bottom *Macrocystis* blades during 4-day and 10-day exposures to Los Angeles County wastes diluted with fresh sea water, April, 1960. Photosynthesis is expressed as % of the initial capacity.

	Young blades		*Mature blades*	
Medium	*4-day (96-hour)*	*10± 1-day*	*4-day (96-hour)*	*10± 1-day*
	(% of initial photosynthetic capacity)			
Control sea water (a)	91	101	115	101
(b)	84	102	110	140
1% Whites Point effluent, April 14 collection	140	172	116	119
1% Whites Point effluent, April 15 collection	99	131	106	117
2% Whites Point effluent, April 14 collection	82	93	111	119
1% General Petroleum refinery waste water, April 14	11	0	74	58
1% General Petroleum refinery waste water, April 15	4	2	92	103
1% crude oil field brine	55	76	87	59
0.5% purified oil field brine	102	102	107	109
1% purified oil field brine	35	45	69	59
2% purified oil field brine	3	0	46	10
1% Dominguez Channel water, mid-stream	86	135	107	135

The results that have been obtained with successive collections of Los Angeles County waste waters (Dec. '59 to April '60) are believed sufficiently consistent to warrant the following conclusions.

1. Composite samples of the waste water presently being released into the ocean off Whites Point is not measurably toxic to young *Macrocystis* blades after 50- to 200-fold dilution with fresh sea water, and in some cases caused stimulation of photosynthesis in the laboratory.
2. Oil field brines and oil refinery waste water under the same conditions are toxic to the kelp blades after either 50-fold or 100-fold dilution.
3. Phytoxic constituents are retained in the oil field brines after treatment in the purification plant of Oil Operators Inc.
4. The examined samples of Dominguez Channel water have been much less toxic to *Macrocystis* than oil refinery waste water and oil field brines.

Red Tide Studies, 1958

During the summer of 1958, an opportunity arose for research on "red tide" along the coast of Southern and Baja California. This work was mainly conducted by members of the Marine Life Research Program, and especially by B. M. Sweeney, who has for years been investigating bioluminescence and other physiological aspects of the red tide organism, *Gonyaulax polyedra*. A few aspects of this study relating to the present program are summarized below.

1. The dominant alga was the luminescent armored dinoflagellate *Gonyaulax polyedra*, which pre-

dominated in all of the dozens of red coastal water samples which were collected (June 1958 onward) over a distance of several hundred miles between Los Angeles and Ensenada.

Algal cell numbers ranged from a few hundred per ml up to the highest that has ever been observed in southern California red tide (20,000 cells/ml), which was attained off the SIO pier August 15, 1958.

2. In laboratory culture, *G. polyedra* requires organic growth stimulators which are supplied as soil extract. In nature, these organic nutrients are presumably supplied by micro-organisms.
3. In Ensenada Harbor, odorous decomposition of *G. Polyedra* occurred. This red water caused destruction of young kelp fronds resembling that which occurred in concentrated sewage, and also caused rapid death of fish. The cause of this detrimental effect appeared to be associated with high bacterial activity, since it was overcome simply by aerating the odorous red water. Healthy *Gonyaulax polyedra* suspensions of greater density collected in the field and also produced in the laboratory did not have these damaging effects on plant and animal life. The critical factor with reference to mortality in *Gonyaulax polyedra* red tides appears to be the health of this red tide organism: when these organisms remain healthy, they are harmless, but when they decompose, presumably oxygen levels decrease and other marine life succumbs to suffocation. Additional effects of red tide on kelp probably arose through competition for light, and through increased food supplies for encrusting organisms such as *Membranipora*. (The latter organism was observed to feed on the *Gonyaulax* cells). These effects on kelp are also to be expected when phytoplankton populations are increased by extra nutrients in the vicinity of ocean outfalls. The effect of a red tide sample collected at Ensenada on kelp photosynthesis is shown in Table 44.

Table 44

Effect of red tide on kelp blade photosynthesis. Red tide organism was *Gonyaulax polyedra* and the sample came from Todos Santos Bay, near Ensenada, Mexico.

Incubation time, days	*% of initial photosynthetic activity*	*Remarks*
1	90	--
4	10	Tissue disintegrating

GRAZING

Introduction

Quite early in the investigation it was appreciated that large populations of grazing animals existed in those areas at Pt. Loma and Palos Verdes where kelp had disappeared. The rocky bottoms were typically covered only with sparse vegetation or were completely devoid of plants and an abundance of benthic grazers, particularly sea urchins, obviously were preventing re-establishment of permanent algal cover. Clearly a better understanding was needed of the movements of grazers, factors influencing their abundance, feeding rates, and many other facets of the grazing problems; a substantial proportion of the total effort, therefore, was channeled into studies related to grazing.

The Grazing Populations

For convenience, seaweed grazers can be divided into two broad groups: the benthic organisms and the non-benthic. The benthic group is much the easier to observe and evaluate; the non-benthic includes relatively sluggish animals which inhabit the upper erect or floating portions of large seaweeds but also embraces highly motile forms, particularly certain fishes and crustaceans which often leave or hide when man enters an area. An abundance of information has been gathered on the benthic grazers but we still have much to learn about the importance of the highly motile forms.

Another gap in our knowledge concerns the activities of extremely small grazers such as protozoans and minute crustaceans. These small grazers may exert considerable control on algal spores and other microscopic stages of seaweeds. Filter feeding organisms may also affect the pelagic stages of plants (spores, sperm, etc.).

In general, the most abundant grazers we have observed in the beds of southern and Baja California have been sea urchins *(Strongylocentrotus purpuratus, Strongylocentrotus franciscanus, Lytechinus anamesus)*, isopods *(Idothea resecata)*, abalones *(Haliotis rufescens, Haliotis fulgens)*, wavy top snails *(Astraea undosa)*, brown turbans *(Norrisia norrisii)*, and the opaleye *(Girella nigricans)*. Photographs of these animals are shown in Figure 60. At certain locations or under special circumstances, other grazing animals may exert considerable influence, and the above list is intended only to indicate general conditions. As we shall see below, abundance is not the only factor determining which species is of controlling importance, other considerations being plant preferences, feeding rates, migration capabilities, and so forth.

Laboratory Studies

Laboratory work was accomplished using 11 common benthic grazers and 2 non-benthic seaweed consumers. Information was obtained on feeding rates as a function of temperature, size, species of grazer, and species of seaweed. The nutritional values of different seaweeds were studied and growth rates of the grazers were established. Attraction of grazers by seaweed scents was investigated and the preference and nutritional values of different parts of the giant kelp, *Macrocystis*, were established.

Description of methods and detailed accounting of results is beyond the scope of this report; an introduction to the work may be found in Leighton (ms in preparation), and only a summary of results is provided here.

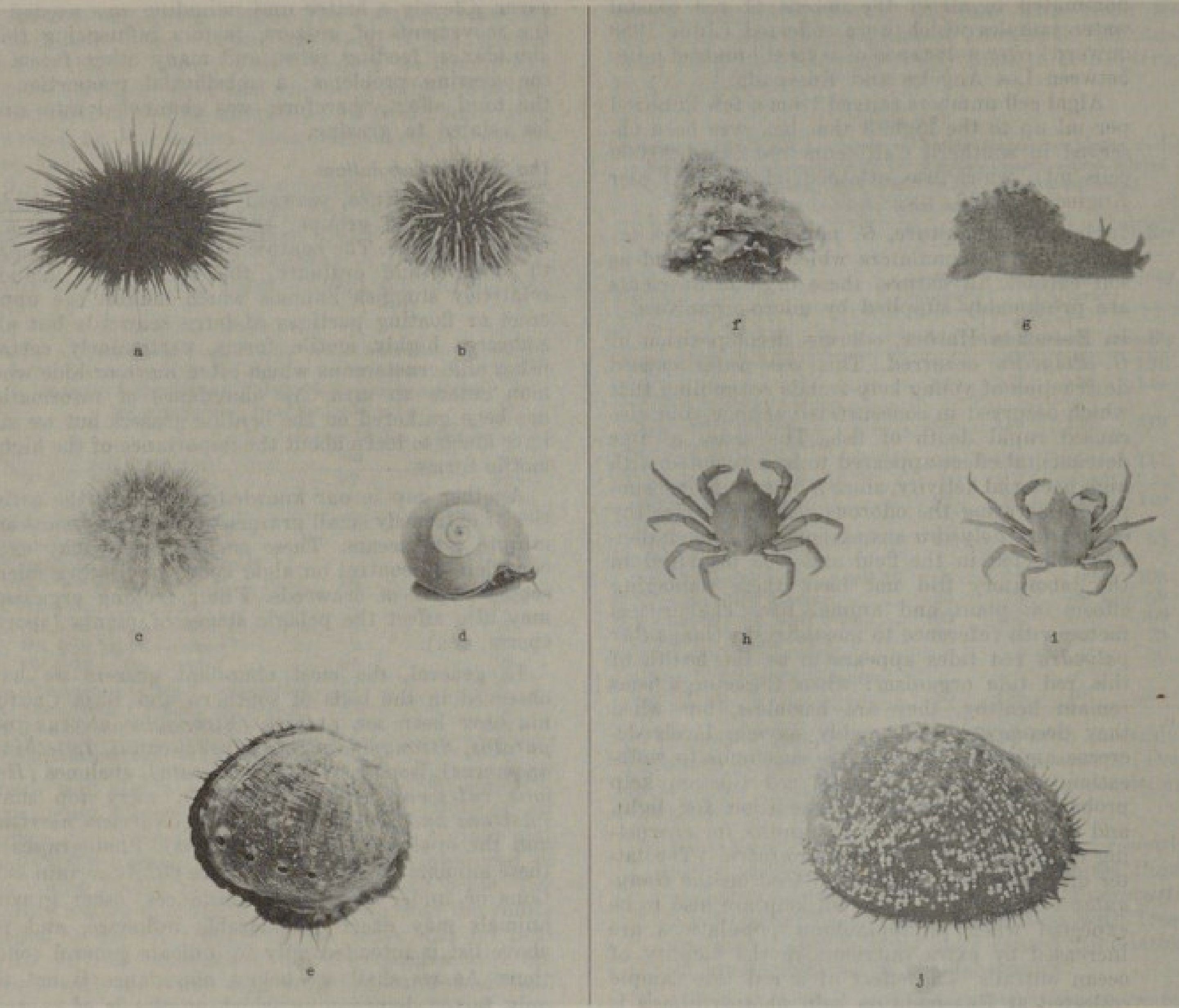


Figure 60. Common benthic grazers of southern California kelp beds: a. Strongylocentrotus franciscanus, b. Strongylocentrotus purpuratus, c. Lytechinus anamesus, d. Norrisia norrisii, e. Haliotis rufescens, f. Astraea undosa, g. Aplysia californica, h. Taliepus nuttalli, i. Pugettia producta, j. Haliotis fulgens.

Food Plant Preferences

When *Macrocystis* was presented to grazers together with six other most common algal species of kelp beds, each in equal quantity and random selection permitted, *Macrosystis* was shown a high degree of preference by all grazers (with one exception, the juveniles of *Pugettia producta*). Species' distinctive patterns of preference became evident from a large series of experiments. Although some grazers exhibited great contrast in preference for different algae, others did not give evidence of strong discrimination in food choice. In general, these animals fall into three categories according to the dominant preferred food item (Table 45). The dominant algal choices are indicated together with foods of subordinate, yet still of relatively high preference, in Table 46. These tables summarize the results of over 150 experiments.

A more complete concept of diet selection was developed through further experimentation in which additional common algae were provided. Several species of red algae, including three species of coralline algae, and the surf grass, *Phyllospadix scouleri,* were offered to each animal species. The coralline algae employed are common from the intertidal zones to depths of moderately deep water kelp beds. *Phyllospadix,* while not common at depths greater than 15 or 20 feet, is extremely prevalent on rocky shores of southern California. These abundant plants might supply nourishment to grazers when the common larger brown algae are absent. The detailed results of this aspect of the preference studies are provided elsewhere (Leighton, in preparation). Coralline algae and surf grass were never shown high degrees of preference when provided together with the algae named in

Table 45. However, if provided alone, *Bossiella, Corallina* and *Lithothrix* (coralline algae) were consumed by all grazers except *Astraea* and *Aplysia*. *Phyllospadix* was consumed in small amounts by grazers other than *Haliotis refuscens, H. corrugata, Norrisia* and *Aplysia*.

Table 45

Grazers grouped according to the alga most preferred in feeding experiments.

Food plant	*Grazing species*	
Macrocystis pyrifera	*Astraea undosa*	*Strongylocentrotus franciscanus*
	Haliotis rufescens	*Strongylocentrotus purpuratus*
	Pugettia producta	*Taliepus nuttallii*
Egregia laevigata	*Aplysia californica*	*Haliotis fulgens*
	Haliotis corrugata	*Norrisia norrisii*
Gigartina armata	*Lytechinus anamesus*	

Table 46

Three algal foods shown highest preference by eleven common benthic grazers.

	Macrocystis	*Egregia*	*Laminaria*	*Eisenia*	*Pterygophora*	*Cystoseira*	*Gigartina*
Aplysia ----	X	X *		X			
Astraea ----	X *	X					X
Lytechinus --	X		X				X *
Norrisia ----	X	X *	X				
Pugettia ----	X *	X	X				
H. corrugata-	X	X *			X		
H. fulgens --	X	X *					X
H. rufescens-	X *	X	X				
S. purpuratus	X *		X				X
S. Franciscanus ----	X *		X				X
Taliepus ----	X *	X		X			

Those items indicated by an asterisk (*) are most highly preferred.

Data pertaining to the desirability of various parts of the giant kelp plant were obtained through a series of experiments in which equal quantities of blades, sporophylls, stipes and haptera were provided. The results, presented as mean relative consumption values (Table 47), indicate that few grazers readily ingest haptera. Sporophylls, on the whole, are most readily accepted, followed closely by blades. The fact that some grazers are mechanically unable to cope with coarse or relatively rigid stipes and haptera (i.e., crabs, abalones, etc.) explains the result that greater relative values of preference are found for blades and sporophylls in experiments with those grazers.

Feeding Rates. Feeding rates have been found to vary with temperature, animal size, food type, reproductive state (Richard Boolootian, personal communication), feeding readiness and general health. Time of day and light conditions had little effect on feeding rate in the sea urchin *S. purpuratus*. Water temperature and animal size had a most profound effect upon feeding rate, however, and were studied in detail.

Temperature affects the rates of most chemical reactions, as well as animal activity dependent upon such chemical processes, hence feeding behavior would be logically expected to vary with temperature change just as does, for instance, oxygen consumption or motility. Poikilothermic animals are able to subsist only within the temperature range compatible with normal function of the body processes. It has been found that marine invertebrates usually have an optimal temperature of body activity which is nearer to the maximal than the minimum lethal temperature (Gunter, 1957). A curve of feeding rate may be expected to approach a peak toward the warmer values. This type of curve has been found for both *Strongylocentrotus* species, but the majority of invertebrates displayed highest activity at temperatures approximately midway between minimum and maximum lethal temperatures.

Table 47

Relative preference mean—parts of *Macrocystis* plant

Grazer species	*Blades*	*Sporophylls*	*Stipes*	*Haptera*	*No. obs.*
Aplysia ----------	65.6	29.1	1.3	4.0	5
Astraea ----------	42.9	41.7	14.7	0.7	5
Haliotis corrugata	38.6	47.4	6.9	7.1	5
H. fulgens -------	55.8	27.4	15.9	0.9	5
H. rufescens ----	31.3	50.1	15.0	3.6	5
Lytechinus -------	49.5	41.1	6.7	2.7	5
Norrisia ---------	31.8	51.0	11.1	6.1	9
Pugettia ---------	28.0	60.7	5.6	5.7	5
Strongylocentrotus franciscanus ---	32.7	51.4	10.3	5.6	8
S. purpuratus ---	40.2	41.7	13.0	5.1	12
Taliepus ---------	21.3	69.6	6.7	2.4	5

Groups of animals of from 2 to 10 individuals were given equal quantities of blades, sporophylls, stipes and haptera. After feeding periods of 1-2 days, remaining fragments were blot-dried, sorted and weighed. Quantities consumed were then equated to relative values (%).

Greatest attention was given to the purple sea urchin, *S. purpuratus*. Feeding rate (expressed in grams consumed per 100 grams of sea urchin per day) were made at various temperatures throughout the range tolerated. A minimal lethal point was found in southern California specimens at 1.5°C, measured during winter, and a maximal lethal point, measured during summer, at 29.5°C (see Fig. 61). The optimum shifted from approximately 18°C to 16°C between summer and winter respectively. It may be emphasized, however, that longer exposures to lower temperatures than those indicated as maximal lethal temperatures (Table 48) will produce death. *S. purpuratus* did not survive 24 hour exposures to temperatures of 24.5°C. *S. franciscanus* had a slightly lower optimum and a higher minimal feeding temperature.

Grazers subjected to temperature tolerance and feeding rate studies are listed below together with relevant data (Table 48).

The feeding capacity was directly proportional to organism size. The study employed small to medium sized individuals since these are more numerous in nature, and they are more easily kept in a healthy state in the laboratory.

While overall feeding capacities rise with increasing body size, feeding rates per unit of body weight decline with increase in body size (Table 49).

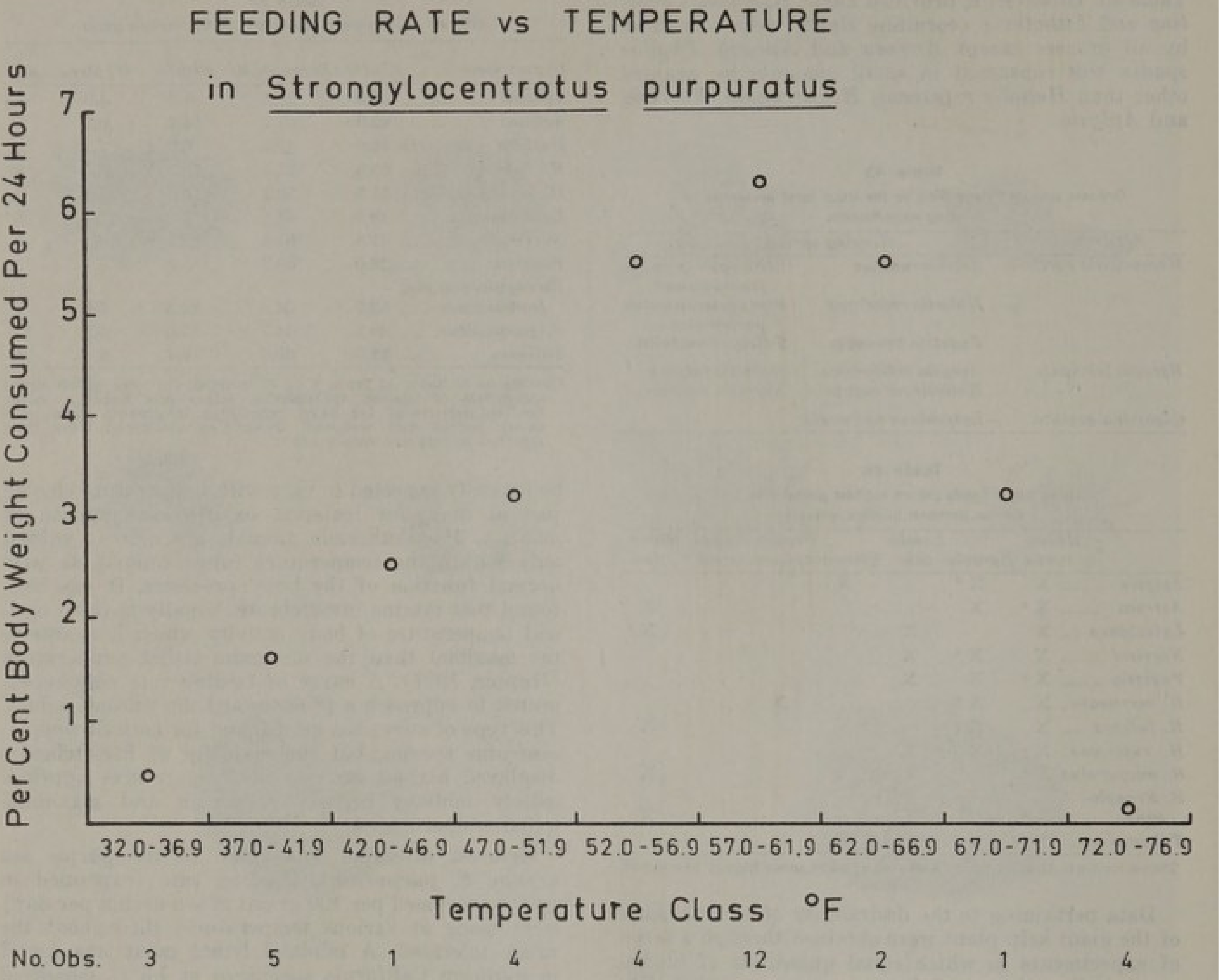


Figure 61. Variation of feeding rate as a function of temperature for the sea urchin, Strongylocentrotus purpuratus.

Table 48

Critical and optimal temperatures for nine important benthic grazers.

	Temperature levels of Feeding Activity ° C.			*Upper lethal ° C. Exposure*
	Minimum	*Optimum*	*Maximum*	*1 hour*
Astraea undosa	8.0	17.0-18.5	23.0	35.0
Haliotis corrugata	7.8	16.5-18.5	24.0	35.0
Haliotis rufescens	10.0	17.0-18.5	20.0	33.0
Lytechinus anamesus	7.5	16.0-18.5	26.5	31.5
Norrisia norrisii	8.0	15.5-17.5	24.5	34.5
Pugettia producta		variable		32.5
Strongylocentrotus franciscanus	6.0	15.5-17.0	25.0	29.5
Strongylocentrotus purpuratus	1.5	17.0-18.5	23.8	29.5
Taliepus nuttallii		variable		32.0

Minimum and maximum levels of activity are the temperatures at which feeding ceased. Upper lethals were actual death points at exposures of one hour. Due to the general lethargy produced by cold, 1 hour exposure death points could not be determined accurately for the lower temperatures.

Table 49

Decline of feeding rate of *Strongylocentrotus franciscanus* with increasing size.

	Size group (test diameter)			
	45-50 mm	*50-55 mm*	*55-60 mm*	*80-85 mm*
Mean feeding rate of four observations	8.1	6.0	5.1	3.9

Values given are the quantities consumed (grams) per 100 grams fresh sea urchin weight per 24 hour period. Experiments were maintained between 15 and 17° C.

Data were compiled for experimental feedings performed in the temperature environment 13 to 14°C, a range not uncommon in the lower water column in kelp beds of moderate depth in southern California (Fig. 62). It may be seen (Table 50) that larger animals, such as the abalones, large sea urchins, and adult crabs (*Taliepus*) consume greatest quantities of plant foods per unit time, as would be expected.

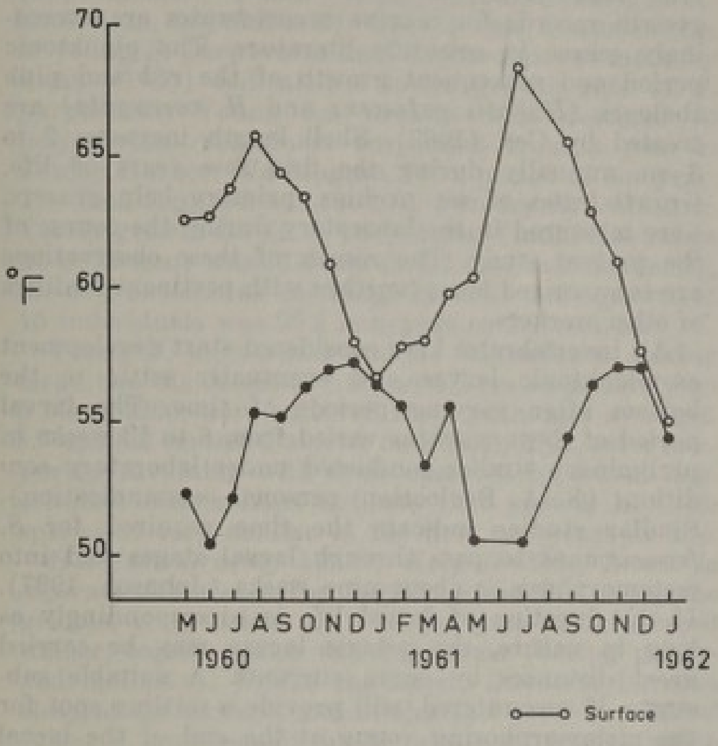


Figure 62. Seasonal variation of ocean temperatures in a kelp bed off La Jolla. Water depth was 65 feet. Monthly averages of 257 readings are shown.

Table 50

Feeding rates and capacities of "average adults" at 13-14° C over six periods of six days each. Fresh food was supplied every two days.

	Feeding rate g consumed/100 g animal/ day	*Feeding capacity g/animal/ day*	*Number individuals per experiment*	*Average weight g*
Astraea	1.5	2.6	2	190
Haliotis corrugata	1.8	8.7	2	580
H. rufescens	2.5	12	2	450
Lytechinus	5.2	0.2	10	0.4
Norrisia	1.5	0.6	4	37
Pugettia	3.5	1.9	2	54
Strongylocentrotus franciscanus	2.3	5.8	2	240
S. purpuratus	2.3	1.7	4	82
Taliepus	2.7	3.1	2	120

Foods consisted of *Macrocystis, Eisenia, Pterygophora* and *Laminaria.*

Feeding rates and capacities of "average adults" were determined in experiments maintained over periods of six days. The extended period provides a measure of average feeding activity throughout a period of several days. As many animals feed at high rates immediately following starvation periods, the grazers employed in these experiments were well fed up to a time one day preceding the feedings. One day of starvation was enforced to prompt active feeding during the experiments.

The relations of preference to nutrition become more sharply defined when some evaluation of food "usefulness" is available. Although no large scale studies of this aspect of the feeding habits of the grazers could be carried out under the limitations of the scope of this research, the two primary grazers, *S. purpuratus* and *S. franciscanus* were provided several limited diets and the gross effects observed. The commonly preferred *Macrocystis* and *Egregia,* and the moderately preferred *Pterygophora,* and a plant of least preference, the coralline alga, *Bossiella* sp., were employed. Similar pairs of adult specimens of *S. purpuratus* and *S. franciscanus* (46-56 mm test diameter) were supplied single algal foods for two months and their weight increases, conversion efficiencies, and gonadal development measured. The results follow in Table 51.

Table 51

Efficiency of utilization of 4 algae by pairs of sea urchins.

Food	Total consumption	Weight increase	Ratio of consumption to 1 g increase	Mean gonadal index* at term.
Strongylocentrotus franciscanus				
Macrocystis	182.2 g	9.5 g	19.2	0.124
Egregia	276.3	13.8	20.0	0.119
Pterygophora	138.1	3.3	41.8	0.146
Coralline alga (*Bossiella* sp.)	237.9	4.9	48.5	0.073
Starvation group	0.0	—7.6	----	0.044
Strongylocentrotus purpuratus				
Macrocystis	251.0	13.3	18.8	0.188
Egregia	256.6	12.8	20.0	0.102
Pterygophora	195.8	5.2	37.7	0.128
Coralline alga (*Bossiella* sp.)	265.7	2.1	126.5	0.072
Starvation group	0.0	—3.7	----	0.015

* The gonadal index represents the ratio of gonad volume in ml to total body wet weight.

Greatest weight increases in *S. franciscanus* and *S. purpuratus* were achieved on diets of *Macrocystis* and *Egregia. Macrocystis* was utilized most efficiently; 19.2 and 18.8 grams of *Macrocystis* promoted weight gains of 1 gram in *S. franciscanus* and *S. purpuratus* respectively. The coralline alga was utilized least efficiently, particularly by *S. purpuratus.*

As no measurement could be made of the gonadal volumes at the beginning of the experiment we have no absolute measure of gonad bulk increase. However, in both the coralline alga and the starvation groups, gonads were so small at the end of the experiment that sex could not be determined. A control in which other specimens were provided a variety of algal foods gave no indication of departure of the gonadal index from the range 0.1 to 0.2. Those animals limited to a diet of *Bossiella* and those starved gave greatly lower figures. The gonads are resorbed during starvation, hence are thought to serve as food and energy stores. Samples of *S. purpuratus* from Pt. Loma in an area devoid of large algae revealed similar gonad reduction.

Considerable harm to kelp plants can result from both internal and external grazing of holdfasts, hence it is of interest to know the rate of hapteral feeding and of holdfast excavation by sea urchins. At the same time it is desirable to learn the nutritive value of *Macrocystis* to sea urchins relative to other algae and whether nutritional requirements appear satisfied when haptera form the only food. Experiments were designed to demostrate growth rates of juvenile sea urchins of these two species when provided either *Macrocystis* haptera, blades, or a variety of algae. The results of a typical study are provided in Table 52.

It is clearly shown, and supported by results of pilot experiments formed on a smaller scale (Leighton, unpublished), that *S. purpuratus* utilizes *Macrocystis* blades or haptera as well as it does other foods. On the other hand, *S. franciscanus* grew little when provided haptera alone, though a substantial volume of that tissue was consumed.

The values for conversion efficiency (Table 52, bottom) reveal that a much greater amount of haptera was required by *S. franciscanus* than by *S. purpuratus* to net a gain in weight of one gram. *S. purpuratus* exhibited little difference in the quantities consumed of any food to promote comparable weight gains.

The holdfast would appear, therefore, to serve as a satisfactory food for the purple sea urchin, but is less nutritious than kelp blades or varied algae for the giant red sea urchin.

Growth Studies of Sea Urchins. Knowledge of the rate of increase in size of the chief kelp grazers is of primary importance to the study of kelp bed ecology. One measures the productivity of a biotic community in order to assess the efficiency of the community as a complex energy distributing and integrating living unit. Growth rates, and rates of utilization or manufacturing of food, then, are key processes in the general productivity of a community. Unfortunately, growth records for marine invertebrates are exceedingly scarce in scientific literature. The planktonic period and subsequent growth of the red and pink abalones (*Haliotis rufescens* and *H. corrugata)* are treated by Cox (1962). Shell length increases 2 to 3 cm annually during the first few years of life. Growth rates of sea urchins, primary kelp grazers, were measured in the laboratory during the course of the present study. The results of these observations are summarized here, together with pertinent findings of other workers.

All invertebrates here considered start development as planktonic larvae and eventually settle to the bottom after varying periods of time. The larval period of *S. purpuratus* varied from 6 to 13 weeks in preliminary studies conducted under laboratory conditions (R. A. Boolootian, personal communication). Similar studies indicate the time required for *S. franciscanus* to pass through larval stages and into metamorphosis is about nine weeks (Johnson, 1937). If the duration of larval life is correspondingly as long in nature, the pelagic larvae may be carried great distances by ocean currents. A suitable substrate, if encountered, will provide a settling spot for the metamorphosing young at the end of the larval dispersion period. Although small specimens of *Strongylocentrotus* (2 to 9 mm) were commonly encountered in holdfasts of the giant kelp, they were also found in samples of coralline algae collected from a variety of depths near La Jolla.

Successful rearing of *S. purpuratus* from zygote to adult has been achieved in the laboratory. Some individuals have attained test diameters of 24.7 mm

Table 52

Size and weight increases of small sea urchins held on restricted diets.

	Strongylocentrotus purpuratus			*Strongylocentrotus franciscanus*		
Date	Blades	Haptera	Variety of Algae	Blades	Haptera	Variety of Algae
Aug. 4, 1961 *Mean Test Diameter (mm)	28.4	27.8	28.2	28.3	27.8	28.3
Total group weight (g)	101.4	94.0	108.0	117.2	107.3	111.7
Aug. 19, 1961 Mean Test Diameter (mm)	29.2	28.9	29.6	28.6	28.1	28.8
Total group weight (g)	113.5	104.5	120.6	123.5	109.7	117.6
Algae Consumed (g)	88.2	75.6	68.9	82.2	67.7	86.8
Sept. 5, 1961 Mean Test Diameter (mm)	30.8	30.4	30.7	29.7	28.2	29.6
Total group weight (g)	133.0	120.8	134.8	132.7	117.0	127.2
Algae Consumed (g)	104.2	111.1	108.9	84.8	99.4	94.3
Sept. 19, 1961 Mean Test Diameter (mm)	31.8	30.8	31.3	30.0	28.5	30.4
Total group weight (g)	145.5	131.5	148.0	140.8	118.3	135.1
Algae Consumed (g)	77.8	84.0	64.3	52.2	73.5	71.2
Increase of mean test diameter (mm)	3.4	3.0	3.1	1.7	0.7	2.1
Total weight increase (g)	44.1	37.5	40.0	23.6	11.0	23.4
Mean conversion ratio	6.3	7.3	6.0	9.6	32.8	8.1

* Groups of ten individuals each were carefully composed at the initiation of the feeding experiments to be as closely similar as possible with respect to size. To assure comparative results, all were 28.0 mm, ± 1.5 mm, on August 4, 1961. Water temperature ranged from 13-17° C. throughout the 45-day period.

(approximately 1 inch) within the first year (R. A. Boolootian, unpublished). Growth rate measurements of young *S. purpuratus* and *S. franciscanus* made by Swan (1961) indicated a lower growth rate of *S. purpuratus*. Young sea urchins were retained in polyethylene containers suspended from a pier at Friday Harbor, Washington, for a period of one year. The food supplied was the kelp *Nereocystis leutkeana*. Yearly growth for 12 *S. purpuratus* (intial size range 24 to 28 mm) was 16.6 mm or 1.4 mm/mo. Similarily, for *S. franciscanus* size range 26 to 31 mm) growth of 15 individuals was 25.2 mm/year or 2.1 mm/mo.

Young *S. purpuratus* and *S. franciscanus*, having mean test diameters of 1.0 and 1.2 cm respectively on 8 Nov., 1960, were cultured for 2 years and averaged 5.0 and 6.2 cm test diameter on 8 Nov., 1962, rates comparing favorably with those observed by Swan. Logarithmic comparisons indicate that growth in these species is very similar in the first two years of life.

Holdfast Grazing by the Kelp Gribble, Limnoria algarum Menzies. The isopod genus *Limnoria*, the gribble, is notorious as a major pest of submerged timber, together with the shipworms (boring pelecypod mollusks). Unlike the latter, *Limnoria* burrows close to the surface, and erodes the wood in a larval stage; it must remain in its calcareous tunnel, which communicates with the outside by only a small pore. The most common gribble, *Limnoria lignorum*, is about 4 mm. long when full-grown, and only the female bores galleries, up to 25 mm. long (Yonge, 1951). A male usually accompanies the female in the burrow; the young (one-fifth the length of adult upon hatching) may burrow from the sides of the parents' hole. Heavily infested wood may have 400 animals, mostly juvenile, per cubic inch (Johnson, 1935). The typical burrow is parallel to the surface of the wood, with openings for respiration at regular intervals (Fig. 63). These evenly spaced holes are also seen on kelp haptera infested with *Limnoria algarum;* the wood—and holdfast-inhabiting gribble prefers the hard woody haptera of older holdfasts to the yellow or purple softer tissue of younger rhizoids or upper parts of holdfasts.

There are four species of *Limnoria* on the Pacific Coast: three, of the subgenus *Limnoria (L. lignorum, L. quadripunctata, L. tripunctata)* are woodborers. The fourth, *L. algarum*, is of the subgenus *Phycolimnoria*, which has never been found in wood; conversely the wood-borers have never been found in algal holdfasts (Menzies, 1957).

The known range for *Limnoria algarum* is Cape Arago, Oregon to at least Turtle Bay, Mexico, in holdfasts of *Egregia, Eisenia, Laminaria, Macrocystis,* and *Postelsia.* It is the only alga-boring gribble (subgenus *Phycolimnoria*) known from North America. During the course of this work, this *Limnoria* has been secured from holdfasts of three of the above brown algae at La Jolla, Point Loma, and Turtle Bay. It probably ranges as far south as the host algae (the southernmost, *Eisenia,* is reported from Magdalena Bay).

The species of *Limnoria* are distinguished mainly by ornamentation on the rear segment, or pleotelson.

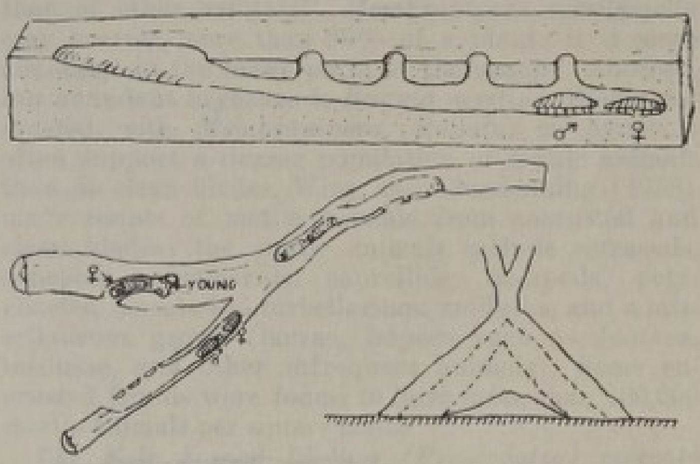


Figure 63. Typical burrows of Limnoria lignorum in wood and Limnoria algarum in a kelp haptere. Also shown diagrammatically is a kelp holdfast in cross-section with the zone most frequented by limnoria bounded by dotted lines.

Limnoria algarum is about 6 mm when full grown, and is a dull white color (Fig. 64). It may roll up pill-bug fashion when removed from a burrow, or swim short distances. The young, like those of other isopods, are essentially miniature adults, without a larval stage.

In *Macrocystis* a haptere may have several small burrows at a given cross-section; or one large burrow making it a hollow tube. Old holes are inhabited by other isopods, amphipods, copepods, or polychaetes, which do little or no burrowing themselves, or the holes may become filled with sand or mud. Eventually a burrowed rhizoid rots away; a holdfast heavily infested with *Limnoria* may be far more easily detached by surge during a storm than are other holdfasts. Even old holdfasts vary greatly in the density of gribbles, while holdfasts of young plants are not likely to harbor any appreciable numbers because of the apparent preference for older, hardened tissue. Because of its size and ramified structure, a well-developed *Macrocystis* holdfast may have many more animals than those of the other brown algae.

Typically, the center of an old *Macrocystis* holdfast is rotted out, and attachment is provided by younger rhizoids which grow down around the outsides of the cone. Adjacent to the rotted-out center are hollow tube-like rhizoids which have been abandoned by the gribbles and are filled with sand or mud, or inhabited by secondary forms. The gribbles are active in the zone between the dead and the youngest rhizoids (Fig. 63). Limbaugh (1955) ascribed the inevitable death of the inner rhizoids of old holdfasts to *Limnoria.*

Some holdfasts washed up on the beach after a storm show evidence of grazing on the primary stipe at the apex, but these borings only occasionally cause the primary stipe to break off the holdfast. These burrowings are entirely open to the outside, unlike typical *Limnoria* holes, and are probably not of *Limnoria* origin; they could be the work of a large herbivore.

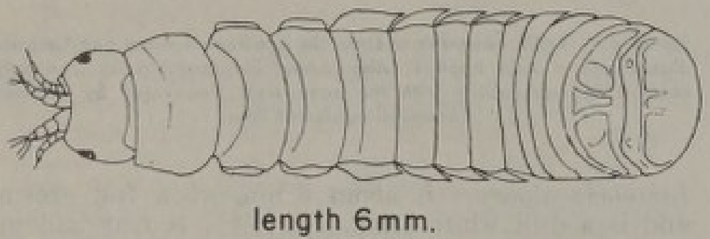


Figure 64. Limnoria algarum, the kelp gribble.

It appears that *Limnoria* does cause a weakening of the kelp plants' attachment to its substrate by hollowing out the rhizoids and causing their destruction. The plant in this condition is easy prey for heavy surges which pull and detach the holdfast at its base. Most kelp plants washed up on the beach appear to retain their holdfasts, which makes it appear that detachment of the holdfast from the substrate causes more loss of plants than breakage of the primary stipe above the holdfasts. If the latter occurs, the primary stipe can regenerate new fronds, provided a growing point just above the holdfast remains after the breakage. In old, large holdfasts, growing points may be nearly enveloped by the outer rhizoids.

Experiments have been carried out with *Limnoria* placed in jars with unburrowed sections of *Macrocystis* holdfast (Table 53). The animals and rhizoid sections are weighed separately, and the two placed together for a period of days. Reweighing indicates the amount of rhizoid material removed by the gribbles, and their weight changes. Old woody rhizoids and younger fleshy ones, either all yellow in color, with a brown "skin" and yellowish interior, or with a purple exterior (due to an iron-tannin complex) were used in the experiments. During the experimental period of 7 or 12 days, the animals and woody rhizoids remained in good condition (the water in the jars was changed at least every other day) but the younger holdfast material tended to rot or soften, and be attacked by a white fungus. Such rotting occurred in the last experiment, in which both young and old rhizoids were presented to animals in the same jars, and probably contributed to the result that nearly all the animals entered the old, durable rhizoids. Out of 36 animals in two jars with eight pieces of old and eight of young rhizoids, only one animal, and another burrow (empty) were seen among the fresh rhizoids. After 12 days the dark rhizoids harbored 26 animals.

The whole group of animals to be placed in a jar were weighed together and the average taken, because of their extremely small individual weights. The animal lengths were from about 2 to 5 mm. Occasionally a brood of young appeared in the course of an experiment; these were not included in the final weight. Only the initial and final weights were taken, because rhizoids containing the animals had to be carved up in order to extract the gribble, and consequently the

Table 53

Summary of Experiments with *Limnoria algarum*

Number of days	Conditions of rhizoids	Initial number of animals	Change in population + = gain — = loss	Average initial weight of animals (mg)	Average weight change of animals (mg)	Total initial weight of rhizoids (g)	Total weight loss of rhizoids (g)
12	old brown	20	—6	3.46	—.61	1.9516	.4700
12	old brown	20	—6	3.36	—.54	4.3383	.4069
12	old brown	15	0	1.81	—.53	2.0265	.2566
	yellow	(—1 of above)				2.0183	.1365
12	old brown	21	—9	1.47	—.18	2.0290	.4215
	yellow	(none of above)				1.6554	.3644
7	old brown	6	—1	2.67	.25	1.1945	.1055
7	purple	6	—1	1.52	.48	2.7263	.0913
7	yellow	6	—3	.87	1.06	1.3790	.1096
7	old brown	control				1.0335	—.0098
12	old brown	control				1.4414	—.0063
	yellow	control				1.9478	.1157
7	yellow	control				1.3292	.0130
12	old brown	control				1.8740	.0179
7	purple	control				2.4911	.1151

plant tissue was useless for continuation of an experiment after the second weighing. The animals are rather delicate, and after extracting them from their original holdfasts, even though they appeared whole after extraction, were actually fatally injured, and may account for most of the loss in population during an experiment. Gribbles apparently keep well for extended periods in holdfasts placed in tanks of running sea water. Some of the animals were from Turtle Bay holdfasts which had been kept for some months.

Both animals and rhizoids were superficially dried on tissue paper, and then weighed in a pan of water. Weight losses by the animals seem to be at least as prevalent as gains; according to Yonge (1951) the burrowing is probably mainly for protection; the animals may feed partly on water-borne detritus or plankton and partly on the wood or rhizoid substance.

Studies on the Smaller Herbivorous Invertebrates Inhabiting Macrocystis Canopies and Holdfasts in Southern California Kelp Beds. The primary subjects of this research were small crustaceans (amphipods and isopods) and gastropod mollusks. The larger kelp-grazing animals, such as the crab *Taliepus* and the turban snail *Norrisia,* and which often climb up into the upper part of the *Macrocystis* plant and its canopy, are treated in another section.

Among the smaller canopy grazers, the isopod *Idothea* (Pentidotea) *resecata* (Stimpson) and a gammarid amphipod, the kelp curler *Ampithoe humeralis* Stimpson, were found to be important in the diets of fishes (Quast, ms in preparation) and were therefore studied intensively. These crustaceans cling to the blade or stipe surfaces by hooked feet provided with spines, and are able to swim for short distances between different kelp surfaces. Investigations of other abundant canopy invertebrates included two small snails, *Mitrella carinata* and *Lacuna unifasciata,* but our studies indicated that they account for only a small fraction of kelp consumed by grazers. A great many other invertebrates have been observed in kelp canopies, but they are either filter-feeders on plankton and suspended detritus, or if they do feed on kelp, occur so sporadically as not to be important. For example, a few foraminifera, (*Rosalina*) were observed in small pits in kelp blades, but these may have been occupying pre-existing holes made by grazers such as crustaceans (Wing, Lankford, and Clendenning, 1959). Encrusting forms, mainly the bryozoan *Membranipora,* do hasten the deterioration of blades. The small shelled serpulid worm *Spirobis* also encrusts blades abundantly. Limbaugh (1955) listed all animals that he observed in the canopy as well as other parts of *Macrocystis* beds: the communities included 30 to 40 species of crustaceans, 20 to 30 mollusks, various echinoderms, bryozoans, worms, brachiopods, hydroids, and small fish. Among canopy mollusks Limbaugh listed *Tegula aureotincta, Calliostoma arincolor* (probably *tricolor*), Lacuna unifasciata, and *Pecten latiauratus* (kelp scallop). He defined a "mid-kelp biotope" as that portion of the kelp plants from 10 feet above the bottom to 10 feet below the top of the canopy. *Mitrella, Pecten latiauratus,* and the isopod *Paracereis* are "more characteristic of the mid-kelp than of other habitats". *Membranipora serrilamella* may encrust more than 90% of a plant; it is more abundant in the lower parts of the canopy. Another, less abundant bryozoan is *Bugula neritina.* Blades encrusted with *Membranipora, Bugula,* or hydroids often support a denser population of motile animals than do clean blades. Wing and Clendenning (1959) made counts of motile animals from encrusted and clean blades; the motile animals include ostracods, copepods, gammarids, caprellids, decapods, polychaetes, nematodes, turbellarians, mollusks, and a miscellaneous group (larvae, isopods such as *Idothea,* medusae, and other infrequent animals). Some encrusted fronds were found to have more than 100,000 motile animals per square meter.

The Kelp Isopod Idothea (Pentiodotea) resecata (Stimpson). The genus *Idothea* has a very wide diet range; different species feed on living and dead animal tissue as well as plants. Naylor (1955a) ran preference experiments with *I. emarginata* and *I. neglecta,* and found that both ate *Laminaria* and scallop muscle if the plant and animal tissue were presented together, and *I. emarginata* also ate living *Arenicola.* Dead fish were cleaned to the skeleton, even if the isopods had been fed exclusively on *Laminaria* for several preceding days. The diet may vary with the locality (e.g. *I. neglecta* was found to be a dead "weed" scavenger in a British bay and exclusively carnivorous at a Norwegian locality). Stage of growth may also affect preference: small individuals of *I. granulosa* eat the associated *Cladophora* and large ones eat fucöids (Naylor, 1955b). *Idothea emarginata* is mainly a sublittoral form on beds of living or dead algae. *Idothea* will also eat its own cast skin, dead *Idothea,* and even cannibalize on living animals of the same species, especially molting ones. The mouthparts of *Idothea* are designed for biting and scraping on large food masses. It cannot filter food from suspension, but was probably evolved, like other Paracarida (amphipods and isopods), from a filter-feeding ancestor. The remnant of the filtering mechanism apparently brushes into the mouth food particles which escape the biting parts.

Idothea resecata has a reported range of Karta Bay, southeastern Alaska, to southern California. This can be extended at least to Bahia Tortugas *(Turtle Bay),* Baja California, where it occurs sparingly on *Macrocystis.* It could range as far as the *Macrocystis* itself, which continues to Punta San Hipolito and possibly to areas of maximal upwelling off Isla Magdalena (Dawson, *et al*, 1960); Punta San Hipolito is 70 miles southeast of Turtle Bay.

Idothea resecata was first found in abundance on eelgrass (*Zostera*) in Tomales Bay, and it was concluded, in spite of occurrences in the open ocean or in kelp beds, that the isopod appeared to be predominantly a sheltered-bay inhabitant (Menzies, 1950). Menzies had also seen it in the open sea, far from kelp. We have not seen it locally, however, on either *Zostera marina* (in Mission Bay) or *Phyllospadix torreyi* (La Jolla) despite repeated searches. Both of these marine grasses have been offered to *Idothea* experimentally, but it never appeared to consume any

Phyllospadix, and only negligible amounts of *Zostera*. A few of the experimental animals gained weight slightly but much less than control animals presented *Macrocystis* concurrently. Animals placed in jars with more than a few blades of *Zostera* invariably died after a few days. Animals isolated with no plants other than *Phyllospadix* showed evidence of starvation, and the blade-like leaves remained whole.

The kelp isopod has been found in the field on the elk kelp, *Pelagophycus porra* as well as on *Macrocystis* and it has grazed on several other brown algae presented to it in the laboratory. Tests have been made with *Idothea* on *Egregia laevigata, Eisenia arborea* and *Pterygophora californica,* in addition to *Pelagophycus*. In the laboratory, *Egregia* decomposed more readily than the others, but evidence was finally secured after many unsuccessful experiments that *Idothea* can grow on it. One animal grew from 26 mm to 31 mm in length within 8 days when fed exclusively on *Egregia*. *Eisenia,* among the most durable of the brown algae, was kept in a grazing experiment for 15 days. After this period, a section of *Eisenia* blade exhibited a grazing pattern similar to that on *Macrocystis* blade.

Experiments were designed to measure the weight gain of the isopods and the simultaneous weight loss of the *Macrocystis* being consumed. Typically, one fresh blade with pneumatocyst was suspended in a widemouth three-gallon pickle jar, with one or more animals, depending on their size. These jars were kept at the prevailing temperature of the SIO sea water supply system (within about 2°C of the ocean temperature at the intake) by immersion in a tank. Fluorescent lights, left on continuously, illuminated this tank and caused a slight weight increase of the control kelp blades, in jars without animals. The water in the jars had to be changed at least every other day; it was found that a complete rinsing out of the jar was needed during each change; otherwise, the fecal pellets left after successive water changes considerably hastened the deterioration of the kelp, killing the animals. It was also found that overcrowding the jars caused a high loss of animals; of 10 small (ca. 14 mm in length) animals placed in one container, six survived after eleven days and one after 26 days. Also in this first grazing-rate experiment, only one of three other individuals, each in a separate jar, survived for the latter period. In a subsequent trial, all the animals survived for 32 days, the duration of the experiment. In the first experiment the water in the jars was changed several times a week, but the jars were not completely washed out during the changes. The water temperature was usually 14° to 17° C. In the summer and early fall, when the temperature exceeded 18°, the kelp stored in the tanks or used in the experiments deteriorated rapidly, and animals were less healthy in the laboratory and less abundant in the field.

A summary of weight increases (in grams), kelp consumption (in grams) and efficiencies of the conversion of kelp substance into animal substance is given in Table 54. A more detailed analysis of this work will be reported in a future paper (Clendenning and Jones, ms in preparation). Efficiency represents animal weight gain divided by the kelp consumed. Underestimation of the food consumption would result from any growth of the kelp blade by photosynthesis during the experimental period. No correction has been made for this in Table 54, but the blade-growth data on control blades without grazing animals has been included and is seen to be a minor factor.

The animals were weighed by differences in a beaker of water, after light swabbing and a few seconds exposure to air. The reproducibility of this manner of weighing was within a range of .032 gram for six weighing of a .535-gram (average weight) animal, or a standard error of 2.24%. Kelp blades were superficially dried with paper towels, "polished" with tissues, and then weighed in a plastic bag at 100% humidity. The method yields results reproducible to about 1%. Areal decreases of kelp blades were measured to acquire two types of information:

1. The pattern in different parts of the blade—preferred portions, if any—and shape of grazing holes.
2. A check on the data concerning blade weight loss.

Tracings were made of blades in plastic bags on an illuminated table, cut out, and weighed. A rectangle of the tracing paper with measured sides was weighed for calibration. There is roughly a linear relation between blade weight and area, as would be expected. Grazing on a particular blade shifted its weight substantially off the line relating blade weight and area. The pattern of grazing is shown for a sample blade in Fig. 65.

The preferred portion of the blade grazed by the *Idothea* is near the point of attachment to the pneumatocyst, where there is apparently a higher concentration of plant nutrients (carbohydrates). These products of photosynthesis must travel through the "neck" of the blade in order to reach the rest of the plant. The blade is slightly thicker at this point than at the periphery, and might be the last portion to rot away if grazing animals were not present. This mode of attack of the blades by *Idothea* causes loss of the blade by severance from the rest of the plant long before the blade is completely consumed. In the pickle jars during the grazing-rate experiments, blades were repeatedly severed from the pneumatocyst well before the end of the experiments. Sometimes the pneumatocyst and blade together are severed from the plant, presumably by grazing, and these float in the water; appreciable numbers of *Idothea* have been seen on such blades being carried in by the surf on the beach at SIO. The fact that blades are often lost before they are completely consumed amplifies the amount of destruction to the kelp over that which is actually consumed by the grazers. Blades cut off from the pneumatocysts sink to the bottom where they are presumably abandoned by the *Idothea,* which readily swim to nearby intact kelp surfaces.

Idothea, therefore, forms an intermediate in the food chains of the kelp beds. Efforts to eradicate sup-

Table 54

Growth rate and kelp consumption of the isopod *Idothea resecata*.

Initial animal weight (grams)	Initial kelp weight (grams)	Animal weight gain (grams)	Kelp weight loss (grams) (negative = weight gain)	Animal efficiency (percent)	Period (days)	Average growth rate (mg./day)
.0342	16.91	.0741	1.02	7.26	18	4.11
.0342	16.91	.0928	4.89	1.89	32	2.90
.0931	20.82	.0589	.69	8.55	11	5.35
.1035	18.44	.1125	1.79	14.2	18	6.25
.1035	18.44	.2905	6.09	4.78	32	9.08
.1146	17.66	.0578	1.29	4.48	11	5.25
.1156	19.10	.0301	.64	4.70	18	1.67
.1156	19.10	.1014	2.70	3.76	32	3.18
.1305	16.05	.0115	.64	1.80	11	1.04
.1305	16.05	.0040	2.53	.158	26	.15
.1980	15.80	—.0226*	.79	------	18	—1.26
.1980	15.80	.0317	6.07	.523	32	.99
.528	15.83	.007	1.16	.604	4	1.75
.528	15.83	.032	5.38	.595	15	2.13
.528	15.83	.067	10.38	.646	25	2.68
1.220	16.12	.019	2.67	.712	4	4.75
1.220	16.12	.030	8.20	.366	15	2.00
1.220	16.12	.036	11.72	.307	25	1.44
control	16.38		—.47		18	
control	16.38		—.47		32	
control	16.83		+.01		31	
control	18.94		—.63		18	
control	18.94		—.16		32	

* Animal had given birth to young during experiment period. The young were not included in the subsequent weighing.

posedly harmful canopy grazers with a view towards preserving the crop are not to be undertaken without first estimating the deleterious effect that their removal would have on fish. Furthermore, large bottom grazers, such as the sea urchins (*Strongylocentrotus*), probably destroy far more kelp by feeding on holdfasts and cutting stipes near their bases. Living sea urchins are not important food sources for fish, although sheephead (*Pimelometapon pulchrum*) will congregate and feed on a freshly crushed specimen (personal observation and Quast, ms in preparation).

Reference experiments were conducted by placing several types of food in open pickle jars placed in a laboratory tank, together with a jar containing several isopods. The animals were able to swim into any of the food jars through the tops which were about 2 to 5 cm below the water surface. *Macrocystis* (blades, stipe lengths, or growing ends), *Eisenia, Cystoseira, Egregia,* fleshy reds, fresh and old *Macrocystis* holdfast rhizoids, and *Pelagophycus* stalks sections were presented. It appears that the type of food is not as important as the fact that the animals tend to stay together (Table 55); few animals, however, were found in jars without brown algae. Between 10 and 20 animals were released in each experiment, with a size range of 10 to 35 mm. Experiments ran for about 24 hours unless otherwise indicated. Six jars contained food, and a seventh contained the animals at the start of an experiment.

The kelp isopod is scarce in kelp beds when the water temperature in the surface levels is above about 18° C. Respiration-rate measurements have been made at various temperatures. A fall-off in respiration and presumably metabolism is observed at 25° C, at which point some mortality is experienced. The optimum temperature is 15°, with only a slightly smaller respiration rate at 20°. Measurements were made at 0, 5, 10, 15, 20, and 25° C; only the latter temperature was lethal to any of the experimental animals. Breathing movements were very slow at 10°. Warm water also has an adverse effect on *Macrocystis;* a level of much over 18° C. held for several weeks is harmful. Beds are rapidly decimated at or above 24° (Brandt, 1923). In the late summer, when these temperatures are approached, the canopy is often in poor condition, and *Idothea* was practically absent. Seasonally, this animal appears to be most abundant in the winter and early spring, when the plants are the most healthy.

Idothea has seven pairs of walking legs, one from each segment in the thorax. Each foot ends in a sharp claw of two points accompanied by at least three spines. The hooked claws enable the animal to cling to the surface with considerable tenacity, often mak-

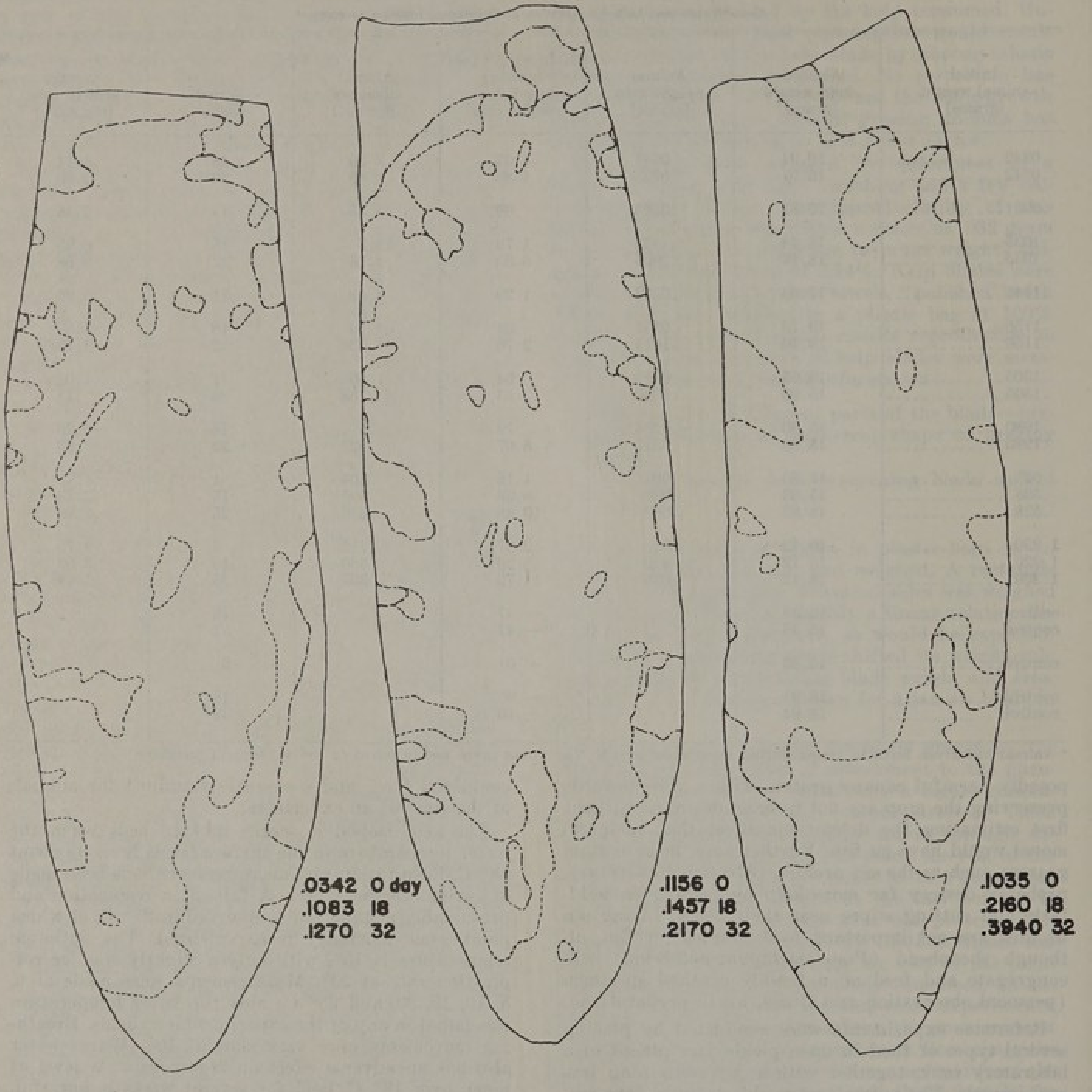


Figure 65. Blade grazing patterns from kelp exposed to Idothea resecata.

ing it difficult to remove the animal without possible injury. Even dead specimens, when placed on a finger, will cling to it. Figure 66 shows the arrangement of a foot, typical for all the walking legs. In order to get a firm hold on the kelp blade, necessary for preventing dislocation in rough water, the animal must puncture it. Such punctures, together with grazed areas, might become centers for black rot, bacterial, or fungal infections of blades. In warm water, injuries to the blades by grazing or puncturing probably hasten their deterioration. Areas of blades covered by colonies of the bryozoan *Membranipora serrimella* were also seen to become centers of rotting when such blades were held in laboratory tanks during the summer. It cannot be said, however, that *Idothea* is the sole or chief agent causing blade deterioration by

Table 55

Summary of Preference Experiments involving *Idothea resecata* and marine algae.

Number of animals released	Type of food in each jar found with animals, and number of animals in that jar	Other types of food, in jars without animals
1. 15	*Mac.* blades 1, *Mac.* ends 4, *Mac.* stipes 7	*Eisenia*, *Cystoseira*, two fleshy reds.
2. 11	*Mac.* blades 1, outside jars 10[*]	*Mac.* stipes, rhizoids.
3. 10	*Mac.* blades 6[**], old rhizoids 1, others outside	*Mac.* stipes.
4. 15	*Mac.* blades 7, *Mac.* blades 4, old rhizoids 2, outside 1	*Mac.* stipes.
5. 14	*Mac.* blades 4, *Cystoseira* 2, outside 7	*Mac.* stipes, rhizoids.
6. 13	*Mac.* blades 1, *Mac.* blades 3, *Cystoseira* 9[***]	*Mac.* stipes, rhizoids.
7. 13 (48 hr)	*Cystoseira* 10, [***]outside 3	*Mac.* blades and stipes, rhizoids.
8. 10 (72 hr)	*Mac.* blades 1, outside 9	*Cystoseira*, fleshy reds, *Pelagophycus* stipe.
9. 10 (48 hr)	*Mac.* blades 1, *Pelagophycus* 1, outside 8	*Cystoseira*, fleshy reds.
10. 10 (48 hr)	*Mac.* blades 2, outside 8	*Cystoseira*, fleshy reds, *Pelagophycus* stipe.

Mac. = *Macrocystis*

[*] The only food source in the tank outside the jars was green algae on the walls.

[**] The jar had 6 blades, but 4 of the 6 animals were on one blade.

[***] The animals had obviously been eating the *Cystoseira*, leaving many droppings in the jar.

providing loci for infection; *Membranipora*, is usually far more numerous in the summer when kelp decay is at a maximum, and at such times the isopod is scarce.

In the field, we have taken *Idothea resecata* only on the giant kelp *Macrocystis pyrifera*, and on the elk kelp *Pelagophycus porra*, which grows on the outside of *Macrocystis* beds in deeper water. This isopod occurs mainly in the canopy region, on blades and stipes, but may range down to the holdfast biotope (Limbaugh, 1955). We have not seen *I. resecata* in holdfasts, but have observed another species, provisionally identified as *Idothea (Idothea) urotoma* Stimpson, a gray-black isopod, smaller than *I. resecata*, principally occurring intertidally on rocky coasts (Menzies, 1950). A large colony of juveniles was discovered by accident in an unused laboratory tank with running sea water, apparently feeding on organic debris there.

A Surfgrass Relative of the Kelp Isopod. An elongated green isopod, tentatively identified as *Idothea (Pentidotea) montereyensis* Maloney, has been found on the surfgrass *Phyllospadix* in the open rocky-shore, intertidal at La Jolla. It is shaped and colored for maximum camouflage; it always sits parallel to the axis of the narrow blade-like leaves, and has about the same width. In the laboratory, it feeds on the *Phyllospadix* leaves, but will not touch any *Macrocystis* presented to it. It grazes along either side of the surfgrass blade, leaving a portion intact along the opposite side. Like *I. resecata*, this isopod is in the subgenus *Pentidotea* (five segments on the maxilliped palp, rather than four as in the other subgenus *Idothea* S. S.).

The Kelp Curler Ampithoe humeralis Stimpson. The feeding rate of *Ampithoe* was measured the same way as with *Idothea resecata*, usually with one animal on one blade with pneumatocyst per jar. The gammarid is a somewhat more difficult subject than the kelp isopod for these determinations because it may lie dormant in a "nest" made by curling the blade inward and not feed to any appreciable extent for a period of over a week (shown by the first *Ampithoe* experiment run). These nests, where they are effectively hidden from sight, are used as a refuge to which the animals retreat after a feeding excursion. Several animals, such as a brood of young accompanying a parent, may use the same nest. Mucus is used to secure the overlying edge of the blade to the surface at the inner edge of the nest.

When the animals are actively feeding, their food consumption rates, growth rates, and efficiencies are within the range indicated by *Idothea*, except that one gammarid showed a slightly higher efficiency than any isopod tested (Table 56).

Table 56

Growth rate and kelp consumption of the gammarid *Ampithoe humeralis*.

Initial animal weight (grams)	Initial kelp weight (grams)	Animal weight gain (grams)	Kelp weight loss (grams) (negative= weight gain)	Animal efficiency (percent)	Period (days)	Average growth rate (mg/day)
.0420 (8 animals)	16.13	.0465 (4 animals)	----	----	20	----
.0420	16.13	.0628 (1 animal)	----	----	40	----
.0558	14.45	.0402	.25	2.01	20	2.01
.0558	14.45	.0949	1.85	2.37	40	5.12
.1594	14.32	0.676	.55	12.3	20	3.38
.1594	14.32	.1714	4.72	3.63	40	4.29
.300	21.54	.0030	2.22	.014	11	.25
Control	15.50		—.29	----	20	----
Control	15.50		—.60	----	40	----

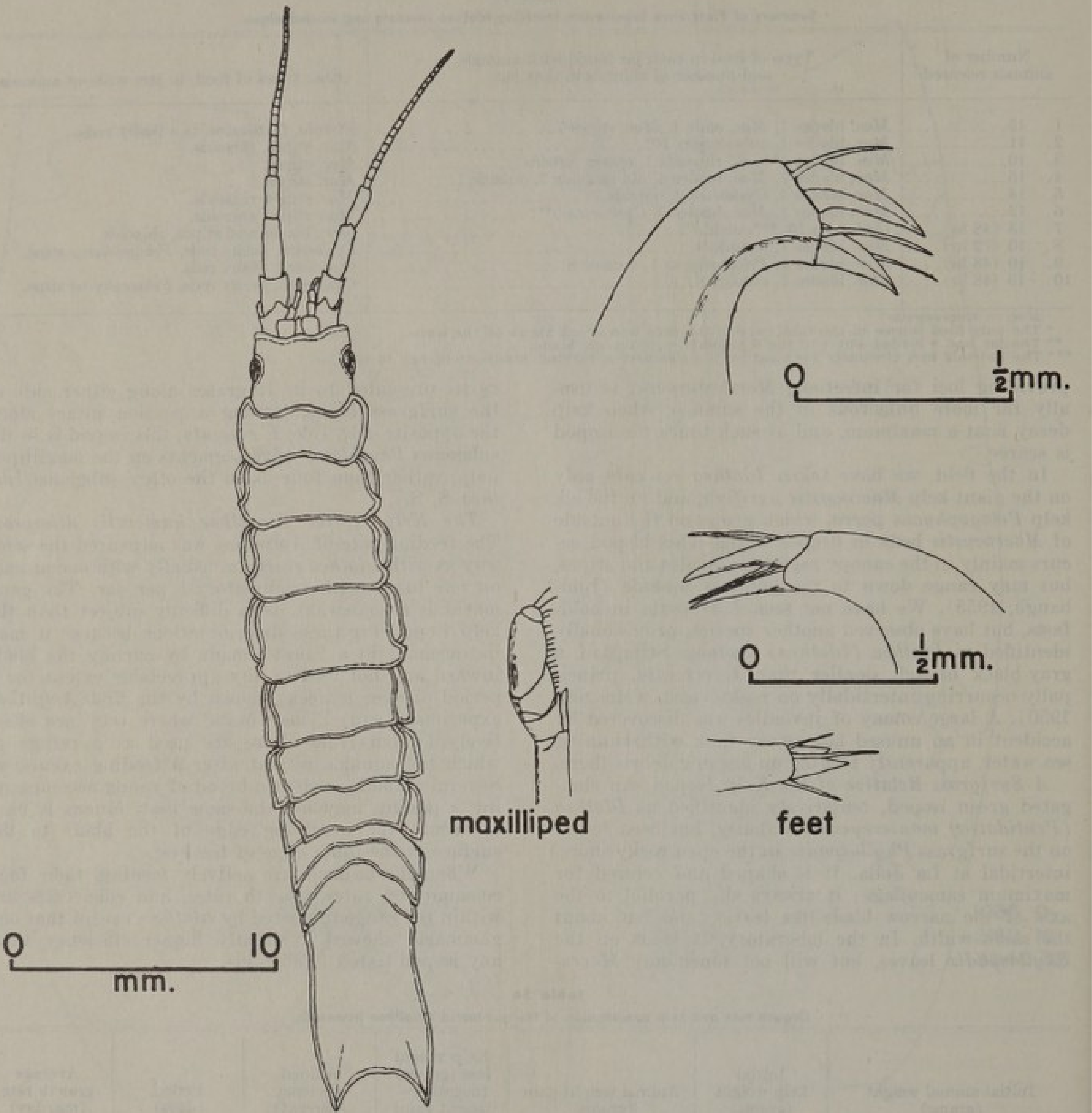


Figure 66. Idothea resecata, the kelp isopod.

Like many other crustaceans, gammarids are provided with many spines, as well as hooked ends of the walking legs (see Fig. 67). The animal moves on its side on a kelp blade, adhering to it with the aid of these spines and hooks, or claws. The possible effect of puncturing kelp surfaces has been discussed above. It is possible that *Ampithoe* and other gammarids feed only on the blades, and not the stipes.

The Kelp Snail Mitrella Carinata Hinds. The small gastropod, *Mitrella carinata,* is sometimes the most abundant macroscopic animal living attached to the *Macrocystis* canopy surfaces, but it appears to be an unimportant link in the kelp food chain. An experiment, supplemented by other observations, indicated that this snail grazes very little of the kelp tissue, but, instead, receives its nourishment from microscopic detritus adhering to kelp blades and other surfaces, such as the walls of a jar in which they were placed. Twenty-seven of the snails, with shell lengths of 2 to 7 mm (a typical range), were isolated in a jar

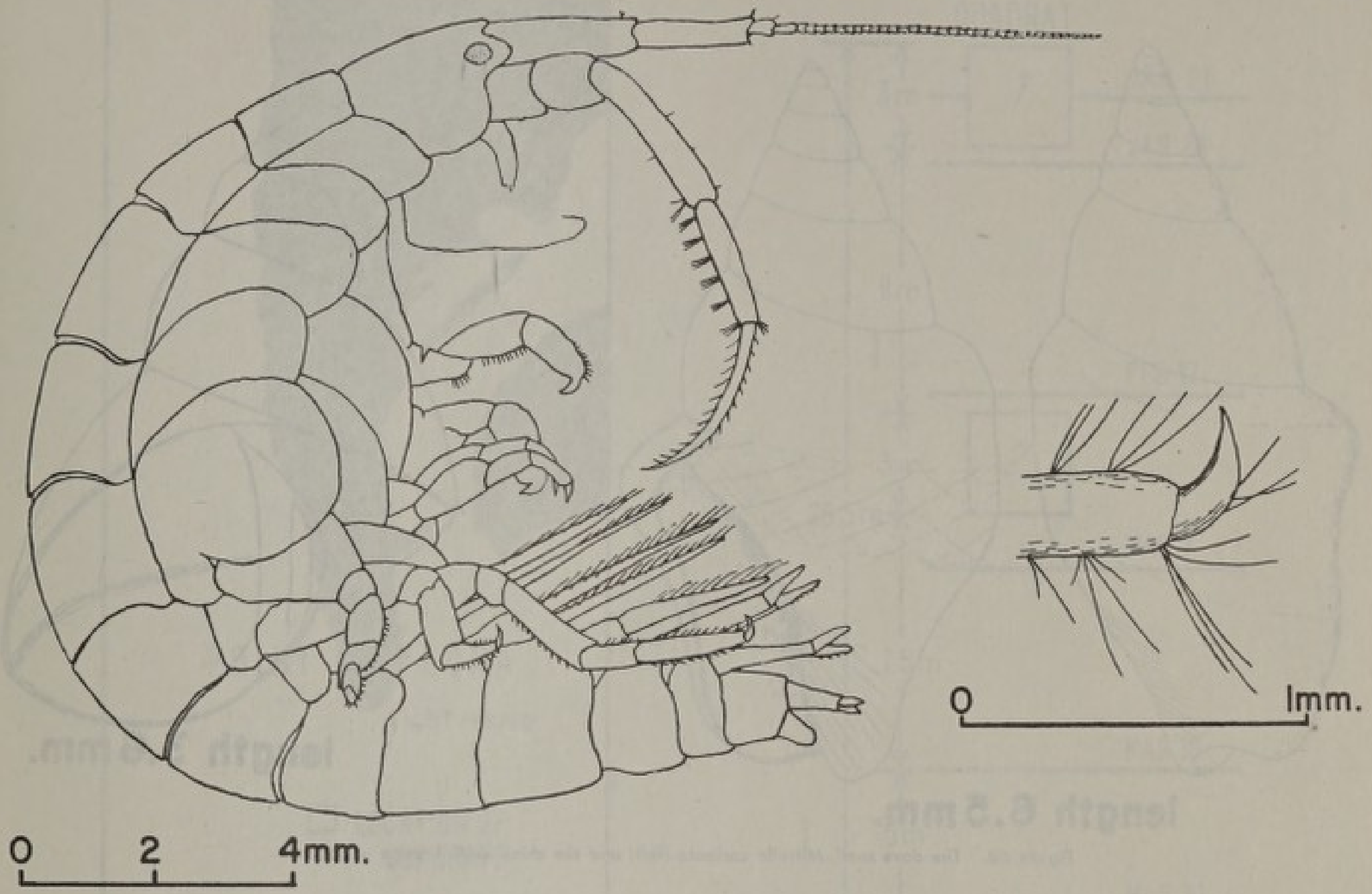


Figure 67. Ampithoe humeralis, the kelp curler.

with a kelp blade for a total of 37 days. The blade was examined after 2, 15, and 27 days. Small grazing areas, where the top cell layers of the blade were removed but which rarely penetrated, had a maximum size of about 20 mm^2. Some holes were undoubtedly enlarged by subsequent rotting of the blade; the lower half was badly rotted by the end of the experiment. The number of holes were as follows: after 2 days 12; after 15 days $13 + 11 = 24$; after 27 days $24 + 17 = 41$; after 37 days about 21 holes in the unrotted portion of blade. Grazing areas covered about 40% of the pneumatocyst attached to this blade but did not penetrate to much depth.

A count was made of various canopy animals from a surface sample collected over a depth of 50 feet in Turtle Bay, Baja California, November, 1961 when *Mitrella* was abundant, but this should not be considered as an average or even a typical sample. There was also a high abundance of the scallop *Pecten latiauratus* (all juveniles of a limited size range of 2 to 6 mm, dorso-ventral). There were 850 *Mitrella*, 400 scallops, 18 brittle stars, 9 *Lacuna* and four other mollusks. No kelp crustaceans were recovered in this count.

Mitrella is not only a *Macrocystis* dweller; it is also common on the ocean floor among coralline or fleshy red and smaller brown algae. It outnumbered other animals enumerated in square-meter samples from the bottom off La Jolla Cove, in 25 to 40 feet of water. Evidently this snail is a wide-ranging microcarnivore and detritus-feeder, more or less associated with kelp and other algae.

The Chink Shell Lacuna unifasciata Carpenter. The second most common shell-bearing gastropod locally found on kelp blades is another small form, tentatively identified as *Lacuna unifasciata* Carpenter. The shells of this genus are distinguished by a hollow or "chink" in the columella. This species has a rounded aperture and a single dark brown band at the suture, and has a reported range from Monterey to Lower California, clustering on seaweed. We have found this snail on *Macrocystis* in the San Diego area and at Turtle Bay, always in lesser numbers than *Mitrella*. In the Turtle Bay animal count mentioned above, there was about one *Lacuna* to 100 *Mitrella*, but later qualitative inspections of a shallow-water kelp bed at a depth of 15 feet gave the impression of a less extreme ratio. Grazing experiments indicate that *Lacuna* feeds on the material of the stipe; after 20 days with sixteen snails, of which seven survived about 13 small pits, largest about 6 mm^2 in area and 1.5 mm deep, appeared on a length of stipe. Snails commonly were seen during the experiment at the cut ends of the stipe, which they had apparently hollowed out, leaving the skin intact. *Lacuna* also has been found on coralline-algae-encrusted sand-rock bottom, in smaller numbers than *Mitrella*.

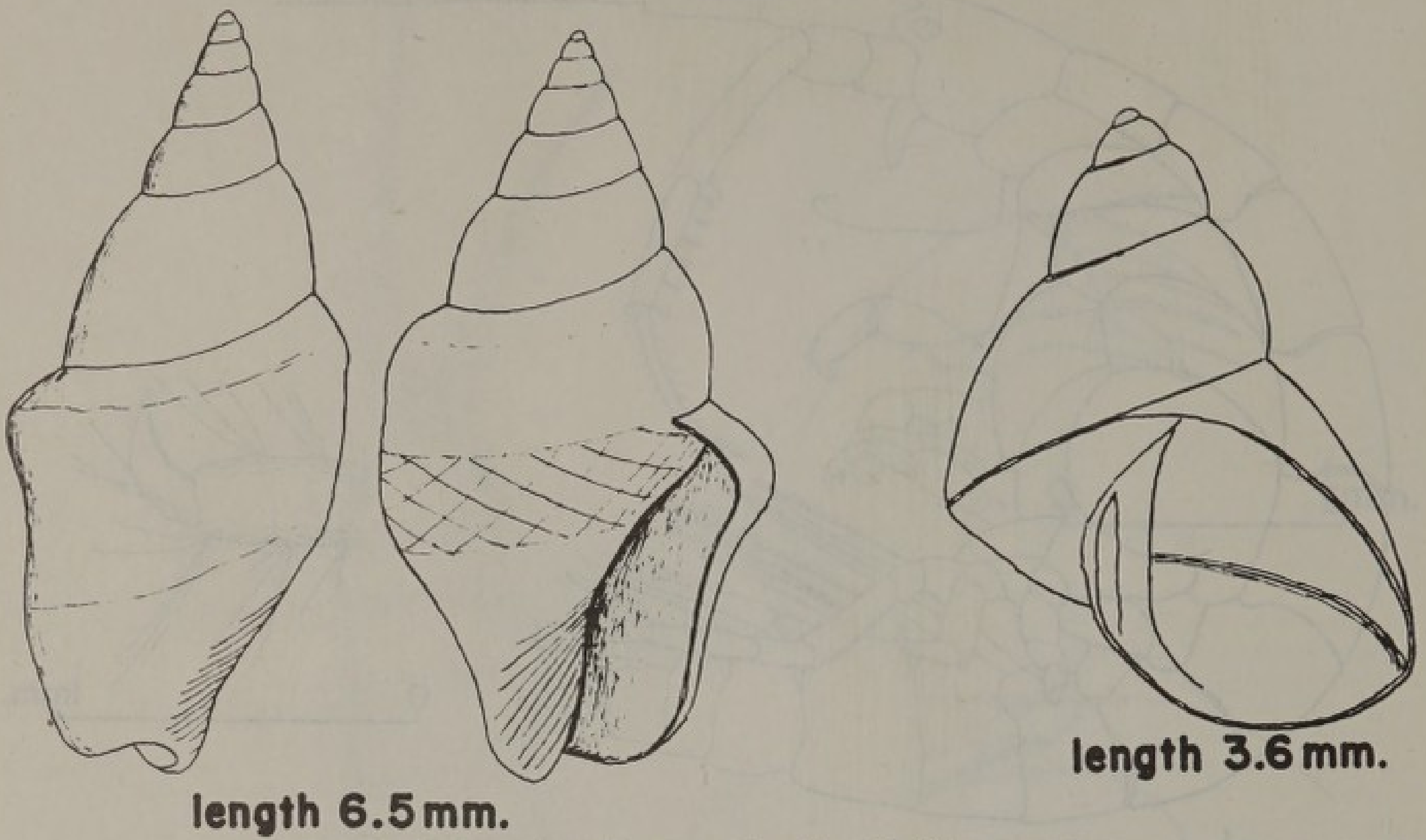


Figure 68. The dove snail, Mitrella carinata (left) and the chink shell, Lacuna unifasciata.

The Pillbug Paracerceis sp. A second isopod occasionally occurs in the *Macrocystis* canopy, and has been found locally and at Turtle Bay. This pillbug (*Paracerceis* sp.) is rounded in outline, more than half as wide as it is long, and of a pale brown color much lighter than that of kelp.

Paracerceis probably gets most or all of its nourishment from the kelp, but it feeds slowly and grows slowly. An animal, with a weight of about 83 mg, did not show any measurable growth within nine days although a few grazing areas appeared on the kelp blade.

Field Studies

Many instances were found of active destruction of plants by grazers at Palos Verdes and Pt. Loma. An intensive study was conducted in the winter of 1959-60 on a small bed that had developed at the tip of Pt. Loma and which was destroyed by dense populations of sea urchins.

Sea Urchin Grazing in the Field. A portion of the Pt. Loma kelp bed (#2) growing in water approximately 40 feet deep was found to be suffering plant loss at an alarmingly high rate due to stipe and holdfast grazing by two sea urchin species, *Strongylocentrotus purpuratus* and *S. franciscanus*, in December, 1959.

To study the composition and dynamics of the sea urchin population and to measure the rate of advance of the grazing front upon the kelp bed, two nine square meter quadrats were employed. The quadrats were constructed by driving steel spikes into the bed rock and passing a nylon cord between them through rings welded on each spike. Quadrats were placed in the ungrazed portion of the kelp bed, one directly adjacent to the urchin front and the other eight meters inward toward the center of the kelp bed (see Figs. 69 and 70).

Observations and recordings made in each quadrat at that time (21 Jan, 1960) and at subsequent visits were: the number of kelp holdfasts and number of stipes emerging from each holdfast (recorded one meter above the bottom); a measure of the number of sea urchins of each species present; records of other species of marine algae within quadrat bounds; and the position of the grazing front with respect to the quadrats. Temperatures on the bottom ranged from 11.0 to 13.0° C during the observational period from 21 Jan. to 31 Mar., 1960. The data are summarized in Table 57. Data of Table 57, Quadrat I are also presented in graph form in Fig. 71.

The band of sea urchins was approximately 30 m wide and appeared to surround the north portion of the kelp bed. Several spot dives on the south border indicated the urchin concentrations were high there also. Greatest concentrations of urchins were found at and near the kelp bed border. The border (created by the grazers) progressively moved toward the center of the kelp bed at a rate of 10.2 m (approximately 33 ft.) per month. By the end of March the little bed had vanished.

Figure 69. Location of the grazer study with respect to Pt. Loma. Depth, 40 ft.

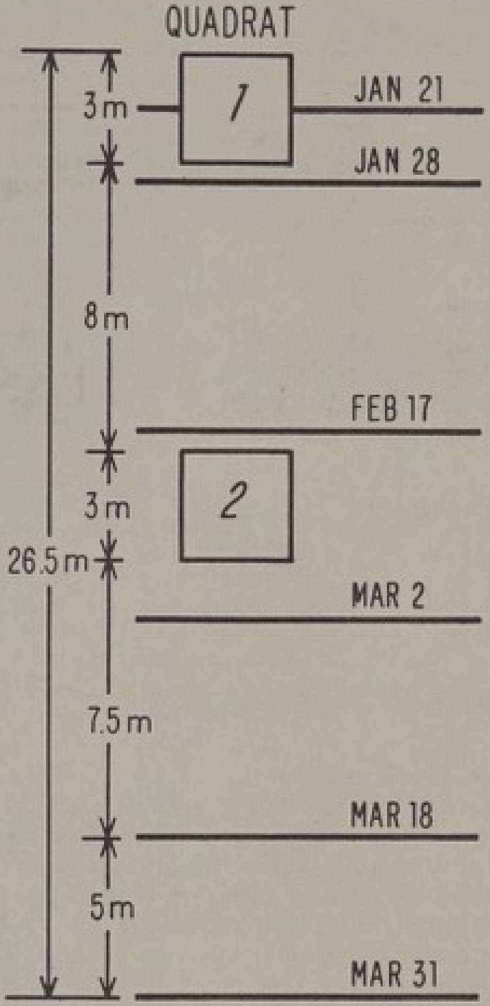


Figure 70. The position of the sea urchin grazing front on six dates within the two-month observation period, January 21-March 31, 1960. The rate of advance of the sea urchin band was found to be approximately 33 ft. (10.2 m) per month.

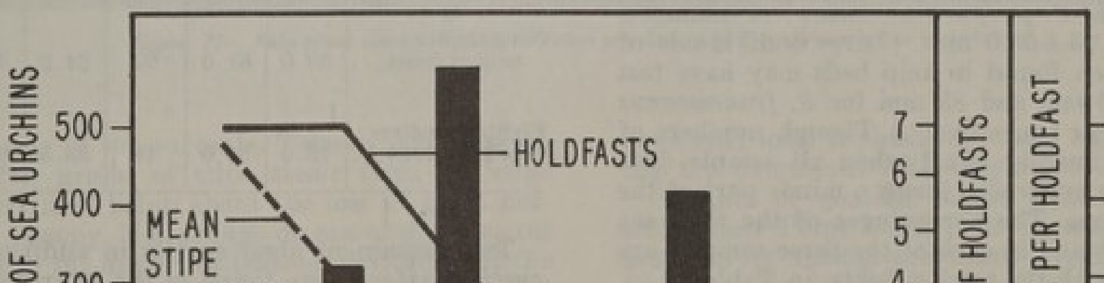


Figure 71. Changes in sea urchin and kelp plant concentrations in Quadrat No. 1, January 21-March 31, 1960.

Table 57

Summary of data gathered from counts of grazers and plants in quadrat study.

Date	Total urchins per Quadrat	Percent *S. franciscanus*	Percent *S. purpuratus*	Number of holdfasts	Range stipes/ holdfast	Mean stipes/ holdfast
			Quadrat 1			
1/21/60	76	95.0	5.0	7	5–16	9.7
1/28/60	312	90.0	10.0	7	0–15	5.9
2/17/60	572	44.5	55.5	4	0	0
3/ 2/60	204	42.5	57.5	0 (3)*	0	0
3/18/60	414	15.2	84.8	0 (2)	0	0
3/31/60	248	12.1	87.9	0 (2)	0	0
			Quadrat 2			
1/21/60	0	0	0	5	6–43	25.2
1/28/60	0	0	0	5	6–41	23.6
2/17/60	0	0	0	5	4–48	20.6
3/ 2/60	230	90.0	10.0	4	0–15	4.8
3/18/60	558	38.8	61.2	2 (4)	0	0
3/31/60	479	18.5	81.5	2 (4)	0	0

* Figures in parentheses indicate the number of recognizable holdfast remnants. Figures not enclosed in parentheses represent the number of holdfasts with grazable haptera.

A square meter sample taken of sea urchins at the grazing front illustrated a preponderance of *Strongylocentrotus franciscanus* at that position in the sea urchin zone. Samples taken at 9 and 18 m behind the front showed decreasing numbers of that species and increasing numbers of *S. purpuratus* (see Table 58). The same distribution is implied in data of Table 57 where measurements were made at quadrat locations on six occasions throughout the two and one-half month interval while the grazers advanced across the quadrats. Size and weight frequency determinations show an absence of the larger individuals of both species. Both populations are composed of sub-adults; *S. franciscanus*, mean test diameter, 50.6 mm, range 25.0-92.0 mm, and *S. purpuratus*, mean test diameter, 31.5 mm, range 24.4-53.0 mm. (Large individuals of these species often found in kelp beds may have test diameters of 120 mm and 85 mm for *S. franciscanus* and *S. purpuratus* respectively.) Though numbers of each are approximately equal when all sample data are summed, *S. purpuratus* forms a minor part of the sea urchin biomass. The percentages of the total sea urchin weights found in each of the three samples are given, together with the total weights, in Table 58.

Photographs showing a recently attacked kelp plant and a well grazed holdfast are included (Figs. 72 and 73).

Sporophylls and stipe bases appeared to be grazed by the grazing front. *S. franciscanus* concentrations were high when this grazing was observed (Fig. 71, period January 28 to February 17, 1960). General holdfast routing may be effected by both urchin species, but the gradual holdfast reduction occurs when concentrations of *S. purpuratus* are high. These facts suggest that in this instance (Pt. Loma kelp bed) *S. franciscanus* was the chief offender while *S. purpuratus* formed a "clean-up crew", reducing the remaining holdfast tissue to rubble.

Table 58

Concentration and biomass of two sea urchin species in square meter samples taken at three positions across grazing band.

Sample number and position	Relative density in numbers		Total urchins per m²	Relative density in weight		Total urchin weight per m²
	S. fran. (%)	*S. purp.* (%)		*S. fran.* (%)	*S. purp.* (%)	
1 At grazing front..	94.0	6.0	32	99.3	0.7	2,486 g
2 Nine meters behind front...	39.0	61.0	62	64.0	36.0	1,942 g
3 Eighteen meters behind front...	15.0	85.0	46	33.5	66.5	1,253 g

Two prominent algal species in addition to *Macrocystis pyrifera* were found in the ungrazed portion of the bed, namely *Pelagophycus* and *Pterygophora*. These plants were grazed along with the kelp of the quadrats. In the trail of the sea urchins no algae remained, save the ubiquitous *Lithothamnium*. An increase in the amount of pebbles and small rock pieces was found in the denuded area. Perhaps the anchorage given this material by haptera was lost.

More importantly, large numbers of recently emptied juvenile abalone shells were noted. These were primarily of the species *Haliotis rufescens*, *H. assimilis* and *H. wallalensis*.

Grazing by but a few sea urchins on or about the apex of the holdfast is generally sufficient to weaken or break the stipe bases. Such divorced stipes are then

Figure 72. Kelp plant under attack by a dense population of Strongylocentrotus franciscanus.

carried the way of the currents. Thus by consumption of a very few grams of stipe tissue from the stipe bases, grazers may bring about the loss of great portions of the canopy. Not always do sea urchins mount the holdfast to the apex, but instead, cavitation of the holdfast proper may occur. In this case the holdfast base may be so weakened that storm surge may dislodge the entire plant.

That portion of the kelp plant above the level of the sporophylls is essentially outside the grazing range of sea urchins, though occasionally an individual will manage to ascend a stipe for some distance above the holdfast. The lower levels of the plant are, however, most vulnerable in view of the fact that relatively minor grazing in that area may cause waste of large quantities of stipe and canopy.

Other quadrats were established during the summer of 1960 in advance of sea urchin fronts in another area off Point Loma. The same phenomenon was observed; total denudation of the algal flora (excepting the ubiquitous *Lithothamnium*).

Samples of gonadal tissue from sea urchins collected near Point Loma from an area grazed bare as much as six months previously revealed no reproductive activity. Gonads existed as mere rudiments. Stomachs contained little matter, primarily surface scrapings. An increased rate of mortality was evident in the empty, but perfect tests found in large numbers. Conversely, sea urchins collected from a relatively algal rich area about 400 yards from the former area had at the same time full intestines and fully developed gonads.

In addition to the observations made at Pt. Loma, a small bed of *Macrocystis* near the south jetty of Mission Bay was studied which suffered attack by the smooth brown turban snail. That area was visited during 1960 and 1961 in which time kelp plants declined markedly in the late autumn and winter.

Figure 73. Holdfast remains after the plant base was destroyed by sea urchins.

Macrocystis plants were apparently protected from grazing pressures during the spring when other brown algae *(Cystoseira, Halidrys, Egregia, Laminaria* and *Pterygophora)* formed luxuriant new growth. These plants flourished through mid-summer. Following the deterioration of decoying algae, the turban snails moved onto the giant kelp plants. A relative increase in numbers of snails on kelp plants at a time when water temperatures were high (warmer water consequently causing an elevation of feeding rates of grazers and perhaps also increasing the deterioration rate of *Macrocystis*) led to heavy damage in the early fall months.

In general, sea urchins appeared to be the most destructive grazers observed at Pt. Loma and Palos Verdes and they persisted long after other species such as abalones, wavy tops, etc. had become reduced in numbers or had disappeared. In the laboratory, urchins can be starved to death over periods of a few months to about a year, but large populations of adult animals have been continuously widely distributed at Pt. Loma and Palos Verdes since the start of the project in 1957, a period of nearly six years. At Santa Barbara, however, on a sand-mud bottom, very few urchins were ever observed.

To characterize the urchin populations, samples were gathered from 3 locations at Palos Verdes and 4 sites at Pt. Loma in the latter half of 1962 (Figs. 74, 75). Square quadrats varying in size from ¼ to 1 m on a side were employed, the size depending on the density of urchins. Blind casts were made and all animals lying within the quadrat were collected for laboratory measurement. Results indicated that the populations were not uniform in their size distributions (Fig. 76),

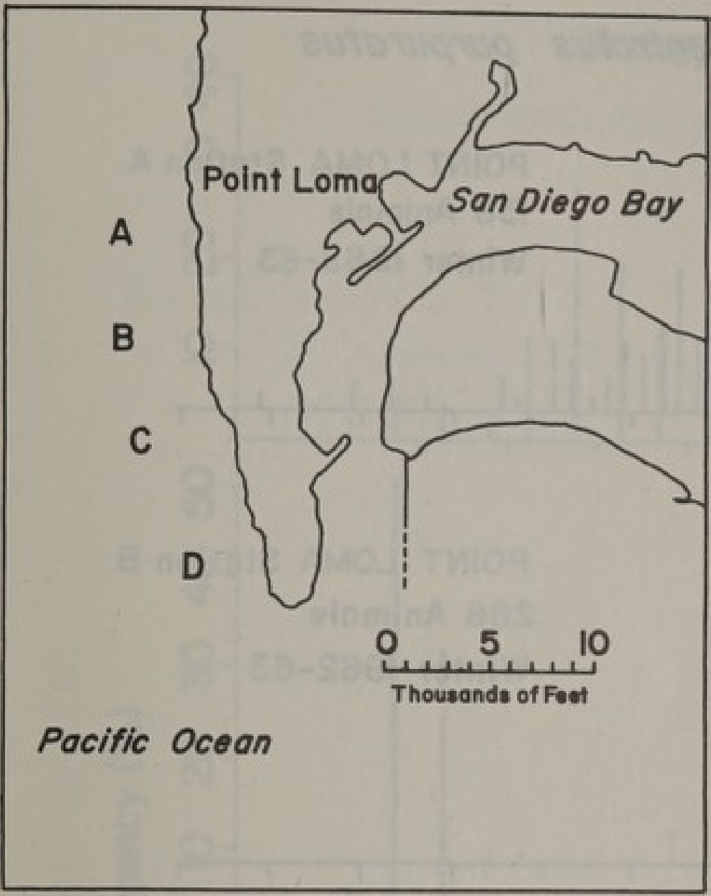


Figure 74. Chart of Pt. Loma, showing the sites of collections of sea urchin samples, denoted by A, B, C, and D.

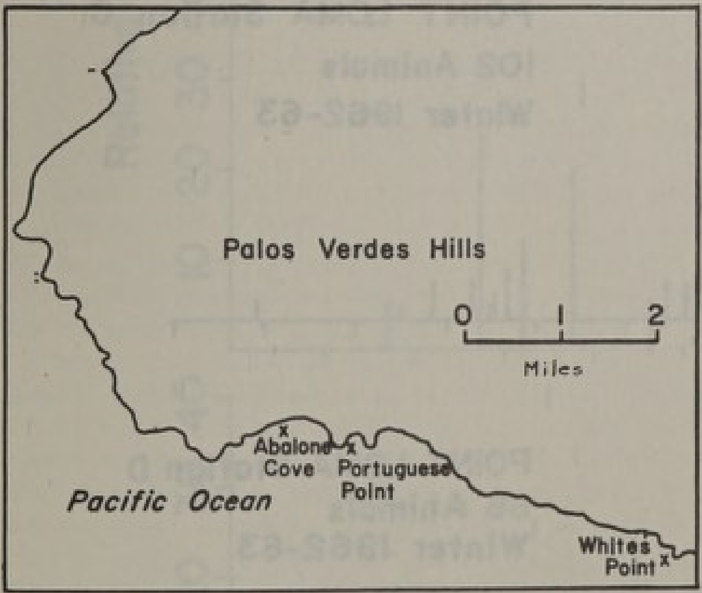


Figure 75. Chart of the Palos Verdes peninsula, showing the sites of collections of sea urchin samples, denoted by Xs.

and it is very likely that urchins at the different locations are not related as to time of origin, food sources, intermingling by migration, etc. Examination of body tissues usually showed reduced gonad volume and gut contents were typically composed largely of inorganic sand crystals or amorphous material (Fig. 77). Urchins gathered from an algal rich area at La Jolla during the same period had voluminous gonads and gut contents clearly of vegetable origin (Fig. 78).

One noteworthy disappearance of kelp which did not involve destruction by sea urchins but was presumably caused by highly motile grazers, was noted in Bed 14 off Flatrock Point, along the Northwest face of the Palos Verdes Peninsula in the fall of 1958 Every kelp plant examined was missing virtually every blade, although the stipes and pneumatocysts were usually intact. The basal areas where blades attach to the pneumatocysts were severely chewed, no clean breaks or deterioration or sloughing was apparent. Since the damage extended from the bottom to the surface and was observed in scores of plants distributed over a considerable area, it seems likely that highly motile grazers were responsible, probably schools of fish. A month later all of Bed 14 had vanished and has not reappeared. No recent surveys have been made by the authors in the area, but local sport divers report the bottom is now infested with sea urchins and is quite barren of vegetation.

Effects of Urchin Elimination. Oyster beds can be cleared of predating starfish by spreading lumps of calcium oxide (quicklime) over the bottom. The chemical apparently is quite toxic to the starfish but is tolerated by the oysters (Loosanoff and Engle, 1942). Experimentation with sea urchins on the Mission Bay jetty showed that quicklime was similarly harmful to these echinoderms.

This suggested field experiments to test the effects of eliminating urchins from an area of ocean bottom sufficiently large so that complications from migrating urchins would not arise for a few weeks or months. It was desirable to know if the urchins were the chief grazers or if other animals, especially motile forms such as fish, also were of importance in keeping rocky areas near outfalls barren of kelp. Accordingly, a site was chosen at Abalone Cove, on the Palos Verdes peninsula, where a *Macrocystis* bed disappeared in November-December, 1961, in the presence of thick concentrations of the urchins *Strongylocentrotus franciscanus* and *S. purpuratus*. This site is approximately five miles west of the Los Angeles County Sanitation Districts' submarine outfall at Whites Point. The rock bottom changes to sand at depths of from 20 to 25 feet and in the zone of change, sizeable "islands" of rocks, surrounded by sand, occur. Since these urchin species are not common on sand, it was hoped that the finer sediments could help act as a barrier to migration, and one of the rock "islands" was selected as the test area. This isolated reef is about 30 by 70 feet in dimension and quadrat sampling indicated that there were more than 50 urchins per square meter of rock bottom at this location, or an amount in excess of 10,000 animals to be killed.

Seven hundred pounds of pebble quicklime were scattered by hand from a skiff over the test site on 26 May, 1962. Diving revealed that the urchins and other echinoderms were severely affected, but fish and other animals did not seem to be influenced. The area was revisited on June 4 and it was estimated that perhaps a 95 to 99% kill had resulted. *Strongylocentrotus franciscanus* was affected more severely than the

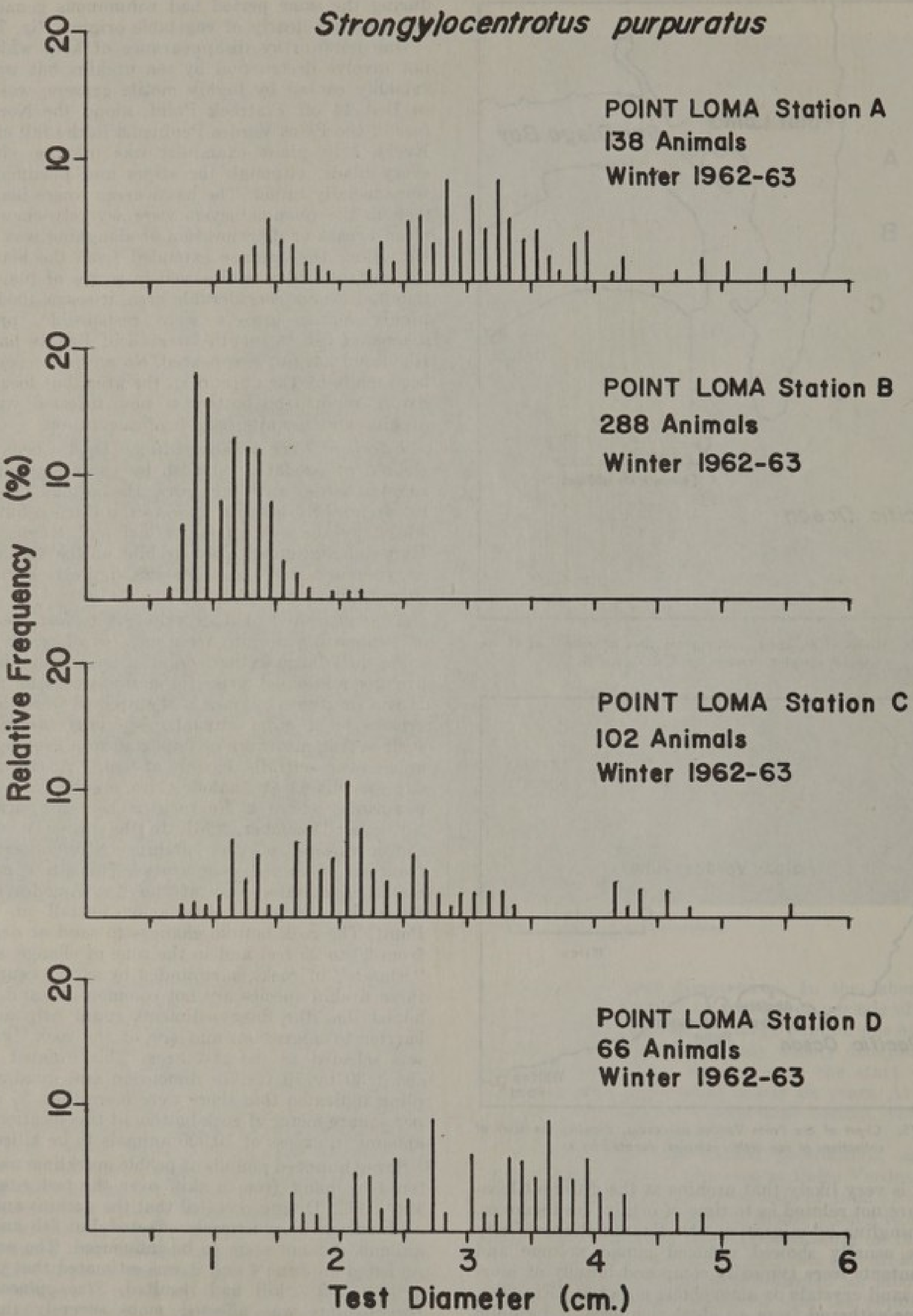


Figure 76A. Size distributions of S. purpuratus populations at the Pt. Loma stations.

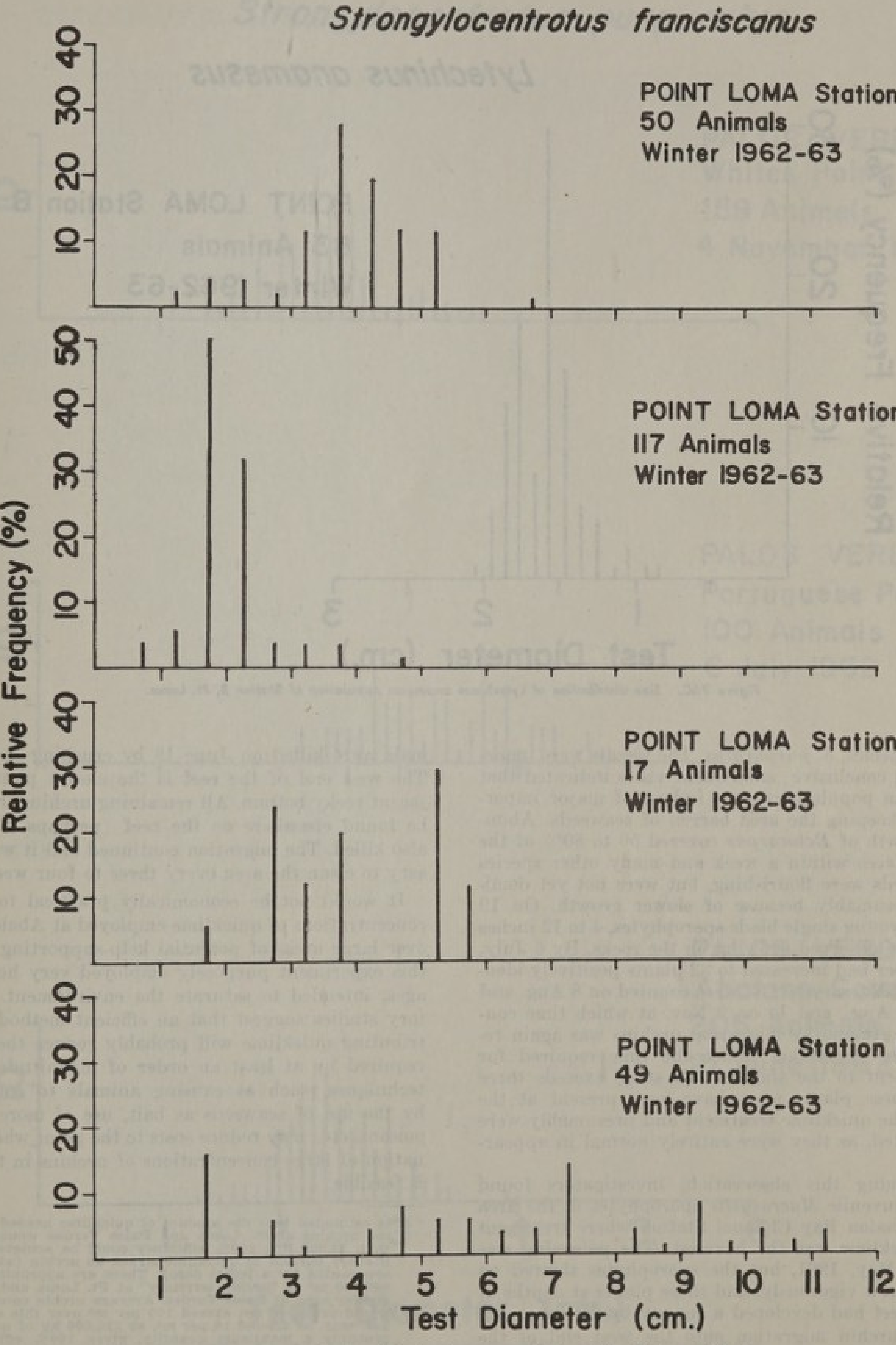


Figure 76B. Size distributions of S. franciscanus populations at the Pt. Loma stations.

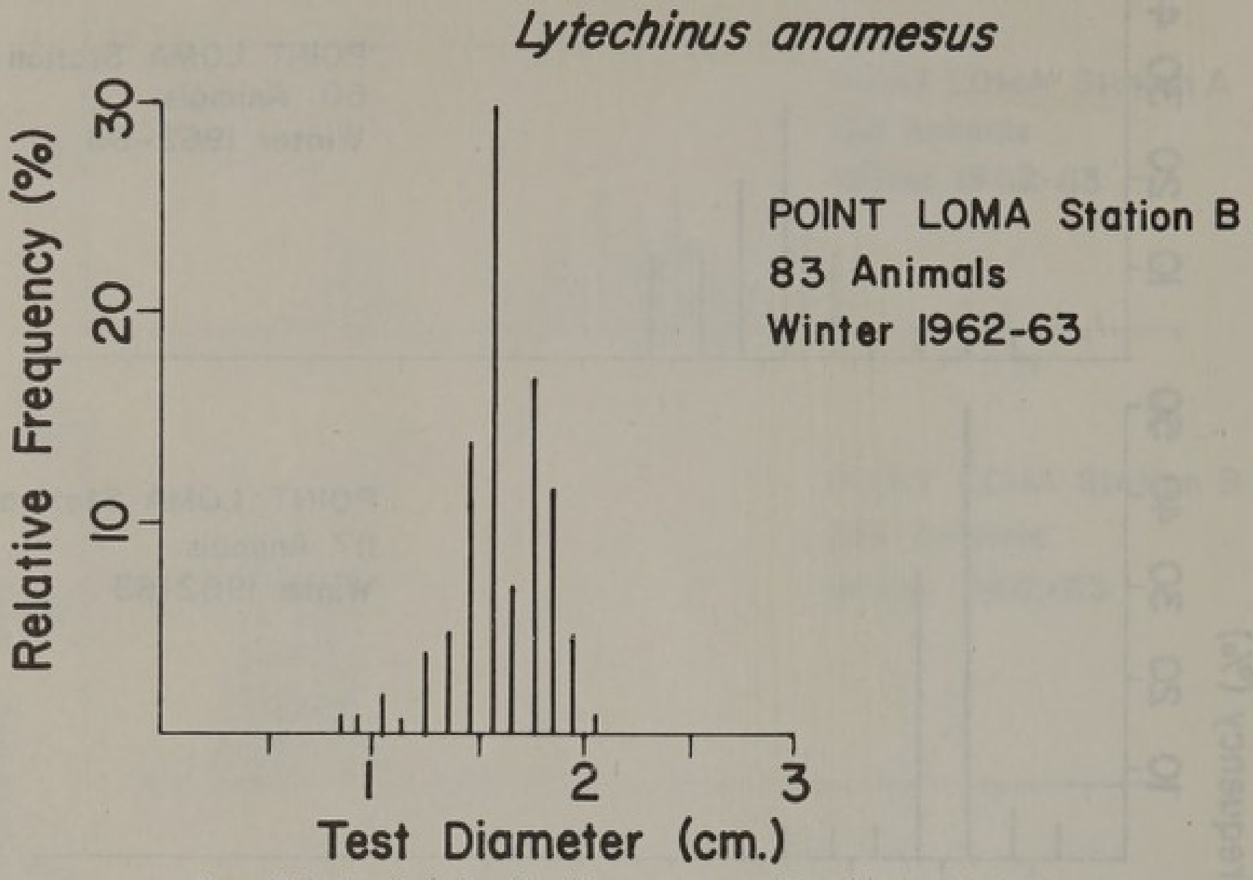


Figure 76C. Size distribution of Lytechinus anamesus population of Station B, Pt. Loma.

smaller species, *S. purpuratus*. The results were immediate and conclusive; subsequent visits indicated that the urchin populations were indeed of major importance in keeping the area barren of seaweeds. Abundant growth of *Ectocarpus* covered 50 to 80% of the rock surfaces within a week and many other species of seaweeds were flourishing, but were not yet dominant, presumably because of slower growth. On 19 June, 10 young single blade sporophytes, 4 to 12 inches high, were observed growing on the rocks. By 6 July, the number had increased to 32 plants positively identifiable as *Macrosystis;* 33 were counted on 8 Aug. and 35 on 28 Aug., and 14 on 2 Nov. at which time considerable grazing by migrating urchins was again reducing the vegetation. Since the time required for development to the single blade stage exceeds three weeks, these plants must have been present at the time of the quicklime treatment and presumably were not affected, as they were entirely normal in appearance.

Confirming this observation, investigators found over 30 juvenile *Macrocystis* sporophytes in the area at the Mission Bay Channel Station where treatment with quicklime was the heaviest. The poisoning was done 31 May, 1961, but the sporophytes showed no injury, grew vigorously, and those plants at depths of 5 to 10 feet had developed a canopy by 21 June.

Some urchin migration onto the west end of the reef at Abalone Cove was observed and about 400 animals were killed on June 19 by crushing their tests. The west end of the reef is the closest point to adjacent rocky bottom. All remaining urchins that could be found elsewhere on the reef (perhaps 200) were also killed. The migration continued and it was necessary to clean the area every three to four weeks.

It would not be economically practical to use the concentrations of quicklime employed at Abalone Cove over large areas of potential kelp-supporting bottom; this experiment purposely employed very heavy dosages, intended to saturate the environment. Laboratory studies suggest that an efficient method for distributing quicklime will probably reduce the amount required by at least an order of magnitude.[*] Other techniques, such as causing animals to concentrate by the use of seaweeds as bait, use of more efficient poisons, etc., may reduce costs to the point where elimination of large concentrations of urchins in the ocean is feasible.

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[*] It is estimated that the amount of quicklime needed to kill all the urchins at Pt. Loma and Palos Verdes would cost less than $4,000 if a 100% efficiency could be achieved, that is, if every particle of quicklime struck an urchin (about 50 mg are needed for a lethal dose). There are approximately 12,000,000 m^2 of "urchin territory" at Pt. Loma and perhaps a similar area at Palos Verdes. Average urchin concentrations would probably not exceed 100 per m^2 over this entire area and may be around 10 per m^2, so 120,000 kg of quicklime is probably a maximum quantity, given 100% efficiency; at $30 per 1000 kg, $3600 would suffice to eradicate the approximately 3 billion urchins.

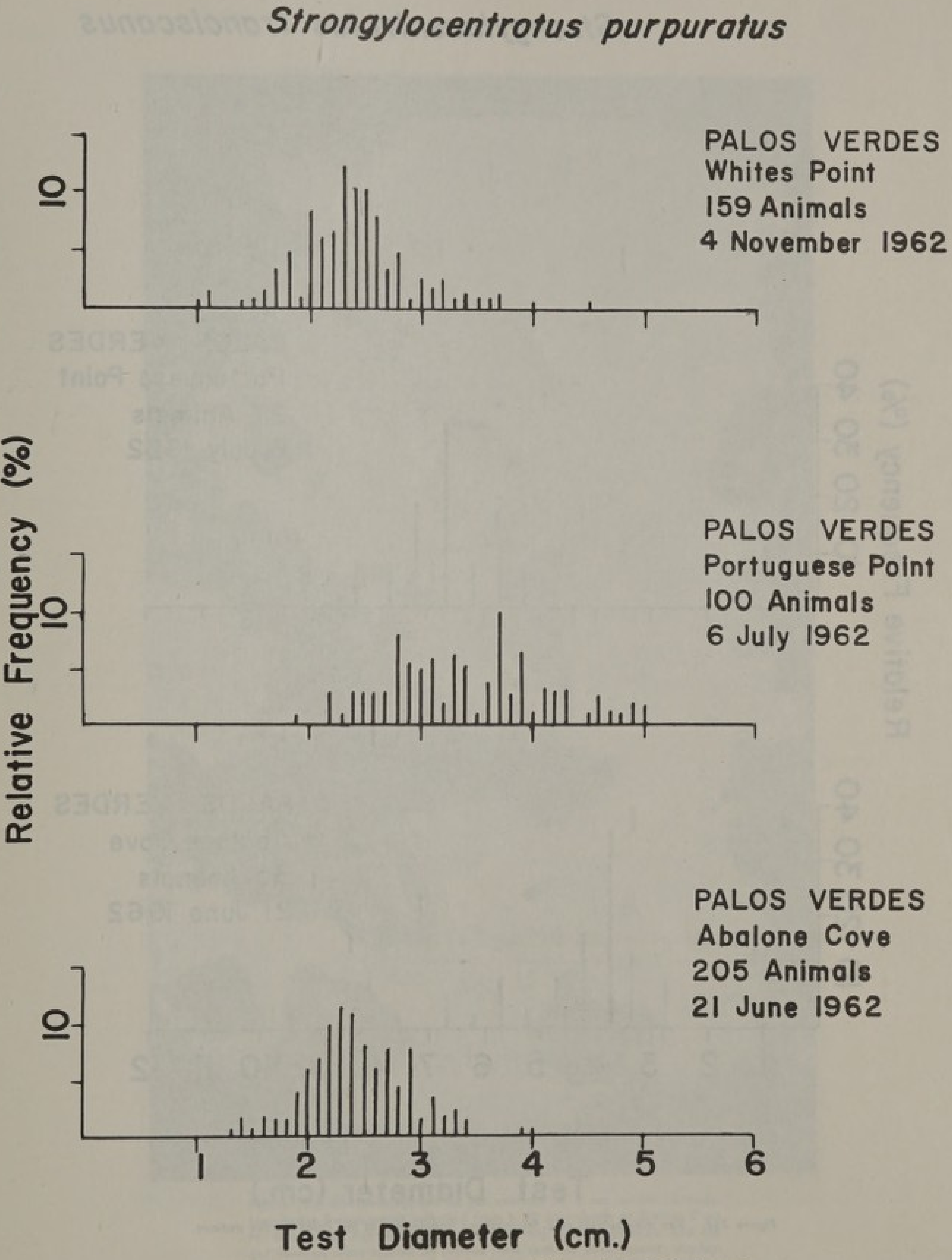


Figure 76D. Size distributions of S. purpuratus populations at the Palos Verdes stations.

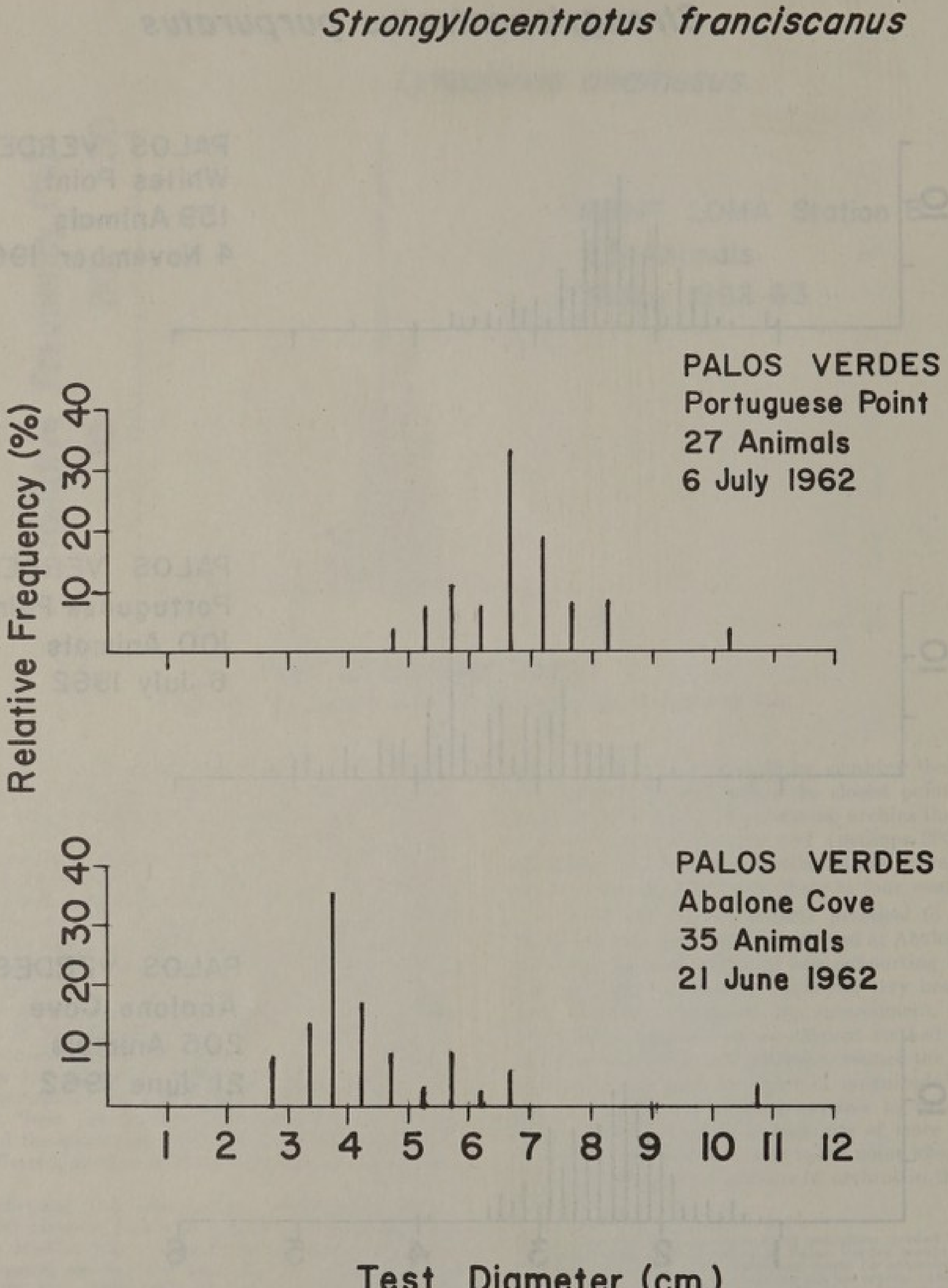


Figure 76E. Size distributions of S. franciscanus populations at the Palos Verdes stations.

Figure 77. Photomicrograph of gut contents of a sea urchin (Strongylocentrotus franciscanus) collected from a 40 foot depth at Station C on Pt. Loma (Fig. 74). The area supported very little vegetation and the gut contents were typical of urchins from such an environment, displaying chiefly sand particles and amorphous material, with little evidence of cellular structure.

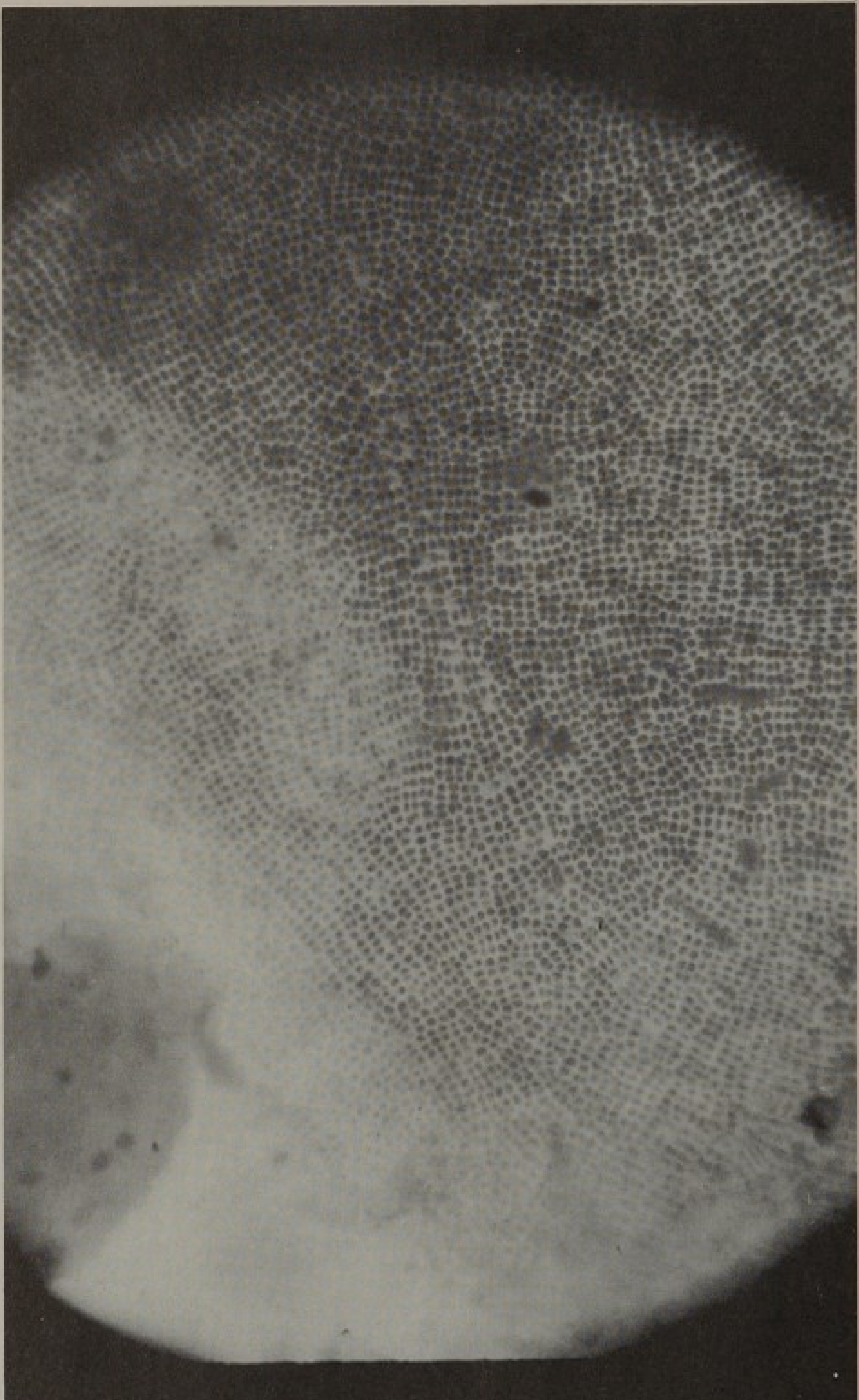


Figure 78. Photomicrograph of gut contents of a sea urchin (Strongylocentrotus franciscanus) collected from a 40 foot depth off La Jolla in an area rich in vegetation. The gut was crammed with material displaying cellular structure.

TURBIDITY

Introduction

An adequate supply of light energy must be available a substantial portion of the time in the region of the bottom if attached vegetation is to exist. An outstanding exception is the climax community of adult *Macrocystis* plants which often shade the bottom so effectively that little or no small-statured vegetation remains, even including very young, developing *Macrocystis* itself. Because of the short average lifespan of adult plants in most beds, such a climax community is usually not a permanent feature and replacement by juvenile growth must occur if kelp is to maintain itself in a region.

How much of a change in water clarity is needed to eliminate bottom vegetation? This fundamental question has received much attention; it is treated on a theoretical level below, by the use of simplified mathematical models. These provide enough understanding so that when taking the field data into account, a reasonably accurate assessment can be made of the potential influence the practice of waste discharge may have on turbidity.

Theoretical Considerations

Figure 79 shows the light intensities that may be expected at different depths in the ocean for waters of different absorbencies (the absorbency is here defined as the percentage of the incoming light which is absorbed by a given water mass per meter of transit). The curves of figure 79 assume water of uniform attenuation properites, but in practice, if one were to determine the percentage of the light remaining at a given depth with respect to the incoming radiation just under the surface, one could describe the loss (at that depth only) as the equivalent of an average attenuation per meter, even though the water is inhomogeneous.

The curves of figure 79 derive, of course, from the Lambert-Beers law,

$$\frac{I}{I_o} = e^{-KCL} \qquad (1)$$

where I_o is the incident radiation intensity and I is the intensity after traveling a distance L in a medium of absorption coefficient K and a concentration of absorbing particles C.

The relationship of such curves to actual conditions at sea may be seen when comparing them with curves obtained by Neushul (1957) at La Jolla (Fig. 80). The logarithmic decline as depth increases is clearly evident. Absorption of the different colors, of course, is not the same, as seen in Figure 81 (Neushul, 1957).

Figure 82 shows relative values of photosynthesis determined for adult blades of the giant kelp, *Macrocystis pyrifera*, by Clendenning and Sargent (1957). A photosynthesis to respiration ratio of 22 was used, and on the ordinate scale a value of 3 corresponds to the compensation point, that is, where the production of plant tissue by photosynthesis just equals its metabolic needs. The illumination required at this point was found by Clendenning to be 15 foot-candles of white light.

The curve of figure 82 shows features common to photosynthetic curves of plants in general. First is a compensation point, described above; second is a more or less linear initial ascending portion of the curve,

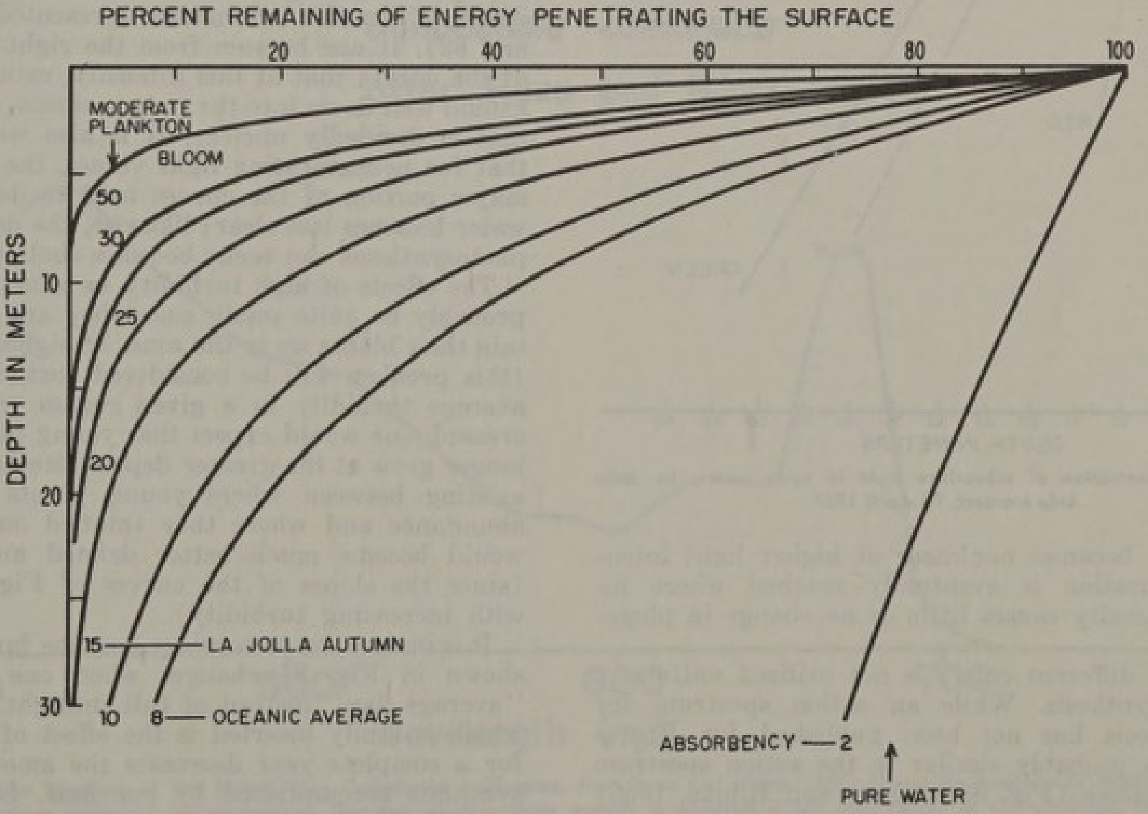


Figure 79. Theoretical curves showing the percent of incident light remaining at any given depth for waters of different absorption coefficients.

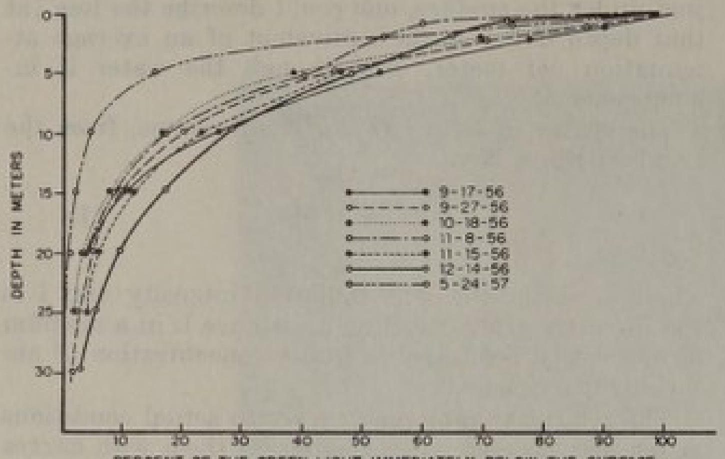
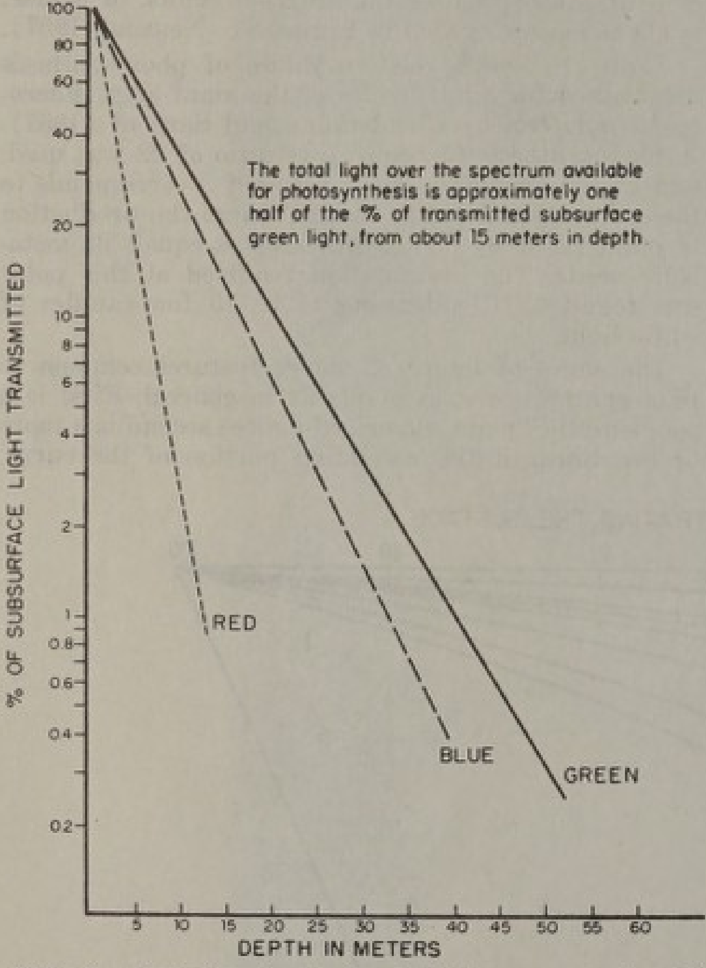


Figure 80. *Percent of subsurface radiation—green.*



The total light over the spectrum available for photosynthesis is approximately one half of the % of transmitted subsurface green light, from about 15 meters in depth.

Figure 81. *Penetration of subsurface light in open water, La Jolla kelp transect, 18 April 1957.*

which then becomes nonlinear at higher light intensities; saturation is eventually reached where increased intensity causes little or no change in photosynthesis.

Light of different colors is not utilized uniformly for photosynthesis. While an action spectrum for photosynthesis has not been published for *Macrocystis,* it is probably similar to the action spectrum for *Coilodeseme* (Fig. 83) (Haxo and Blinks, 1950) according to Haxo (personal communication).

The discussion below will relate the curves of figures 79 and 82 to each other in order to present a theoretical picture of changes in photosynthesis at different depths for various degrees of water clarity. It might be well at this point, however, to indicate the variables or influencing factors which we will neglect in our presentation for the sake of simplicity or because of insufficient knowledge to enable adequate treatment:

1. Stratification in the water column may result in variations of the absorption coefficient with depth. For simplicity, we will treat water masses as having a uniform absorbency.
2. The photosynthesis to respiration ratio for *Macrocystis* varies considerably with the type and age of the tissue under consideration. Our calculations are based solely on the curve of Fig. 82, where a ratio of 22 is assumed, this value being about average for adult blades.
3. The photosynthetic capacity of *Macrocystis* has been found to vary not only seasonally but also with the type and age of the tissue, with the temperature, and with the geographical source of the plant. These effects have been ignored in the discussion below.
4. The discussion will be limited to effects of polychromatic light because insufficient knowledge is available to treat the subject from a monochromatic standpoint.

Fig. 84 shows how the relative photosynthesis may be expected to vary with depth for water masses of different absorbencies at a light intensity of 10,000 foot-candles (approximately the intensity of direct sunlight) entering the surface of the sea (Fig. 84 derives from the information presented in Figs. 79 and 82). It can be seen from the right-hand portion of the curves that at this intensity, saturating values extend well down into the water column, even in water that is decidedly unclear. It is also worthy of note that for nonsaturating light values, the slopes of the major portion of the curves tend to decrease as the water becomes less clear; likewise, the depth at which photosynthesis can occur becomes shallower.

The effects of high turbidity on adult plants would probably be quite small, since they are able to maintain their blades up in the zones of higher illumination (this problem will be considered further on). If the average turbidity in a given region were to be increased, one would expect that young plants could no longer grow at the greater depths. Moreover, the zone existing between where young plants appeared in abundance and where they thinned out to nothing, would become much better defined and less broad (since the slopes of the curves of Fig. 84 decrease with increasing turbidity).

It is instructive to consider how the family of curves shown in Fig. 84 changes when one considers an "average day" instead of full sunlight. A correction which is easily inserted is the effect of night, which for a complete year decreases the amount of photosynthesis accomplished by one half. Less easily accounted for are the effects of varying angles of the

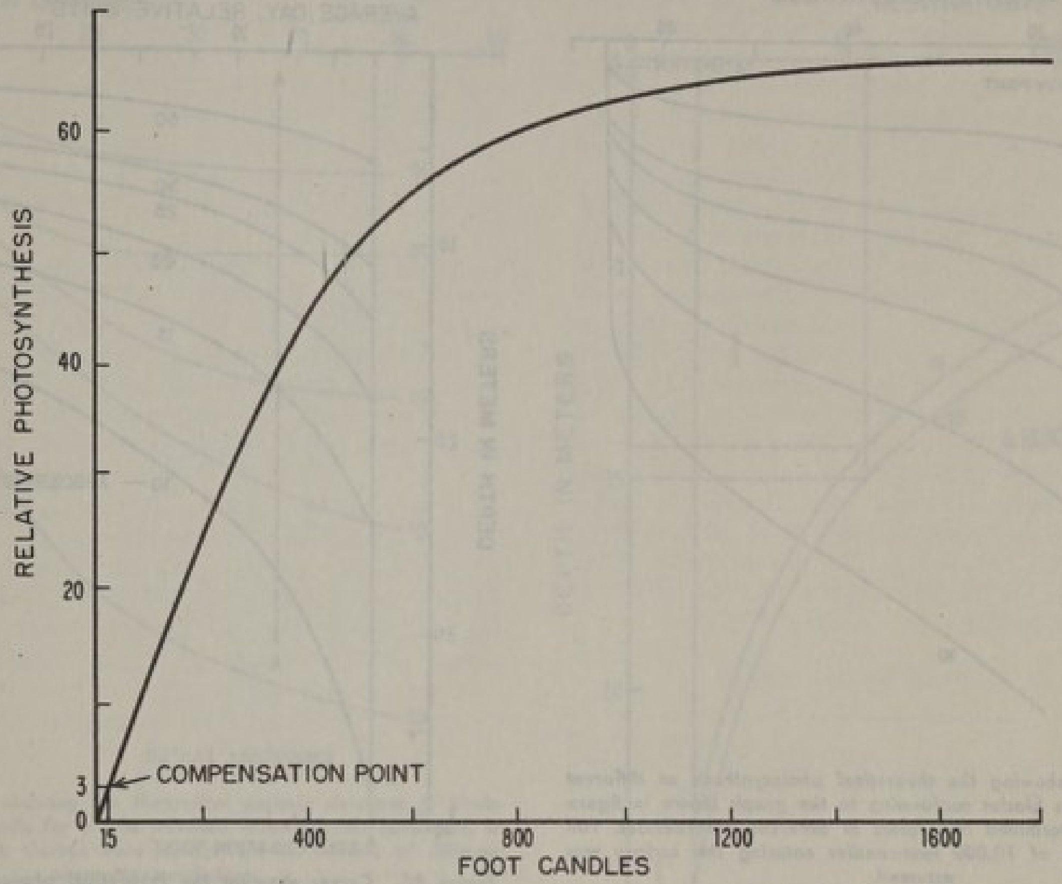


Figure 82. Graph illustrating the changes in photosynthetic rate in adult Macrocystis blades as a function of light intensity. Modified from Clendenning and Sargent (IMR Ref. 57-4).

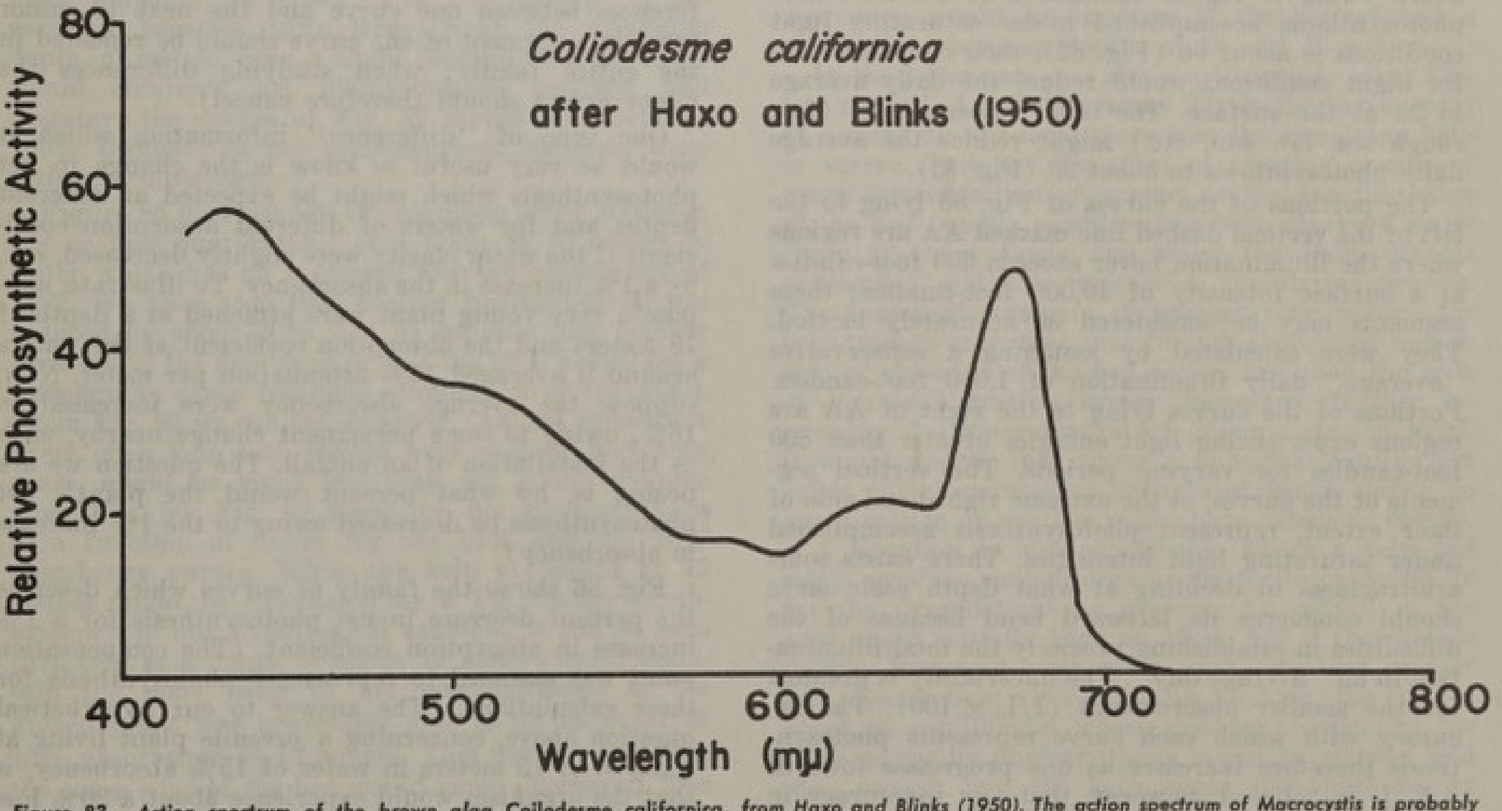


Figure 83. Action spectrum of the brown alga Coilodesme californica, from Haxo and Blinks (1950). The action spectrum of Macrocystis is probably closely similar (Haxo, personal communication). Greatest photosynthetic activity is centered in the blue region of the spectrum, with a sharp peak in the red.

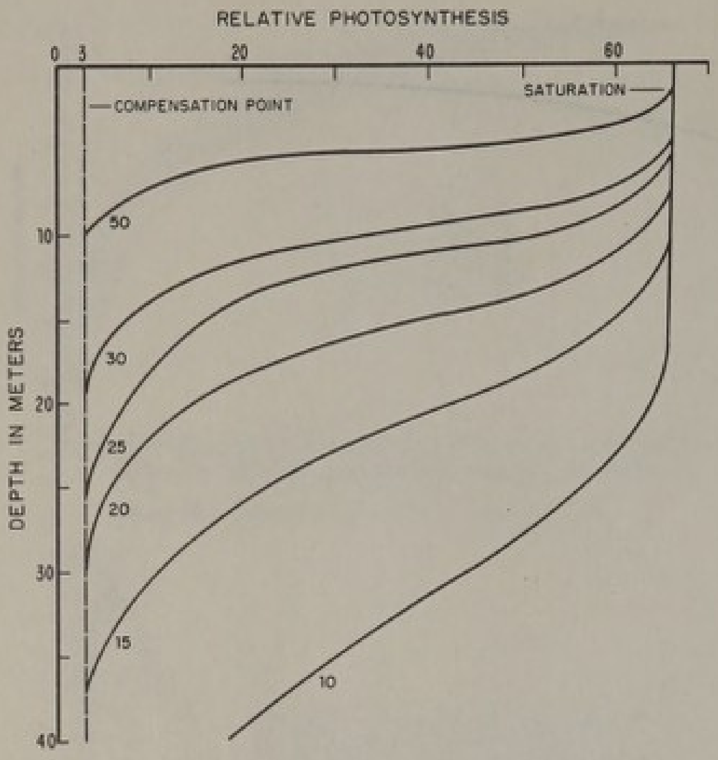


Figure 84. Curves showing the theoretical photosynthesis at different depths of Macrocystis blades conforming to the graph shown in figure 82. Curves were determined for waters of different absorbencies. Full daylight illumination of 10,000 foot-candles entering the surface was assumed.

sun from the horizon, condition of the sea surface, and percentage of the time when illumination is reduced owing to fog or cloudiness. If the maximum photosynthesis accomplished under saturating light conditions is about 66 (Fig. 82), then our correction for night conditions would reduce the daily average to 33 at the surface. The other uncertainties (fog, rough sea, low sun, etc.) might reduce the average daily photosynthesis to about 30 (Fig. 85).

The portions of the curves of Fig. 85 lying to the left of the vertical dashed line marked AA are regions where the illumination never exceeds 600 foot-candles at a surface intensity of 10,000 foot-candles; these segments may be considered as accurately located. They were calculated by assuming a conservative "average" daily illumination of 1,000 foot-candles. Portions of the curves lying to the right of AA are regions experiencing light energies greater than 600 foot-candles for varying periods. The vertical segments of the curves, at the extreme right-hand side of their extent, represent photosynthesis accomplished under saturating light intensities. There exists some arbitrariness in deciding at what depth each curve should commerce its leftward bend because of the difficulties in establishing precisely the total illumination in an "average day". The uncertainty is greatest for the smaller absorbencies ($I/I_o \times 100$). The accuracy with which each curve represents photosynthesis therefore increases as one progresses towards AA. It is believed, however, that any inaccuracy in the representation is minor and that it is entirely safe to utilize the graph for considerations based on differences between one curve and the next (a minor error in a segment of one curve should be repeated in the entire family; when studying differences the minor errors should therefore cancel).

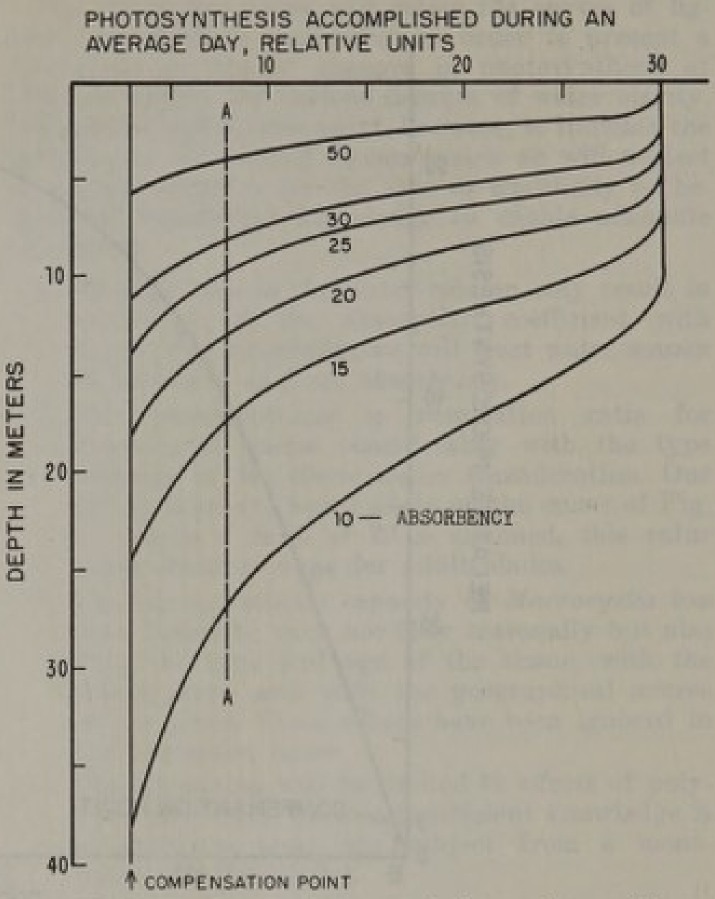


Figure 85. Curves showing the theoretical photosynthesis at different depths of Macrocystis blades conforming to the graph of figure 84. Curves were determined for waters of different absorbencies. Average conditions as described in the text were assumed.

One type of "difference" information which it would be very useful to know is the change in net photosynthesis which might be expected at different depths and for waters of different absorption coefficients if the water clarity were slightly decreased, e.g., by a 1% increase in the absorbency. To illustrate, suppose a very young plant were attached at a depth of 15 meters and the absorption coefficient of the waters around it averaged 15% attenuation per meter. Now, suppose the average absorbency were increased to 16%, owing to some permanent change nearby, such as the installation of an outfall. The question we are posing is, by what percent would the plant's net photosynthesis be decreased owing to the 1% increase in absorbency?

Fig. 86 shows the family of curves which describe the percent decrease in net photosynthesis for a 1% increase in absorption coefficient. (The compensation point was assumed to represent 0 photosynthesis for these calculations.) The answer to our hypothetical question above, concerning a juvenile plant living at a depth of 15 meters in water of 15% absorbency, is that the organism would experience about a 20% loss in net photosynthesis owing to increase in absorbency to 16%.

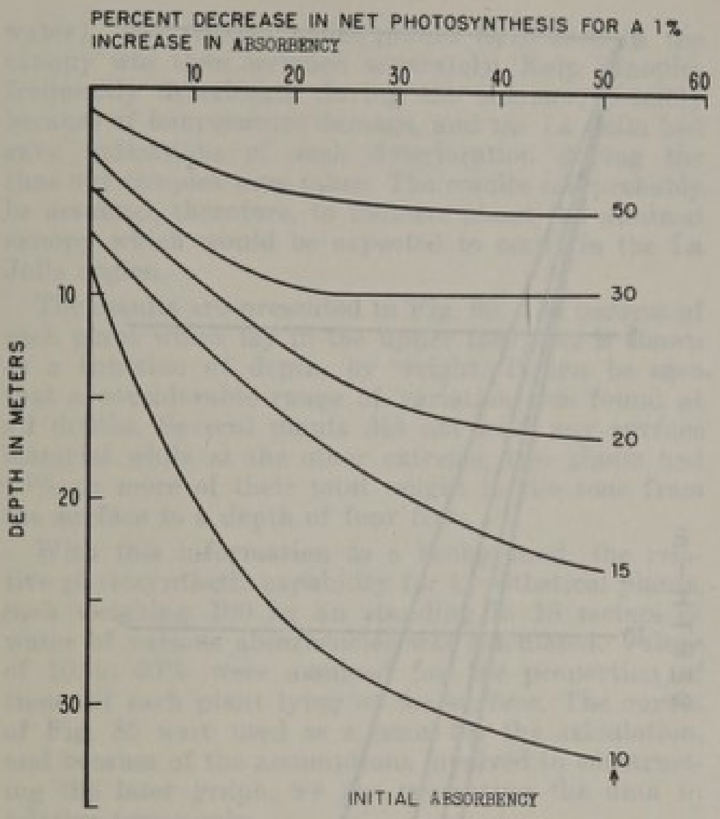


Figure 86. Curves showing the theoretical percent decrease in photosynthesis of Macrocystis for a 1% increase in absorption coefficient, as a function of depth. Curves were determined for waters of different absorption coefficients.

It can be seen from Fig. 86 that, as depths are approached where light intensity becomes more and more limiting, the effect of a 1% increase in absorbency becomes quite large. Near the maximum depth, of course, even a slight increase in absorbency would eliminate net photosynthesis entirely, and therefore the curves of Fig. 86 should all extend to 100% decrease in net photosynthesis as their theoretical terminations.

Figure 86 does not tell the complete story, however. Let us take our example of a plant at 15 meters in water which has an increased average absorbency of 16%. We have seen that the net photosynthesis was reduced by about 20%. Let us suppose that grazing pressure in the area is such that the 20% reduction is sufficient to cause complete elimination of the plant. From Fig. 87 we can see, however, that the immediate effect on a kelp bed, spread over shallow and deep zones, might be much less than one would suppose from Fig. 86. Fig. 87 gives the net photosynthesis as a function of depth for the 15% and the 16% absorbency curves. While the kelp at depths of 15 meters might be eliminated by a 1% change in absorbency in our hypothetical example, it can be seen that kelp at a depth of about 14 meters could maintain the same value of net photosynthesis as the grazed plant was previously able to do in water of 15% absorbency at 15 meters. This would mean that the outer edge of the bed would move shoreward. The net effect on the total area covered by the bed would be slight if the bottom had a steep slope, but a greater regression would be expected if the bottom had a gentle slope between depths of 14 and 15 meters.

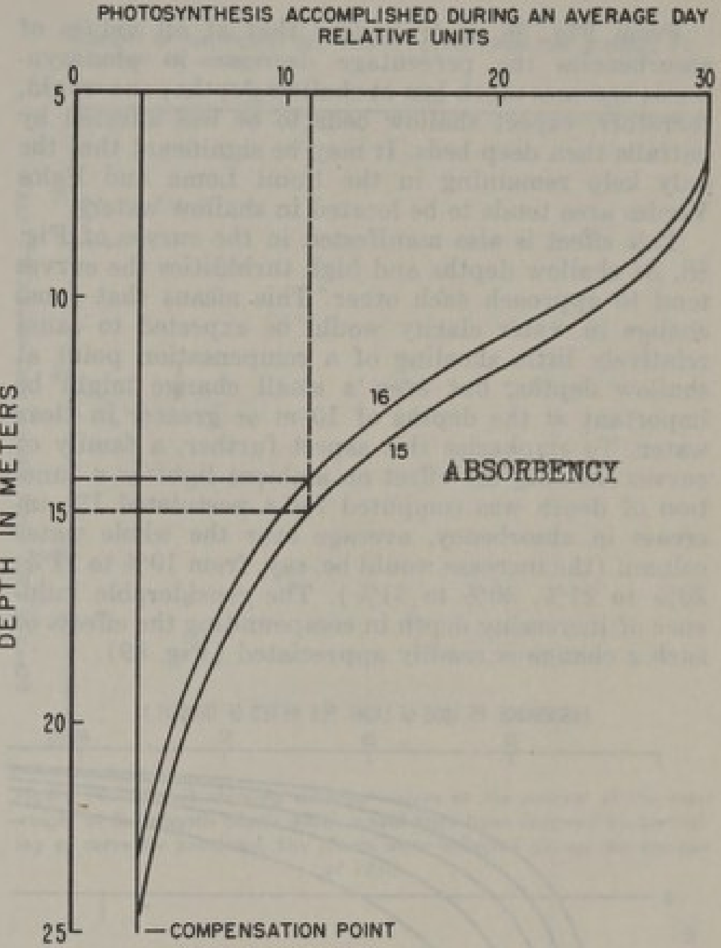


Figure 87. Curves showing the theoretical photosynthesis of Macrocystis as a function of depth for waters of 15 and 16% absorption coefficients.

In the latter case one also must consider other factors as well. Any kelp grazers left in the barren part of a receding bed must move into the remaining kelp or starve. This has the effect of creating a zone of heavy concentration of grazers at the receding edge of the bed (such a condition has been observed many times at Point Loma and along the Palos Verdes peninsula) and this may be a cumulative process. The increased numbers of grazers may reduce the kelp to such an extent that further shoreward regression of the edge of the bed occurs and then the zone of increased grazing moves shoreward, further increasing the concentration of grazers, etc. In brief, it would appear that where a biological equilibrium exists, slight permanent changes of water clarity in one direction or another might have extensive results.

A situation is also conceivable where a kelp bed might produce enough organic matter to outweigh by far the depredations by grazers. An outfall in the area might initially have no effect, but if the effluent volume increased year after year, creating greater and greater light attenuation in the area, the critical point of equilibrium where grazing outweighed the replacement by photosynthesis might be reached and then passed, and the kelp might disappear rather quickly even though it had survived in the field of influence of the outfall for many years.

From Fig. 86, it is evident that at all values of absorbencies the percentage decrease in photosynthesis becomes much less at shallow depths; one would, therefore, expect shallow beds to be less affected by outfalls then deep beds. It may be significant that the only kelp remaining in the Point Loma and Palos Verdes area tends to be located in shallow waters.

This effect is also manifested in the curves of Fig. 88. At shallow depths and high turbidities the curves tend to approach each other. This means that gross change in water clarity would be expected to cause relatively little shoaling of a compensation point at shallow depths, but even a small change might be important at the depths of 10 m or greater in clear water. To emphasize this aspect further, a family of curves showing the effect on ambient light as a function of depth was computed for a postulated 1% increase in absorbency, average over the whole water column (the increase would be, say, from 10% to 11%, 20% to 21%, 30% to 31%). The considerable influence of increasing depth in compounding the effects of such a change is readily appreciated (Fig. 89).

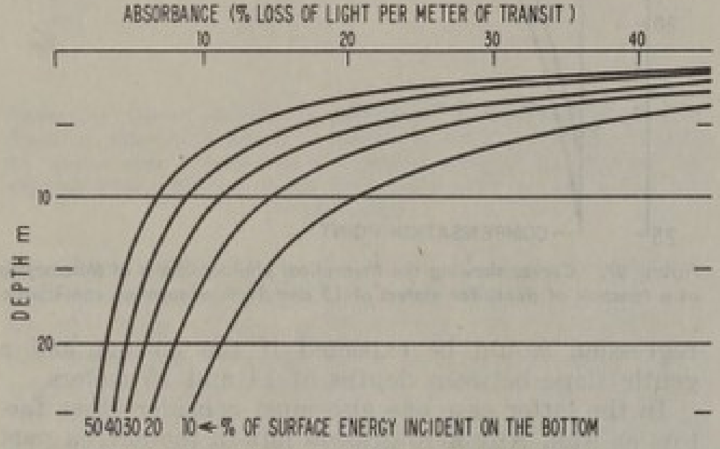


Figure 88. Loss of light with depth.

It can be seen that the actual process of dilution of sewage by seawater does not necessarily increase the amount of light incident on the bottom, since path length as well as concentration is involved (see equation (1)). That is, it does not matter if sewage is layered on the surface or spread throughout the water column because of the interplay between the factors of concentration of absorbing substances and the path length light must traverse before reaching the bottom. Dilution will help, however, if the diluted mixture is carried into shallower water and the path length is thereby reduced.

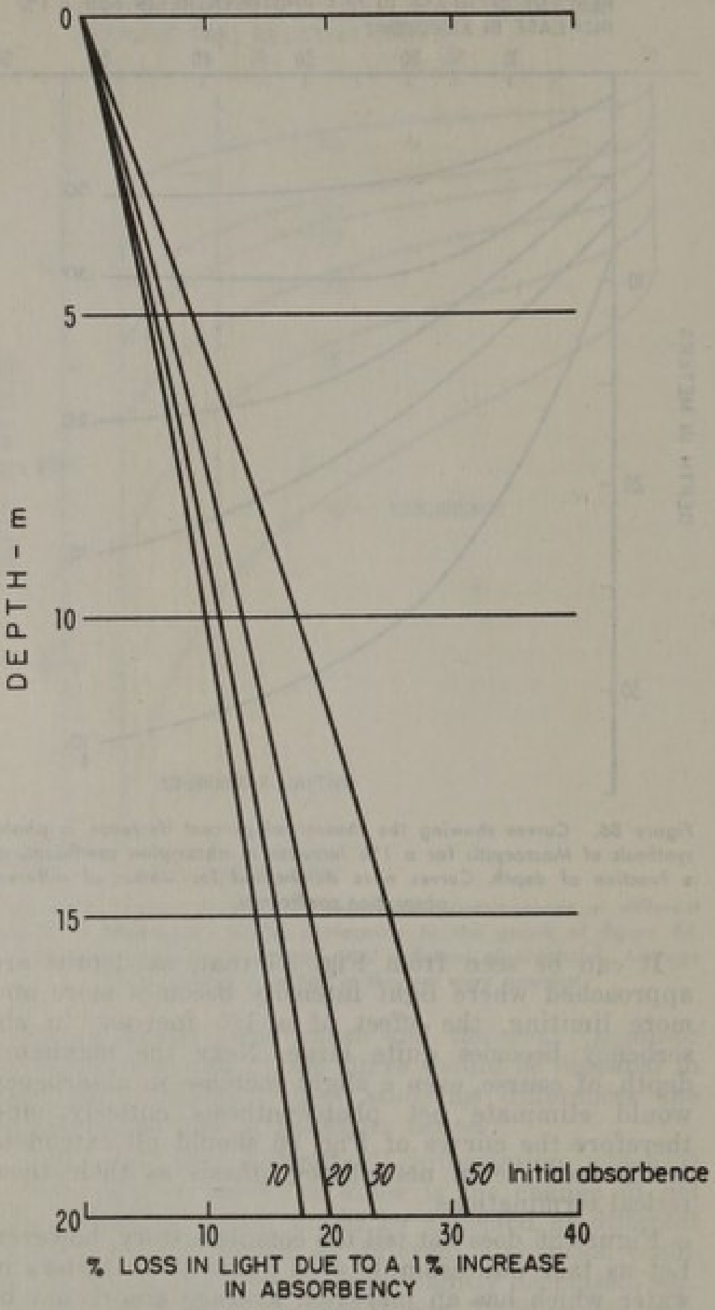


Figure 89. Graph showing the theoretical percent reduction of light at different depths when the absorbency is increased by 1%. (i.e. from 10 to 11% or 20 to 21%, etc.) Curves are given for waters of different initial absorbency characteristics.

The Effect of Turbidity on Adult Plants

A slight change in water clarity may have a profound effect on short plants in deep water. What is the effect on adult *Macrocystis?* Before this can be answered one must have an idea of the distribution of plant tissues through the water column, especially determining what portion lies near the surface where presumably light is always above the compensation point, even in very turbid water.

In order to assess this important problem, 67 adult plants were gathered from the La Jolla bed during the summer of 1958; the depth where they were taken was accurately determined with a sounding line. There was no selection of plants with respect to the proportion of tissue contained in the canopy, since the divers were never able to see the surface from the bottom because of the excessive turbidity caused by plankton blooms. (The plants were cut off at the bottom.)

The severed plants were brought ashore, weighed fresh, and then cut into two sections at a point which would have been four feet below the surface if the plant were extending straight up from the bottom. (A point four feet below the surface would presumably be above the compensation point for kelp for all degrees of turbidity normally encountered in coastal water). The portion which would have been in the canopy was then weighed separately. Kelp canopies frequently deteriorate during the summer, possibly because of temperature damage, and the La Jolla bed gave indications of such deterioration during the time our samples were taken. The results can probably be assumed, therefore, to indicate about the minimal canopy which would be expected to occur in the La Jolla region.

The results are presented in Fig. 90. The percent of each plant which lay in the upper four feet is shown as a function of depth, by weight. It can be seen that a considerable range of variation was found at all depths. Several plants did not have any surface material while at the other extreme, two plants had 60% or more of their total weight in the zone from the surface to a depth of four feet.

With this information as a background, the relative photosynthetic capability for hypothetical plants, each weighing 100 kg an standing in 18 meters of water of various absorbencies was calculated. Values of 10 to 60% were assumed for the proportion of tissue of each plant lying at the surface. The curves of Fig. 85 were used as a basis for the calculation, and because of the assumptions involved in constructing the later graph, we are presenting the data in relative terms only.

Fig. 91 shows the total photosynthetic capability of the hypothetical 100-kg plants described above (any shading effects by the canopy were at first neglected). It is evident that decreasing water clarity has a noticeable effect even on plants with a high proportion of their total weight near the surface.

The model was then modified to include a factor for shading. It was assumed that the canopy absorbed light energy in direct proportion to the percent of the plant by weight existing at the surface. Thus, for example, it was assumed if 50% of the weight of the plant were at the surface, this material would reduce the penetration of light by 50%. The changes which this assumption makes in our former model are shown in the same figure. For clear water the total photosynthetic capability actually decreases slightly with increasing percent of the plant at the surface if shading is taken into account. With increasing turbidity, however, the advantages provided by maintaining photosynthetic tissues in the well-illuminated zones outweigh the shading effects produced thereby.

The model described above can probably be justifiably criticized in that the effects of shading are probably underestimated for the denser canopies. Neushul (1957) observed that a kelp blade aborbed about a third of the incident green light energy and he found that illumination underneath dense canopies in the field could be reduced to less than 1% of the value in open water under comparable conditions. The greatest reduction indicated in our calculations and figures was 60%. It is doubtful, however, whether the relationship of the different curves to each other would be significantly altered, and it is this relationship which gives rise to the conclusion. Turbidity does influence substantially even adult *Macrocystis*.

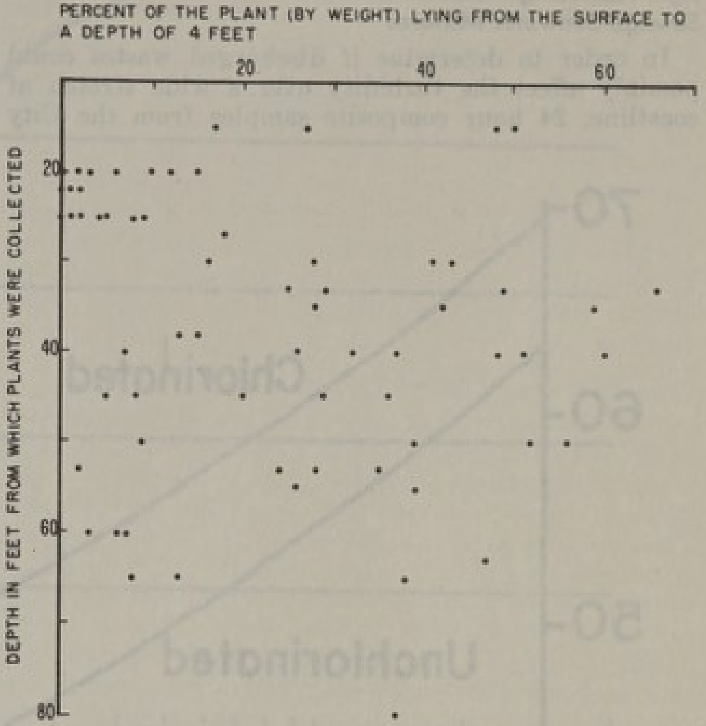


Figure 90. Graph showing different values of the percent of the total weight of Macrocystis plants which would have been removed by harvesting as currently practiced. The plants were collected during the summer of 1958.

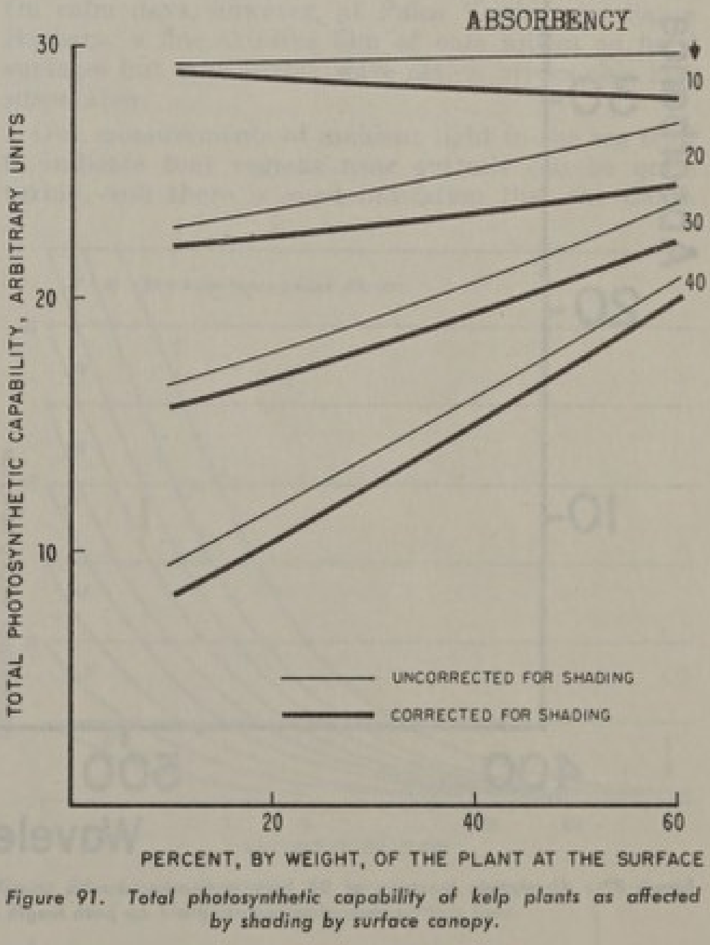


Figure 91. Total photosynthetic capability of kelp plants as affected by shading by surface canopy.

Light Absorbing Characteristics of Sewage-Seawater Mixtures

In order to determine if discharged wastes could possibly affect the turbidity over a wide stretch of coastline, 24 hour composite samples from the City of San Diego's treatment plant were analyzed in a Beckman D U Spectrophotometer as to their spectral absorption characteristics (Fig. 92). A path length of 1 cm was used and to convert these absorbencies to the absorption coefficients used in the discussions

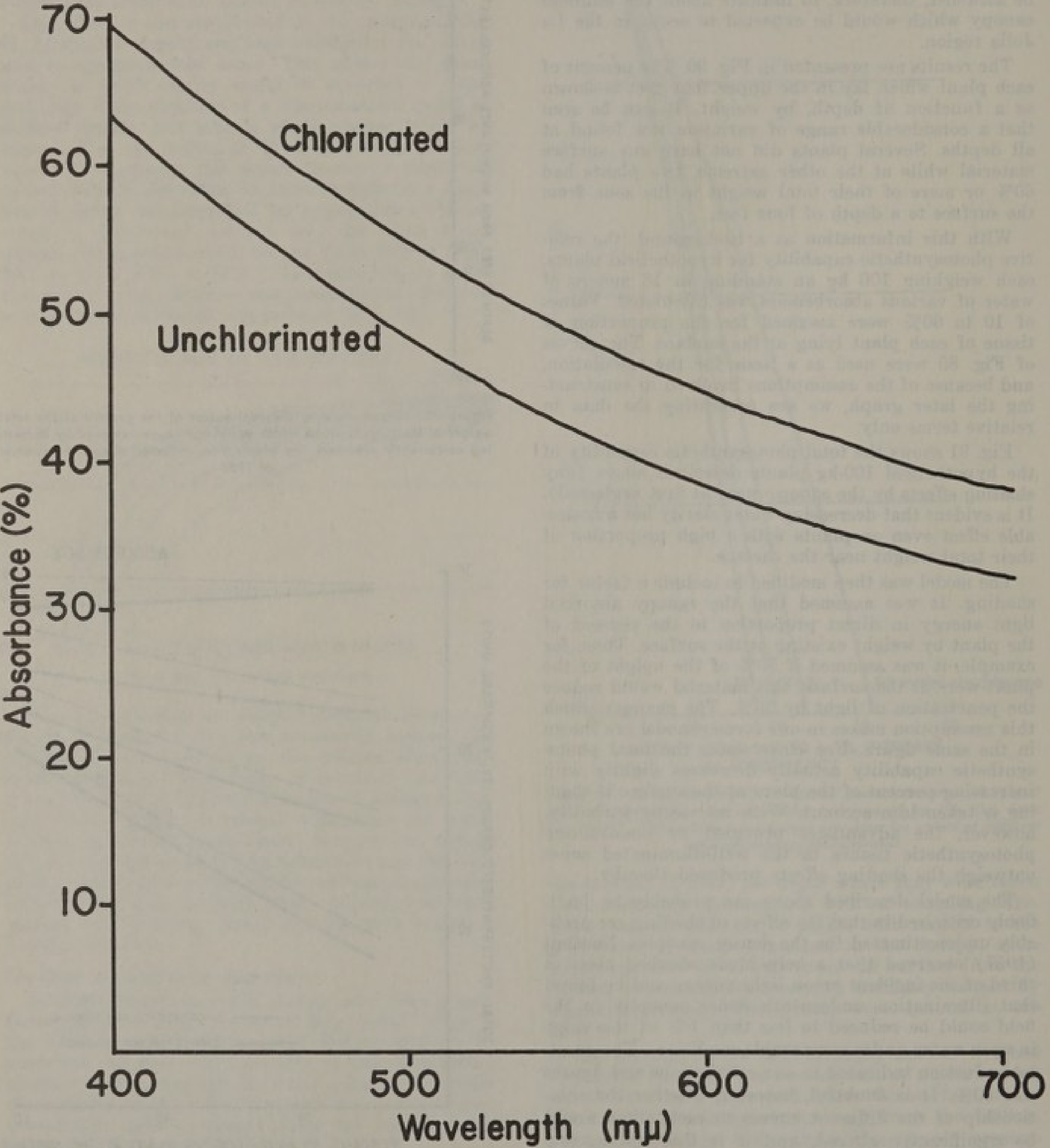


Figure 92. Absorption spectrum of 24 hour composite sewage samples collected at the sewage treatment plant of the City of San Diego. Curves were obtained using a 1 cm path length quartz cell in a Beckman DU spectrophotometer.

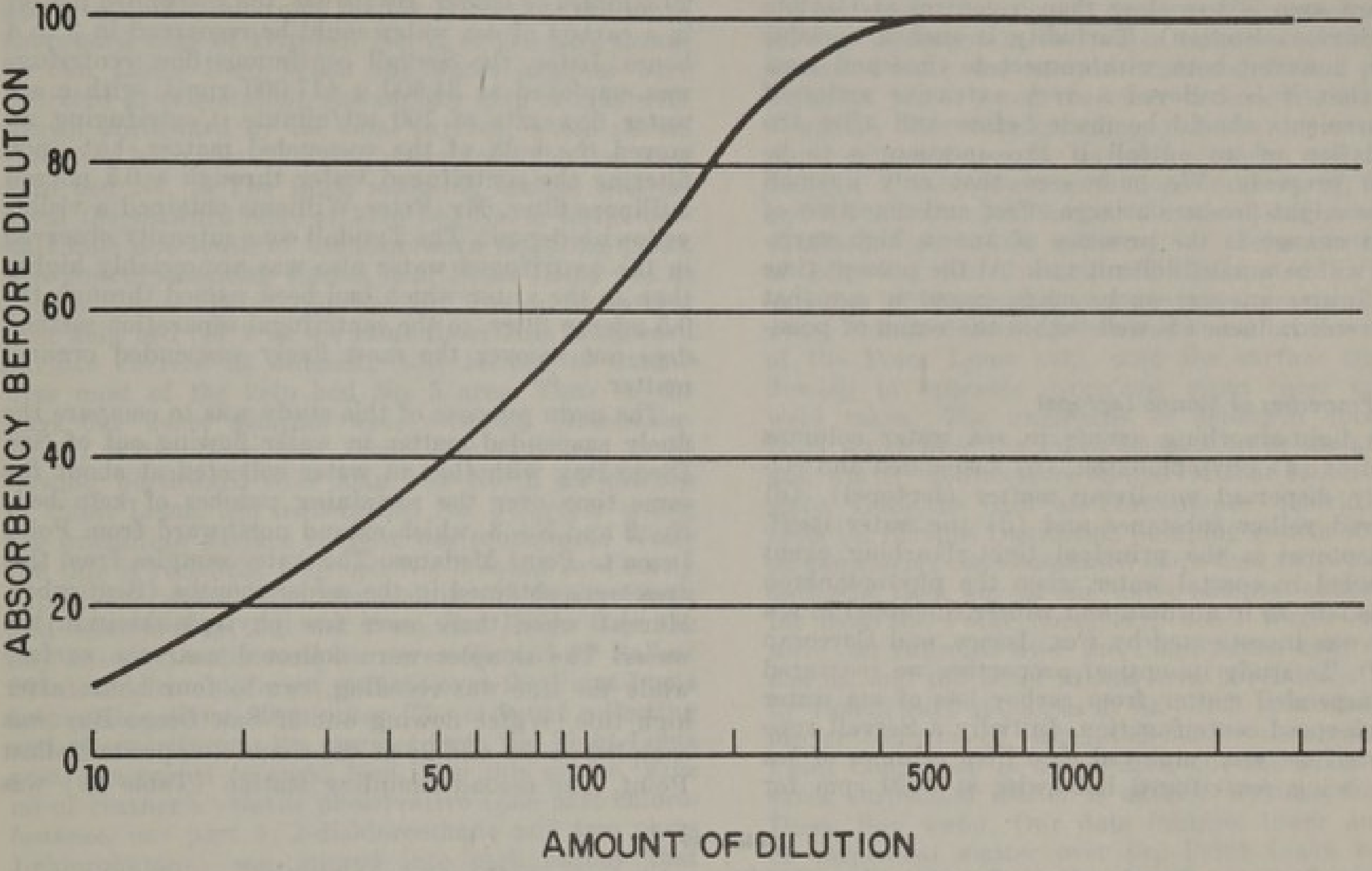


Figure 93. Curve showing the dilution required to decrease the absorbency to a 1% value.

above, calculations for a path length of 1 meter must be made, ultilizing equation (1). A value of 1×10^{-20} was computed for the absorption coefficient at 500 mu, representing a spectral region important for kelp photosynthesis and intermediate in the range of values for absorption coefficient over the whole spectrum.

We have noted above that increasing the average absorbency by only 1% is sufficient to produce a substantial change in ambient light at depths of 10 m (33 ft.) or greater, typical of the kelp bed zone. The amount of dilution required to lower the absorption coefficient so that the final mixture is increased only by 1% can be computed from a family of dilution curves (Fig. 93) and is shown as a function of absorbancy before dilution (Fig. 94). For the values of absorbancy obtained above, a dilution of at least a thousand fold seems desirable.

Use of these calculations requires that the optical character of the sewage-seawater mixture does not change with the passage of time. In practice there are almost certainly profound changes, but what these are in the open sea, and exactly what influence is exerted on water clarity remains to be established. Gunnerson (1948) ascribes a major portion of the disappearance of *B. coli* in receiving waters to rapid sedimentation of suspended solids in the sewage-seawater mixture. We have noted no sludge deposits in the nearshore areas of Point Loma, Palos Verdes, and Santa Barbara, but the immediate vicinity of the outfalls has not been examined (our kelp station at Santa Barbara is about 1000 feet from the outfall terminus). On calm days, however, at Palos Verdes and Santa Barbara, a fine skinlike film of ooze settles on hard surfaces but appreciable wave action brings this into suspension.

Our measurements of ambient light in the sea tend to indicate that regions near outfalls can be quite turbid, and there is good indication that the Santa

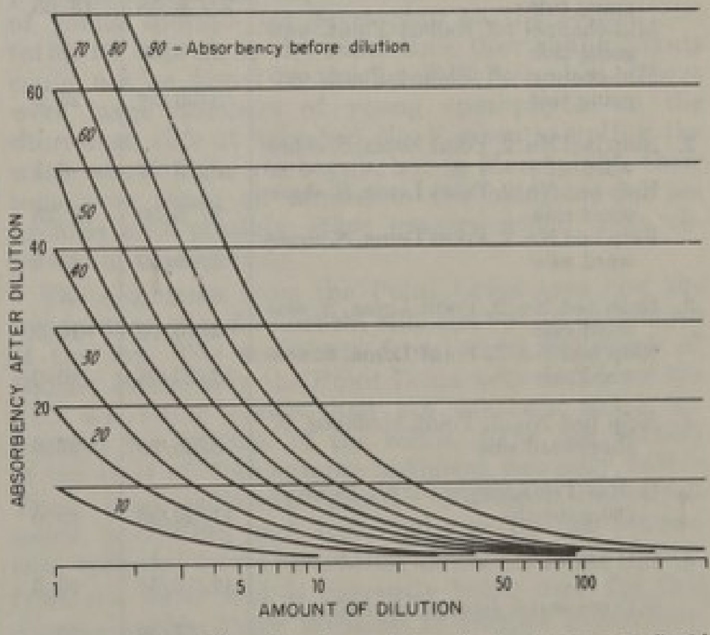


Figure 94. Curves illustrating the variation of absorbency as a liquid is diluted with a non-absorbing fluid.

Barbara area is less clear than a control at Gaviota (see Surveys Section). Turbidity is such a variable factor, however, both with respect to time and location, that it is believed a very extensive series of measurements should be made before and after the installation of an outfall if the question is to be settled properly. We have seen that only a small change might produce a large effect and detection of such a change in the presence of known high variability will be a most difficult task. At the present time no definitive answer can be made except to say that an adverse influence is well within the realm of possibility.

Some Properties of Marine Leptopel

The light-absorbing agents in sea water columns consist of (a) phytoplankton, (b) suspended and colloidally dispersed non-living matter (leptopel), (c) dissolved yellow substance and (d) the water itself. The leptopel is the principal light-abosrbing agent suspended in coastal water when the phytoplankton crop is low, as in autumn and winter. Leptopel in sea water was investigated by Fox, Isaacs, and Corcoran (1952). To study its optical properties, we recovered this suspended matter from carboy lots of sea water by high-speed centrifugation. Initially a Servall type G centrifuge was employed, two liter volumes of sea water being centrifuged batchwise at 3400 rpm for 20 minutes or longer. By its use, the suspended matter in a carboy of sea water could be recovered in 3 to 4 hours. Later, the Servall continuous flow centrifuge was employed at 34,800 g (17,000 rpm), with a sea water flow rate of 100 ml/minute. Centrifuging removed the bulk of the suspended matter, but upon filtering the centrifuged water through a 0.5 micron millipore filter, Mr. Peter Williams obtained a visible yellowish deposit. The Tyndall cone intensity observed in the centrifuged water also was appreciably higher than in the water which had been passed through the 0.5 micron filter, so the centrifugal separation method does not recover the most finely suspended organic matter.

The main purpose of this study was to compare the finely suspended matter in water flowing out of San Diego Bay with that in water collected at about the same time over the remaining patches of kelp beds No. 2 and No. 3, which extend northward from Point Loma to Point Medanos. The water samples from this area were obtained in the colder months (September-March) when there were few phytoplankton in the water. The samples were collected near the surface while the tide was receding, two to four hours after high tide. Water flowing out of San Diego Bay was sampled in the middle of the channel opposite Ballast Point. The second sampling station (Table 59) was

Table 59

Amounts and properties of leptopel recovered from coastal sea water by high speed centrifugation.

Sea water sample	Date collected	Sample volume, liters	Appearance	Sediment characteristics			Volume of sediment, ml/m^3
				packed mm^3 volume	solids, mg	ash, mg	
1. Mid-channel off Ballast Point, outgoing tide	9/15/58	8.0	gelatinous upper fraction over fine mud	400	54.1	33.6 (62%)	50.0
Mid-channel off Ballast Point, outgoing tide	12/15/58	13.65	Brownish grey mud	110	12.5	6.9 (55%)	8.1
Mid-channel off Ballast Point, outgoing tide	2/ 5/59	18.1	Brownish grey mud	110	----	----	6.1
Mid-channel off Ballast Point, outgoing tide	3/26/59	25.2	Brownish grey mud	100	12.8	7.9 (62%)	4.0
2. Kelp bed No. 2, Point Loma, S. shoreward side	9/15/58	2.1	Brownish grey mud	8	----	----	3.8
Kelp bed No. 2, Point Loma, S. shoreward side	2/ 6/59	28.25	Brownish grey mud	125	----	----	4.4
Kelp bed No. 2, Point Loma, S. shoreward side	3/26/59	33.3	Brownish grey mud	120	20.8	13.5 (65%)	3.6
3. Kelp bed No. 2, Point Loma, S. seaward side	12/15/58	16.0	Brownish grey mud	25	----	----	1.56
Kelp bed No. 2, Point Loma, S. seaward side	12/23/58	40.0	Brownish grey mud	50	4.4	1.5 (34%)	1.25
4. Kelp bed No. 3, Point Medanos, N. shoreward side	3/26/59	27.6	Brownish grey mud	98	13.2	7.0 (53%)	3.55
5. Gulf of Tehuantepec 97°W., 14°20′N. (60m depth)	11/30/58	45.0	Brownish grey mud	110	6.6	1.6 (24.3%)	2.44
6. SIO sea water (stormy period)	12/16/58	10.5	Brownish grey mud	140	17.9	10.1 (56.5%)	10.33
SIO sea water (stormy period)	1/27/59	10	Brownish grey mud	150	29.9	20.9 (70%)	15.0

about two miles out from Ballast Point over the south shoreward edge of kelp bed No. 2, or the part closest to San Diego Bay. When the water samples were collected at this station, the surface kelp fronds were drawn northward by the tidal current, which should therefore have been bringing water from the Bay over kelp bed No. 2. The third sampling station was beyond the seaward edge of kelp bed No. 2, about one-half mile due south of the shoreward sampling point. The fourth sampling station near Point Loma was at the northern edge of kelp bed No. 3 opposite to that over kelp bed No. 2 at the same time. This southward surface current at outgoing tide seemed to extend over most of the kelp bed No. 3 area. Thus on the days our water samples were collected (December-April) water from San Diego Bay appeared to be flowing northward over kelp bed No. 2 off the tip of Point Loma, but in kelp bed No. 3 farther north, the prevailing surface current was southward. While the tide is receding, kelp bed No. 3 could be directly exposed to water from the vicinity of Ocean Beach and Mission Bay, but not from San Diego Bay. On any one day, water samples were collected off Ballast Point and from different stations over the Point Loma kelp within about 90 minutes. The order of collecting and of centrifuging the samples from the Point Loma area was varied to avoid bias from this source. Five ml of Hutner's volatile preservative (one part chlorobenzene, one part 1, 2-dichloroethane and two parts 1-chlorobutane) was stirred into each carboy that could not be centrifuged within a few hours after collection. (Mercuric chloride was not used as a preservative because it contributes ash to the sediments.) The Gulf of Tehuantepec sample was provided by Galen E. Jones for comparison. This 45-liter sample was collected 85-90 miles offshore at 60 m depth in a relatively unproductive oceanic region. Samples of sea water from the Scripps Institution pumping system were also examined on two stormy days when the water was rendered unusually turbid by surf action and runoff.

The sea water samples sometimes contained a few large pieces of debris (fragments of kelp, etc.) which were strained off on a screen of one millimeter mesh. The largest particles recovered by centrifuging were of visible size, up to about one mm in diameter. The present water samples did not seem to contain any particles which rose when centrifuged. The centrifuged water was always examined visually before being discarded and it appeared to be as clear as distilled water. The suspended particles formed aggregates when centrifuged down; when the sediments were resuspended, they would settle spontaneously. Packed volumes were measured in hemotocrit tubes or graduated centrifuge tubes which were spun on clinical centrifuge for twenty minutes. The packed sediments were resuspended and washed three times with distilled water, then transferred with distilled water to tared crucibles. Solids were measured after drying the crucibles overnight at 100°C. The crucibles' contents were then ashed to constant weight at 575-600°C.

The largest variation in contents of suspended matter was observed in the water samples collected off Ballast Point; one sample contained 50 ml packed sediment per m^3, and the other three contained 4 to 8 ml/m^3. The corresponding sediment volumes for water collected over the exposed southern end of kelp bed No. 2 were lower and more uniform (3, 8, 4.4, and 3.6 ml/m^3). Still lower volumes of sediment were obtained from water collected on the seaward side of kelp bed No. 2 (1.56 and 1.25 ml/m^3). Equal amounts of suspended matter were recovered from water collected over the northern and southern ends of the Point Loma kelp, with the surface currents flowing in opposite directions when these samples were taken. The quantities of sediment recovered from water over the Point Loma kelp in the autumn and winter months were similar to that found in the water from the Gulf of Tehuantepec. Turbid water from the Scripps Institution pumping system obtained on two stormy days contained more than twice as much sediment than any of the water samples collected so far over the Point Loma kelp beds. Water samples were not collected over the Point Loma kelp during storms, and the water in this area is rendered turbid by violent surf action, as at La Jolla. It is likely that higher contents of suspended matter occur over the Point Loma kelp in mid-winter, but the cause of the extra suspended matter is adverse weather, not San Diego Bay water. Our data indicate lower amounts of suspended matter over the Point Loma kelp in calm winter weather than in the water flowing out past Ballast Point in San Diego Bay, but even off Ballast Point the amount of suspensoids recovered from the water was not large (4 to 8 ml/m^3) during the winter months (December-March). Our studies of the water in the Point Loma area could be improved by the use of composite samples, by tracking the water mass, and by synchronizing the water sampling with light penetration studies. Remarkably enough, the southern portion of kelp bed No. 2 which is most exposed to San Diego Bay water has had an abundance of young sporophytes developing on the bottom (50 to 60 ft. depth) at the same time that young plants could not be found in the La Jolla kelp bed. There were large numbers of young sporophytes on the shoreward side of kelp bed No. 2 when sampling the water above them was begun, but in March 1959, their tops were eaten off almost to the holdfasts by sea urchins and possibly other grazers which were observed in that vicinity.

The sediments from the Point Loma area had the appearance of a fine brown silt, sometimes gelatinous at the top. The sediments from water collected off Ballast Point, over the Point Loma kelp and from the SIO sea water system had ash contents which accounted for 50-70% of the solids. (The ash content of the Gulf of Tehuantepec sediment was only 24%.) These local sediments became distinctly red when ashed, indicating high iron contents. In this connection, colloidal ferric hydroxide absorbs organic matter from sea water and is currently being used for this purpose by Mr. Peter Williams at Scripps Institution. It has long been known that iron exists as particles of ferric hydroxide in sea water. These iron particles presumably have formed part of the sediments we have collected.

SEDIMENTATION

At no time at Point Loma, Palos Verdes, or Santa Barbara was any substantial accumulation of sediments observed which could be attributed to discharged waste material. Shifting and filling in by sands was often observed, but these processes are a normal feature of the sea floor, unrelated to the discharging of wastes. The immediate vicinity of outfall termini at Palos Verdes and Santa Barbara was not inspected, and it is posible that sludge and other sediments of sewage origin might be found in close proximity. Wave action, however, keeps fine sediments in suspension at the depths ordinarily occupied by kelp. At times of extremely flat seas a fine scum covered most surfaces at Palos Verdes, but was easily brought into suspension by slight wave surge along the bottom.

At our Santa Barbara growth station, occupied over a year and a half, several lengths of iron pipe, about 9 inches diameter, had been discarded. They were thickly covered with barnacles and remained exposed about the same amount throughout the study; no burial by sludge or other sediments occurred. The station was about 1000 feet from the outfall terminus.

Sludge was found on the floor of San Diego Bay at the outfall terminus and about a mile northwest at the 28th Street Mole. The sludge did not inhibit all life, however, as the surface was oxidized and a wide variety of organisms were observed thereon (North, 1958a).

No sedimentation has ever been observed on kelp blades in the open sea, although silt and sludge have been observed adsorbed onto the blades of *Sargassum* in Florida waters; in contrast to the microbiota-poor water, such siltation is rich in ciliates, colorless flagellates, euglenids, and diatoms. Sedimentation has been found on *Macrocystis* blades where quiet water exists, such as in bays, but this is not necessarily related to sewage discharge as the phenomenon may be found in areas such as Turtle Bay, Mexico, far removed from submarine outfalls.

Although there is apparently little or no permanent accumulation of sediment of sewage origin in the shallow zones near outfalls, considerable quantities of material are discharged by the larger installations. Computations of the amount of suspended solids component discharged annually by the Los Angeles County Sanitation Districts facility at Whites Point and the City of San Diego treatment plant, based on rounded figures for recent years (Table 60) indicate that there is probably sufficient material to cause noticeable accumulations if it were distributed as sediments within a square mile surrounding the outfall terminus. The organic matter contributed to the receiving waters is substantial when compared with the average annual production of organic matter by phytoplankton (0.05×10^6 ft^3 per square mile). For animals which can utilize the organic matter in the suspended solids, a tremendously rich environment should result.

Table 60

Calculated annual discharge of suspended solids from Whites Point and San Diego, based on rounded figures for recent years.

	Daily discharge MGD	Suspended solids ppm	Annual discharge of suspended solids, millions of ft^3	Annual discharge of organic matter in suspended solids, millions of ft^3*
Whites Point	250	300	3.6	2.4
San Diego	50	85	0.26	0.09

* Assuming that the suspended solids are $\frac{2}{3}$ organic matter, after *Imhof, et al.* (1956).

PHYTOPLANKTON

Introduction

Phytoplankton and associated microbiota were of interest to the study for several reasons. It is possible that they compete with attached plants for light and nutrients. Likewise any discharged toxic substances harmful to life might affect the microbiota as well as vegetation such as kelp. It has long been known that discharged wastes can affect the composition and abundance of phytoplankton. Hence knowledge of expected normal populations might be of use in analysis of conditions in kelp beds located near outfalls.

Preliminary Studies of the Phytoplankton of San Diego Bay

H. E. Miller and I. Nusbaum investigated the photosynthetic activity of phytoplankton in San Diego Bay, and showed that photosynthesis in this contaminated water serves as an important source of oxygen. Very marked oxygen enrichments were observed throughout most of the bay during "blooms" in the spring and summer months. The lowest dissolved oxygen concentrations in San Diego Bay were observed by these investigators during the fall and winter months; these low values were attributed to reduced photosynthetic activity (Miller and Nusbaum, 1952).

In connection with the foregoing investigation, the types and numbers of photosynthetic organisms in different parts of San Diego Bay were determined by Dr. Beatrice M. Sweeney, Department of Marine Botany, SIO. This work was based on water samples collected by Mr. I. Nusbaum in the summer and autumn of 1952 at known dates, depths, and locations. Sea water samples collected off the SIO pier were examined at the same time as controls (Table 61). This unpublished 1952 study revealed characteristics of the San Diego Bay phytoplankton which have appeared again in more recent studies. The bay water samples usually contained a high proportion of small, naked, photosynthetic flagellates. Some, at least, of these organisms are positively phototactic, which presumably allows them to congregate in the illuminated surface zone of the turbid water. Representatives examined in the laboratory have shown organic growth factor requirements, which should be supplied by organic wastes in the bay water. Because of their

Table 61

Phytoplankton of San Diego Bay and of uncontaminated coastal water (Counts and identifications by Dr. B. M. Sweeney).

Date	Location	Total Phytoplankton	Small naked flagellates	Diatoms	Dinoflagellates
7/11/52 (depth 1 foot)	B St. Pier	5,360	5,000	nil	360
	Rowing Club	6,160	5,700	nil	460
	28th St.	3,200	2,970	nil	230
	SIO Pier, La Jolla	260	absent	20	240
7/17/52 (depth 2-3 feet)	B St. Pier	330	50	80	200
	Rowing Club	270	200	40	30
	28th St.	545	100	(not counted separately)	
	17th St. Channel	4,000	3,000	1,000	none
	F St. Shore	500	(not counted separately)		
	Foot, Armory-Silver	1,850	1,850	nil	nil
	Glorietta Bay	1,730	1,100	400	230
	SIO Pier, La Jolla	335	nil	90	140
10/23/52	28th St.	70	55	10	5
	SIO Pier, La Jolla	0.3	nil	0.1	0.2
Mid-summer, 1954 (R. W. Holmes)	Pier No. 11	21,130	11,630	1,050	8,450
12/6/57	28th St.	110	95	8	7

fragility and small size, these flagellates can escape notice in routine plankton analyses; they pass through fine plankton silk, disintegrate or become unrecognizable when stored in 5 percent formaldehyde, and they are easily destroyed by centrifuging. The green marine Euglenoid, *Eutreptia viridis* has usually been present in the San Diego Bay water samples, and in some of these, it was observed in concentrations above 1000 cells/ml. This organism has been maintained in laboratory culture at SIO since 1952. *Eutreptia* has not been observed in sea water samples collected off the SIO pier. Although diatoms and dinoflagellates are usually present in San Diego Bay water, the species tend to be of small size.

Seasonal changes and depth profiles in phytoplankton density have not been examined in detail, but the seasonal trend appears to be similar in the bay and outside. Phytoplankton are more abundant in spring and summer than in fall and winter, but the photosynthetic microorganisms are usually much more numerous in the bay, and with a different species composition.

Accelerated corrosion of ship hulls moored in San Diego Bay was shown to arise in part from the high oxygen concentrations resulting from intense photosynthetic activity in the surface water (Kittredge and Corcoran, 1955). In connection with the latter study, phytoplankton identifications and counts were provided by Mr. Robert W. Holmes for water samples collected at the surface off Pier No. 11, which is about one km south of the municipal outfall. The phytoplankton densities observed by Mr. Holmes were remarkably high (20,000 photosynthetic cells per ml). The naked flagellate group again predominated, but diatoms and dinoflagellates were also present in "bloom" proportions. Fourteen different types of algae were identified in Mr. Holmes' study (Kittredge and Corcoran, 1955).

During 1957-58, additional samples of San Diego Bay water were examined. A bloom which occurred in the spring of 1957 near Shelter Island was mainly comprised of cryptomonads, a type of naked flagellate, but also contained the marine Euglenoid, *Eutreptia*, as well as several types of diatoms and dinoflagellates. Cryptomonads and *Eutreptia* could not be found in sea water samples collected at the same time off the Scripps pier. Sea water collected off the 28th Street Mole in late autumn 1957 showed a preponderance of naked marine flagellates, which again included *Eutreptia* (Table 61). The relatively low numbers of cells per ml observed in this December sample accords with the 1952 autumn sample obtained at the same location. Water collected at the San Diego municipal outfall was essentially devoid of all phytoplankton; only four cells were seen in several slides, even after concentrating 100-fold.

In May, 1958, a dense bloom occurred in the bay which was found to contain 17,500 cells/ml. by Mrs. Anne Dodson. The predominant organism in this extensive bloom was a small unarmored dinoflagellate, identified as *Massartia* by Drs. B. Sweeney and E. Balech. This organism has frequently been seen in water samples from San Diego Bay, but not from off the SIO pier.

Phytoplankton in Coastal Waters, 1958

The importance of phytoplankton as competitive light-absorbers within kelp beds was revealed in studies this year of conditions prevailing at the bottom of a selected station in the La Jolla kelp bed. There was insufficient daily photosynthesis by young kelp fronds near the bottom to balance daily respiration, on clear days in January, March, May, and June, 1958. This observation was confirmed in the laboratory by reproducing the green light intensities observed at midday in the field, which proved to be insufficient for net photosynthesis. At first the dense shade was attributed to the surface canopy, but examination of the entire water column revealed high turbidity which doubtless contributed to the low light intensities near the bottom. The cause of the turbidity throughout the water column was sought by Dr. B. Sweeney and Mrs. Anne Dodson through microscopic examination of water samples. From May onward through the summer, the cause of the turbidity at this station was phytoplankton, present to the extent of 200 or more cells per ml. upwards. These observations refer to uncontaminated coastal water at the north end of the La Jolla kelp bed. With other conditions the same, heavier crops of phytoplankton are to be expected when extra nutrients are supplied from organic wastes.

Microbiota of San Diego Bay and Point Loma, 1959

The phytoplankton, protozoa, and sulfur bacteria in San Diego Bay, in Kelp Bed No. 2 near the bay entrance at Point Loma, and off the Scripps Institution of Oceanography pier at La Jolla were investigated during the summer of 1959.

As noted above, observations in previous years (1952-1958) by B. M. Sweeney and Anne Dodson had revealed substantial differences between the phytoplankton of San Diego Harbor and of coastal water sampled off the SIO pier (Clendenning, 1958a, 1958b, 1959a, 1959b). One of the purposes of our investigation was to define these differences taxonomically and by quantitative population measurements. A second objective was to determine the effects of San Diego harbor wastes on the Point Loma kelp through studies of the phytoplankton and other microorganisms.

Six stations were selected in mid-channel at approximately two-mile intervals throughout the navigable length of San Diego Bay (Station I was at the southern end of the channel opposite Chula Vista, Station VI off Ballast Point, etc.). The seventh station was located in the Point Loma kelp about one mile offshore alongside the harbor entrance. Station VIII was the SIO pier which served as a control. Surface water was collected weekly off the pier and at outgoing tide from the San Diego Bay Stations I-VII. Later in the same week, the sediment-water interface was sampled at the bottom under these eight stations by divers. All samples were examined promptly without use of preservatives.

The following types of microscopic algae were identified to genus or species:

- Dinoflagellates
- Diatoms
- Cryptomonads
- Chrysomonads
- Chloromonads
- Euglenids
- Xanthophyceae
- Volvocales
- Chlorococcales
- Blue-green algae

When any organism was present in large numbers, the population density was also determined, and otherwise frequencies of occurrence were recorded.

Over 100 species were observed in the dinoflagellates alone, and a total of 145 phytoplankton blooms were observed in the samples. (Diatoms 73, Chlorococcales 30, Chrysomonads 14, Cryptomonads 13, Volvocales 13, Dinoflagellates 1, *Eutreptia* 1 (occurrences of over 500 cells/ml).)

Largest number of dinoflagellate species, greatest frequency of their occurrences and densest dinoflagellate populations were observed at the control station at La Jolla, followed by the Point Loma kelp station. Within San Diego Bay, the dinoflagellate populations decreased progressively with increasing proximity to the municipal outfall. This limiting effect of the harbor water was expressed on the sedentary species inhabiting the sediment-water interface as well as on the planktonic species collected at the surface. Dinoflagellates commonly predominate in the coastal phytoplankton during the summer solstice, and the leading coastal species are well known from several decades of preceding work at SIO. These leading coastal species were present as usual at the two coastal stations (La Jolla and Point Loma), but they were absent at the inner San Diego harbor stations I-IV, which spanned the bay from Chula Vista to the 10th Avenue pier. The outer harbor (Shelter Island to Ballast Point) was intermediate in this respect, showing fewer dinoflagellates than the coastal stations and more than were observed in the inner harbor. This finding is borne out by less detailed observations made in previous years. Thus, in the summer of 1958, *Gonyaulax polyedra* was absent or insignificant in San Diego harbor while *Gonyaulax* red tides were occurring along the coast. Certain types of algae were favored by the extra nutrients in San Diego harbor, but the opposite was true of the dinoflagellates, and most especially the leading types of coastal dinoflagellates which were excluded.

Cryptomonads were judged highly characteristic of the fertilized harbor water, but cryptomonads were not more abundant in the samples collected from the Point Loma kelp than from the SIO pier at La Jolla. From the work of Dr. M. B. Allen, it is known that certain species of the *Chlorococcales* (a group of green algae) attain vast numbers in sewage oxidation ponds (10^6 to 10^7 cells/ml). *Chlorococcales* bloomed frequently in inner San Diego harbor, but the population densities were from several hundred to several thousand times lower than were observed in Dr. M. B. Allen's study. (This is to be expected since over 600 gallons of sea water are exchanged tidally by San Diego Bay per gallon of clarified sewage released by the municipal outfall and sewage oxidation ponds therefore receive much higher concentrations of nutrients such as nitrogen and phosphorus.) The *Chlorococcales* were not more abundant in the Point Loma kelp than off the SIO pier at La Jolla. There were more diatom blooms in the Point Loma kelp than off the SIO pier, but this was balanced by decreased numbers of blooms in other phytoplankton categories.

Relative frequencies of phytoplankton blooms throughout the summer of 1959 in the outer part of San Diego harbor, in the Point Loma kelp and off the SIO pier are reported in Table 62.

Table 62

Phytoplankton blooms observed in water collected in outer San Diego harbor (the portion of the bay most closely resembling the outside waters and presumably freest from influence of wastes), in the Point Loma kelp, and off the SIO pier, July-August 1959.

	Shelter Island (Station V)	*Ballast Point (Station VI)*	*Point Loma Kelp (Station VII)*	*SIO Pier, La Jolla (Station VIII)*
Dinoflagellates	0	0	0	1
Cryptomonads	2	2	0	0
Chrysomonads	3	0	1	3
Chlorococcales	5	4	1	3
Volvocales	2	1	1	1
Diatoms	14	12	9	5
Total Phytoplankton Blooms	26	19	12	13

Phytoplankton blooms were observed more frequently off Shelter Island and off Ballast Point than at either of the coastal stations. This difference arose mainly from small diatoms, which also were observed in bloom more frequently in the Point Loma kelp than at the coastal control station at La Jolla. But for phytoplankton blooms as a whole, their frequency of occurrence did not differ significantly at the two coastal stations (12 blooms in the Point Loma kelp vs. 13 at the SIO pier, La Jolla).

The Microbiota of Mission Bay and of the Coastal Kelp Area Between Point Loma and Bird Rock (La Jolla) 1961

Research on the microscopic algae of Mission Bay and of the coastal kelp areas extending from kelp bed no. 2 to bed no. 4 was conducted during the summer of 1961. The area of investigation included the entire coastal kelp area between San Diego and Bird Rock, La Jolla, plus four stations within Mission Bay. Three of the 1959 stations were used again in 1961, which allowed comparisons between years. Positions of the regularly sampled stations were fixed by shore markers:

No. 6	Ballast Point
No. 7	Point Loma kelp, southern end
No. 8	SIO pier
No. 10	Convair gantry, one mile offshore
No. 11	Sunset Cliffs Park, southern end, one mile offshore
No. 12	Ocean Beach, one mile offshore
No. 13	Bird Rock end of kelp bed No. 4, La Jolla
No. 14	Mission Bay entrance, within the breakwater
No. 15	Mission Bay, near projected Oceanarium site
No. 16	Mission Bay, by F. A. A. tower
No. 17	Mission Bay Yacht Club

Stations 10, 11, 13, 16 and 17 were sampled early on Monday mornings during the summer of 1961, and the remainder were sampled at ebb tide on Wednesdays. The offshore stations were sampled at depths of 50 feet as well as at the surface, using Van Dorn samplers lowered with a windlass. Water temperatures of each sample were recorded at the time of collection, and the samples were brought promptly to the laboratory immersed in water. The coldest or bottom water samples were analyzed first. The main block of information was obtained from these regular samplings which involved sixteen boat cruises with a crew of two or more. Every third week was left free for special studies. Shallow sections of Mission Bay which could not be navigated by the large motor launch were sampled in these periods, and samples also were taken along San Diego Bay as a check on the 1959 study. The groups investigated remained the same as in the 1959 study.

1. There was a large standing crop of phytoplankton in Mission Bay all summer. This was especially evident in small lagoons leading off from the main body of Mission Bay. Turbidity of this water throughout the summer was mainly caused by living algae rather than by suspended soil particles. Mission Bay occupies about four square miles which has been completely transformed by dredging and filling. Over 20 miles of artificial shoreline have been created within Mission Bay, and during two years, 1960 and 1961, over twelve million cubic yards of soil were dredged from Mission Bay. Mission Bay is reserved for recreational use and receives no industrial or municipal wastes. The abundant crops of phytoplankton in Mission Bay may have been fostered by nutrients released by the soil. The dredging system that was in use during this study operated on a closed cycle basis, which retained the soil but presumably allowed soil leachings to percolate into Mission Bay.
2. The leading phytoplankton species of Mission Bay during the summer of 1961 were the unarmored dinoflagellates *Gymnodinium flavum* and *Protodinium baltica*, this being the first record of their occurrence there. Both of these species have golden chromatophores, and *Protodinium baltica* is now in laboratory culture for the first time. *Gymnodinium flavum* became so abundant in parts of Mission Bay that the water was colored distinctly yellow. Rising numbers of this species were monitored at Station 17 (Mission Bay Yacht Club) over a period of a few weeks. Then on the weekend of July 22nd, dead and dying fish began drifting into Asher Cove, a public bathing beach near Station 17. The yellow water now had a rank odor, and lifeguards reported that at least twenty different kinds of fish were killed. Water samples collected at this time in Asher Cove contained 1800 cells/ml of *Gymnodinium flavum* which was the cause of the yellow water and presumably of the fish mortality. It was observed in smaller numbers at several other stations, even miles outside Mission Bay, but was not detected in the 1959 study (Lackey) or in any other plankton study in the San Diego area.

Only one bloom of this golden dinoflagellate had ever been recorded previously. In July 1914, this species turned the coastal water yellow near La Jolla for a period of three weeks, and it was during that earlier occurrence of "yellow tide" that *Gymnodinium flavum* was discovered and named (Kofoid and Swezy, 1921). Why this organism faded from the scene for 47 years (1914-1961) and then suddenly recurred in large numbers is a mystery. *Gymnodinium flavum* has yet to be cultured in the laboratory and essentially nothing is known concerning its physiology. The fish kill in Asher Cove, Mission Bay, is the first on record for California that was associated with a *Gymnodinium* bloom.

3. A major difference between the algae in 1959 and 1961 was the predominance of diatoms in 1959 and of dinaflagellates in 1961. The biomass of the dinoflagellates usually exceeded that of all other groups during the 1961 investigation. *Ceratium facatiforme* was a dominant species, especially in regard to biomass. Such continued dominance of this species of *Ceratium* over a period of time has not previously been observed in California coastal waters.
4. Most of the inshore photosynthetic nannoplankton were green *Volvocales* and *Chlorococcales*, most of the offshore or oceanic nannoplankton belonged to the *Chrysophyceae*. Small unarmored dinoflagellates have been quite abundant in the inshore samples. Most of these dinoflagellates are poorly known and very few of them have ever been cultured or studied physiologically.
5. The crops of phytoplankton at the offshore (ocean) stations were sometimes large but fluctuated widely. The algal populations were consistently smaller at 50 foot depth than in the corresponding surface waters. The populations of microscopic algae ranged from about 2 to 20,000 per ml during this study.
6. The major populations and the majority of species represented in the 1961 collections were dinoflagellates (greatest biomass), diatoms relatively few species and *Chrysophyceae*. Despite a paucity of species. *Cryptophyceae* have also been abundant. Large populations of the green euglenid, *Eutreptia*, were encountered, and at times *Coccolithophora*, which should be considered members of the *Chrysophyceae*. *Silicoflagellata* have been constantly present but in small numbers. *Volvocales, Chlorococcales, Chloromonadida, Rhizopoda, Ciliata* and *Zooflagellata* have been few in numbers and species.
7. New species of algae discovered during this 1961 study include: at least three of *Chrysochromulina*, a new species of *Chlamydomonas*, and a new *Amphidinium*. The *Diplosalis* encountered early in the summer resembled *D. lenticula*, with recognizable differences. Additional details have been provided for species heretofore incompletely described such as *Protodinium baltica*.

MICROBIOLOGY

Collection Methods

Inhibition of bacterial growth by kelp frond material makes definitive counting of the bacterial populations attached to kelp surfaces a complicated affair. The sampling technique employed requires that the sample be suspended in unsterilized water from the kelp bed. An underwater sampling device is used with which a diver punches out discs of kelp blade tissue as he swims through the kelp bed, the discs being deposited as they are collected in a sterilized sample bottle. No handling by the operator is required, reducing to a minimum, loss of organisms from the samples and also contamination. Since the kelp is suspended in sea water with its own population of bacteria, a definite volume of this sea water must be taken with the kelp sample to minimize error from this source. The counting procedure for such a sample requires that a count be made of the sea water population and this value is then subtracted from the value obtained from the combined sample of sea water and kelp sections. To take account of the inhibitory action, the plate counts of kelp frond material are determined by running a third set of counts in which the inhibitory effect against the sea water bacteria is ascertained. In the laboratory, standard methods of enumeration, identification, culturing, etc., were employed. The following conclusions were reached during a 2 year investigation of the microbiology of kelp areas:

Temperature of Optimum Growth

Concurrent with each bacterial plate counting series a determination was made of the optimum temperature for maximum growth of the bacteria of the kelp bed in the sample. In this procedure 0.1% proteose peptone was added as a nutrient source to a suspension of kelp bacteria made by shaking kelp blades in sea water from the kelp beds where the blades were taken. Aliquots of this suspension were incubated at temperatures ranging from 12°C to 46°C at two-degree intervals (18 temperatures in all). Bacterial growth in the suspensions was measured in a nephelometer after a period of growth sufficient to produce a dense turbidity at the temperatures of maximum growth (8 to 18 hours, depending primarily on the initial bacterial count of the suspension).

Results of these experiments showed that two distinct optimum temperatures existed for the growth of bacteria from the kelp frond surfaces. Figure 95 shows the results from one such experiment with a sample taken from the "Five-minute Kelp Bed" at South Coronado Island. As is indicated in the curve, two maxima occur, one at 26°C and another, less distinct in outline, at 34-38°C. Results from three other experiments, one from each sampling area, give substantially the same results, with the shapes of the curves being slightly different but indicating the same points of maximal growth. One previous experiment from the "Five-minute kelp bed," on January 28, 1960, gave the results shown in Figure 96 in which the higher optimal temperature at 34-38°C was not present. From the small amount of data now available

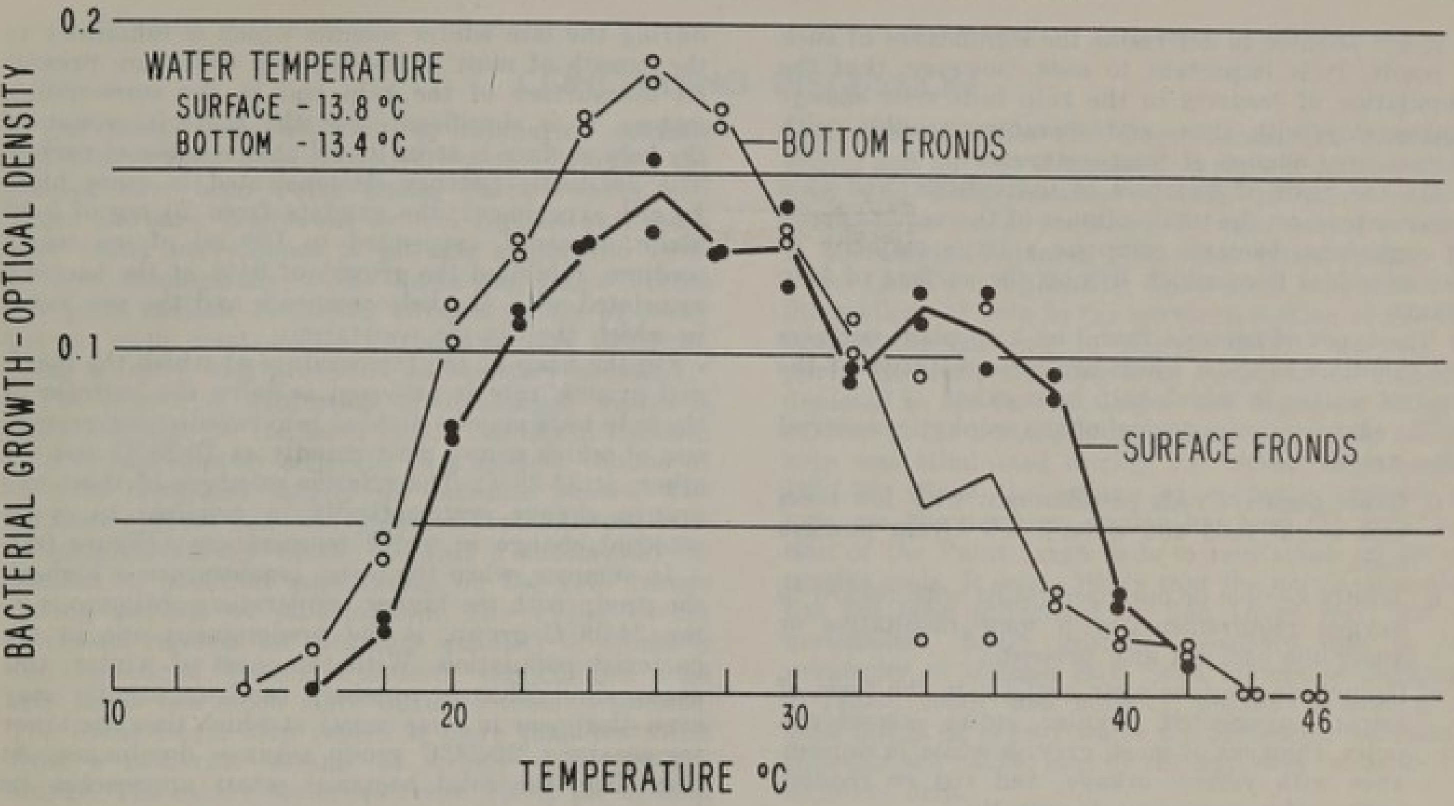


Figure 95. Growth of bacterial suspensions of kelp frond origin, March 9, 1960.

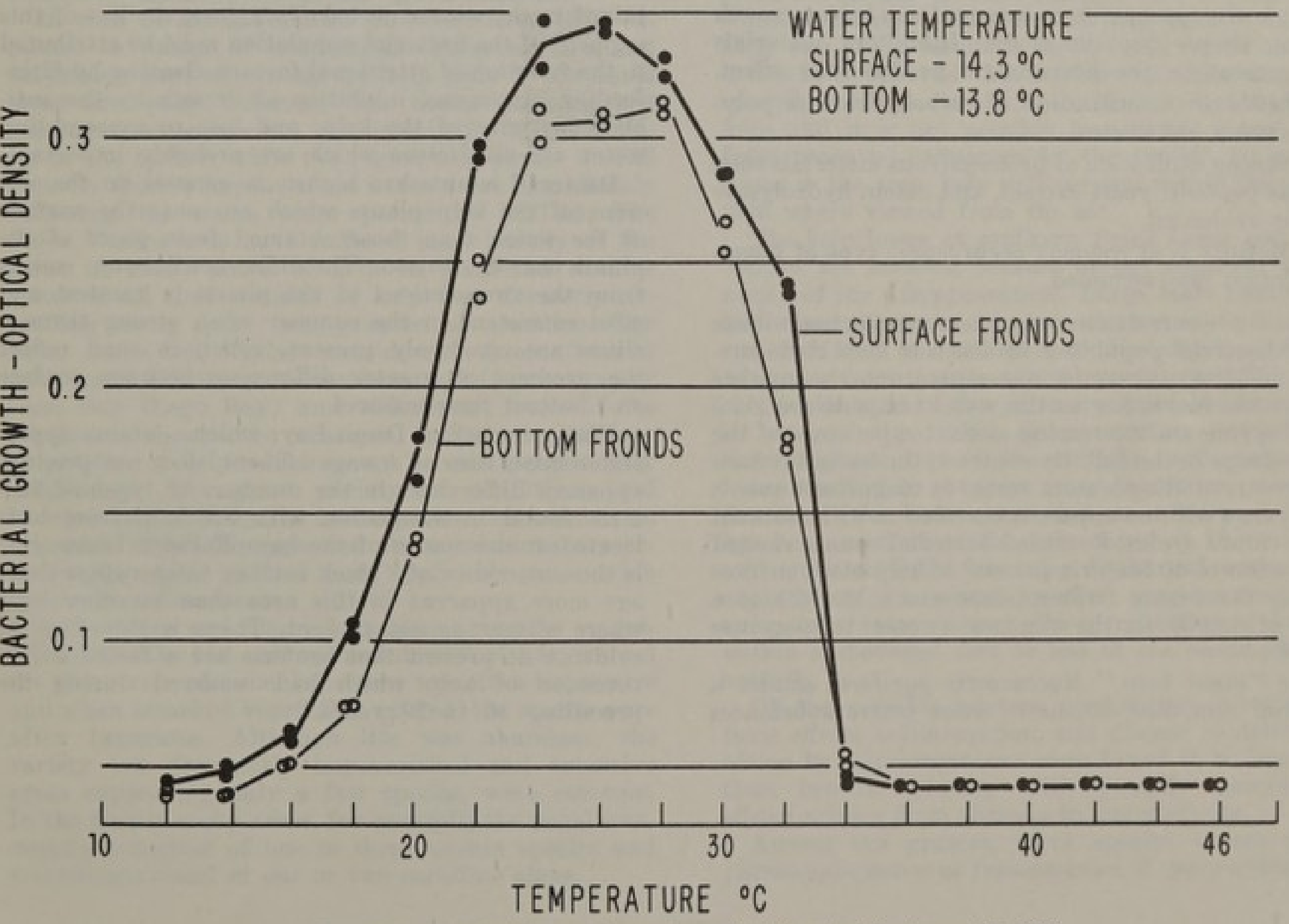


Figure 96. Growth of bacterial suspensions of kelp frond origin, January 27, 1960.

it is not possible to determine the significance of such a result. It is important to note, however, that the population of bacteria in the kelp beds does change appreciably with time, and therefore possibly with the seasonal change of temperature.

On the basis of numbers of individuals, and to a lesser extent, on the total volumes of the various types of organisms, bacteria comprise a large majority of the microbial flora which live on the surface of kelp plants.

The types of bacteria found on kelp plant surfaces are the same as those which are representative of the littoral waters in which kelp beds exist.

The characteristics typical of the epiphytic bacterial flora are as follows:

a. Gram negative rods predôminant with few cocci and spiral rods and a very few Gram positive rods.

b. Mostly aerobic or microaerophilic with regard to oxygen requirements with some facultative or anaerobic bacteria also present.

c. Growth on peptone agar medium in the form of smooth, pigmented, circular, entire, convex colonies. Pigment of most, greyish white in appearance with yellow, orange, and red or reddish brown also occurring frequently.

d. Poor growth, if any at all, on kelp homogenate agar medium at any concentration. Where growth appears, organism produces better growth on simple peptone media. Inhibitory materials present in the homogenate produce the effect.

e. Little or no utilization of carbohydrate or polyalcohol substrates.

f. Strong utilization of proteinaceous materials such as peptone, yeast extract, and casein hydrolysate is evidenced.

g. Motility is of common occurrence; type of flagellation undetermined.

A positive correlation exists between the magnitude of the bacterial population attached to kelp blade surfaces and the environmental temperature, the number of bacteria increasing as the water temperature rises in the spring and decreasing as the temperature of the water drops in the fall. By contrast, the bacterial flora of the surrounding waters varies in magnitude over a wide range with no apparent correlation with seasonal temperature cycles. Recorded bacterial counts ranged from a low of 40 bacteria per cm^2 of kelp blade surface during the winter (water temperature 13.4°C) to a high of 12,000 in the summer (water temperature 17.3°C).

The "giant kelp," *Macrocystis pyrifera,* exudes a material composed of one or more active substances during the late winter months which is inhibitory to the growth of most of the bacteria which are present on the surface of the kelp and in the surrounding waters. It is significant that the bacterial count of the kelp surface is at its lowest at this seasonal period. The antibiotic potency demonstrated is quite high. In one experiment, the exudate from 20 mg of kelp blade segments, suspended in 100 ml of sea water medium, inhibited the growth of 94% of the bacteria associated with the kelp segments and the sea water in which the sample was taken.

On the basis of the temperature at which the maximal growth rate is achieved *in vitro* the bacteria of the kelp beds may be divided into two distinct groups, one of which grows most rapidly at 26-28°C and the other, at 34-38°C. The relative numbers of these two groups change systematically in response to cyclic seasonal change in water temperature (Figure 96).

In summer, when the water temperature is highest, the group with the higher temperature optimum, e.g., the 34-38°C group, is the predominant one in the bacterial population. With the onset of winter, this group diminishes in numbers (and apparently may even disappear in some cases) at which time the lower temperature, 26-28°C group assumes dominance. At this time, the total bacterial count approaches its lowest point.

The 34-38°C group is nonetheless capable of growth *in vitro* at temperatures much lower than those attained in the winter period. Therefore, the loss of this segment of the bacterial population must be attributed to the function of attritional factors. Grazing by filter-feeding organisms, inhibition of growth by the antibiotic activity of the kelp, and loss to surrounding water are all factors which are probably important.

Bacterial counts are higher in general on the sections of the kelp plants which are near the surface of the water than those obtained from parts of the plants near the bottom. The difference between counts from the two sections of the plants is greatest and most consistent in the summer when strong thermoclines are commonly present, which in turn reflect the presence of greater differences between surface and bottom temperatures.

Water from San Diego Bay, which contains appreciable quantities of sewage effluent, does not produce apparent differences in the numbers or types of bacteria found in association with the kelp from beds located at the mouth of the bay off Point Loma. Nor is the occurrence of "black rot" or temperature damage more apparent in this area than in other beds where effluent is not present. There is therefore no evidence at present that bacteria are a factor in the recession of kelp which had occurred during the preceding 10 to 20 years.

CONCLUDING DISCUSSION

The three areas adjacent to submarine outfalls which have been most intensively studied during the project have been Point Loma, Palos Verdes, and Santa Barbara. Numerous control regions have been kept under surveillance to provide a basis for comparison. Ecologically, Point Loma and Palos Verdes are quite similar, consisting predominantly of rocky bottom open coast. Santa Barbara is very different, being a fairly well protected sedimentary bottom.

The degree of subjection to discharged wastes is quite different for the three areas. The Santa Barbara kelp is immediately adjacent to a modest volume of effluent, composed largely of domestic wastes. The intimate contact was clearly demonstrated by our microbiological survey which revealed a substantial reduction in bacterial populations on the kelp fronds during periods of chlorination. The Palos Verdes peninsula receives an enormous quantity of domestic and industrial wastes. Formerly the contact with kelp zones was much more intimate than at present. The Point Loma kelp region is more than ten miles from a moderate volume of largely domestic discharge. The rather torturous route which the diluted effluent must travel through San Diego Bay before it reaches the open sea provides considerable opportunity for modification of the waste materials.

In view of the differences in environment and exposure to wastes of non-similar character, it is not surprising that effects on the kelp beds of the three areas are quite different. The Santa Barbara bed has regressed somewhat, but principally in the vicinity of the harbor, while the region nearest the outfall actually showed improvement in the years immediately following the warm water period of 1957-59. The Palos Verdes beds have suffered most heavily of the three. A small patch of kelp in protected shallow water is all that remains of kelp beds formerly extending along some twenty miles of coastline. The Point Loma bed displays considerable fluctuations in extent and density at its northern end (furthest away from San Diego Bay) and widespread losses at the southern end, with the occasional sporadic appearance of patches of kelp which never become permanently established. The great variety of conditions and changes embraced by the investigation necessitated an approach of broad scope and the conclusions are accordingly quite general and applicable to a wide range of environments.

No evidence was obtained that any area near an outfall studied by the authors was devoid of life; indeed the abundance of animals present was often impressive and when attached vegetation existed, the stands were often luxurious. Although life was abundant, the variety was frequently impoverished and extensive areas supporting only a few species, were common. In the deeper rocky areas, for example, the usual community consisted of one to three urchin species and a moderate stand of one or two coralline algae.

At Palos Verdes and Point Loma, the historical charts and harvest statistics first show a gradual thinning and disappearance of kelp in those regions closest to an outfall; subsequent losses tended to occur at increasing distances from this initial point. At Point Loma a complicating feature has been extensive fluctuations of kelp in the northern section of the bed nearest the entrance to Mission Bay. This may be partly an artifact arising from the smoothed contours depicted in the earliest charts, but much variation is evident in the aerial photographs and virtually all the kelp was eliminated during the warm water period 1957-59. Since the return of colder temperatures, however, the northern section has been the only portion of the Point Loma beds to reestablish on an extensive scale. It seems likely that the northern section has not been influenced by San Diego Bay, but is, nonetheless, fairly unstable, possibly due to the proximity of Mission Bay. Such factors as dredging, increased small boat activity, possible alteration of such things as nearby water temperatures, sedimentation characteristics, etc., by the bay, may influence the adjacent kelp.

At Santa Barbara the outfall terminus is about ½ mile southwest of the harbor entrance and this zone from the harbor to the outfall is now almost barren where formerly a thick bed of kelp existed. Immediately east of the terminus the bed still exists, however, hence it is believed that harbor activities may have contributed importantly to the documented decline of kelp and it is not possible to separate these effects from potential influences by the outfall. In spite of losses in the area, kelp still persists within the sewage field where viewed from the air.

The kelp losses at southern Point Loma and Palos Verdes are unusual because of the apparent permanency of the disappearances. Large scale fluctuations and disappearances are not uncommon in beds far removed from the influence of discharged waste, but sooner or later (up to several years) reestablishment occurs. Because of the permanency of the losses, and in view of the initial disappearances occurring in those regions nearest the outfalls, with subsequent losses tending to progress away therefrom, there is a firm basis for suspecting that an adverse influence has been exerted on the kelp zones at Palos Verdes and southern Point Loma by discharged wastes. Any explanation of how such an effect operates must, however, take into account the persistence of kelp to within a thousand feet or less of the Santa Barbara outfall.

Of the possible adverse mechanisms investigated, toxic effects sedimentation, and disease or deleterious action by microorganisms were found to be less likely than benthic grazing with possible complicating effects arising from changes in water clarity.

Among the grazers, three species of sea urchin (*Strongylocentrotus franciscanus, S. purpuratus,* and

Lytechinus anamesus) often occur in such numbers in the regions now devoid of kelp that it is extremely doubtful if attached vegetation could become established. These dense urchin populations have persisted during five years of surveillance. Urchins can be starved to death in the laboratory in a year or less, hence, it is likely that the populations at Point Loma and Palos Verdes are deriving sustenance from suspended detritus or from organic-rich sediments or both. Phytoplankton studies over a limited period did not reveal any substantial differences between the suspended flora of a control station at La Jolla and a station off southern Point Loma. The Mission Bay and San Diego Bay phytoplankton were, however, in many respects quite different from the microbiota of the offshore stations. The sources of urchin nutrition, therefore, may not reside in abundant phytoplankton production and as yet remain obscure, but the presence and persistence of these grazers is well established for the Point Loma and Palos Verdes barren areas. They are found only rarely at Santa Barbara, even though *Lytechinus* occurs commonly on sedimentary bottoms.

Our preliminary experiments on poisoning urchins at Abalone Cove support the conclusion that these animals prevent attached vegetation, including kelp, from developing.* It is possible that other unnoticed grazers were also killed by the quicklime used to eliminate the urchins, but certainly the urchins were present in sufficient numbers (over 100 per yd^2) to keep the bottom devoid of algae. The winter, 1960, study of a kelp patch off Point Loma Light, during the course of its complete destruction by *Strongylocentrotus franciscanus* and *S. purpuratus*, plus many other observations of plant denudation by these species, leave little doubt that the dense populations now present along many miles of coast at southern Point Loma and Palos Verdes must be totally effective in preventing reforestation by *Macrocystis*. The presence of abundant seaweed stands in shallow water (down to 25 feet at Point Loma and down to 10 feet at Palos Verdes) may be a result of sufficient light penetration to maintain plant productivity combined with enough wave surge to make the shallow environments unfavorable for grazing by urchins.

An adequate explanation for the permanent disappearance of kelp is thus provided, as is the problem of why the Santa Barbara outfall has not produced a similar widespread loss in adjacent kelp beds. If the effluents in some way encourage establishment and survival of urchins, and if a change in water clarity occurred which reduced plant productivity in deep water, the historical record of initial disappearance of that kelp nearest outfall with subsequent losses progressing away from this site, becomes understandable, as does the persistence of good seaweed growth in shallow water. The question of urchin control and the relation of submarine waste discharges to the ecology of these species is currently under investigation.

The Turbidity Section defines the problems of measuring effects of outfalls on water clarity; an abundance of data describing turbidity before and after installation of a discharge is needed and was beyond the scope of this program.

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* Note added in press: Considerable additional work on urchin control strongly supports this conclusion. A description of these 1962-63 studies is contained in Final Report, Kelp Habitat Improvement Project, University of California, Institute of Marine Resources, 1963. IMR Ref. 63-13.

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Institute of Marine Resources

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2 = quarterly period 1 April to 30 June
3 = quarterly period 1 July to 31 September
4 = quarterly period 1 October to 31 December
Example—K-1-57 = Quarterly Kelp Program Report for 1 January to 31 March, 1957

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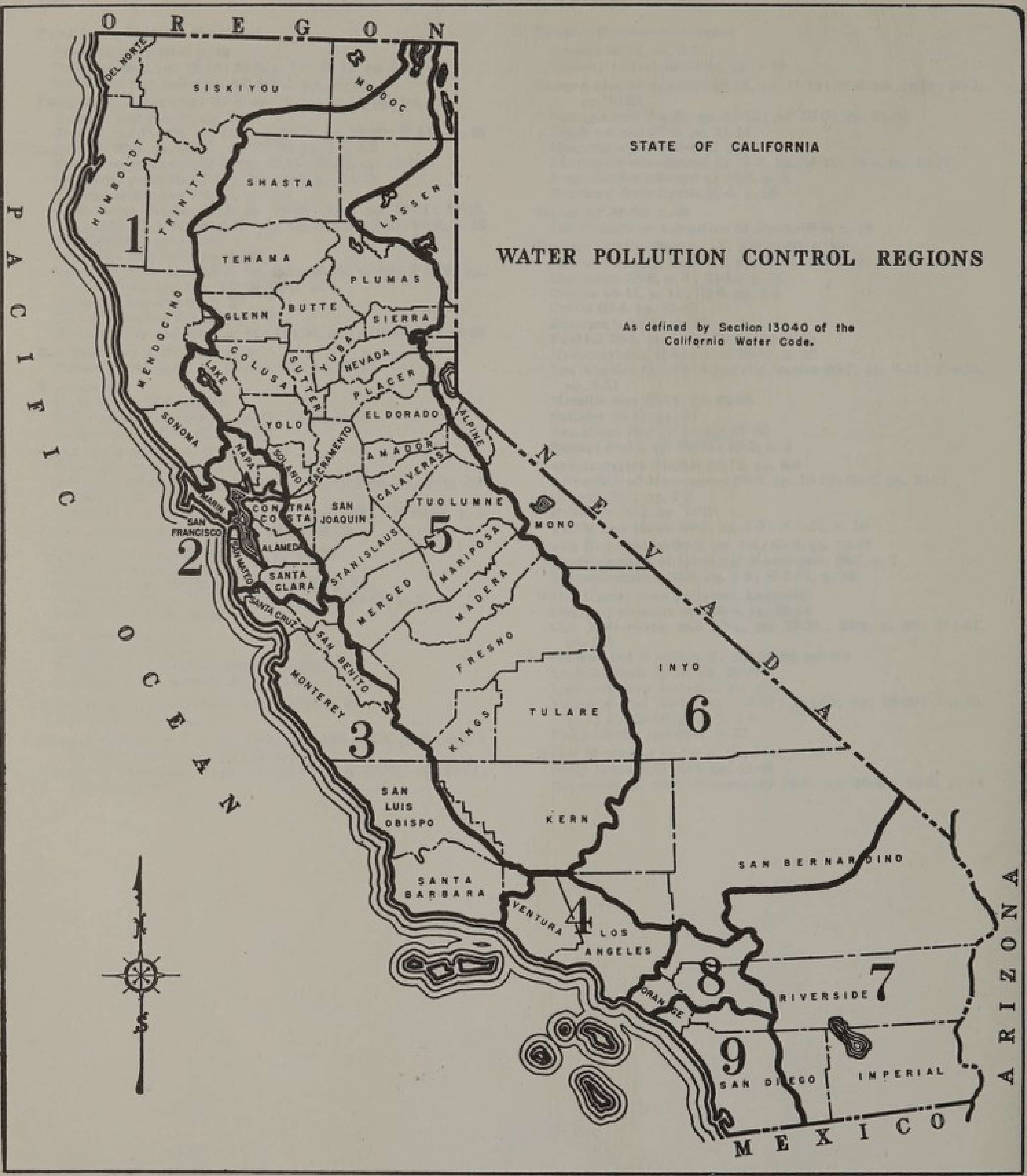

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