# Marine Algae of California

*Isabella A. Abbott and George J. Hollenberg*

With contributions by six specialists and a history of West Coast algal study by George F. Papenfuss

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and George J. Hollenberg

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Dedicated in Admiration and Affection
to
GILBERT MORGAN SMITH (1885–1959)
and
ELMER YALE DAWSON (1918–1966)

# Preface

THE MARINE ALGAE of North America's Pacific shores, though forming a distinct and complex flora, have never been comprehensively studied as a geographic unit or treated in a single volume. Excellent monographs on particular groups do exist, such as Setchell and Gardner's *Chlorophyceae* (1920b) and *Melanophyceae* (1925). And there are a number of good though geographically limited studies, such as Scagel's *Marine Algae of British Columbia and Northern Washington* (1966), Doty's *Marine Algae of Oregon* (1947), Smith's *Marine Algae of the Monterey Peninsula, California* (1944; with *Supplement*, 1969), and Dawson's series *Marine Red Algae of Pacific Mexico*. Of these, Smith's work has been the most widely used, partly because of its superb descriptions and luxuriant illustration, but chiefly because the species it covers range beyond the Peninsula itself to Alaska and Mexico; Dr. Smith himself, however, scrupulously limited his actual descriptions of species to Monterey Peninsula specimens.

What we have sought to do in this book, *Marine Algae of California*, is to extend the descriptions offered by Smith to embrace the variations shown by the species, as we understand them, throughout their California distribution. This treatment may be unsatisfactory for those working with small and perhaps little-changing populations, but it is not for these specialists that we have written. Rather, we have written for those who, like most of our students, have come from elsewhere to the Monterey Peninsula and have found on returning home that Smith's descriptions, *sine qua non* for the Monterey area, do not "fit" the specimens collected elsewhere. This book, then, is intended to replace Smith's study, but only in the sense that it describes the marine algae of the Monterey Peninsula and a good deal of the coastline beyond. It cannot be expected to replace the detailed specific descriptions given by Smith, for in treating the more varied populations of a much longer coastline, and half again the number of species, we have necessarily prepared descriptions that suffice for a species as a whole rather than for a few small or limited populations included within that species.

The book is thus intended to be used as a manual—a combined laboratory and field reference for identifying the marine algae of California. It

differs from its predecessors (Smith 1944; Hollenberg & Abbott 1966) in placing less emphasis on a previous knowledge of lower plants ("cryptogams"), a decision that should render the material a bit more accessible. It is evident that fewer college students are trained in the lower plants today, owing in part to the consolidation of botany departments into biology departments and in part to the need to forgo some of the more classically oriented courses in favor of molecular biology. Moreover, a good many zoologists, ecologists, environmental-impact analysts, sanitary engineers, and the like, all of them lacking the classical lower-plant training, are taking a professional interest in algae. And an increasing number of nonprofessionals are finding marine algae both attractive and useful: the plants are interesting and often beautiful, and many are valuable sources of food or industrial chemicals.

The late E. Yale Dawson, realizing this shift in emphasis, had asked the authors to join him in writing a book of the present scope, and a contract was signed in 1966. When Dr. Dawson died in a drowning accident, just three months later, the authors invited Dr. Paul C. Silva of the University of California, Berkeley, to join them. In time, Dr. Silva found other commitments too pressing and was unable to meet deadlines. His text assignments were accordingly shared by the authors or taken up by a number of colleagues, three of them specialists: Dr. Susan Loiseaux of France (the Myrionemataceae of the brown algae), Dr. H. William Johansen of Clark University, Massachusetts (the Corallinaceae of the red algae), and Dr. Elise Wollaston of Australia (*Antithamnion, Antithamnionella, Hollenbergia, Scagelia,* and *Platythamnion* of the red algae). Three other sections were written by former students: Dr. James N. Norris (*Blidingia* and *Enteromorpha* of the green algae), Dr. Nancy L. Nicholson (the Laminariales and Fucales of the brown algae), and Dr. Joan G. Stewart (the Gelidiaceae of the red algae). A very valuable contribution on the history of West Coast algal exploration and study has been added by Professor George F. Papenfuss of the University of California, Berkeley.

In 1970, Dr. Nicholson offered us a large and fascinating collection of intertidal and subtidal algae from the Channel Islands of southern California. Working this material into the descriptions and records, which had been drawn mainly from mainland material, took a good deal of time.

In late 1971, Dr. Peter Dixon was asked to read the entire manuscript for accuracy and consistency. This reading in itself prolonged the final writing, for it became necessary to determine once again whether the species of many of the older authors had been validly published. Many, especially those first appearing in the collections of dried algae known as the Phycotheca Boreali-Americana, or familiarly as the P.B.-A., were not. Each of these cases necessitated a search for a valid name. These searches prompted us, in fact, to decide that the nomenclatural information provided (the

data following the heading for a species name and author) would be kept to the minimum consonant with good taxonomic practice.

In the Smith, Hollenberg & Abbott (1969), which combines the 1944 first edition of Smith and the 1966 *Supplement*, there are 448 species. This new volume describes 669 species. The gain in number of species is due partly to our subsuming the previous California records of species not occurring on the Monterey Peninsula, and thus not treated in Smith; to new additions to the California marine flora in the form of species newly described since 1969; to a few geographical extensions (into the Monterey Peninsula) of species previously known only to the north or to the south; and to a few reassignments of former varietal epithets as species.

Space-saving was an important concern throughout this process, for we hoped to put into a book the size of the Smith (1944)—or at least not much larger than the Smith, Hollenberg & Abbott (1969)—roughly half again as many species. This meant writing each description as tightly as possible, emphasizing the more diagnostic characters. It also meant carefully controlling the content of the illustrations, to ensure that each drawing expresses not only the way the species appears in nature but also contains the characters mentioned in the description. Extending the coverage from the Monterey Peninsula to the entire California coastline abetted our efforts to condense, since a description that suffices for a great many populations necessarily entails more generality in individual characters than does a description based on one or a few highly homogeneous local populations.

We know that we have not included all species of large marine algae occurring in California: we ourselves have collected specimens of perhaps a dozen that are yet undescribed; and others, perhaps already described for other floras, we cannot identify with certainty because we lack fertile material. (Except for *Neoagardhiella baileyi*, in fact, we have not added any change of name made since 1972.) Even so, we believe that we have included at least 98 percent of the species that have been collected along California's long coastline prior to 1976. It will be clear to the reader that in this project we have depended heavily on the previous major studies of Pacific Coast algae, especially those of Setchell and Gardner, Smith, Dawson, and Scagel, as well as our own. Some descriptions (e.g. those for *Ceramium* species) are literally those of Dawson, generally because he had had more material than we upon which to base his descriptions.

In carrying through both condensation of detail and expansion of coverage, we have tried to retain some of the more valuable and successful features of the Smith (1944). Thus there is a greatly expanded Master Key to the Genera, which holds the use of specialized technical terms to a minimum and can easily be used by those with only a meager grounding in biology. The Literature Cited section has been rigorously assembled as a reference list for species only (more general references are discussed in

the Introduction). And we have continued Smith's strong emphasis on excellence in illustration. In our combined 28 years of teaching courses in marine algae at the Hopkins Marine Station, we have become very much aware that a great many people who have studied California algae have relied on Smith's own figures as the basis for taxonomic judgment.

Each of the 669 species described in this work is illustrated by one or more line drawings, as are all but a handful of the infraspecific taxa. In all, the book employs 891 separate drawings, reproduced at substantially larger scale than are those in the Smith. About half of these have been newly drawn for this book, but wherever possible we have made use of the superb original drawings from the Smith (1944), all of which are by Jeanne Russell Janish. A few of these, passed through many hands over the years, were lost and have been redrawn from new specimens. A few have since been shown to be inadequate representations of the species they were intended to illustrate and have been replaced. And of course, a number of California species and varieties do not occur near Monterey or have been described in the years following the original publication of Smith's work. For many of these last we have used drawings from the *Supplement* to the Smith (Hollenberg & Abbott 1966); for others, new drawings have been prepared; and in a few cases, drawings from other sources have been borrowed (as indicated in the legends) or copied (so signified by "after").

For all of the new drawings, we have tried to maintain the quality of illustration set by Mrs. Janish, and wherever possible we have prepared them using fresh material. In many cases a pencil drawing—typically a microscopic cross section—was prepared by one of the authors, then inked by an artist. This is indicated in the legends by combining the initials of the two: for example, "(DBP/H)" means that Dana Bean Pierce inked a drawing by George Hollenberg; "(SM/A)" means that Susan Manchester inked a drawing by Isabella Abbott. Mrs. Janish's initials are routinely combined with Smith's, since it cannot be determined, at this remove, where Dr. Smith initiated an illustration and where he did not—thus "(JRJ/S)," in all cases. Those whose illustrations appear in this book are the following:

| | | | |
|---|---|---|---|
| IA | Isabella Abbott | NLN | Nancy L. Nicholson |
| EYD | E. Yale Dawson | DBP | Dana Bean Pierce |
| LH | Lisa Haderlie | WAS | William A. Setchell |
| GJH | George J. Hollenberg | CS | Cathy Short |
| JRJ | Jeanne Russell Janish | JGS | Joan G. Stewart |
| HWJ | H. William Johansen | FT | Frances Thompson |
| SM | Susan Manchester | EW | Elise Wollaston |

No two people, no matter how persistent, could have written this book without the help of contributors and of other colleagues, friends, and students. We are grateful first of all to Peter S. Dixon for his time, effort, and

advice on all aspects of the book. Michael J. Wynne provided much useful advice on the brown algae. And we wish once again to thank those who have contributed text material: George F. Papenfuss, Elise Wollaston, H. William Johansen, Joan G. Stewart, Susan Loiseaux, James N. Norris, and Nancy L. Nicholson.

We express our appreciation for the continued loan of herbarium materials, so essential to the preparation of an extensive flora, to the keepers and curators of collections at many institutions: Agardh Herbarium, Lund University, Sweden (Dr. Ove Almborn); Muséum National d'Histoire Naturelle, Paris (Dr. Pierre Bourrelly); Farlow Herbarium, Harvard University (Dr. I. MacKenzie Lamb); New York Botanical Garden (Dr. Clark Rogerson); Smithsonian Institution (Dr. Arthur Dahl); University of British Columbia (Dr. Robert F. Scagel); University of Washington (Dr. Richard E. Norris); University of California, Berkeley (Dr. G. F. Papenfuss, Dr. Paul C. Silva); University of California, Santa Barbara (Dr. Michael Neushul); Allan Hancock Foundation, University of Southern California (Dr. Nancy L. Nicholson, Robert Setzer); University of Hawaii (Dr. Maxwell S. Doty); Hokkaido University (the late Prof. Yukio Yamada, Prof. Munenao Kurogi); and Tokyo University (Prof. H. Hara). We record our thanks, as well, to Dr. Richard S. Cowan of the Smithsonian Institution for allowing us to use the notes and illustrations of the late E. Yale Dawson.

We thank also Stanford University Press, for permitting us to use as many of the Smith illustrations as we needed; the University of Redlands, for some of the secretarial help; the secretaries at Hopkins Marine Station; and especially Faylla Chapman, at Hopkins, for much technical, secretarial, and editorial help. James Norris, Nancy Nicholson, Lester Hair, and Robert Setzer are among the numerous students who contributed specimens. Dr. Wheeler North contributed outstanding subtidal collections from throughout California.

The first-named author acknowledges with pleasure her indebtedness to the U.S. Office of Naval Research (Contract N-00014-67-A-0112) and the U.S.-Japan Cooperative Science Program (Grant GF-219). Their support provided most of the funds needed to illustrate this book, allowed the examination of related Japanese specimens in the herbarium and in the field, and sustained much curatorial assistance. We gratefully acknowledge also a gift from The David and Lucile Packard Foundation toward production costs of the book.

Five artists, among those mentioned earlier, spent many tedious hours during the past eight years in making the algae we have added to this volume come alive on paper. It has been an instructive and altogether pleasant experience working with Dana Bean Pierce, Frances Thompson, Cathy Short, Susan Manchester, and Lisa Haderlie.

In the 10 years that we have worked with him in the course of writing the *Supplement* (1966) and this volume, we have come to know William W. Carver, Executive Editor of Stanford University Press, as a friend, and we thank him for his cheerfulness and his patience. We must also thank Barbara E. Mnookin, Elizabeth Spurr, and James R. Trosper, of the Press, who contributed in many ways to the editorial task, and Albert P. Burkhardt, who designed this volume and prepared the maps for the Introduction.

Finally, to Naomi Hollenberg and Donald Abbott, we say in public, thank you for your patience and support while we devoted so much time to what proved to be both an intellectual challenge and a physical strain.

IAA GJH

# Contents

# Introduction

FOLLOWING THE precedent set by Smith (1944), this book treats only benthic (sea-floor) marine algae of multicellular structure and macroscopic size. Within these limits, we have tried to include all previously described species found along the California coast, with the exception of the blue-green algae (Cyanophyta). The taxonomy of the blue-greens is extraordinarily complex, and can be adequately dealt with only by specialists. There are few published accounts of California blue-greens; and in any case very few taxa in this division are marine. One might also question our omission of the unicellular greens; and Smith in point of fact did include a few taxa from this group (e.g. Volvocales). Smith, however, was perhaps the foremost specialist of his day in the freshwater algae, many of which are unicellular greens. In general, these microscopic greens, like the blue-greens, should be left to those trained in the elaborate electron-microscopy and culture techniques their study requires.*

## CLASSIFICATION, FORM, AND PHYSIOLOGY

Following a classification that has not been challenged in its major categories for more than 125 years, we recognize three phyla (sometimes called divisions by botanists) among the macroscopic marine algae: the green algae (Chlorophyta), the brown algae (Phaeophyta), and the red algae (Rhodophyta). As the names indicate, these groups were originally set off by their colors, which are apparent to the eye; the validity of these colors as a distinguishing characteristic has since been demonstrated by chemical means. In limiting our coverage (with one exception) to these three divisions, we have excluded several other algal divisions in the ocean whose total biomass and diversity (species numbers) surpass those of the macroscopic algae. These are the microscopic Bacillariophyta (diatoms) and

* See J. D. Pickett-Heaps. 1975. *Algae: Structure, reproduction and evolution in selected genera.* Sunderland, Mass.: Sinauer Assoc. 606 pp. Along the California coast, marine unicellular algae often coat granite rock in thin sheets or form darker patches in shady crevices. These have been collectively named GATGORE ("green algae that grow on rocks everywhere") by Stanford University undergraduates, who know that most may be identified if cultured but are extraordinarily difficult to study in field-collected material.

Pyrrophyta (dinoflagellates, including the luminescent *Noctiluca* and some "red-tide" organisms). Groups with smaller numbers of species (e.g. the euglenoid flagellates) also occur in the ocean. Some of the yellow-brown algae (Chrysophyta) are marine, but the group is far more numerous and diverse in freshwater (P. Bourrelly. 1968. *Les Algues d eau douce, algues jaunes et brunes*, Vol. 2. Paris: N. Boubée. 438 pp.). From this phylum, however, we have decided to include the single genus *Vaucheria*, a macroscopic alga (most other Chrysophyta are unicellular). In the form of thin patches on the substratum, *Vaucheria* occurs at many points in California; moreover, it is familiar to many students owing to years of laboratory use as a "representative" alga (though incorrectly considered one of the green algae for most of this time).

For Californian waters, our treatment of the algae embraces the following:

| Phylum | Classes | Orders | Families | Genera | Species |
|---|---|---|---|---|---|
| Yellow-browns (Chrysophyta) | 1 | 1 | 1 | 1 | 1 |
| Greens (Chlorophyta) | 2 | 6 | 10 | 27 | 72 |
| Browns (Phaeophyta) | 1 | 10 | 20 | 69 | 137 |
| Reds (Rhodophyta) | 2 | 7 | 35 | 186 | 459 |
| TOTAL | 6 | 24 | 66 | 283 | 669 |

The book also treats two subspecies (beyond one per species), 41 varieties (beyond one per species), and three formae (beyond one per species or variety), as well as nine entities of questionable status (these set off by quotation marks). All 669 species and all but 23 of the 55 infraspecific taxa (701 taxa in all) are illustrated.

All major groups of algae occur in both marine and freshwater habitats, though the browns and reds are predominantly marine. Certain orders of green algae are predominantly or entirely marine (Siphonocladales, Codiales), and some are wholly tropical (Caulerpales, Dasycladales). Among the brown algae the order Laminariales is of temperate seas, its members occurring almost entirely in water temperatures lower than 24°C.

As regards structure, the macroscopic algae may in general be expected to have a holdfast, a stipe, and a frond or blade. Most may be characterized in this fashion, but many will lack one or more of these structures, owing to morphological modification and adaptation. The three structures of a typical alga may appear to be equivalent to the root, stem, and leaf of a flowering plant. However, the resemblance is entirely superficial: algal tissues are not modified internally to assume the specialized structural and translocatory functions of the "higher plants," even those of the mosses (Bryophyta). The larger brown algae, or kelps (e.g. *Macrocystis*), some of which are taller than most trees, do not have the highly modified internal tissues of any tree, for they are supported by the water in which they live. The roots of a tree, to take another example, contain cells and tissues spe-

cialized for their purpose and quite unlike those in most other parts of the plant; by contrast, the rootlike holdfast of a large kelp, though modified on the external, macroscopic level, is composed of vegetative cells largely similar to those of the stipe or blade.

All macroscopic algae have plastids containing one or more chlorophylls (and usually other pigments). The paler epiphytic species sometimes show the remnants of plastids in thin sections prepared for the electron microscope, and this finding brings into question the parasitic or nonparasitic nature of the epiphyte. Moreover, one may encounter very small, colorless gall-like structures that contain no plastids and are now suspected of being fungal, bacterial, or viral infections: several of these continue to be accorded taxonomic status as algae.

It is generally known that the free-floating phytoplankton of the oceans fix carbon in respectable amounts through the photosynthetic process. Many benthic algae and sea grasses also fix large amounts, even though these plants are restricted to the relatively narrow continental shelves and shallower waters. *Macrocystis*, for example, can fix from 1 to 4.8 kg of carbon per square meter of plant surface each year (W. J. North, personal communication). Other species may display even higher productivities, offering abundant food and shelter for a variety of marine animals, and forming the base of an elaborate food web and an important part of the biogeochemical cycle.

The depth at which effective photosynthesis can take place is determined by a number of factors, of which temperature and penetration of light are the most important. On the California coast very few benthic algae are found below 40 meters. Some of the larger kelps (e.g. *Pelagophycus*) may be attached to the substratum near or below this limit; but these species have generally developed floatlike pneumatocysts that keep stipes and fronds much nearer the surface.

The high productivity and potential food value of many of the macroscopic algae have been recognized most notably by the Japanese, who depend heavily on seaweeds for food. Hundreds of metric tons of dried seaweed are imported by the United States each year; very little of it is used directly as food, though much is added to foodstuffs. Except for the giant kelp, *Macrocystis*, few native algae are used commercially in the United States. *Macrocystis* yields alginic acid, used for dozens of purposes as diverse as preparing dental molds, brewing, and making candy and fancy pastry. Industrial and sewage pollution have taken their toll of the kelp beds, apparently causing conditions incompatible with balanced growth and the maintenance of the species. The effort to restore and manage these kelp beds has been a valiant and at times disheartening struggle over the last 15 years (W. J. North, ed. 1971. Biology of the giant kelp beds. *Nova Hedwigia*, 32. 600 pp.). Regulated by the State of California, and leased for private exploitation, the kelp beds are worth several hundred thousand

dollars annually to the State, and many times that to the kelp harvesters. American investment in *Macrocystis* and other seaweeds totals many millions of dollars annually.

It is not feasible, of course, in a book like this, to furnish detailed information on all aspects of algal classification, morphology, cytology, and related topics. *Marine algae of California* is oriented toward the needs of the field and laboratory worker, and it is essentially a guide for the identification of the California algal taxa as we presently understand them. Obviously, there is more to phycology than this; and the interested reader will find much useful material on the biology and classification of marine algae in the following general works:

Chapman, V. J. 1970. *Seaweeds and their uses,* 2d ed. London: Methuen. Bot. Monogr. 10. 304 pp. A very readable account of the folk and industrial uses of seaweeds, covering both nutritional and economic value.

Dawson, E. Y. 1966. *Marine botany, an introduction.* New York: Holt, Rinehart & Winston. 371 pp. An extremely useful general book, requiring very little advance technical knowledge, and containing the best life-history diagrams given by the books listed here. It also reflects the good nature and interests of the late Dr. Dawson.

Fritsch, F. E. 1935, 1945. *The structure and reproduction of the algae.* 2 vols. Cambridge: Cambridge University Press. 791 and 939 pp. These two books summarize in great detail what was known of the morphology and reproduction of algae up to 1945. Cell development and structure are explained on the basis of an example in each taxonomic group, and differences or similarities in close relatives are discussed. The time and expense necessary to bring these volumes up to date would be prohibitive—and it is possible that no one person could do the job, inasmuch as knowledge of the algae has mushroomed in the interval that has passed.

Smith, G. M. 1955. *Cryptogamic botany* (2d ed.), Vol. 1. New York: McGraw-Hill. 546 pp. A generation of American phycologists, including most of the more established teachers of phycology, were brought up on this work. Like Fritsch, it is out of date not so much because the basic information is old, but because ultrastructural, physiological, and cytological discussions are completely lacking. Nonetheless, the data included are essential to an understanding of the place of algae in the plant kingdom.

Stewart, W. D. P., ed. 1974. *Algal physiology and biochemistry.* Berkeley, Calif.: Univ. Calif. Bot. Monogr. 10. 989 pp. Current information on the physiology of the algae is masterfully summarized in this volume. It should be read with current research papers on ultrastructure in hand.

*Proceedings of the I–VIII International Seaweed Symposia.* Published separately following each Symposium, at about five-year intervals. The last to appear was VII, edited by K. Nisizawa and published by the University of Tokyo Press in 1972. Offering a wide variety of papers, both classical and technological, these volumes are excellent places to learn in what direction some research is leading, and what some of the new approaches are.

Besides these general works, there are a number of useful monographs on the different algal groups, both for the Pacific coast and for other marine provinces:

Cupp, E. E. 1943. Marine plankton diatoms of the west coast of North America. *Bull. Scripps Inst. Oceanography*, 5. 238 pp. Although this volume treats chiefly the southern California diatoms, it is as useful in Monterey Bay, Puget Sound, or even Hawaii. Until a similarly useful volume is written to replace it, it will probably continue to be used internationally.

Dawson, E. Y. 1953–63. Marine red algae of Pacific Mexico. *Allan Hancock Pac. Exped.*, 17 (398 pp.) and 26 (208 pp.). *Pac. Naturalist*, 2: 1–126; 189–375. *Nova Hedwigia*, 5: 437–76; 6: 401–81. Baja California, Mexico, the region chiefly served by these publications, may be defined as "warm-temperate" or "subtropical." These publications will continue to be essential reading for southern California phycologists, since new records for the flora are likely to be made from the south rather than from the north.

Dixon, P. 1970. The Rhodophyta: Some aspects of their biology, II. *Ann. Rev. Oceanogr. & Marine Biol.*, 8: 307–52. A review of the contributions of recent research to our knowledge of the red algae, particularly in the areas of life history, morphology, and physiology.

———. 1973. *Biology of the Rhodophyta*. New York: Hafner. 285 pp. Most recent information on the red algae appears in scattered research papers, or is published in German or French. This short review of the biology of red algae is sufficiently detailed for the serious student.

Kylin, H. 1956. *Die Gattungen der Rhodophyceen*. Lund, Sweden: Gleerup. 673 pp. Well-illustrated and relatively expensive, this is the one book a serious student of the red algae must have. The genera are characterized and described; the structure and reproduction of orders and families are delimited; and distribution is given at the species level. Although more and more studies of the red algae are under way, much of this research simply fills in the chinks in Kylin's classification, rather than disturbing its overall arrangement.

Scagel, R. F. 1966. Marine algae of British Columbia and northern Washington, Part I: Chlorophyceae (green algae). *Nat. Mus. Canada Bull.*, 207. 257 pp. The thoroughgoing scholarship evident in the pages of this work makes it one of the most reliable handbooks for the Pacific coast. It accords the green algae, which tend to be overlooked in favor of the larger brown algae and the more attractive red algae, a firm place in the flora.

———. 1966. The Phaeophyceae in perspective. *Ann. Rev. Oceanogr. & Marine Biol.*, 4: 123–94. Although ten years old, this review of the brown algae is so well done that it will be used for years to come. It shows excellent balance and judgment in its selection and explanation of topics.

## THE CALIFORNIA COAST

As is well known, the California Current* brings cold water southward from the North Pacific; indeed, summer surface temperatures show a difference of only 5–10° C from north to south along the California coast. In the winter the northward-flowing Davidson Current hugs the coastline north of Point Conception, bringing from the south oceanic water with different temperature and salinity characteristics.† Upwelling, most intense

* The California Current is the eastward extremity of the Japanese Current, or Kuroshio. After warming southern Japan with tropical waters, the Kuroshio, flowing northward and mixing with the arctic Oyashio Current, turns east across the North Pacific, bringing cool waters to the California coast.

† The effect of this current on the phytoplankton community structure in Monterey

in late winter and spring, also occurs along the coast, and altogether a cool temperature prevails, accounting for a fairly uniform algal flora. The commonest species (perhaps 20 percent of those described for the flora) may be found all along the California coast, with more distinctive species or forms occurring in the northern or southern reaches,* on the outer coasts, or in protected bays, particularly where local wind and bottom configurations allow water temperatures to rise higher than those of the adjacent coast (Newport Bay is a good example). The more uniform subtidal temperatures at 20 m appear to encourage the development of a flora largely different from the intertidal flora.

The most dramatic temperature change along the coast, affecting plant but especially animal species composition, occurs at Point Conception, near Santa Barbara; here the California coast turns sharply eastward, and the California Current continues south and west. The effects are especially noticeable in the California Channel Islands: the northern islands support a fauna and flora similar to those of, for example, Pacific Grove; the southern islands, especially Santa Catalina, support a subtropical flora more closely allied to that of Baja California and the Pacific coast of Mexico. Many species of algae found in the southern islands, and occasionally at La Jolla as well, are the northern distribution records of essentially more southern species.

East and south of Point Conception, seawater temperatures usually remain above 18°C at the surface, whereas north of the point they are usually below 18°C. This difference is reflected both in kinds of algal species and in the diversity of their forms. Northward, the Laminariales are the most conspicuous brown algae; southward, it is the Fucales that are common. Northward, the large, fleshy, often foliose red algae, such as *Iridaea*, are common; southward, the shores are dominated by shorter and more densely branched species, such as *Laurencia* and *Pterocladia*. In the north there is frequently a greater biomass comprising fewer species per square meter (lower diversity); in the south it is usual to find a lesser biomass but more species (higher diversity).†

Throughout California each year, tons of shifting sand move onshore from deep water, offshore from the intertidal, or laterally along the beaches, uncovering rocks not previously seen or covering over rocks with existing

Bay is especially noteworthy. See R. L. Bolin and D. P. Abbott. 1962. Studies on the marine climate and phytoplankton of the central coastal area of California, 1954–60. *Calif. Coop. Oceanic Fish. Invest. Bull.*, 9: 23–45.

* I. A. Abbott and W. J. North. 1972. Temperature influences on floral composition in California coastal waters. *Proc. VII International Seaweed Symposium*, pp. 72–79.

† M. M. Littler and S. N. Murray. 1974. The primary productivity of marine macrophytes from a rocky intertidal community. *Marine Biol.*, 27: 131–35, presenting the first report on primary productivity for algae in southern California, showed a clear relationship between effective productivity and structure. In general, the sheetlike or finely branched species were found to have greater production rates.