A CONSERVATION FOUNDATION STUDY

LIVING RESOURCES of the SEA

Opportunities for Research and Expansion

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Foreword

This book concerning life within the oceans is of extraordinary value and interest. It deals with a subject that is of importance to people throughout the world, summarizing in a manner not heretofore accomplished our present knowledge concerning the living resources of the sea.

In a major respect the book is unusual, if not unique. So often writings on any given subject represent compendia of accumulated knowledge and that is the end of them. The striking characteristic of this book is that its author, with restless purpose, seeks to demonstrate not so much what is known as what is *not known.* While this book is replete with existing information concerning marine resources, its great significance lies in the fact that it so vividly emphasizes what still remains to be learned about the life that lies within the most extensive element of our earth.

The author is under no illusion that these areas of ignorance can be easily dispelled. He recognizes, as we all must, that the dramatic advances that have occurred in the physical sciences are due in large part to the fact that the phenomena that physicists work with are regular in their properties and act predictably under given circumstances, whereas, as the author expresses it, "the principles that underlie the behavior, the abundance, the very existence of wild plants and animals, particularly those that live out of sight in the depths of the sea, are exceedingly elusive—much more difficult to discover than laws of matter and energy."

It is not as if the conquest of ignorance concerning marine life is desirable merely for some theoretical reason. Mankind has compelling need for the immeasurable quantities of self-generating resources that could be drawn from the oceans if there were sufficient knowledge and skills at our command. It is an undeniable fact that at the present time the production of organic resources from land cultivation is not meeting the basic food requirements of today's world population in an adequate manner. This expresses the situation even too temperately, for the truth is that the majority of the world's people suffer undernourishment in varying degrees of intensity. Today the world population is increasing by more than 100,000 each day or more than 40,000,000 annually. The urgent and essential value of this book, therefore, is its contribution to thought and action so that the pressing needs of human beings can be better satisfied.

It is evident that there is a marked shortage of well-trained researchers in marine biology. With today's competition for scientists of ability, this field is not attracting its due share of talent. Further, fundamental research in marine biology must be coupled with research in the social and behavioral sciences if the sea is to become a more abundant source of food and other resources and if its products are to be widely used. The author clearly recognizes that fundamental research is expensive and demands prolonged dedication on the part of the worker. However, it is this type of research that especially calls for greater talent as well as funds, because applied research, geared to produce short-run economic returns, can more readily attract financial support. Yet such applied research can never resolve the fundamental problems that are involved.

The qualifications of Lionel Walford as the author of this study are exceptional. He is not only eminent in his field of science but at the same time is sensitive to conditions affecting human welfare. He is enriched by his contacts throughout the world, both with the scientific fraternity and with people engaged in the practical aspects of developing marine resources. He happens to have a warm interest in the problems of less developed areas and is realistic enough to be aware that the people of these countries have to resolve social as well as technical questions before increased marine resources become available to them. He rightly maintains that fundamental knowledge will best be advanced in countries that can command trained personnel and afford costly equipment. Yet he envisages that the new knowledge to be derived can, in turn, be put to use in underdeveloped countries.

The imagination of the world is presently captivated by explorations into interplanetary space, accomplished through the expenditure of huge sums of money and the exercise of remarkable talents. Yet at our doorstep, so to speak, are the great oceans containing riches that may be put to man's use but of which we still know so little. Even though there may be no cessation of man's dramatic quests into the outer universe, is it not of first importance to discover ways of supplementing the essential requirements of humanity on the only planet which promises any guarantee of continuing existence? May this book, then, prove of far-reaching influence in pointing the way to a great and immediate task.

Fairfield Osborn
President
The Conservation Foundation

Preface

The sea is a wilderness. Threadbare though that phrase may have become in poetic literature, it still expresses an overwhelming fact. The sea is a mysterious wilderness, full of secrets. It is inhabited only by wild animals and, with the exception of a few special situations, is uncultivated. Most of what we know about it we have had to learn indirectly with mechanical contrivances designed to probe, feel, sample, fish.

This study was undertaken to determine how the harvest of sea fisheries could be substantially increased for the benefit of humanity. Human food needs are world-wide, and so therefore is the scope of this study. Emphasis, however, has been placed on the problems of those regions where population pressures and food needs are most critical.

What I have written is addressed, in effect, to everyone who is interested in the rich possibilities of the marine wilderness and is concerned with using the planet intelligently. Specifically, I hope it will prove both helpful and stimulating to fishery scientists and students who are preparing for careers concerned with fisheries; to government administrators of marine fishery agencies; to commercial fishermen, brokers, and processors; and perhaps most of all to those who direct philanthropic organizations and seek ways to disburse grants for furthering human welfare.

Although we have conquered the land as we have conquered our ignorance about it, the problem of conquering the sea is much more formidable and complex. The sea cannot be cleared or plowed, sown or fertilized, or set apart for the exclusive use of the desired animals and plants. The open sea will probably always be essentially a wild place, and we who concern ourselves with it had best accept that fact. But as we become more intimate with the world of the sea, and with the natural laws governing its inhabitants, we can develop a science of exploiting its resources and to that extent the sea need not remain a complete wilderness. One hopeful point of attack is the inshore environment which borders many coasts. Now largely wasted, these could be cultivated economically and made to yield wondrously rich returns.

The chapters which follow focus more on what is not known than on what is known. They concern themselves with gaps, with relatively neglected subjects, and draw attention to important problems which must be solved before sea fishing can reach a level of technical competence commensurate with agricultural science. We must accept the fact that our philosophies and technologies cannot be radically changed in a hurry. It will take many years to amass the knowledge, to learn to apply it, and to persuade people to apply it. Therefore, this study is attentive as much to the foreseeable problems of generations hence as it is to those of today.

The material rewards of the special effort which all this research would require cannot honestly be foretold. The rewards in knowledge, however, could not be anything but rich, so little is our present store, and at the very least that would be its own reward.

This study was sponsored by the Conservation Foundation, and its President, Fairfield Osborn, showed monumental patience with the slow tempo of its progress. So did Lucille, my wife. Information, advice, and criticism have been sought from many people in America and abroad, and their response has been generous indeed. To all I am most grateful. Among those who have been especially helpful are Robert Snider and Peter Stern of the Conservation Foundation; John Lyman and the Hydrographer, U.S. Navy Hydrographic Office; Albert Tester, Paul Thompson, Paul Galtsoff, Raymond Gilmore, Herbert Graham, Clyde Taylor, Charles Butler, Norman Wilimovsky, John Clark, Reynold Fredin, Robert Rucker, and George Rounsefell of the United States Fish and Wildlife Service; Alfred Redfield of the Woods Hole Oceanographic Institution; Roger Revelle of Scripps Institution of Oceanography; Richard Fleming, Erling Ordal, and James E. Lynch of the University of Washington; Henry Bigelow, Elizabeth Deichmann, William H. Weston, and William Schevill of Harvard University; George S. Meyers of Stanford University; Michael Graham, D. H. Cushing, and John Corlett of the Fisheries Laboratory at Lowestoft, England; L. H. N. Cooper of the Marine Biological Laboratory at Plymouth, England; Harold Barnes, of the Marine Station, Millport, Scotland; Neville Woodward of the Institute of Seaweed Research, Midlothian, Scotland; Cyril Lucas of the Marine Laboratory, Aberdeen, Scotland; N. B. Marshall of the British Museum; Georg Wüst of the Institut für Meereskunde, Kiel, Germany; H. Friedrich, Director of the Institut für Meeresforschung, Bremen, Germany; A. Büchmann

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These good friends must not be saddled with any responsibility for the conclusions, which are wholly my own. Nor do the conclusions represent official policy in any way.

I am indebted to the American Geographical Society and to the Twentieth Century Fund for permission to use and adapt a number of maps that appeared in publications sponsored by these two organizations. The map projection I have used is the creation of William A. Briesemeister of the American Geographical Society, who also prepared the outline of the continental shelf for a map in this volume. The remainder of the graphic work was done by Gale Pasley of the Woods Hole Oceanographic Institution.

Lionel A. Walford

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THE MARINE WILDERNESS

1

The Problem

Some time ago, The Conservation Foundation, an organization devoted to the proper use of natural resources for the welfare of mankind, asked me to explore the following question:

What scientific researches, apart from those which are in progress, would contribute significantly toward learning how to enlarge the yield of food from the sea in answer to human needs?

Back of this question are these assumptions: (1) We have not yet learned how to exploit the food resources of the sea fully; (2) scientific research will show the way; (3) there are gaps in present research programs which need filling. What are those gaps? This chapter begins by discussing the world food problem. Populations in various parts of the world are suffering from ills caused by protein deficiency. Much more protein food of animal origin is needed than is now being produced, and still more will be needed in the future. The sea evidently does have untapped food resources, but we do not know how extensive they are, nor how to exploit some of them; nor have we explored fully all of their possible uses. This ignorance limits exploitation of the sea's food resources but so also do factors in the fields of economics and sociology.

A great deal of research about the sea and its resources is going on in many parts of the world. Most of this is conducted by governments, and for the most part it is concerned with established fisheries and is aimed directly at practical application. Applied sea fishery research is given considerable attention. It is in the realm of pure or fundamental research that the most important gaps occur and where augmented support is most needed. This book will explore those gaps.

People living today know more about the conditions of their fellow men than was possible in any previous generation. Those who cannot read may study the photographs in the picture magazines and newspapers that now find their way into the remotest places, or they may hear about life in other countries as broadcast by radio, or even behold it on the cinema or television screen, for these things have spread everywhere. The most important agent for bringing men together has been the airplane. Twenty years ago a trip abroad would have been a great undertaking, even an impossibility, for many of us who now can almost casually visit the middle of Africa or India and be back home in a week. We put down on an airstrip near a village that a short while ago may hardly have known that such people as we or such a life as ours existed. Now they know. And we in turn know about them. We know of the wretched lives that other men must endure, and they must suspect from the glimpses they have had that such a life may not be necessary. This was probably the most significant consequence of the last war, when soldiers of many countries traveled all about the world—plain, simple men who might have thought themselves poor in their private lives, but who found themselves supremely wealthy with their lavish supplies of chocolate sweets and tins of beef. How can the well-fed ever be complacent again? How can the starved ones possibly accept their lot?

Among the questions that emerged from the war, one aroused the most widespread interest and seemed the most baffling. Is it necessary that the majority of people in the world—the *majority*—should never have enough to eat?

This problem has troubled political scientists and economists for a long time but never before has it been the subject of such a "movement" as is now underway. Since World War II the Food and Agriculture Organization of the United Nations has been born and has spread its work widely. An impressive body of literature has appeared to document the present situation, which can be described simply thus: Human populations are growing tremendously; in some regions they have far outstripped their food supply. Starvation—food deficiency of one kind or another—is widespread throughout the world. No country is quite free of it, not even the United States, and in some countries it is a chronic public ill. It is a problem that cannot be solved simply by shipping excess supplies from the richer to the poorer regions. There is not enough excess for that, and if there were there would not be the means to pay for it. In what ways, then, can needy peoples magnify their food supplies by their own efforts?

This is one of the most perplexing problems of our time. It occupies the attention of authorities in many different fields, and they reach conclusions which are often conflicting. Their disagreement is a measure of the difficulty of the problem and a sign that they have not yet found a solution. Indeed, perhaps none can be found. Some authorities conclude, after weighing all possible means of increasing food production, that the situation is hopeless. Only wholesale birth control can solve the problem, and the barriers to that seem insuperable. Other authorities feel more optimistic. Technological improvement in the use of our planet, they say, can add enormously to food production. This, coupled with the fact that birth rate levels off as standards of living improve, should eventually bring food supply and populations into a more satisfactory balance than they are at present.

This opinion is bolstered by the fact that agriculturists are improving the use of the land, and they are working constantly by many different lines of research to improve it still further. For example, by selective breeding they develop strains of plants and animals that have desirable qualities such as disease resistance and fast growth; by the scientific blending of feeds they reduce the cost of raising cattle and poultry; by the proper use of fertilizers they increase the productivity of soils. They have made spectacular progress in developing poisons for destroying insect pests.

Yet even with the benefits of agricultural science, production is still not enough to satisfy world needs. Some other source of very large quantities of food, especially of animal protein food, must be found. Where? Many food economists have pointed to the sea as the most likely place. This idea seems logical. The sea occupies 71 per cent of the earth's surface. Not only is it broad (139 million square miles) but it is deep (about 2⅓ miles on the average). Anyone who has looked through a well-illustrated natural history book knows that the sea is filled with wondrously rich fauna and flora composed of galaxies of strange forms. Drifting at the surface or in layers at intermediate depths are vast meadows of minute plants and swarms of small and large animals grazing upon them and preying upon each other. On the bottom are fields of all kinds of sedentary creatures feeding on the rain of disintegrating plant and animal bodies that falls from above. Chemists have analyzed enough of these strange organisms to know that many of them have about the same food values as fishes, shrimps, oysters, and clams.

The species of animals and plants in the sea number hundreds of thousands. There are 20,000 species of fishes alone. People who earn their living from the sea fisheries know they use only a part of what they catch or could catch. North Atlantic fishermen who seek haddock or cod throw away vast amounts of other species. Argentine fishermen are well aware of shoals of pilchard off the coast of Patagonia, but have developed no important fishery for them. Many similar examples come to mind—hake off the west coast of North America, cod in the Bering Sea, tunas and herring off West Africa, sardines in the Indian Ocean, and many kinds of invertebrates in all seas. These are all rich in nutrients. They seem to be abundant. They are not queer-looking monstrosities but commonplace kinds of animals that are easily recognized as edible. Many of them occur close to areas where people are suffering from protein starvation. Fishermen also take enough specimens of odd things to know there is much which their nets and hooks miss, which might have value if caught in sufficient quantities.

We know from experience that certain parts of the sea are extremely fertile. Some regions which are heavily fished yield large quantities of food. Such are the fishing grounds of the North Atlantic and North Pacific Oceans, where 19 million tons are produced annually, or about 78 per cent of the world's total. These are not the only rich grounds. There are other regions which might yield comparable quantities if they were fished as intensively. Some of these have hardly been touched. Thus untapped food resources do exist in the sea; there are regions and species which are not fished to capacity, and others which are not fished at all.

Since there is a human need and since there are supplies, why not use them? There may not be enough to satisfy all the protein requirements, but what there is ought to go a long way. Why not open up this untapped world of the sea and use those of its resources which we now neglect? What stops us?

A complex of obstacles stops us. It appears that the ocean is being exploited about as much as economic and social conditions and technological knowledge will permit. As many men engage in marine industries as are willing to. Fishermen use methods they know will work and catch as many pounds as they can sell at prices which will induce them to persist in so dangerous and uncomfortable an occupation as fishing. They take all the kinds of marine animals and plants that their markets will accept. They preserve their catches as well as they know how, but only as much as will keep for foreseeable uses. They ship as much into the interior regions of their countries as transportation facilities and economic conditions permit. As many people as have money to buy fishery products do so as often as they want them in preference to something else. As many men now invest as much capital in marine industries as they will risk against the uncertain supply of raw materials and the heavy operating costs involved in working with marine environments.

These general principles apply everywhere but in differing ways. Moreover, we must reckon with many sorts of geographic variations. The fertility of the sea varies over a wide range. The distances between rich areas and good port facilities and good markets vary. The length of the period during which weather is favorable enough for work at sea varies. The capacity of the fishery resources to withstand intense exploitation varies. The conditions of men who have access to the sea—their culture, economy, politics, physical well-being, education, enterprise, wealth—vary. The tastes of people vary from one place to another, as well as willingness to try unfamiliar foods.

Thus, to meet human food needs by increasing exploitation of the sea requires attacking all sorts of problems in a number of different fields—in economics, sociology, anthropology, education, as well as biology, oceanography, and technology.

If the human problems can be solved—and they are being attacked by such organizations as F.A.O.—a large amount of sea food will be needed. Merely to keep the present per capita consumption in step with the growing population will necessitate increasing production of sea food over the next fifty years by about 8.5 million tons. To include the entire population of the world (i.e., the proportion which is now starving), the increase during that period would have to be something of the order of 50 million tons.

Such an amount cannot come simply by expanding present fisheries. Species of vertebrates and invertebrates which are now neglected would have to be utilized, new fishing grounds exploited, new methods of fishing invented, and perhaps a new philosophy of exploiting the sea would have to be developed. At this point we do not know how to accomplish all of these things. We do not know all the species of sea animals or all their possible uses. We do not know all the fishing grounds or how to reach or catch certain species which we believe to be abundant. We have measures of abundance for only a few of the more intensively exploited species and for none of the unexploited ones. Thus a wall of ignorance about the sea fishery resources would impede our exploiting them, quite apart from the human problems.

In judging possible yields to be derived from the sea, people often assert that fishery is analogous to agriculture. There is an important difference, however. An agriculturist manipulates the environment. He fertilizes, tills, weeds, eliminates animal pests, and fights diseases. He selects particular species for cultivation and within those species particular strains which have desirable qualities. A farmer can do all that; a fisherman cannot. A fisherman generally uses the marine environments only as hunting grounds, accepting conditions as he finds them. Sea farming is practiced in a few places, but for the most part it is primitive compared with land farming. There is no marine environment of which we have much more than rudimentary knowledge about the properties which are essential to sea life. We know nothing about the genetics of any marine species and therefore cannot engage in selective breeding. We know next to nothing about the diseases of marine organisms. Save in a few special cases, we do not know how to rear marine animals on a commercial scale. No one has yet learned fundamental causes of fluctuations in abundance and occurrence of marine organisms. A few transitory correlations have been found, but no causes. There is the problem. We are too ignorant of the sea and its resources to know how to intervene to the degree possible in farming. We cannot do what agriculturists do; we cannot manipulate the environment. Nor will we until we have acquired a great deal more knowledge than we now have.

This is not to say that the sea and its food resources are neglected subjects of study. Actually, more effort is going into fishery and oceanographic research than ever before. Many governmental and international agencies are working diligently all over the world to stimulate new industries, particularly fisheries, and to determine the most profitable rates of exploitation. They carry on all sorts of activities—biological, oceanographic, and technological studies, governmental regulation for conservation, exploratory fishing, technical assistance to necessitous countries, advertising and educational campaigns, and so forth. In reading the journals about fisheries no one can fail to be greatly impressed by the multiplicity of activities directed toward improvement of fishing industries and toward the full, rational use of the sea's food resources.

In general, these programs are directed toward practical goals. Altogether, people engaged in them are coping with a tremendous job. The phrase "vast ocean" gives no inkling of how vast it really is. Exploration of only a small area of the sea requires more money for operating ships than is ever available for the purpose. The task of inducing an underdeveloped country to fish and eat fish takes more trained personnel than existing organizations can ever spare. The problems of increasing the use of ocean resources far exceed the means of attacking them. Fishery research-and-development programs are concentrated in only a few areas, so that very great stretches of fertile sea remain almost completely unexplored, and many underdeveloped places are without fishery aid programs. Present effort might be added to or multiplied and still leave large geographic gaps. One simple way to attack our problem would be to fill in some of those gaps by starting new programs in regions that are now neglected, and by contributing to existing programs that are now inadequately supported. However, that would be to ignore gaps of another sort.

Most of the questions which existing programs pursue are tied closely to the known, and researchers are obligated to practical application. For example: How are known kinds of fishes distributed in unexplored regions? How can fishing by known methods be expanded? How can known techniques of fishing and technologies of handling fishery products be improved? How can they be adapted to local conditions? How can rates of fishing the known exploited resources be controlled to produce optimal yields? How do the abundance and availability of fishery organisms relate to known properties of the environment? How can people use or manipulate the *known* to their advantage?

By far the largest part of present marine biological research is concerned with questions of this sort and is conducted almost wholly under governmental direction. These are not the only questions that government fishery agencies study—governmental research deals with a great diversity of problems—but they are dominating questions. In general, the research conducted to answer them is limited in the extent to which it deepens or broadens our understanding of the marine environment, and it does not arouse the interest of scientists whose preference it is to carry on fundamental research.

Most of the financial and moral support goes for these purposes, to achieve ends which can be easily foreseen. On the other hand, negligible support goes for probing the unknown, for simply enlarging knowledge of the marine environments and the life which they contain, and for doing this without the obligation of showing an eventual application. It is in this kind of undirected research that principles of wide application are most likely to be discovered and from which the now undreamed-of treasures of knowledge are most likely to emerge. There is an evident gap which marine research institutions are neglecting. Scientists often call this kind of research "fundamental" or "basic," in contrast to "applied."

Fundamental research is the wellspring of a science. Nevertheless, it is difficult to define because it does not have clear-cut boundaries. And however it may be defined, it is often difficult to defend.

It is not, as some people imagine, aimless pottering. I doubt that a good scientist indulges in such a whimsy except for relaxation. Fundamental research is generally aimed toward the discovery of natural laws, that is, principles which underlie great processes. It is closely akin to a fine art. It grows at its own pace, depends heavily on logic, respects intuition, is rarely fruitful when pushed or nagged. It is the kind of work that a man is driven to do by inner necessity because he is passionately interested in the doing of it, without thought of an ultimate application.

The most highly developed sciences, chemistry and physics, are founded on systems of principles. These were discovered through fundamental research that was impelled only by a desire to understand mysteries of nature and carried on with no predetermination to produce a mechanical age. Yet not one of the marvels of today—automobile, diesel engine, airplane, radio, electric light, telephone, synthetic chemicals, or atomic force—would have been possible without prior knowledge in such fields as mechanics, light, heat, sound, electricity, and behavior of molecules, which had emerged from seemingly impractical studies in laboratories over the course of two centuries. These principles give chemists and physicists the necessary tools for thinking ahead, for predicting, and hence for inventing.

Presumably populations of living organisms in the sea also react predictably under given circumstances, but we have yet to resolve the multiple parts of the controlling circumstances. Of course the materials that physicists and chemists work with are superbly regular in their properties. Molecules respond to law with nice precision, always in the same way under given circumstances. Principles which underlie the behavior, the abundance, the very existence of wild plants and animals, particularly those that live out of sight in the depths of the sea, are exceedingly elusive, much more difficult to discover than laws of matter and energy. The most obvious lack in marine research programs is the pursuit of principles.

2

Geography

In this chapter we introduce and discuss a series of maps that were especially prepared to serve as visual reference material for the chapters that follow. These maps reveal the regions of the world in which the need for new sources of protein is greatest. They also reveal the extent of our ignorance about the resources of the sea off the coasts of many of the densely populated underdeveloped regions of the world.

We shall see in this study that although most of the marine part of the world, from polar seas to tropics—"the sea"—may look monotonously like nothing but water, it is actually composed of many kinds of environments. Like land environments, these range in fertility from desert to rich pasture. They range from salt marshes to open seas, from the surface water masses to great depths at the bottom, and on the bottom, from great sandy plains to rolling hills and rocky mountains. They vary in the amount and quality of the organisms which they contain. Not all of those organisms which might be useful can be reached, for the prevailing weather varies from one place to another; therefore, the amount of time that can be spent fishing varies. In any given area, the abundance and availability of fishery stocks vary, going through rhythmic seasonal changes, as well as sporadic fluctuations.

Variation affects every facet of our problem, not only those that relate to the seas but those that relate to human affairs as well. Human environments are as variable as those of the sea. Human populations also differ in many ways. Like fishes, they are unevenly distributed, being densely concentrated in a few areas that are particularly favorable to human life and sparse in other (and very large) areas that are unfavorable. There are many populations, with differing cultures and traditions and differing demographic properties. Birth rates and death rates vary widely from one population to another, and consequently, the age composition varies, as well as the rate of population growth and the prognosis for future courses.

The problems of producing enough food to support these growing populations differ according to the geography. There are large regions where masses of people have long suffered from chronic starvation. The extent, severity, and causes of this starvation vary. We are concerned with protein deficiency. This varies from one region to another. Therefore, the need of increasing the production of protein foods varies.

The means of increasing it also varies, for the wealth of nations is unevenly distributed. Economic systems and conditions differ; consequently the opportunity of the average man to improve his lot and the number of people in a position to invest money differ from one country to another. Some peoples strive ceaselessly to improve their living standard; others seem less interested in, or even passive toward, material advancement. This lack of ambition may be one symptom of starvation. It is hard to judge how much a prevailing lack of drive may be attributed to innate qualities, how much to malnutrition, and how much to choice.

One detail of human culture which bears most directly on sea fishery is love of the sea. Maritime peoples do not have this in equal degree. Those that have developed it most strongly are rich in ships and seafaring traditions. They are not afraid to go out beyond sight of land to fish on far distant banks or to trade with other countries. It is one thing to foster new sea fisheries in countries where there are already plenty of skilled shipbuilders, net-makers, marine engineers, sailors, and fishermen. It is quite another thing to attempt this in countries which are deficient in such labor forces and where there is no immediate enthusiasm to live on the sea. How to stimulate such enthusiasm is a problem in itself.

The degree of exploitation of marine resources varies over the world. In some regions, particularly in the North Atlantic and North Pacific oceans, where the oldest of the great sea fisheries are carried on, most of the usable fishery stocks are known and at least partly used. A few are overfished and could be made to yield larger returns only by scientifically controlling fishing rates. Obviously it is not there but in the underfished areas that efforts to increase production of sea foods might be intensified most effectively.

Laboratories for marine research tend to be more numerous in regions that are heavily fished than in those which are underfished. Thus the means of study and exploration, that is, the laboratories, research vessels, and scientists, are unevenly distributed over the world, and it is to be expected that knowledge about the seas and their resources should follow a similar pattern.

Whatever is done to encourage expansion in the use of the sea's resources to help satisfy human food needs, whether simple exploratory fishing or research in biology, oceanography, technology, or economics, it should be carried on where the needs are greatest, that is to say,

Where human populations are densest
Where protein starvation is most serious
Where poverty is most severe
Where the least is now known about the sea and its resources
Where fisheries are least advanced
Where the weather is favorable to fishing
Where the most countries could share in the benefits of the work

Thus we are dealing with a geographic problem. What are the regions that best meet all these criteria? The maps that follow provide some of the information needed for an answer. However, the correlation of the geographic factors remains a challenge for students of population and resources.

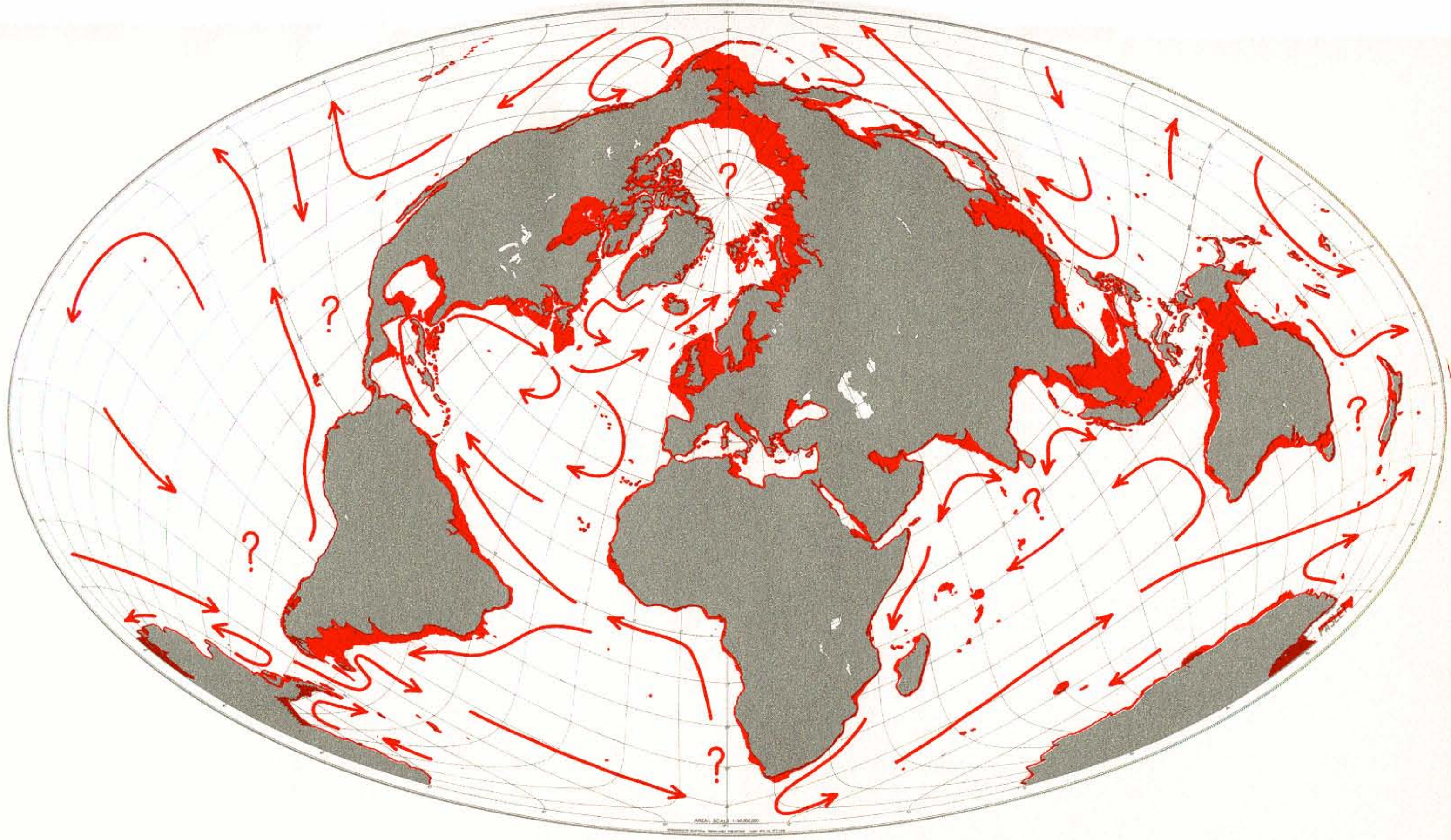

Fig. 1. The continental shelf and the principal ocean currents.

Discussion of Figure 2

Over 2,600 million people live in the world today. They are unevenly distributed, two thirds of them being concentrated within four regions, which together comprise only about one tenth of the land surface. The densest populations are in eastern Asia (China, Korea, Japan and Java), India, Europe, and the urban centers in northeastern United States.[1]

The distribution of people is influenced by combinations of many factors such as climate, soil fertility, physical relief, accessibility to the sea and to land routes of commerce, availability of raw materials, and the varying development of human institutions, culture and skills.

In any given area population growth is influenced by many factors, among them fluctuations in economic conditions, the practice of birth control, the incidence of calamities such as war, disease, and famine. Consequently it is impossible to predict with a very high degree of certainty the future of human populations. Nevertheless, demographers, studying assembled data in the light of indicated trends of population growth, agree that during the second half of the twentieth century, the number of people in the world will increase by some figure between 850 and 945 million. How this increase will be distributed (according to one estimate) is shown in the following table:

TABLE 2-1. POPULATION OF THE WORLD, BY CONTINENTS 1950–2000

(millions)

	1950	2000	Increase 1950—2000
World	2,400	3,250	850
North America	166	220	54
Middle and South America	162	280	118
Europe, excluding U.S.S.R.	396	440	44
U.S.S.R.	193	260	67
Asia, excluding U.S.S.R.	1,272	1,750	478
Africa	198	280	82
Oceania	13	20	7

SOURCE: W. S. Woytinsky and E. S. Woytinsky, *World Population and Production* (New York: The Twentieth Century Fund, 1953), p. 260.

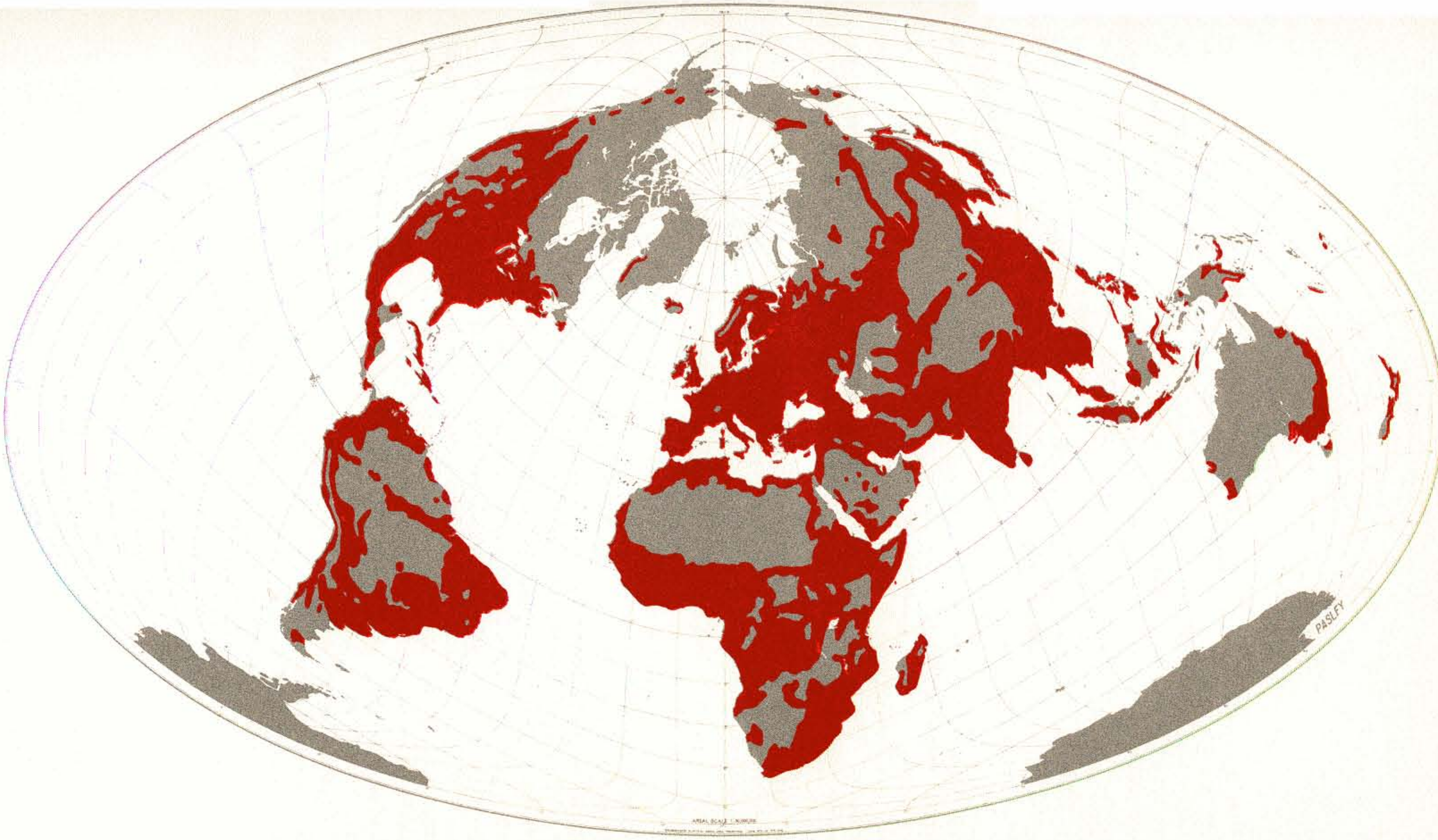

FIG. 2. Populated areas of the world. Courtesy American Geographical Society.

Discussion of Figure 3

In many areas of the world people suffer from partial starvation. They may get enough food to satisfy conscious feelings of hunger and yet not enough to satisfy their physiological needs. Growth and replacement of tissues in the human body depend on a diet containing carbohydrates, proteins, fats, minerals, and vitamins. If any one of these classes of nutrients is deficient for a long enough period, disease is the inevitable result. Because carbohydrates are cheap, filling, and a rich source of energy, those are the foods with which people in the poorer classes must usually fill themselves. In doing this they may appease the sensation of hunger, but they suffer in more obscure ways for want of other essential nutrients, and they die prematurely.

The most important of the other essential nutrients are proteins. These are derived from various sources, such as leguminous vegetables, cereals, milk, eggs, cheese, and the flesh of animals. Proteins differ in composition and consequently in their value for the synthesis of tissue. Proteins are complex nitrogenous compounds consisting of amino acids bound together by peptide linkage. The amino acid composition varies widely from one protein to another. Of the twenty-six or more known amino acids, the human body can synthesize all but ten. These ten, known as the "essential" amino acids, must be ingested in foods and must all be present in the body at the same time, in fairly specific proportions, if optimum tissue synthesis is to take place. The foods which contain the ten essential amino acids are called complete proteins, while those in which one or more of the amino acids is lacking are called incomplete. Proteins from animal sources, including fish, are complete, while those from vegetable sources, such as legumes and cereals, are incomplete.

It is possible to get the full complement of the essential amino acids in a suitable combination of protein-containing vegetables. However, to do this requires special knowledge which most people lack. It also requires an assortment of vegetables which is often not available in local markets. Proteins of animal origin, being complete, present no such problem. Unfortunately they are expensive. Indeed, in many parts of the world they are beyond reach of the great majority of people in anywhere near adequate amounts.

The results of amino acid deficiency are felt in several ways. One of the first, and perhaps the most widespread, is lethargy and reduced productivity. Reduced resistance to infectious diseases is frequent, and a number of pathological conditions, such as the syndrome called kwashiorkor, result from animal protein deficiency.

These illnesses impose a terrible drain on the economy of a country where they are prevalent. If they could be eliminated, an enormous improvement in productivity and living standards should result.

Figure 3 shows areas where diseases attributed to protein starvation are common.[2]

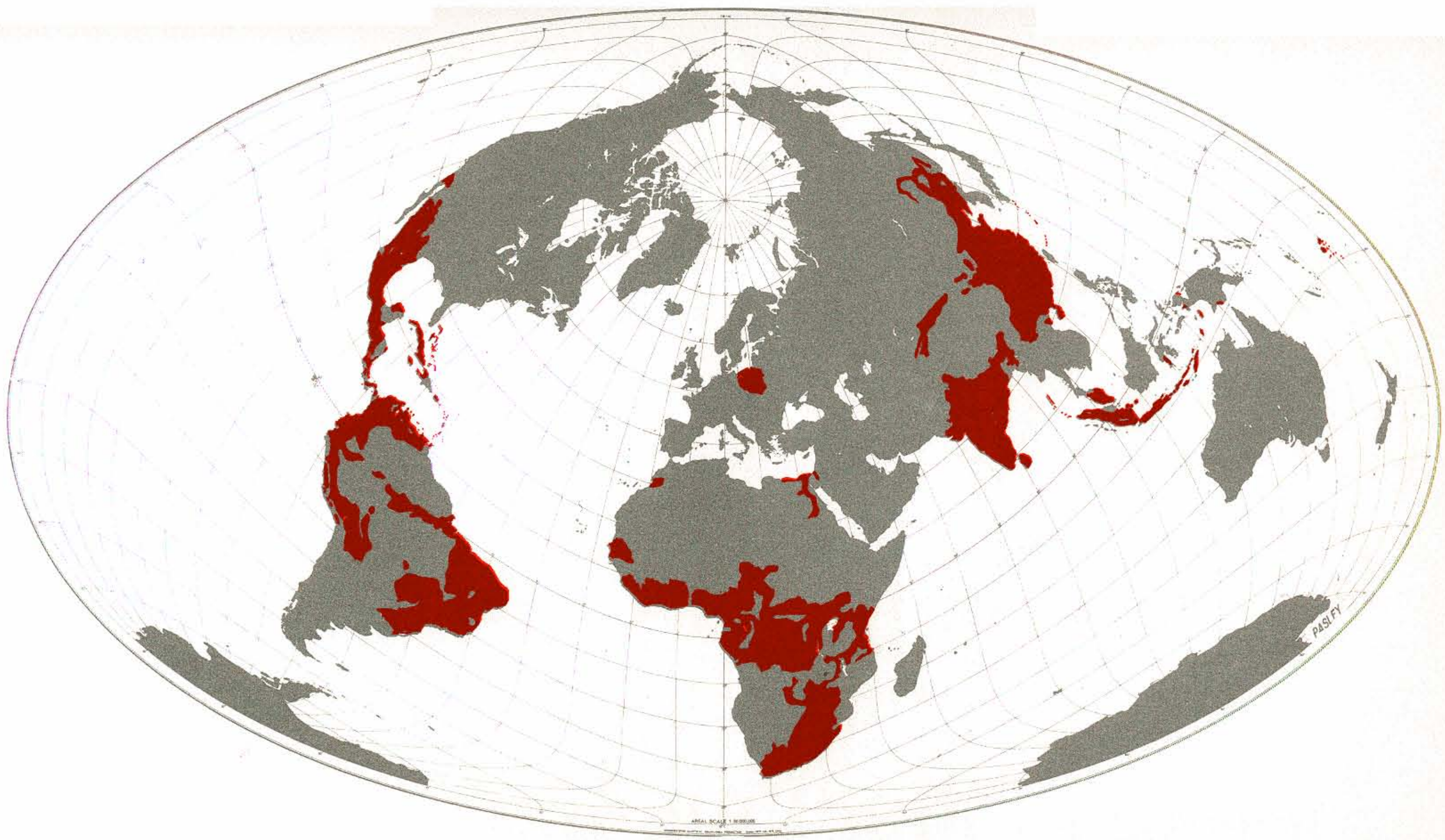

FIG. 3. Areas of protein starvation. Courtesy American Geographical Society.

Discussion of Figure 4

Figure 4 shows the distribution of the two types of economies.[3] In the regions shaded red, which include 74 per cent of the world's habitable area and 76 per cent of its people, a peasant agricultural economy predominates over all activities.[4] People grow crops, raise livestock, carry on primitive hunting and fishing, and engage in handcrafts primarily for home use. Only sometimes, after paying taxes and the profits owing to the landowner or boat owner, does a subsistence farmer or fisherman have left any surplus that he can sell on the local market. Although subsistence producers sometimes manage, on the whole, to satisfy their moderate needs, they are, as a class, among the poorest people in the world. In general, it is in these countries that effort to improve fishery industries is most needed, and it is in these countries that the most difficult obstacles to industrialization will be found.

In the stippled areas, the market-and-money economy prevails; that is, people produce food and goods primarily for sale or exchange. There is much variation from one area to another in the proportions of labor devoted to food-producing and non-food-producing occupations. In general, a relatively high proportion of the labor force in industrial production, commerce, and professional services indicates a country that is technologically advanced and rich.

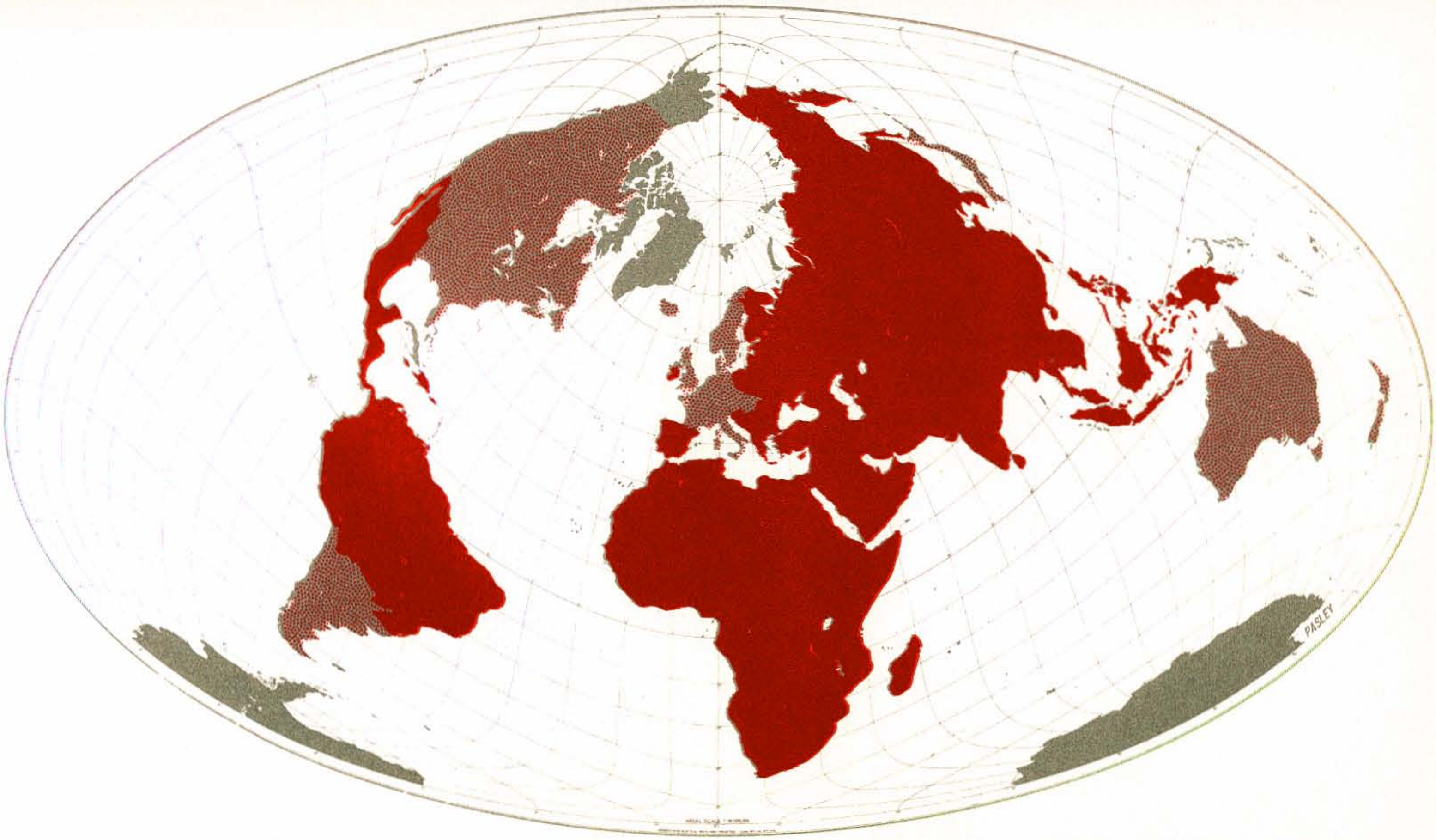

FIG. 4. Generalized types of economic activity: subsistence economy and money economy. Courtesy Twentieth Century Fund.

Discussion of Figure 5

High seas fisheries (as contrasted with shore fisheries) are most highly developed in countries where a seafaring tradition is strongest, and this in turn is reflected in the means of going to sea. In Figure 5 the per capita tonnage of merchant vessels which are 100 gross tons or more has been rated in five orders of magnitude as listed below.[5] Countries whose flag is used by foreign owners and whose per capita tonnage figures would otherwise be similar to those of their neighbors (i.e., Panama, Liberia, Honduras, Costa Rica) are unshaded.

1. Countries with over 0.5 gross ton per capita: Iceland, Norway.
2. Countries with 0.1 to 0.5 gross ton per capita: Denmark, Finland, Greece, Netherlands, New Zealand, Sweden, United Kingdom, U.S.A.
3. Countries with 0.02 to 0.1 gross ton per capita: Argentina, Australia, Belgium, Canada, Chile, France, Germany, Hong Kong, Israel, Italy, Japan, Portugal, Spain, Switzerland, Turkey, Uruguay, Venezuela.
4. Countries with 0.004 to 0.02 gross ton per capita: Brazil, Cuba, Dominican Republic, Ecuador, Egypt, Eire, Mexico, Nicaragua, Peru, Philippines, Poland, U.S.S.R., Union of South Africa, Yugoslavia.
5. Countries with less than 0.004 gross ton per capita: Albania, Bulgaria, Burma, Ceylon, China, Czechoslovakia, Egypt, Guatemala, Haiti, Hungary, India, Indonesia, Iran, Iraq, Korea, Lebanon, Morocco, Pakistan, Rumania, Salvador, Saudi Arabia, Sudan, Syria, Thailand.

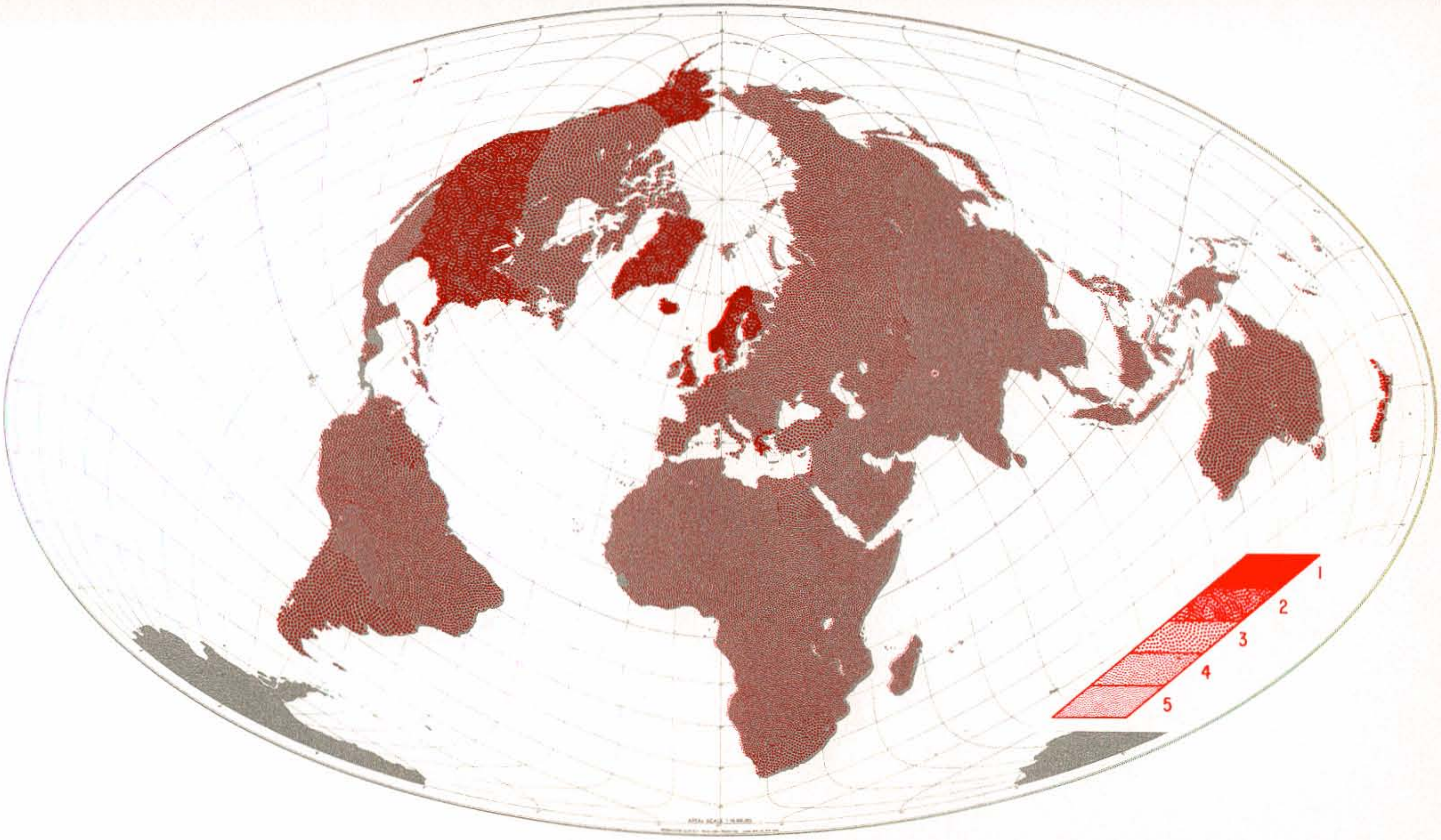

FIG. 5. Merchant shipping fleets of the world. Countries are shaded according to their relative tonnage of merchant shipping, on a descending scale from 1 to 5 (see text discussion).

Discussion of Figure 6

Areas readily accessible by railroads and highways are shown in Figure 6.[6] The distribution of fishery products from sea coasts to consumers living inland depends on fast mechanized transport. Some densely populated areas in Asia, Africa, the Caribbean, and Latin America still depend on animals and men for the transport of goods. Consequently, in these areas the kinds of fishery products that can be transported over long distances are generally restricted to those which will keep in hot weather without refrigeration, that is, dried, salted, or canned fish.

FIG. 6. Areas readily accessible by modern surface transport facilities. Courtesy Twentieth Century Fund.

Discussion of Figure 7

Knowledge about any part of the oceans must be more or less proportional to the number of observations made there. In Figure 7, areas have been shaded according to the number of occasions that research vessels have stopped to collect considerable oceanographic data (i.e., the number of "oceanographic stations occupied") per quadrangle of 5 degrees of latitude and longitude.[7] Probably the number of biological observations is more or less similarly distributed, since biological and physical oceanographic researches are often, if not usually, associated.

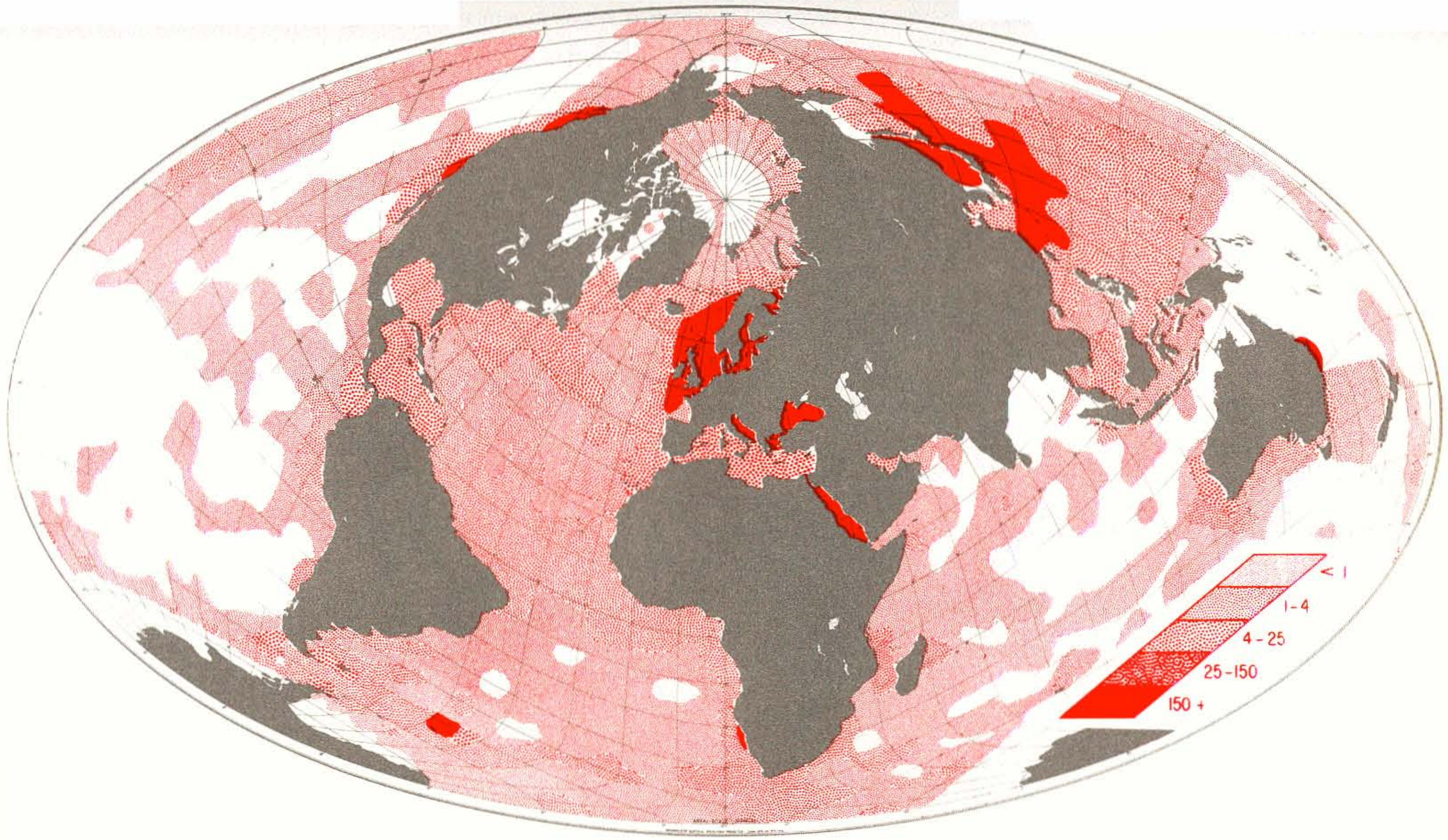

FIG. 7. Knowledge about the seas. Legend indicates the number of recorded occasions on which data were collected by oceanographic vessels, as plotted on quadrangles of five degrees of latitude and longitude.

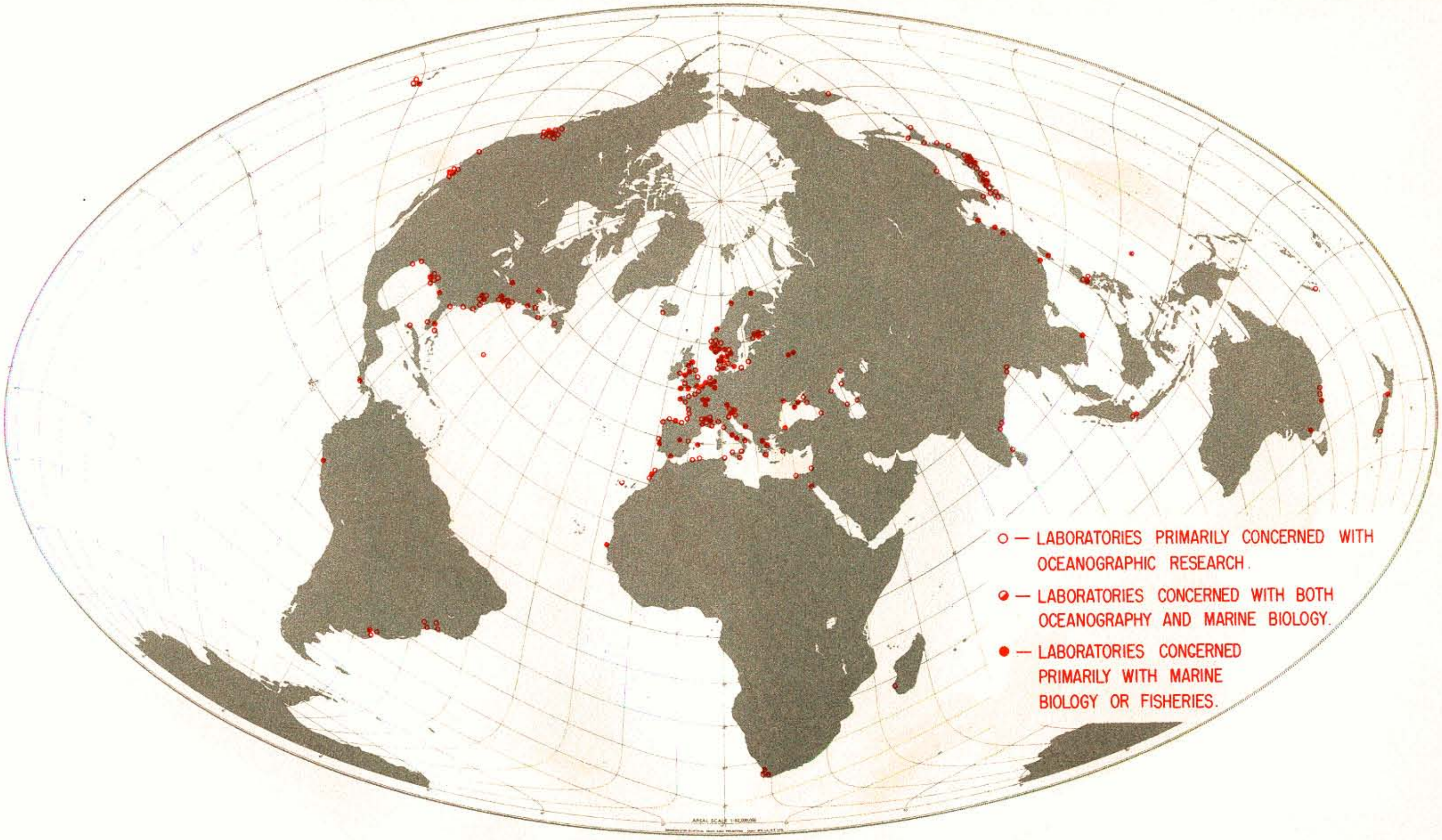

Fig. 8. Distribution of marine laboratories. (See p. 65 for a discussion of this map.)

Discussion of Figures 9-12

In judging where new fisheries might be developed, how much money to invest in an enterprise, and what kind of vessels and equipment would most likely be needed, it is necessary to consider the weather.

In Figures 9 through 12 the isopycnics (lines of equal quantity) represent the average percentage of time that weather would probably be favorable enough for vessels of 100 feet or more to fish during February, May, August, and November, respectively. For smaller vessels conditions would probably be less favorable than the figures indicated on these maps, especially in areas where the percentage frequency of favorable fishing is relatively low.

In drawing up these maps, oceanographers at the U.S. Navy Hydrographic Office assumed that fishing must be limited by sea ice, topside ship icing, high swell, and high winds. They made a statistical analysis of data on all of these factors to reach the indicated estimates. They disregarded ordinary precipitation and assumed that, under modern conditions, heavy fog or other visibility restrictions would not hamper fishing operations, and that the occurrence of very heavy sleet, hail, or snow would be very rare and therefore need not be taken into account.

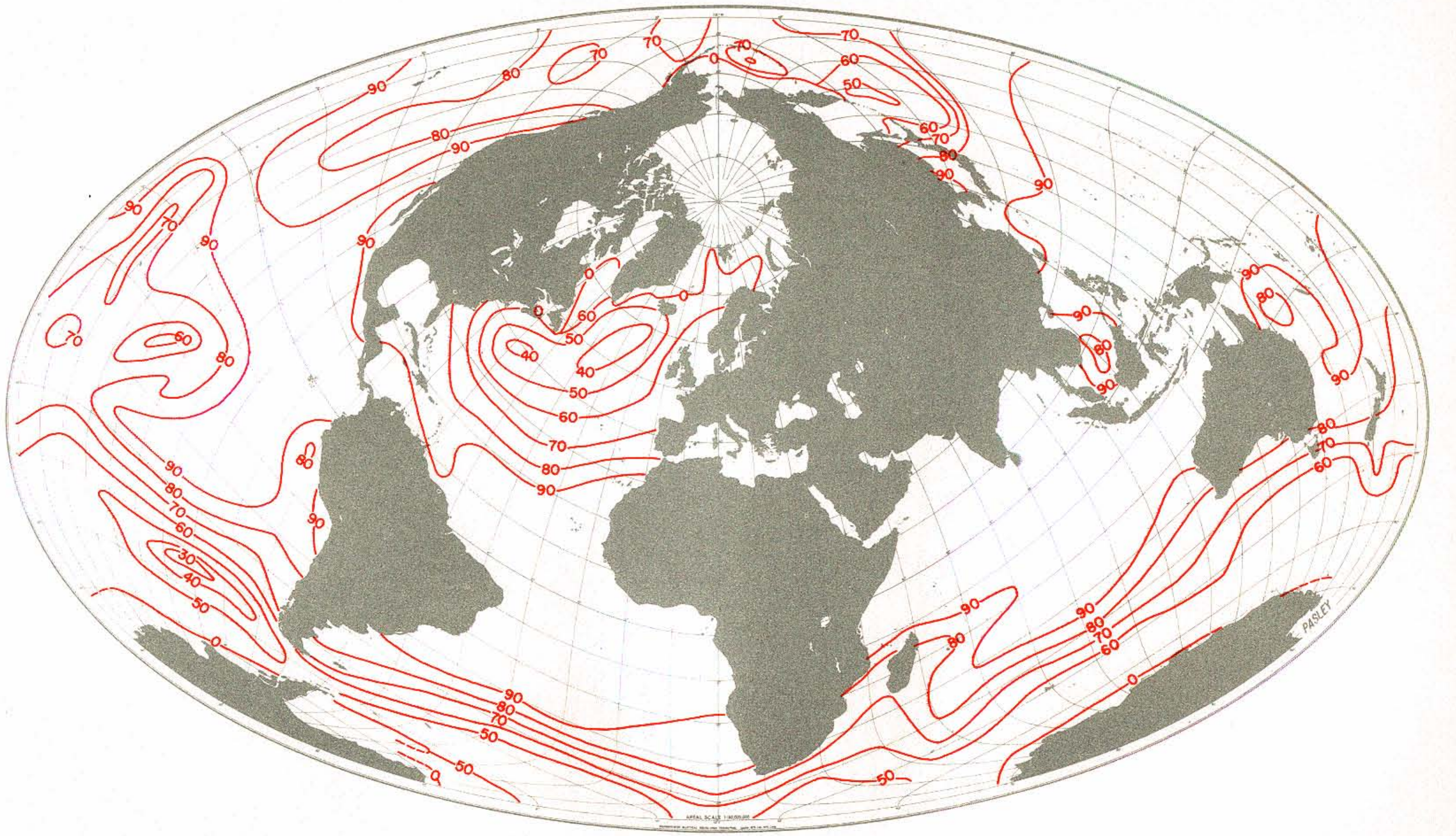

FIG. 9. Weather and fishing: percentage of time fishing is feasible in February.

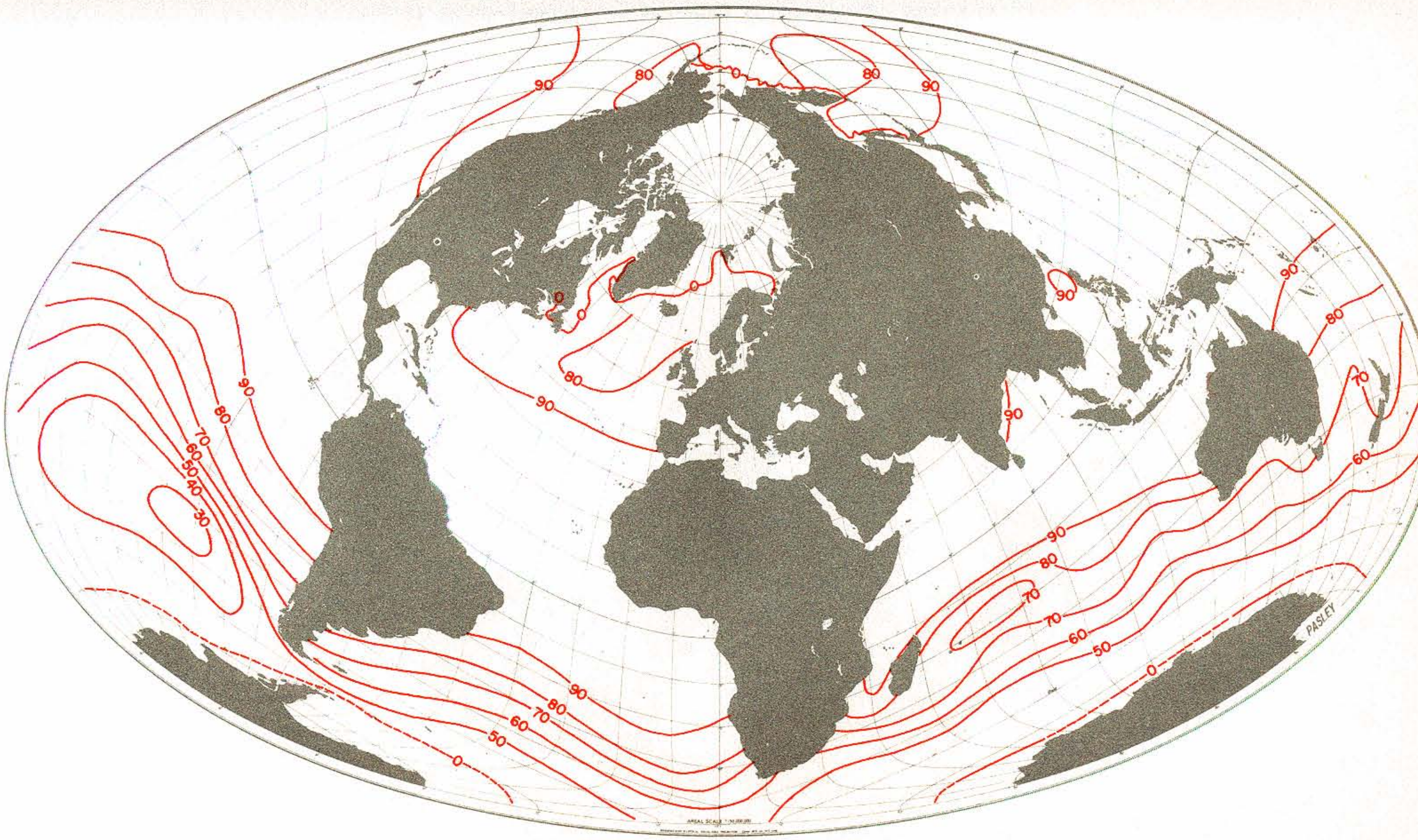

FIG. 10. Weather and fishing: percentage of time fishing is feasible in May.

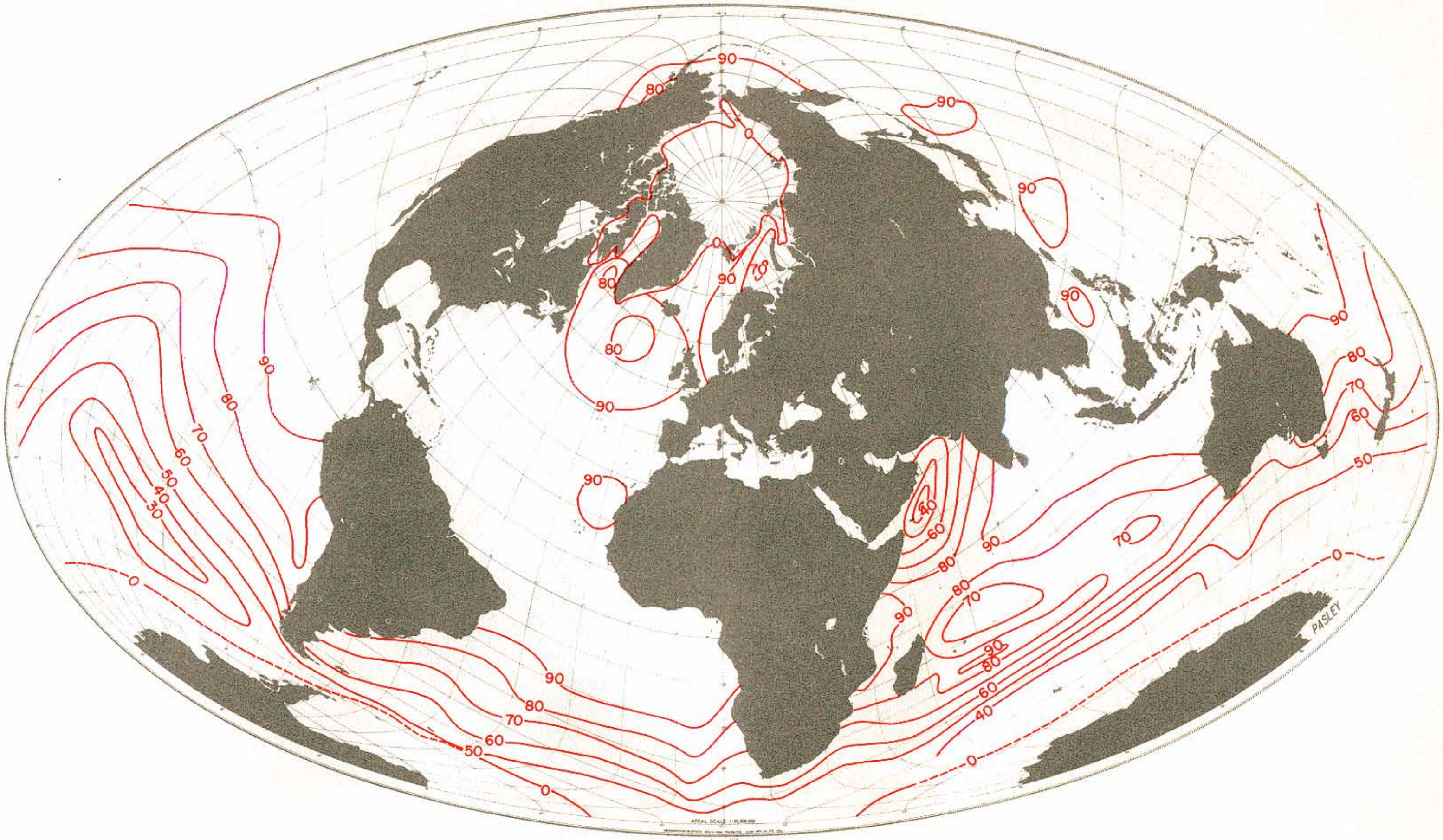

FIG. 11. Weather and fishing: percentage of time fishing is feasible in August.

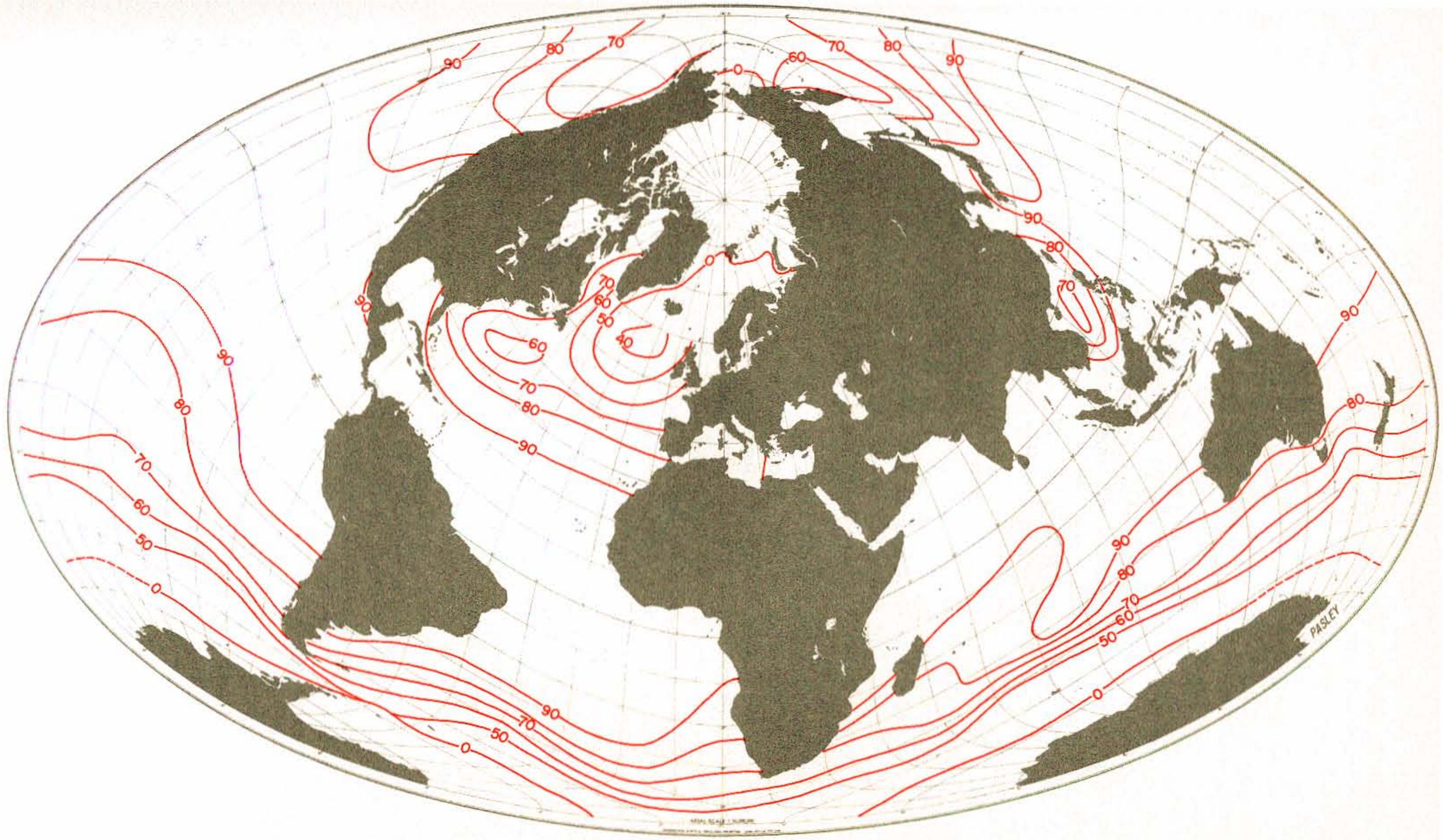

Fig. 12. Weather and fishing: percentage of time fishing is feasible in November.

Discussion of Figures 13 and 14

Taken altogether, the fertile areas of the sea are larger than the arable areas of the land. For the most part they extend far beyond the range of coastal fishing boats such as are operated by fishermen working for their own subsistence or for small, day-to-day markets. It is not only distance which limits the availability of the fertile offshore areas, but weather as well, for some of the most fertile parts of the seas are seasonally too rough for fishing. Even in the favorable seasons, bad weather prevails some of the time, so that vessels must be very stoutly built for distant sea work.

Obviously, offshore fishing is a demanding, difficult, costly undertaking, and one that is profitable only for relatively high-priced species such as tunas, salmons, swordfish, and certain of the groundfishes. The countries where distant offshore fishing is economically and sociologically feasible tend to fit into this common pattern: they have long traditions of seafaring; they are deficient in supplies of protein produced on the land, and therefore fishery products can compete successfully in their markets with meats and poultry; seafaring labor is abundant and relatively cheap.

Countries not fitting into this pattern tend to be more closely bound to the land. Where meat is plentiful and labor scarce and costly, it has generally not proved economically feasible to embark on very long fishing voyages, even though seafaring traditions may be long established. American tuna clippers, for example, stay out three or four months at most; North Atlantic trawlers, two or three weeks. It is hard to induce American fishermen to remain at sea much longer than that.

In the less advanced countries, on the other hand, fishermen do not venture far from land for other reasons. They do not have the traditions, training, or equipment for distant fishing. Furthermore, they are generally too poor to afford the high cost imposed by the operation of ocean-going vessels.

A few countries, notably Japan and the U.S.S.R., send factory ships and mother ships accompanied by fleets of scouting and catcher boats to fish on the high seas for fin fish. These go far from home ports and stay out many months at a time before returning home with their loads, which are sometimes predetermined by quota according to estimated demand. Some Japanese fishing vessels go across the Pacific, through the Panama Canal, and all the way to the coast of Africa on voyages lasting seven months. Others work in the opposite direction into the Indian Ocean. Several countries, chiefly Norway, the United Kingdom, and Japan, engage in whaling in the Southern Ocean, thousands of miles from home.

The problems of exploiting the offshore areas are exceedingly perplexing. Some of these are how to reduce the time required to locate and catch fish; how to operate in marginal weather so as to stretch the short season; how to make it economically feasible to use some of the less recherché species which are now discarded or avoided; how to design small vessels so as to extend the area which shorebound fishermen can exploit. These are problems on which special research needs to be centered in order to improve the utilization of the offshore fertile areas.

Figure 14 shows that the largest fertile areas are in the North and South Pacific, the North and South Atlantic, and the Southern Ocean. The Indian Ocean looks discouragingly poor. Its evident lack of extensive fertile areas on the high seas must limit fishery activities more or less to the use of coastal waters and the cultivation of inshore environments. It must be observed, however, that the Indian Ocean has been studied very little and that its resources have not yet been fully assessed. It is there that extensive marine biological research is particularly needed.

The South Atlantic Ocean has very large fertile areas, rich fishery resources, and therefore high fishery potentialities. Favorable weather prevails most of the year. Countries bordering the South Atlantic need fish, for they suffer severely from protein deficiency. Yet the South Atlantic is far underexploited. There are few laboratories in the maritime countries of Africa and South America and there has been relatively little systematic research into marine fishery resources. Probably nowhere else in the world would fishery research prove more rewarding.

The Pacific Ocean has the largest fertile areas and is a region of tremendous fishery activity. Extensive marine research and offshore fisheries programs are directed from Japan, the U.S.S.R., Australia, the Hawaiian Islands, and North and Central America. The North Atlantic has long been intensively exploited and the subject of fishery research by all the maritime states of Europe and North America.

Considering, then, the criteria set forth on page 13, it is less in the North Atlantic and Pacific that new research is needed than in the South Atlantic and in the Indian Ocean.

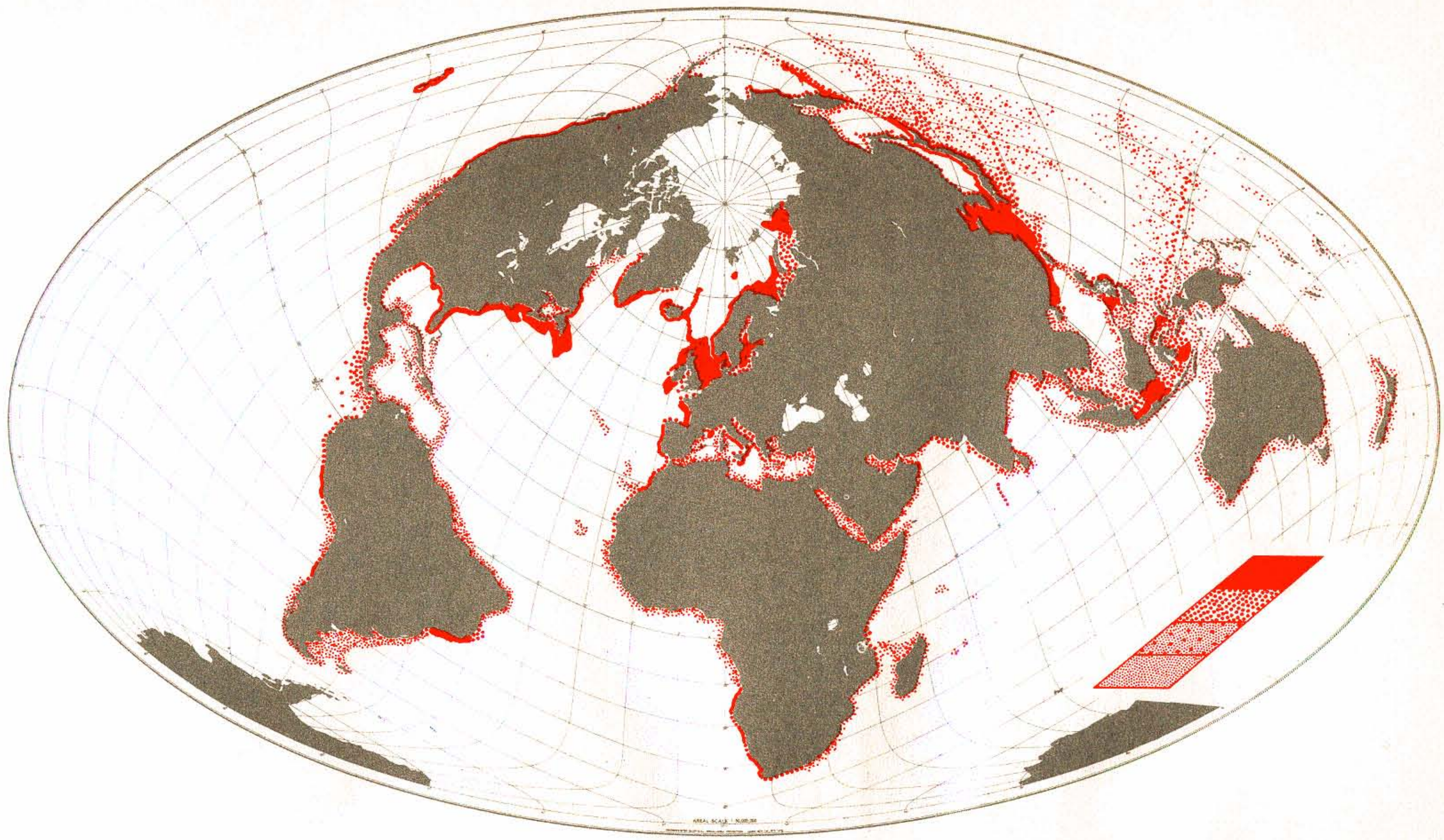

Fig. 13. Distribution of fishing grounds of the world. The yield of the sea is suggested by the relative intensity of the shading.

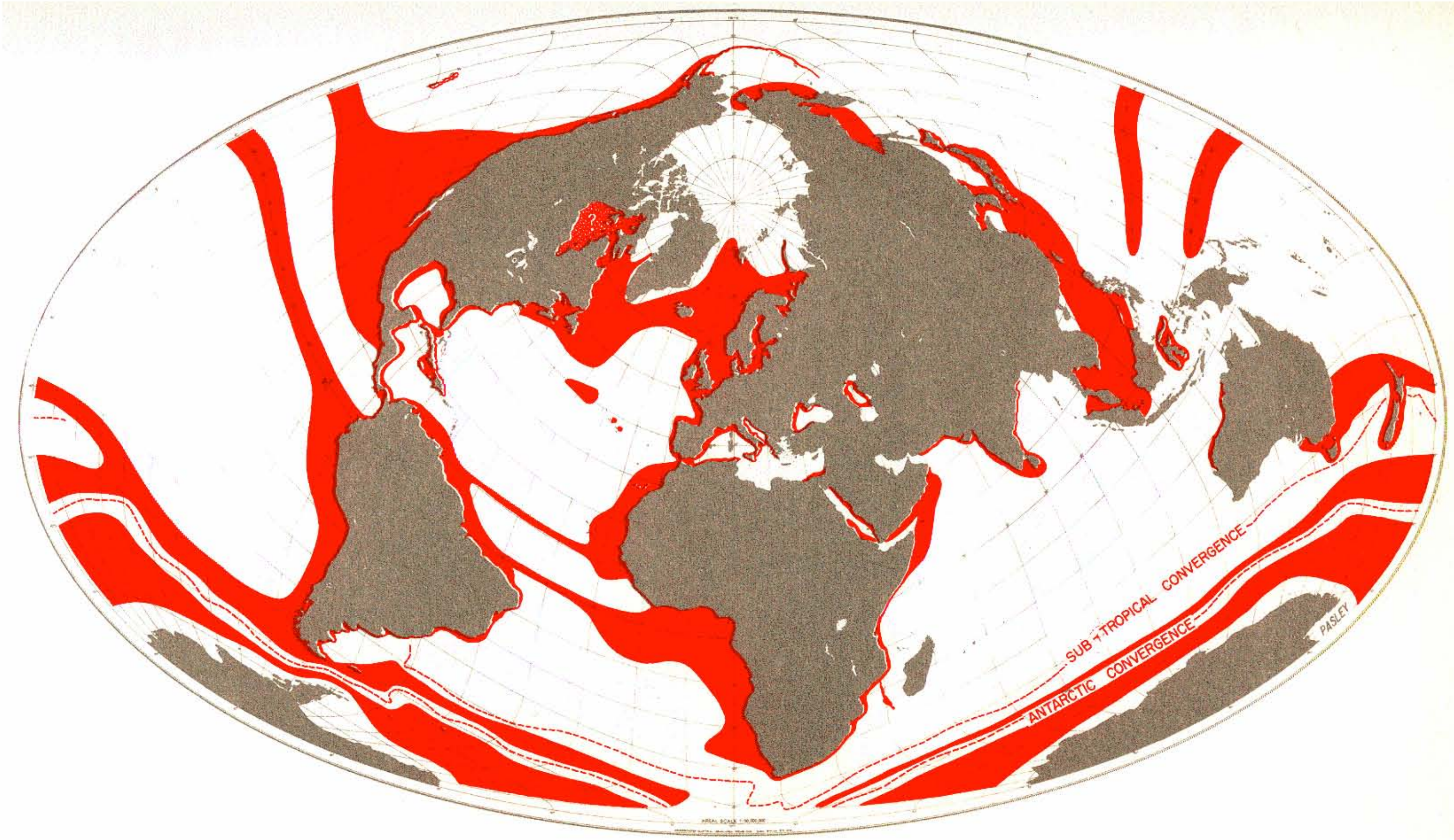

FIG. 14. Fertile areas of the seas. Red indicates areas where oceanographic processes are conducive to enrichment of surface water, hence to production of plants and animals.

3

Conservation

Conservation means the intelligent use of resources. In that sense, this study deals with a conservation problem: how, when, and where to harvest the biological resources of the sea. There are many misconceptions about conservation. Amateurs tend to be particularly opinionated on this subject and often succeed in influencing governmental action, sometimes to bad effect. In this chapter I try to show that conservation of fishery resources is a complex, highly technical subject, better left to experts.? *Fishery research to provide knowledge which is to be the basis of legislation is most appropriately conducted by government conservation agencies. In recent years, such research has been expanding in scope and spreading throughout the world. Government fishery research necessarily concentrates on the relation between intensity of fishing and abundance of fishery stocks. However, fluctuating environment also affects abundance, but in ways which are yet far from understood. There is a need to expand fundamental research about environments from a biological point of view. Much of this should be undertaken by the research laboratories of universities and of private institutions. Meanwhile, study of the philosophy of fishery conservation, of the conservation of fisheries in relation to that of other resources and to human affairs in general, has been much neglected. This chapter suggests how this gap might be filled.*

One of the most direct approaches to expanding the use of marine food resources is to start new fisheries on virgin stocks that have the capacity of sustaining large yields. We know of a number of these in various parts of the world. However, there are usually reasons why they are virgin: they are too remote from markets; consumers are unfamiliar with them; fishermen have no means of catching them; or fishermen are not aware of their value or of their existence. To overcome these obstacles, someone must do some commercial developmental work. That requires capital for boats, equipment, operations, and the expenses of establishing markets and market facilities. However, before many investors would be willing to risk much money in a new fishing enterprise, they would ask what they could expect to get out of it. To give them intelligent a priori advice, it would be necessary to have answers to questions such as the following: Where are the prospective fishing grounds located in relation to port, market, and distribution facilities and to refueling bases? How large are those grounds? What are their boundaries? How abundant are the fishery stocks in the area? How are the stocks distributed in terms of pounds per acre and pounds per unit of human work required in the harvesting? These are the obvious questions which are fairly readily answered from the results of explorations; they are taken up elsewhere in this study. This chapter deals with other questions which are equally important, perhaps more so, but which take much more time and research to answer, and which are usually neglected until sometime after fisheries have become well established and the supply has begun to waver.

How do the stocks shift seasonally? Are they really quite independent and virgin, or are they seasonal migrants from distant grounds which are fished elsewhere in intervening seasons? How much variation is there in availability of the stocks? Is the abundance likely to hold up under a fishery? How large an annual harvest can the stocks sustain, on the average?

The most baffling complex of problems with which all people engaged in fishery industries must contend concerns instability of the supply. This is not necessarily a new condition resulting from the intense mechanical exploitation of the modern age, but in large measure is a characteristic of many, perhaps of all, animals and plants, including those which are not exploited, as well as those which are. The histories of all the great fisheries as far back as records go are studded with sporadic famines and gluts of varying duration. Among the pelagic fisheries there are more than a few instances of stocks disappearing almost completely from fishing areas and remaining absent for many years. How much is fishing responsible for these vagaries? To what extent can fishing be controlled to prevent them? All great fisheries eventually come to a point where they must face these questions with their governments. Hence, we had better consider them in relation to any proposed expansion of the use of fishery resources. They are questions which are associated with the idea of conservation; they are leading topics in the programs of governmental conservation agencies.

Conservation is a great cause of the twentieth century. It was impelled by the tensions of crowded populations and by the experience of people who actually watched some virgin resources become despoiled for want of proper management. The popular use of the word in this sense is new, but the sentiment back of it is timeless, as evidenced by references to fishery problems scattered through ancient writings. These have a familiar ring. Dipping at random into a few likely books, I find that the Sumerians of 4,000 years ago provided for fishing rights and closed areas, and they had fishery inspectors. The Chinese of the Chou Dynasty (about 1000 B.C.) engaged fish wardens, issued licenses, and imposed closed seasons to protect spawning fish. In 1676, the Netherlanders passed a law to prevent exhaustion of their coastal waters. This regulated the size of meshes in nets and prohibited trawl-nets. The first of these provisions was adopted because small meshes destroy fry; the second because trawls kill spawn as well as the fodder on which young fish live. Even then this was not a new idea in Europe; the English had similar laws in the fourteenth century.

Thus it was not people of our time or our country who discovered husbandry of natural resources. Americans merely rediscovered it for themselves. They had lost it for a while during the settlement of the new world when nature seemed boundless. But then eventually symptoms that the land was being spoiled restored awareness of the need for providence. In a long settled country, the awareness comes naturally. People know from experience, if not instinctively, that resources have limits. It is the most obvious logic that unless enough seed is left after each harvest to provide for reproduction of a stock, the stock will dwindle away. Hence, people tend to apply this line of reasoning to aquatic animals, often preventing thereby the taking of full harvests.

The knowledge of how much is sufficient seed to maintain sea-fishery populations does not come by reasoning alone, however. It comes only by scientific study and experiment. Nevertheless, there never has been any lack of opinions on the subject. The commonest of these is that fishing must be restricted so that people "won't take too much." "We can't go on this way" is a frequent cry of fishermen while they proceed with their harvests. The most popular of all opinions about fishery conservation is that fishing must not be carried on at all during spawning seasons, or if that is not feasible, that the spawning females at least must be protected.

> . . . of the great quantities [of tunny] which enter the Mediterranean to spawn, some are caught by the fishermen after spawning, but the great majority before fulfilling that function. How then can we conclude that the cause of this diminution is not owing to the action of men?

That was written in 1888. People usually believe that immature fish must be protected so that they can have the chance to reproduce; and the largest, most aged specimens must be protected too, because they produce great quantities of spawn. Spare the mothers, the young, and the aged.

Other ideas are of fairly recent origin, for example that nets are harmful compared with hook and line, that purse seines are worse than other kinds of nets, that commercial fishing is more destructive than angling, that fish should be used only for human food, and that manufacture into fish flour should be discouraged because it uses dangerously large quantities of raw material. Most of such ideas have emerged full blown because they seem reasonable. It stands to reason that catching too many fish reduces the numbers of spawners, and that the amount of spawn is proportional to the size of broods. If fish have grown scarce, that *must* be because the number of spawners has been depleted; ergo, the process can be reversed by building up the spawning stock. This doctrine of the inviolability of spawn has always been the principal ingredient of popular opinions about the use of fishery resources, and is the basis of much fishery conservation legislation. It is a perfectly reasonable idea. For sea fisheries, however, it has one serious flaw: it is not often clearly borne out by experience, for the volume of spawn is only one of many factors influencing the abundance of a generation, and is rarely the dominating one.

Yet in most maritime countries, the books are studded with fishery conservation laws—closed periods, closed areas, bag limits, size limits, prohibition against certain kinds of gear, against commercial fishing, and all sorts of other restrictive devices largely intended to protect or build up the spawning stocks. Many of these laws are derived from preconceptions rather than from knowledge; they may have little bearing on scientific husbandry and can do more to obstruct than to further true conservation.

I propose now to discuss briefly some principles to show that scientific fishery conservation must be backed by a considerable body of very special information, and that is not a job for amateurs. Instead, in this field, an amateur can innocently, and with a sense of great righteousness, do harm about as easily as good.

Disregarding economic considerations, the harvest of fishery stocks should be permitted up to their "maximum sustained productivity." This is the ideal of scientific conservation: full utilization for the benefit of mankind, not restriction for the benefit of fish. The judgments which must be made to achieve this ideal must be based not on intuition, but rather on knowledge of the biology of the fishery populations.

Fishery biology, which is concerned with the development of this knowledge, is a relatively new field of science, hardly more than seventy years old, still in the process of evolution. It is carried on as a governmental function by nations having important fishery industries, and is gradually building toward a sound basis for scientific direction of fisheries. Fishery biologists have devoted a great deal of study to the effects of exploitation on abundance of fishery stocks and to the causes of variations in the size of year broods. Over the last seventy years, a mass of vital statistics has accumulated on a few heavily fished species in various parts of the world. From these statistics and from experience in regulating fisheries the following pattern is emerging.

Under primeval conditions, with no fishing by man, a stock of fish produces an enormously excessive quantity of eggs. A high proportion of the hatch dies from natural causes such as predation, disease, climatic and hydrographic disasters, and starvation. When man joins the constellation of influences by starting a fishery, he enters into competition with the other—the "natural"—causes of mortality, and the course of his fishery is determined in large measure by the success of this competition.

A young, growing fishery gradually, or often rather quickly, reduces the accumulated stock, and therefore the number of spawners and the production of eggs. But this does not necessarily result in any diminution of the number of young surviving to fishable size. It may even have a beneficial effect analogous to that which results from thinning, relieving the severity of competition both among the young and between the young and the adults. Thus a higher proportion of fish survives the infant stages under a moderate fishery than under primeval conditions. The word moderate, however, requires definition. It means not extreme—not too little and not too much. At one extreme, is the primeval stock, living under a regime of no fishing and composed of a large accumulation of old fish, which by taking up space and food and by cannibalism make conditions unhealthy for their own young, so that the surviving broods are relatively small. At the opposite extreme is a stock reduced to the vanishing point, with few spawners left, producing few eggs and, therefore, small broods. Between these two extremes of population abundance is a point of maximum efficiency of spawning, wherein the number of infants surviving to young fishhood is limited least by competition among their own kind and not at all by the quantity of spawn produced. In this range of abundance, year broods tend to be larger than at the extremes. However, judging from empirical data published in literature, these relations are far from regular, for varying environmental conditions also exert great influence on the survival of young fish. Consequently there are enough records of large broods issuing from the extremes of population abundance and of small ones issuing from the means to discourage generalizations on the matter.

In reducing the accumulation of big old fish, the new intense fishery shifts the mass of the stock toward the young fast growers. In the early days of the American haddock fishery, for example, specimens ten years old were common; whereas, within fifteen years, few were surviving beyond the age of six. Although this effect often arouses people to fear that a stock is on its way to extinction, such fears are groundless. As a matter of fact, from the viewpoint of resource use, big old fish are uneconomical, because they use their environment uneconomically. A few very crude estimates will illustrate the point.

A group of 100 sea bass which are each 20 years old weighs about 3,600 pounds. During the course of a year, 10 of them, say, die from natural causes, and 25, weighing altogether about 910 pounds, are caught by fishermen. At the end of the year, the 65 survivors, having grown in weight by about a pound each, weigh near to 2,400 pounds. Thus, through natural and fishing mortality, this group of bass has decreased in volume and value by a third. It has consumed 30,000–40,000 pounds of food during the year, of which only about 1 per cent has been used for building flesh, the rest having gone into body maintenance.

The same amount of food could support instead 1,700 sea bass, initially weighing 1,700 pounds, in their fourth year of life. During the year, around 170 (10 per cent), say, would die from natural causes. To get the same weight of harvest as the 20-year-old stock yielded in our model (i.e., 910 pounds) would require catching 520 fish. At the end of the year, the 1,010 survivors would weigh about 2,525 pounds. In spite of the depletion in numbers, therefore, the stock has increased in volume and value by 48.5 per cent. Of the food which this group of bass consumed, about 25 per cent went into building flesh, about 75 per cent into body maintenance.[1] Thus in our model, the fast growing younger fish (which predominate in a harvested stock) are shown to use their food more efficiently than the slow growing older fish such as are common in a primeval stock. That is to say, they have used a higher proportion of it for building flesh (25 per cent compared with 1 per cent) and a lower proportion for maintaining existence. The stock has yielded (in this hypothetical example) the same crop, 910 pounds, and it has improved in value by 48.5 per cent, whereas the older stock has depreciated in value by 33.3 per cent.

True, the older fish are more fecund than the younger, the 20-year-old stock of our model producing 225 million eggs, the fourth year stock only 55 million eggs.[2] Yet, judging from actual experience with fisheries on which records have been accurately kept, the population of younger fish in our model will be able to sustain itself unless the fishing rate exceeds the replacement rate.

This model gives a very rough idea of the kind of considerations that must go into managing a fishery resource.

Fish that have passed their period of youthful growth continue to grow, but too slowly to keep pace with an intense fishery. Consequently, the accumulation of big old fish that a new fishery finds is inevitably cropped off and cannot be replaced unless the rate of fishing is adjusted for that purpose. At first the annual catch increases, as more and more men enter the fishery, until it reaches a peak. Then the catch and the catch per fisherman decline sharply, as the old fish are removed, until the stock reaches a level where replacement by growth and new broods normally balance the annual cropping by the fishery and by natural causes of mortality.

In the last twenty years or so, biologists have given a great deal of attention to the dynamics of fishery populations, that is, to the inter-responses of rates of birth, growth, and death. This is at the heart of governmental biological research about marine fishery resources. The fundamental concept behind the mathematical models which are commonly used in these studies is that the rate of decrease in numbers with time is equal to a constant factor (the total mortality rate) times the numbers present at that time. We start with some large population. Under the pressure of fishing and natural causes of mortality the population decreases rapidly at first because the numbers present are large; as time goes on, the rate of decrease diminishes as the numbers left in the population diminish.

This is the familiar idea of compound interest—but in reverse. We learn from the compound interest formula that if we start with some small sum and keep compounding at very short intervals of time, the amount increases more and more rapidly. At the end of a number of years, say ten, we may have a sum many times larger than we started with. If we think of this final sum after ten years as our initial population and then work the compound interest formula backwards, the situation is analogous to the decline of a population. It proceeds rapidly at first, becoming slower and slower as the population gets smaller.

Mathematically, biologists express these relationships in the form of a differential equation:

$$dN/dt = -kN \tag{1}$$

which simply states that the rate of change of the population (dN/dt) with time (t) is equal to a constant factor (k) times the population (N) present at that time.

In a fish population, one usually considers N as the number of fish of some stated age present at a given time, say 10,000 one-year old fish at the beginning of 1952. This number will decrease year by year until the last fish is captured or dies. In our Equation (1), therefore, k will be negative because our original population is always decreasing.

If there is no emigration, the only ways in which fish may be removed from the population are by fishing and by natural death. Our k, therefore, consists of two independent processes, fishing and natural mortality. Let us call the coefficients of these F and M respectively. Substituting F and M for k, we may write Equation (1) as follows:

$$dN/dt = -(F + M)N \tag{2}$$

Integration of Equation (2) gives a conveniently usable form of the relationship:

$$N_t = N_o e^{-(F + M)t} \tag{3}$$

where N_t is the number present at any time, t, and N_o is the number present at the beginning, which we take as $t = 0$.

Further development of Equation (3) is essential to a realistic treatment of population dynamics. A few rather simple mathematical manipulations convert Equation (3) to an equation expressing the yield in numbers at stated rates of fishing and natural mortality. Knowing the rate of growth and the relation between length, weight, and age of the fish, the fundamental equation can be written so as to give the yield in weight. In more complex models, one may introduce adjustments to allow for variations in growth which depend on density, and to allow for variations in natural mortality rate, thus simulating the actual conditions the biologist finds in investigating a population.

In this manner, given precise enough knowledge of rates of births, deaths, and growth under various fishing rates, it is theoretically possible to adjust fishing so as to get the most profitable average annual yield that a resource can afford. What the phrase "most profitable" means is a matter for people who set economic and sociological policies to define. It might mean most pounds of fish, lowest cost of fishing, highest prices of fish, most fish of certain specified sizes. It might mean highest catch per fisherman or highest income per fisherman. But whatever human interests prevail in defining the desirable, it is theoretically possible, given enough of the right kind of information, to achieve it, within the limits of the properties of the resource.

Thus some fisheries could theoretically increase their harvests by as much as 50 per cent—the haddock fishery of Georges Bank, for example, could probably do that—by scientific adjustment of the fishing rate. This may be accomplished in a variety of ways, depending on the kind of fishery and the habits of the fish. For example, it could be accomplished by setting a minimal size at which fish may be caught, or by prohibiting fishing in nursery areas, or by setting catch quotas.

The prediction of how a fishery stock would respond to a given level of fishing intensity results from theoretical synthesis of data. However, theory is one thing, fact another. The theory must be tested by regulating the fishery experimentally and observing constantly the response of the stock. On the basis of this response, the theory can be revised if necessary and the regulation adjusted accordingly. Since regulation is ordinarily a responsibility of government, the research required as a basis for it is better conducted as a function of government than of private research institutions or universities.

The scientific staffs of government conservation agencies characteristically must concentrate their researches on a few most important species and neglect the rest. This is necessitated by the small amount of money appropriated for fishery research; that is, it is small in relation to the magnitude of the job. Disregarding such practical considerations, I shall in later chapters argue a case against this focusing of fishery research on individual species out of context of their environmental systems, against giving too much attention to the effect of fishing on the stocks, and against too complacently assuming that natural conditions which affect adult fish stocks remain constant from year to year. Pertinent though these arguments may be, certain things must be learned about each species, no matter how the fishery for that species is to be managed, whether by judgment or by science, whether the course of the management is to be static or dynamic, whether it is to be species by species, each without regard to the other, or in accord with action of ecological principles, or whether the management is to be directed by government or by the fishing industries themselves.

The first problem to solve in any fishery investigation is the identification and definition of the stocks being fished. A stock remains genetically distinct because of a variety of barriers which may be geographic or biological, or both. Thus two stocks of one species may be kept apart by a continent, by a water mass having a repelling temperature, or by a submarine canyon; or they may intermingle freely part of the year and separate during the spawning season. A stock thus isolated may have distinctive habits, fecundity, growth rate, longevity, resistance to disease, and response to fishing pressure. If so it must be dealt with separately in any conservation action.

For each stock the following need to be studied:

The geographic distribution throughout the year
The abundance
The growth rate
The migratory habits, age by age
The spawning habits, spawning season, and fecundity
The relation between fishing rates and productivity
The mechanisms by which fluctuations in the environment affect natural mortality and distribution of infants and older ages
The features of the environment which affect distribution and habits

Because every circumstance in the lives of marine organisms is affected by external conditions; because the conditions for life in every part of the sea undergo continual changes; because while some of these changes are transitory, others extend over decades or even centuries—for many such reasons, fishery studies on the topics listed above can never end. True, these studies will change their character as information and the knowledge of principles accumulate. True, too, research about a fishery species might in the course of years progress so far that rather simple routine observations carried on by technicians might be enough to provide a strong basis for rational direction of the fishery. So far, however, marine fishery scientists have not yet reached that point for any species. In fact, they have opened up more problems, and more difficult ones at that. This does not mean that fishery biologists are impractical ivory tower residents, as some of their critics often charge, but that they are in the midst of the slow process of developing their science. Because of the nature of their subject, they are forced to feel their way blindly, revising their judgments as fast as they improve their perception of the shapes of facts. Different biologists, groping independently, sometimes reach quite different conclusions concerning the nature of these shapes, and dispute about their differences of interpretation. This is only further evidence that the science of fisheries is one in the making.

Meanwhile fishery research is continually enlarging its scope everywhere. Countries where such work had been going on for many years have lately been providing funds to increase the number of species and the areas studied by their governmental agencies and to expand research staffs and facilities. Other countries that had previously not shown interest in the subject have been establishing marine laboratories and sending students abroad to learn techniques of fishery research. The following commissions and councils have been organized to study problems of intergovernmental interest: Indo-Pacific Fisheries Council (16 nations); Inter-American Tropical Tuna Commission (3 nations); International Commission for the Northwest Atlantic Fisheries (10 nations); International Council for the Exploration of the Sea (13 nations); International North Pacific Fisheries Commission (3 nations); International Pacific Halibut Commission (2 nations); International Pacific Salmon Fisheries Commission (2 nations); International Whaling Commission (17 nations); Atlantic States Marine Fisheries Commission (15 states); Gulf States Marine Fisheries Commission (5 states); Pacific States Marine Fisheries Commission (3 states). It can hardly be said, therefore, that fishery research has been languishing for want of public interest and financial support.

It would be presumptuous to specify any technique or particular line of research which could with certainty speed the achievement of useful results. As in any kind of research institution the production fluctuates in quality and quantity, and it varies in these respects geographically. Even so, taking all things into account, it progresses about as fast as can reasonably be expected.

I have argued that fishery research is best carried on by governments and that it must be carried on along certain lines as listed above. It must be directed toward assembling certain information about the more valuable of the commercially important species. Doing just that much takes all the funds, facilities, and staffs which governments make available, leaving almost nothing for studying species which seem to be unimportant. This includes many commercially worthless but biologically enormously effective predators and competitors, and also all the myriad organisms of the food pyramid including the plants of the phytoplankton. Nowhere are there sufficient funds and talent available to cope with the problems of analyzing the tangle of interrelations among the species of that vast complex or of determining how the physical environment affects the existence of fishery stocks. In short, adequate provision is not made for studying marine environments as such. Consequently, there are only vague concepts of the biologically significant properties and actions of environments. In spite of all the talk about marine ecology and biological oceanography the amount of work done in those fields is negligible in relation to the magnitude of the subject, and in comparison with the effort put into fishery biology and physical oceanography. At the same time fishery biologists on the one hand and physical oceanographers on the other—the two groups now dominating marine research—have not yet found (perhaps not really sought) the kind of questions that would lead toward understanding the role of environments as media for living organisms. Formulating those questions is in itself a research problem.

The study of the environments of the sea is perhaps the widest gap in marine research programs, in which teams of scientists well educated both in biology and in physical oceanography and therefore able to straddle both fields should be engaged. Because such research appears to be remote from practical application, it is hard to justify for the scientific programs of government fishery conservation agencies. On the other hand, it fits without question into the functions of universities and oceanographic laboratories. In general, with a very few notable exceptions, however, such institutions have not concentrated much attention on the subject. How this condition might be corrected will be discussed in following chapters.

Perhaps in the long run greater increase in the harvest of the sea will come from scientific conservation (i.e., control of fishing to produce maximum sustained yields) than from development of new fisheries. However, scientific conservation requires not only information about the animals and plants of the sea. It also requires a willingness on the part of the general public, and especially of interested groups such as fishermen and men in political office, to accept and use this information intelligently as it is acquired. Very little provision is made to encourage this attitude through education. Here I mean education, not propaganda; classroom teaching, book learning, not sporadic television programs interspersing commercial advertising.

The principle that conservation-is-desirable hardly needs to be fostered any more than that honesty-is-the-best-policy. It is already pretty well accepted. The issues of conservation, however, are something else again. People in general, and that sometimes includes government officials, have very fuzzy notions as to just what conservation means. They are hardly aware of the fact that every conservation action requires choosing among several conflicting but often equally appealing human needs. The choice is often made in response to specious sentiment or to the pressure of interested groups rather than according to the judicious consideration of principles and all the needs of the public as a whole.

As is generally true of government centers, the office of a fishery conservation agency is hardly a place for quiet contemplation. Letters come in daily by the hundreds asking for information, demanding courses of action, seeking or giving advice, complaining about conditions here and there. They must all be answered politely and fully—"My dear Mr. Blank: In reply to your interesting letter . . ." Even more insistent is the telephone, and visitors, who come singly and in delegations to pay duty calls, to chat—"Have you a minute?"—or to influence decisions with plausible arguments. Meetings, designated with various degrees of dignity as conferences, hearings, conventions, or convocations, are almost daily occurrences. The demand for appearances, speeches, reports, articles, or formal opinions which comes in a never abating flood must be met affirmatively. All effort to be thoughtful and judicious is confounded by crosscurrents of dogmatically and often authoritatively represented opposing interests advocating or condemning, pushing or pulling, praising or disapproving, accusing or defending.

Of course this is the life of any man in public office. Public officials working in the commoner fields of government like law, economics and political science are probably much more subject to conflicting pressures. But in the background of their learning is a great philosophical literature. This is full of controversy, to be sure, as would be true of any literature on human affairs. What is important about it is that it has grown and matured in the objective atmosphere of scholarly centers. All universities have faculties who devote themselves to teaching and thinking and writing in these fields. They have nothing comparable for conservation in spite of the fact that this is likely to become one of the most pressing subjects of concern in human affairs.

Most of the literature bearing on fishery conservation reports the results of biological research required as a basis for regulation of fisheries or for predicting catches under given circumstances. It covers such topics as life history, migratory habits, rates of birth, growth and death, relative abundance, optimum catch, and recommendations for regulations of fisheries. In the main, this scientific literature has considerable vitality, contributing vigorously to the growth of knowledge. This cannot be said of the literature about conservation as a subject in itself or about conservation of fishery resources as it relates to the conservation of other resources, and as it fits into the whole complex of human problems. Such literature as there is on this subject is appallingly thin and perfunctory stuff. Most of it advances no new thought at all; it merely repeats what has been said before, using uncritically the same examples to support the same arguments over and over.

This state of affairs results largely from the fact that the bulk of the literature is produced by government administrators to order, on short notice—"I need a speech for Friday." How can anything objective and philosophical be thought through under such pressure? In some colleges where fishery science is taught, the professors are in no better position than government men, because they are themselves deeply engaged in governmental work through contracts. In fact they are worse off because they are continually driven by the need of acquiring more contracts to replace those that are nearing conclusion. So they have no more time to think about the larger questions of conservation than do their colleagues in government. Some of the general literature which attempts to deal with the large questions is produced by college professors who are familiar with soil technology or geology or forestry, but who are not authoritative on fishery resources. They make up for this lack by reading and paraphrasing government pamphlets or by inviting government specialists to write the chapter on fishes for their texts. The results usually have the dreary quality of potboilers.

There are a few first-class colleges where conservation study centers have been started in recent years. An authority on fishery problems should be added to the staff of at least one of these centers. He should be a man of broad education who has had successful experience in dealing with conservation problems and who has demonstrated ability to think critically and creatively about the subject. He would direct the education of people planning careers in various aspects of fishery conservation, including biological research and the administration of fishery agencies. What he would do besides would depend, of course, on his interests and background. He might devote himself wholly to collating information on changes in fishery resources in various parts of the world. He might study such problems as these: What national policies on the use of fishery resources should be fostered? How much should a government spend on fishery research? What directions should government-sponsored research take? How should government conservation agencies be organized to carry out their functions most effectively? What are the choices in conservation actions? What should be the basis of those choices?

4

The Identity of Species

All research into marine biological resources depends on precise identification of species and populations. The science of classification, called taxonomy, is pursued primarily in research museums where collections of specimens are housed. During the last thirty years, taxonomy has been seriously neglected and museum work allowed to lapse for want of support. This chapter discusses the importance of taxonomy and urges that museums be given better financial support than they have been receiving.

What scientific researches, apart from those which are in progress, would contribute significantly toward learning how to enlarge the yield of food from the sea in answer to human needs?

If we think about the sea itself and not about such human affairs as economics and sociology, there are four obvious general ways to attack this problem: Survey unexplored areas in search of new food resources; harvest and process animals and plants which are not now used; control rates of exploiting fishery stocks so as to get maximum harvests; farm sea plants and animals in inshore enclosures. With any of these approaches, it is necessary first to take into account certain elementary facts. These may seem absurdly obvious; nevertheless, they are neglected often enough in planning new fishery schemes that they had better be stated:

1. Among the hundreds of thousands of species of animals and plants that live in the sea, only a few are harvestable in commercially significant quantities and only a few are suitable for direct human use.
2. Each species of animal and plant has a particular geographic distribution which is delimited by conditions of environment.

3. The abundance of a stock of a species is greatly influenced by the abundance of species of prey, competitors, and predators. Man is one of the predators.
4. The rates at which average fishing harvests can be sustained at the most productive level are determined by rates of natural mortality, growth, and reproduction. These vary from one species to another and within a species from one population to another, depending to a considerable extent on conditions of the environment. They also vary from year to year.

Underlying each of these four statements is a concept of species as a unique biological entity. It is hardly possible to deal with food resources without in some way recognizing species. To give a very homely analogy: a farmer must distinguish crops from the weeds, the well-growing, disease-resistant strains from those which are less hardy, the vermin from the useful livestock. He kills noxious weeds and insects with specific herbicides and insecticides. He plants particular kinds of vegetables and fruits to meet local conditions of soil and climate. Such practices result from a tremendous amount of research about species.

Species are equally important to those concerned with exploitation of the sea, though in rather different ways. Fishermen must distinguish the species that are marketable from those that are not. They direct their operations according to the distribution of species. The point of reference for marine biological research programs is usually species. In exploring unknown grounds, people are interested in finding familiar species of fishes, say, sardines or tunas or cod. Research to improve pond culture methods is usually tied to one or two species that grow well in ponds, for example, milkfish and prawns. It is an actual or anticipated depletion of particular species that arouses demand for research programs to devise conservation measures; such programs are always focused on the species affected.

The most elementary fact that a fishery biologist must learn about each fishery stock—elementary in the sense not of being easiest, but of coming first—is the identity of the species. What is it that must be dealt with in designing a policy of intelligent fishing? That is the first question that must be answered. For example, snapper fisheries of the Atlantic coast of Central America harvest at least six species which overlap in distribution. How do fluctuations in abundance of one species relate to those of the others? How do their habits differ? In some places fishermen take mostly very small fish of ten inches or so. Do these belong to species of small size, or are they the young of larger fish upon which people elsewhere depend? Answers to these questions would have important bearing on the harvesting practices of the fishermen if they chose to fish scientifically for maximal yields.

Again, wherever people fish along the shores of tropical countries, they find large quantities of jacks (*Caranx*). It is tempting to conclude that in underfished places there must be the basis of a great potential fishery. But the fact is that there are many kinds of jacks which look so alike that experts have not yet been able to establish their identity. Yet they differ in many important ways. While some species are delicious, others are not very palatable, and still others are in some places occasionally poisonous and therefore never safe to eat. Moreover, the various species differ in distribution, in habits, and in vulnerability to fishing pressures. Any plans for developing fisheries in a virgin area would have to take these differences into account.

It is hard to say that any one of a system of lines of activity in a field such as marine biology is the fundamental one. Nevertheless, if one must be so designated, that which comes closest to qualifying is the identification and definition of species. A misconception common among scientists as well as the lay public is that this means naming plants and animals and keeping the names tidily catalogued. Actually, the names are important only as a convenience. Organisms could just as well be designated by call numbers, like books in a library. However, it does happen that by international agreement, zoologists and botanists use a system of Latin nomenclature. This simplifies scientific literature tremendously. But it is not the names that make species interesting, or the bottles of dead specimens of these species in museum collections, but the fact that they represent vital populations.

By definition, every species has a unique anatomy and physiology. This uniqueness limits the geographic distribution of a plant or animal species to only certain areas of the sea, and within those areas to certain habitats where chemical, physical, and biological conditions combine peculiarly to satisfy its specific requirements. The abundance and well-being of a species are maximal where the combination of environmental conditions is most favorable, and they diminish as the combination grows less favorable.

Few species are distributed continuously or are genetically homogeneous throughout their range. Rather, changes in their environment and in the constitution of their genes occurring in the long course of geological time, have divided most species into communal populations or "demes," as they are sometimes called, and given them various degrees of independence. A species is sometimes defined as a system of demes.

Communal populations within species differ from one another in features of anatomy, physiology, and behavior. They also have distinctive geographic ranges or ecological habitats, or both. The more important of them often behave almost like different species and are identifiable as something of lesser rank only because at certain geographic points or in certain anatomical and physiological features they merge with other similar populations, or, if completely separated geographically, cannot always be distinguished from them. These "almost-species" are called subspecies. In marine animals and plants, which, in general, have been studied less than terrestrial ones, subspecies have received little attention. Most marine subspecies are probably still unrecognized. What are now considered to be closely related but distinct species probably in many instances will prove to be subspecies when connecting links are found or recognized.

Subspecies themselves differ from one another in various ways. It is difficult to determine how to designate the degree of distinctness of these populations. Consequently, a great deal of study is necessary to understand the populational structure of almost any species.

Such study is important in the understanding of a fishery, for populations may differ from others in growth rate, in longevity, in productivity, in resistance to disease, in susceptibility to parasites, in migratory habits, in response to fishing, and in many subtle ways. Consequently, any plan to direct a fishery scientifically must take into account not merely the species, but the population as a unit of the species. Evaluation of abundance and of productivity must be by populations. People working to develop methods of fish farming must recognize differences between populations in seeking the best growing, hardiest strains of fish and shellfish. Control of fishing rates to produce maximum yields must be by populations. Fishing is a highly selective process, and may affect different communal populations of a species in different ways. Fishermen deliberately seek certain sizes of fish to satisfy their markets. They fish in certain depths to take advantage of the habits of their quarry which they know, and thus they may miss, or "select against," those of the same species which are adapted to a habitat of differing properties, as, for example, deeper water. Fishing gear often selects sizes of fish. Fish tend to school according to size; the distances which they migrate vary according to size; they are available only while they are passing through the areas where fishermen are working. Certain sizes may be available for longer periods than others. Thus there are many ways by which different sizes can be subject to fishing pressure. Populations differ in size characteristics. By various selection processes, a fishery may be favoring the survival of some populations and the reduction of others. Such undirected selective breeding might be advantageous, but it might equally well have dysgenic effect in the long run.

For all these reasons, it is essential to be able to distinguish populations and to know the relative influence of heredity and environment in maintaining their identity. Environment certainly has a greater immediate effect on the characteristics that identify populations than on those that identify species. Therefore, in our dimension of time, a species is so stable an entity that it must serve as a standard with which all its populations can be compared.

The study of species, their origin, phylogenetic relations, and geography, is the branch of biology called taxonomy. The tremendous impact of Darwin's *Origin of Species* on the intellectual life of the nineteenth century made this the dominating subject of biological research for about fifty years. The great idea which inspired biologists to redirect their interest was evolution. Because evolution gave meaning to classification and purpose to collecting, scientists constantly improved methods of catching animals, especially at sea, where any haul of a net might bring up enough new species for a publication. The most obvious way for philanthropists to contribute to science was to build a research museum, or at least to finance expeditions for collecting specimens. During this period some great museums were founded and they acquired great collections. For a long time, these museums were the center of activity in the field of biology. Their staffs made the most frequent contributions to biological literature. They got the lion's share of bright young students.

In its earliest stages, the study of species was concerned chiefly with comparative anatomy, embryology, and classification, these being the subjects which best demonstrated evolutionary relationship. In time, however, it opened up all sorts of other interesting subjects of inquiry such as comparative physiology, general physiology, experimental zoology, life history studies, and behavior. As biologists turned their attention to these topics, they abandoned the museum for the experimental laboratory or the open field. In doing so, they tended to lose sight of the importance to their work of the definition of species. Thus, between 1910 and 1920, "systematics" went out of fashion. A generation of biologists had found other subjects for enthusiasm, particularly mechanics of the life processes and physiology of the cell. Museums were no longer alive with activity. The rising scientists, at first indifferent to museums and their staffs, became slightly contemptuous. "He is only a natural history man" became a standard epithet. "What difference does it make what you call an animal?" biologists often asked, even while finding it necessary to have the subject animals of their researches identified.

Beginning about 1930, new ideas began to emerge in some fields of biology especially in population genetics, which led to a reexamination of taxonomy itself by forward-looking scientists, a movement which is leading taxonomy out of its dark age and giving it greater prominence. The "new systematics" as it is called, recognizes that all biological disciplines contribute to a knowledge of populations, and systematic problems are now being attacked from the sides of genetics, physiology, ecology, and immunology.

Unfortunately, studies of this sort deal only with one or a very few species. They progress slowly, and the very number of existing species precludes applying the new methods to more than a few of them. At the same time, the need for the kind of basic knowledge of many species provided by the museum specialist continues to grow, while funds for collection upkeep and for the necessary field and museum research diminish.

The great research collections, consisting of thousands to millions of specimens, are housed principally in two sorts of institutions—governmental museums, which often must cater to the general public in their exhibition halls, and university museums whose chief function is to house reference collections. The public museums, often supported by city governments, get funds for public education or entertainment, but little for upkeep of collections or for research. Universities generally support their museums wretchedly. They often do not replace curators who have retired. They may appropriate enough money to keep the specimen bottles filled with alcohol, but little more. In some places even that necessary job now depends on volunteer labor. Thus the continuity of the discipline which was the foundation of modern biology, the handing down from one generation to another of its tradition and skills, stands in danger of breaking up. A student who inclines toward taxonomy, as a few brave souls do, has at best a narrow choice of teachers. He can, of course, learn from books, but that is a poor substitute for the constant guidance of a living authority. For several groups of animals and plants there are but one or two living authorities; for some there are none at all.[1]

A museum collection, which is the basis for taxonomic research, is analogous to a research library. Its value is proportional to the amount of creative work that goes on about it. If a library reduced its staff to a part-time, nonprofessional caretaker, stopped buying new books, failed to catalog those that came in as gifts, and stood them about the floor in piles, it would become a dead place. That is what most natural history research museums are today. They are dead places. Some that are not dead are very quiet. Men of universities who are responsible for the intellectual life of their country should not allow such a situation to continue.

What would it take to restore a sick research museum to healthy life, that is, to the point where it would be a living, intellectual institution, with a constant flow of material and ideas, contributing discerningly to the growth of biological science? Compared with the research in fields of biology that are fashionable today, it need not cost very much. The principal needs are staff and money for travel. One man should not be expected to do all the curatorial work for a collection of world-wide scope, as well as carry on research about his subject of interest, make his own illustrations, do all the measuring and tabulating, teach students, and typewrite his own manuscripts. He needs a corps of assistants. No problem worth investigating can be solved by studying the anatomy of a few dozen pickled specimens. It should be carried into the field, over the entire range of species under study. The museum scientist should have sufficient travel allowance and time to permit this. He must have access to a number of disciplines besides anatomy, particularly genetics, physiology, biochemistry, animal behavior, and mathematics. However, skills in all these subjects will not be found combined in one man. Therefore, a well-balanced museum staff should include several people having among them a wide variety of backgrounds. They should have access to experimental facilities (perhaps in cooperating research institutions) and enough funds to make use of them.

From the point of view of fisheries industries, one of the most valuable functions that a museum staff can perform is the compilation and frequent publication of distributional charts. Since knowledge of distribution is constantly growing and since distribution is constantly changing in response to fluctuations of environment, this must be a continuing job. The almost complete lack of such charts is one of the most serious gaps in recorded knowledge of the sea. The charts that do exist—a few of them are reproduced in this book—contain inaccuracies that severely limit their usefulness.

A much-neglected line of research that is essential to a taxonomic laboratory is anatomy. The internal as well as external anatomy of all species of marine animals must be worked out and described in order to provide a solid basis for understanding their taxonomic position and identity. As it is, less than 2 per cent of the known species of marine animals and plants have been well described, and those mostly before 1900. The status of anatomy today is about as low as that of systematics. A university must support a professor of comparative anatomy of vertebrates since that subject is required for entrance to medical school. However, that is generally as far as the university can go. Any energy the professor has left after lecturing to hundreds of students weekly, he may give to research. One faculty member for teaching invertebrate zoology (including all the land forms) is about as much as can be spared for supporting work in invertebrate zoology in an average university. And museum curators have little opportunity for pure anatomical research. Thus progress is too slow to keep abreast of the needs of other branches of biology. And needs there are. The description of many species of fishes, for example, goes no further than external anatomy. Even studies of races are based only on such superficial features as head length, size of eye, and position of fins. In general, biologists cannot go much further in these studies because they simply do not know the internal anatomy well enough to recognize significant differences in the shape or position of the various organs. Not only taxonomists, but students of behavior and of physiology are handicapped in not having complete knowledge of anatomy.

Characteristics of the digestive system, for example, tell a good deal about the probable feeding habits of an animal. The presence or absence of sensory organs can provide the basis for designing experiments to learn how animals analyze their environment.

The groups that are most obviously pertinent to the problem of exploiting the sea are the marine mammals, fishes, mollusks, crustaceans and algae. But there are other groups of organisms. Are they to continue to be neglected because they seem commercially unimportant? What about the parasitic worms that infest fishes and mollusks? What about the invertebrate animals which are important links in the food chain? What about the starfishes, which are enemies of mollusks, and the pathogenic fungi which infect all sorts of marine animals? If it is true, as is often said, that species can be understood only in relation to their environment, then the ideal natural history museum must comprehend the whole gamut of animals and plants that occur in the sea, for they are all parts of environments in which fishes, mollusks, crustaceans, and algae live.

Where would these ideal natural history museums be placed? There are enough museums already existing so that it is neither necessary nor desirable to establish any new ones. In fact, there are regions where museums that are close together could be consolidated with considerable economic advantage to their supporting institutions. This would require some noble swallowing of pride, but it should be done wherever several mediocre, run-down collections could be combined to help make one good one. As a matter of fact, museum directors of a few institutions, in order to specialize, have already begun a movement to consolidate certain parts of collections by exchange. In any plan to strengthen museums, the highest priority should be given to those which already have great collections with type specimens and which are attached to universities having excellent scientific libraries. These, being close to scientists in fields other than biology, are in the best position to secure imaginative advice for attacking some of the more difficult problems of taxonomy. They are also in the best position to teach principles of taxonomy and the techniques of identification to students of general biology who will later become ecologists, biological oceanographers, fishery biologists, and conservationists.

5

Environment

What kind of biological research would ultimately make the greatest contribution to achieving full utilization of the sea food resources? When I put this question to a number of leading marine biologists and oceanographers of America and Europe, they were remarkably unvarying in their advice: Study environments, seeking to learn how chemical, physical, and biological characteristics of sea water influence its fertility and thereby control the abundance and distribution of organisms. The many elements of environment that combine in various ways to make up qualities of fertility are much less localized in the sea than on land, for they are in constant movement horizontally and vertically. They are carried by currents and are therefore far-reaching in their influence. An event happening in one part of an ocean can eventually, perhaps months later, affect production of living things hundreds of miles away. Every species has its own peculiar set of environmental conditions for optimal production; what is essential to one species may be inimical to another. Thus the production of environments in the sea is an elusive subject to study. What is it? What are problems of understanding it that need to be solved? What is present opinion about the geographic distribution of the more productive areas? What are the important gaps in research programs concerning environments? These are questions which this chapter discusses.

There has been much speculative talk about exploring the depths of the sea to find new species of organisms that could yield large harvests, of diking off salt-water marshes and sloughs and cultivating them for fish farming, and of growing plankton artificially or at least harvesting it in the open sea. Such concepts as these underlie dreams of feeding the world from the sea. What kind of research would be required to accomplish these objectives? What processes would be required to demonstrate their economic feasibility?

Here, as in all scientific pursuits, we must seek principles first, for all of these dramatic measures involve using environments intelligently, somewhat as agriculturists do. That is to say, they involve locating and working the most fertile areas, harvesting selectively to produce the most profitable balance of populations, controlling rates of harvesting, reducing predators, and, in some places and under some circumstances, farming environments by cultivating and fertilizing and by planting stocks which are especially adaptable to local conditions. How successfully we might do any of these things would depend on how intimately and thoroughly we knew the principles by which the intricate mechanisms of environment cooperate to support the lives of useful species. This implies the necessity of studying environments.

Throughout this book I use the phrase "an environment" in an unorthodox way to denote a habitat together with its resident communities of plants and animals. This will avoid some uses of words that fit better in a textbook on ecology.

The environment of a species is its cosmos, the milieu in which it lives. It includes its physical setting—the sea water, with all its mineral salts and dissolved organic chemicals, regimes of temperature and of solar radiation, and structure and composition of the bottom. It includes the whole assemblage of different species of plants and animals that live together and affect each other beneficially or harmfully. It is a system of systems, with inorganic and organic components.

An environment (as I am using the term) is an ecological unit, that is to say, a part of the sea which has peculiar properties that satisfy the physiological requirements of a population or a number of species of populations which live together there. Examples of environments are a deep-flowing water mass, a current at the surface, an area on a bank where the ground is muddy, or an area where it is gravelly. A gently sloping sandy open beach, an estuary, a brackish marsh—all are types of environments. Their boundaries and other characteristics can be extremely plastic, with dimensions, position, and physicochemical properties pulsating continually in response to meteorological and other external influences. The populations which they contain pulsate with them. These changes usually follow a more or less seasonal pattern, superimposed on very long waves with durations of years or even decades, the whole complex pattern marked by brief, sharp fluctuations.

Environments rarely have sharp boundaries, and they are never independent entities, but affect each other in many ways. Events happening in one environment may have consequences in an entirely different one many miles away. Thus it is often difficult, and beyond a certain point, unrewarding, to try to isolate one environment for study without reference to those others that influence it. Few species confine themselves to one type of environment throughout life, but change in response to changing physiological demands. Oysters, for example, which are free-swimming during infancy, settle down to become fixed early in life, and remain so until death. Prawns spend their youth in sloughs and salt-water marshes and later move to sea, eventually traveling rather long distances offshore to spawn. Flounders, like many other kinds of groundfishes, are pelagic during egg and larval stages, during which period they are carried far by currents. After metamorphosis, they settle to the bottom, where they remain thereafter. But even then they are not quite sedentary, for they tend to migrate toward shore in summer and away from shore in winter; and as they get older, they move into progressively deeper water. Herring, on the other hand, are stuck to the bottom during their egg stage, but after hatching, the larvae drift with the currents. After metamorphosis they live very close to shore in bays. As they grow older they seasonally move offshore into deeper water. In inhabiting a succession of environments from birth to death, broods of a species become, in effect, successions of populations, each differing from the others, yet all connected by the strong thread of life history. Events during a brood's sojourn in any one of its environments can prove fateful to the remainder of the life of a brood. Consequently, a proper study of the biology of a species, such as an important food fish, must include the whole gamut of its environments in order to understand the principles controlling its vagaries of occurrence and abundance.

There is a great amount of information about marine environments of the world. Some of it is well organized and easily available in published literature. Much of it is scattered, buried in files, uncollated. Some of it is only in people's heads. What there is originates from various sources. To begin with, fishermen, from the most advanced to the most primitive, living on the sea and depending on its resources as they do, have learned a great deal about what is associated with the occurrence and nonoccurrence of the species that concern them. Quite a few published works are little more than systematized compendia of information gleaned from fishermen.

Valuable though fishermen's knowledge is, however, it often includes a great deal of superstitious lore.

Conclusions from scientific research are more objective, less influenced by tradition, and therefore more dependable than those from fishermen's observations. A large body of systematized knowledge about sea environments has come from expeditions which museums and institutions of marine research have sent out all over the world to take samples of various kinds in various regions. These have collected and described specimens of animals and plants, estimated the abundance of the fauna and flora, and sometimes the rates of its production. They have sampled the water at various depths, analyzed its chemistry, recorded the temperatures, and determined the direction and rates of flow of currents. They have charted the topography, examined the geology of the bottom, and done many other things of scientific interest. The thoroughness of all this work varies geographically, for expeditions have visited some regions much more frequently than others.

The most comprehensive knowledge of environments relates to a few relatively small areas where great fisheries are carried on. This knowledge results from constant systematic study by institutions of marine biology and hydrography which are conveniently located. It is such laboratories which make contributions that have been most valuable to the intelligent use of marine environments. Figure 8 (page 28) shows that these most intensively studied areas of the marine world are in fishing grounds of the North Atlantic Ocean, principally the North Sea, the Baltic, including the Gulf of Bothnia, and the Norwegian Sea; the New England Banks; a segment on the coast of southwestern Africa; the Scotia Sea in the Southern Ocean; the east coast of Australia; the Red Sea; the west coast of North America, principally California and northern Baja California, Puget Sound, and British Columbia; and the northwestern part of the North Pacific in the vicinity of Japan, including the Sea of Japan. Among the least studied areas are the entire Indian Ocean, particularly the Arabian Sea and the Bay of Bengal; the Indonesian Sea; the Arafura Sea; the Coral Sea; and large areas of mid-ocean in the Pacific.

Scientific knowledge about the oceans and their resources is unevenly distributed; so also are marine research facilities. There are about 240 laboratories in the world for studies in marine biology, fisheries, and physical oceanography. Close to 90 per cent of these are in the northern hemisphere; 85 per cent of them are north of 20° N. latitude. In the tropics and the southern hemisphere there are long stretches of coast without benefit of any marine laboratories.

Thus serious gaps in knowledge of marine environments are geographic, and they are associated with a lack of research facilities in the areas about which ignorance is greatest.

In northern regions, the existence of established fisheries had much to do with stimulating the founding of marine laboratories and determining their location. In the tropical and southern regions it is the other way around. There it is proposed to establish marine laboratories to stimulate the founding of fisheries. They should be located as close as possible to production areas. This is an important point, because the sea is not evenly productive. Indeed, much of it is not rich enough to support fisheries at all. Figure 14 (page 37) shows regions where oceanographic conditions are conducive to heavy production of organic matter and therefore, presumably, of fishery stocks. Even though these areas are restricted, they still are very large. Most of them are unexploited or far underexploited. They have been studied very little, and there are few if any facilities for studying them. This is more or less true, for example, of the Benguela Current off southwestern Africa, the north and south equatorial currents of the Atlantic, the northeast coast of South America, the western shores of the Arabian Sea, the Peru Current, and most of the Southern Ocean. Any of these regions would be a profitable area of study for a laboratory.

It is in the long-established institutions of Europe and North America that the classical research techniques of general marine biology, fishery biology, and hydrography have evolved. In general, these laboratories are approaching the advanced and extremely difficult stage in their studies where they must determine how the various elements of environment which they have minutely examined fit together to compose an integrated mechanism—the environment-as-a-whole. It has been taking a long time to reach that point. The road is long and tortuous. There have been many false starts and blind diversions.

A new laboratory can profit by the mistakes which the older ones have made as well as by the principles which they have discovered. Nevertheless it too must go through a long initial stage of exploration and analysis before it can have assembled enough material for synthesis. Even under the most favorable conditions it could not spring into being full-blown. It would be better to begin on a modest scale. From there it would succeed provided it were well backed financially from the start, and provided the people who controlled its existence had the will for it to grow and a sound plan for its future.

The initial program may concentrate on taking a comprehensive inventory of what there is in the region. What are the species of animals and plants? How are they distributed? What are the seasons of their occurrence? As this knowledge grows, the studies should become more quantitative—how much is there? At the same time there need to be built up taxonomic reference collections, a library of world literature on marine biology, physical oceanography, and fisheries, bibliographies of published scientific literature about the region, and all available pertinent unpublished information. As soon as possible, a hydrographic program should begin to determine the characteristics of the water, the pattern of currents, and their connections with the distribution and numbers of animals and plants. Fisheries studies should accompany this developing program, guiding it, fitting into it, taking every advantage of its results, and covering the life histories and behavior patterns of the commercially interesting species.

Gaps in the programs of well-established institutions are not immediately obvious, but nevertheless there are gaps. The principal one is in the interpretation and integration of data relating to all the diverse elements of environment. The center of interest in most marine laboratories is the science either of biology or of geophysics. Marine biologists tend to focus attention on species of animals, physical oceanographers on the chemistry and movements of water. Thus they divide into two groups, each studying a different aspect of environment. What is most seriously needed here is some means of combining these two points of focus to produce a single, full-dimensional picture of the whole environment. This might be best accomplished initially by adding special teams to these institutions. The members would have among them a variety of talents and specialties; nevertheless the subject of their research should always be environment. One of their principal functions would be to assemble all available facts about the various elements of environment to study how they fit together—facts about climate, weather, currents, comparative physiology, life histories, faunal composition, fish catches, sizes of populations, and so forth. In addition, they should engage in laboratory and field studies on such questions as these:

What do animals and plants demand of environment? What are the elements of environment? What are the mechanisms of their actions? What are the boundaries of environment of the various species? Here is needed a tremendous fund of knowledge about the life history and physiology of the many organisms that are part of the more important environments. In the most studied parts of the oceans, such as the Gulf of Maine, research to develop such knowledge has been done for less than 15 per cent of the total species. In other places of interest, such as the coasts of South America and Africa, it has hardly been done at all. The most obvious questions to study about each species are these: Where, when, how frequently and under what circumstances do the individuals reproduce? How fast do they grow? How long do they live? What are their competitors and enemies? What do they eat? How do they behave in response to various stimuli? What are their routes of migration or transport? How are they affected by the submarine weather and climate? How are they affected by such chemical constituents of the water as trace elements and organic substances? What are the forces inducing their oscillations in numbers? What rhythms are in their oscillations? As information on these questions accumulates, it should bring out how the species of any given environment fit together. On that point, which is particularly important in practical fishery problems, our present knowledge is almost nil. How does one species relate to another as predator, competitor, or fodder?

Embodied in these questions is the problem that troubles people in the fishing industries more than any other. What causes fish stocks to fluctuate in abundance and availability? For the last twenty years or so, fishery biologists have centered their researches on the dynamics of fishery populations. Accordingly, they are engaged in acquiring the numerical data for formulas designed to determine the yields to be expected from various levels of fishing effort. One of the most important elements in these formulas is always M. M is a measure of the sum of the fatally adverse effects of environment upon a population. It stands for rate of natural mortality, that is, mortality from causes other than fishing. It is exceedingly difficult and expensive to measure this M; indeed no method of measuring it continuously has yet been devised. For that reason, and also because it is presumed that over periods of several years it fluctuates about a level, the natural mortality rate is treated as a constant. Nevertheless there is evidence to show that the range of its fluctuations can be very great.

There is no universal natural mortality rate in the sea. It differs between species. Within any one species it differs between populations and within a population it differs between localities. It changes throughout life, being highest during infancy and decreasing with age. It fluctuates from year to year. For several years it may be almost negligibly low, but can suddenly assume disastrous proportions. A stock can be reduced almost to the vanishing point by an abnormally long period of unfavorable weather, by an epidemic, or by a rise in the abundance of a species which is a competitor or a mortal enemy.

Marine animals that are not permanently attached, like herring, move in and out of the range of fishing, usually, but not always, with a fairly regular seasonal pattern. Sometimes whole populations or only parts of populations fail to appear on the usual fishing grounds and remain absent for weeks or even for years. Their sporadic and transient reappearances suggest that they have moved to other parts of the sea for a while; in other words, they have become unavailable to fishermen operating on the old fishing grounds. It is sometimes difficult to distinguish such migrations from mortality of the population.

Each of the many biological and physical elements that contribute to mortality in a population fluctuates in one way or another, and its relative importance in the environment of a species may also fluctuate. Consequently, the faunal composition of any environment fluctuates. The more we can understand the mechanisms of these changes, the more accurately we will be able to explain and predict fluctuations in fishery stocks. What is the nature of those mechanisms? To throw light on that baffling question would be one of the most useful achievements of an environmental research team.

What is the causation of variations in abundance, availability, and quality of marine organisms? The practical consequence of these variations is that fishing is a terribly hazardous investment. This is true in varying degrees everywhere, regardless of the fishery, whether it be for fin-fish or for shellfish, in northern seas or tropics. To begin with, the year broods of all species vary in size. That is probably a safe generalization. An extremely good cod brood, for example, may be as much as fifty times greater in numbers than an extremely poor one. A fluctuation may affect all the stocks of a species over a very large area, or only those in a particular locality.

Since the earliest days of marine research, biologists have sought to discover causes of fluctuations by watching for correlations between the size of year broods and those physical attributes of the environment which they know how to measure—temperature, concentrations of inorganic nutrient salts, and speed and direction of currents. To this day, however, no one has found a perfectly consistent correlation that has gone beyond a few seasons. The breakdown of a correlation does not necessarily mean that it was a spurious effect while it lasted, but that elements dominating the mechanisms of survival have given way to others, as they may do sporadically. Not only do year broods fluctuate; virtually whole populations of the adults of some species may disappear from the range of fishermen's activities. This may be the result of mass mortalities, shifts in environment, or overfishing. It is often difficult, with such meager information as is usually available, to be certain which of the three it is. In any event, a species that has thus disappeared sometimes remains absent for ten or twenty years, then reappears in numbers as great as ever. This sort of thing happens with species that are not exploited as well as with those that are. For example, in recent years squat lobsters (*Munida* and *Galathea*) have disappeared from the area about Plymouth, England, where they had previously been abundant. Similarly, sea urchins have become greatly reduced about Cape Cod, Massachusetts. Bluefish are again abundant on the Atlantic coast of North America, where they had been scarce for almost twenty years.

The biochemical composition of marine organisms goes through seasonal cycles which are probably related to the reproductive cycle, but it also varies geographically and undergoes fluctuations from year to year that must be related to something in the environment—perhaps its fertility. For example, in a given locality the menhaden, a herring-like fish used for fish meal manufacture in the United States, may yield no oil in some years, and in others as much as 60 gallons per ton. In a single month of one year it may vary between 5 gallons per ton in one part of its range, and 40 in another. The chemical composition of the marine algae—minerals, vitamins, carbohydrates, and proteins—fluctuates remarkably, and so far, inexplicably (see pp. 276–79). The mechanisms of all such fluctuations are involved with the mechanisms of environment.

Among the organisms inhabiting the sea are pathogenic (disease-causing) bacteria, rickettsiae, protozoa, fungi, and viruses. At times any of these can rise to epidemic proportions and have devastating effects on susceptible populations. Since this subject is discussed in a separate chapter, it is enough to say here that the study of the place of disease in marine ecology has been almost completely ignored in research programs. What elements of environment govern fluctuations in the occurrence of disease? What are the effects of diseases on animal numbers? These are questions with which an environmental research team would be deeply concerned.

A complex of problems centers around the basic fertility of the sea, which is an attribute of environment that bears most significantly on fishery stocks. In studying this topic, it is necessary to draw heavily on the work of fishery biologists on the one hand and of physical oceanographers on the other, and here a team of environmental scientists could serve as a cementing agent to draw the two groups together in planning their respective programs and in interpreting their results. In the following pages, I shall discuss fertility of environments to suggest the scope of a research program in this subject.

Animals of the sea, like those on land, can prosper only in fertile environments; and just as on land, fertility is measured by the assemblage of physical and chemical properties that make it possible for plants to grow. The great bulk of sea plants is in the form of phytoplankton. Although phytoplankton occurs in the surface layers all over the oceans, the rates of its production and the quantities produced vary widely from one situation to another. They also run through seasonal cycles and fluctuate from one year to another. Fertility, through its relation to the production of phytoplankton, is the foundation on which the abundance of all marine resources is based. It is therefore a subject of the greatest pertinence to scientific sea harvesting.

Only plants, through the process of photosynthesis, can transform inorganic chemicals into organic food. Animals cannot do that; they can live only by eating, and they can eat only as much as is produced in their environment or is carried into it by currents. Some species eat mostly phytoplankton; others subsist wholly or in part on other animals; still others are omnivorous. But whatever their food habits, the rate of production of animals in the sea is set by the rate of production of plants. Sedentary animals depend on the food pyramid supported by the plants which occur in the area where they reside. If these animals happen to be carried to an unproductive place during their drifting phase, they starve. Roaming animals, on the other hand, such as swordfish or squid, which have broad environmental tolerances, go searching for areas where food is sufficiently plentiful to satisfy their rapacious needs. When hunting becomes unrewarding in one place, they can go to another. Even though they feed high in the food pyramid, they nevertheless depend on a rich production of phytoplankton to support the food in the various centers which they visit.

The most immediate effect of phytoplankton is on the herbivorous animals, that is, chiefly small invertebrates and very young postlarval fishes. Here there is a reciprocal relation, for the rate at which herbivores crop the phytoplankton influences the rate of its production, and that in turn influences the rates of production, growth, and survival of the grazing herbivores. Among carnivores, the same kind of relation holds between populations of predators and of their prey. Such relations obtain among all the populations living in an environment; they depend on the rates of metabolism, reproduction, and growth of each population. These rates vary widely from one species to another. Within any one species, they vary with temperature and other characteristics of the environment. Obviously, the causes of oscillations in populations are exceedingly complex and therefore exceedingly difficult to trace. However, the fundamental, all-pervading influence is fertility; for the basic food, that is, the plants of the phytoplankton, like those of land, cannot flourish without material with which to synthesize their food.

Phytoplankton can utilize light only in the uppermost 30 to 300 feet of water. That being where they live, that is where they must obtain all their required nutrients. However, the sources of natural refertilization, that is, the waste products of the living plants and animals and the decomposing bodies of the dead, sink continually to levels deeper than the zone which the light required for photosynthesis penetrates. In high latitudes life flourishes in the sea from spring into fall, the phytoplankton and the zooplankton going through alternating cycles, the animals reducing the plants by grazing, and all diminishing to low ebb by late fall. Growth can resume only after the fertility of the surface environment is restored. This is accomplished through seasonal climatic and hydrographic mechanisms which bring about exchange between the nutrient-rich deeper waters and the impoverished surface.

This exchange occurs where cooling in the winter causes the surface water to become denser and heavier than that at lower levels. As this relatively heavy water sinks, it is replaced from below by rising lighter water, which is rich in nutrients. In the spring, in high latitudes, when the amount of daylight increases, the phytoplankton resumes its cycle of production.

Elsewhere, chiefly in lower latitudes, there is another mechanism which brings enriched water to the surface. In certain places, long persistent seasonal winds blow from one direction. For example, northwest winds prevail along the California coast from early spring to midsummer. The water which these winds push is deflected sharply by the action of the earth's rotation (to the right in the northern hemisphere, to the left in the southern) and is replaced by "upwelling" from below. Upwelling is a prominent feature of the hydrography along certain coasts (California, western South America, western Africa). Wherever it occurs it is associated with heavy production of organisms and rich fishery resources. A similar result occurs in the open sea wherever divergences exist. These are zones where the surface currents separate under the combined influences of wind, the earth's rotation, and density differences. To make up for this loss, water rises from the depths. Unlike upwelling or winter overturn, this process may operate the year round, as along the equator in the Pacific.

A meeting of currents from different directions may also result in mixing and local divergences, with rising of deep water, resulting enrichment of the surface, and high productivity. This happens off the northern islands of Japan, where the warm, northward-flowing Kuroshio meets the cold, southward-flowing Oyashio; it happens south of the Grand Banks of Newfoundland, where the Gulf Stream meets the Labrador current. These areas, and others where similar situations obtain, are extremely productive fishery grounds (see Figure 1, page 15).

Exchange between very widely separated places occurs by simple horizontal movement of water. Perhaps the most extreme example of this is the great transport of surface water at a rate of something like 6 million cubic meters a second from the Antarctic up to the far reaches of the North Atlantic. This great mass of water comes from various sources—some of it from the southern hemisphere, some from the Mediterranean, some from around Greenland—all of it water that had become depleted at the surface, had sunk, and flowed southward at deep levels. All along the way it had become replenished with nutrients from the decay of sinking dead organisms. Around the antarctic continent it rises rich in fertilizing substances, to nourish one of the most productive areas of all the oceans; thence it returns ultimately to northerly seas.

Thus it is the vertical movement brought about by such processes as upwelling in some parts of the world and winter cooling in others that brings inorganic nutrients and perhaps also biologically important organic substances from deeper water to the surface where they become available for the growth of phytoplankton. The intensity of these processes varies seasonally and annually, and this has much to do with variations in the production of plants and animals. And it is by the horizontal movement of water, which also varies continually in speed and direction, that all the properties of environment—nutrients, temperature, plankton—are transported, sometimes to places far removed from their regions of origin. John Tait, of the Scottish Home Department, has written the following on this subject:

> Currents control the distribution of temperature and other physical and chemical properties of the sea. They control the distribution of the ultimate food organisms on which all marine life depends. They control further the dispersal of fish eggs and of the youngest fishes until these acquire motive power of their own, and, in the reproductive stage of a fish's life, which, as it were, completes a cycle, they govern very largely, if not entirely, the movement of fishes

towards the places where those physical conditions exist in which alone reproduction will take place.[1]

An example of the influence which movement of water can have on a fish population is the case of the Pacific sardine. Between 1947 and 1953 this species disappeared from the coast of California. During the preceding thirty years the sardine fishery had gradually grown from its inception into the largest of all American fisheries, producing more than 500,000 tons annually. The supply failed first in 1947 in the northern part of what people had assumed was the normal range of the species. For a while it looked as though this might be a local fluctuation and perhaps the fishery would hold up as well as ever off southern California. However, it failed there too, at length, so that by 1954 fishermen caught less than 70,000 tons. Apparently this dramatic disappearance of a great fishery resource is largely the consequence of a change, the nature of which is still unknown, in the regime of hydrographic conditions on the Pacific coast of North America.

The principal elements in this pattern are the California Current, which flows southward, an inshore complex water mass of variable characteristics, which includes a northward-flowing countercurrent, and the northwest winds that prevail along the coast during spring and early summer. At this season, as a result of the action of these winds and of the earth's rotation, surface water turns seaward while deeper water wells up to replace it. This upwelled water carries phosphates and other nutrients that had sunk and accumulated during the preceding winter and fall. Scientists studying sardine problems have described these processes thus:

> Between the California Current and the coast, the region in which sardine spawns and is fished, appear complex systems of countercurrents and eddies, changing with the changing seasons. Winter ordinarily finds a strong, narrow countercurrent flowing northward along the entire coast. When the countercurrent is absent at the surface, as it usually is during the summer, oceanic eddies, great lazily revolving masses of ocean water, form in the inshore region. Such eddies usually form near Central California, near the Channel Islands of Southern California, and near Punta San Eugenio in central Baja California.
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> The most persistent of the eddies is located near the Channel Islands. This giant wheel of water, some 100 miles or more across, rotates slowly counterclockwise. Its center is characterized by the "enriched" water that has ascended to the surface from a depth of 700 to 800 feet ("upwelling"). . . .[2]

These seasonal shifts may be closely associated with changes in the subsurface countercurrent.[3] This current contributes somewhat to upwelled water, at least in the deeper layers. As a consequence of meteorological variations, it fluctuates in intensity and in the distance which it travels at the surface. A strong development of this current seems to be associated with northward incursions of sardines and of their spawning grounds, with large year broods and with good fishing. This may result from the countercurrent transporting the environment optimal for the well-being of sardines, which includes temperature and other physical characteristics of environment as well as food.

The United States Fish and Wildlife Service's Pacific Oceanic Fishery Investigations, under the leadership of Oscar Sette, have demonstrated that divergence and upwelling at the equator enrich the surface waters with inorganic nutrient salts which stimulate the production of plankton. These plankton-rich waters drift northerly to a convergent zone. Experimental longline tuna fishing has consistently proved to be more successful there than in areas adjacent to this system. On this, Sette writes:

> The quantities of catch and the positions of the zone in the north-south direction have varied considerably, probably in response to accelerations and decelerations as well as the swaying north and south of the current system. Although our observations have not had sufficient continuity in time and space to elucidate these variations, it remains quite clear that the divergence-convergence features of the transverse equatorial circulation provide the basic support for a persistent concentrated stock of yellowfin tuna.[4] [Figure 14, page 37.]

Alfred Redfield,[5] of the Woods Hole Oceanographic Institution, has shown how the circulation of water affects the distribution of zooplankton in the Gulf of Maine. The dominant feature in the circulation of this body of water is a great anticlockwise eddy, which in the surface layers flows at an average rate of about seven miles a day. The eddy is fed by water which comes in on its eastern side from over the Nova Scotian Banks; and it loses a corresponding amount which escapes southward and eastward across the end of Georges Bank. This inflow and outflow varies seasonally and from year to year. It is at its peak in winter. The new water that comes in at that time is relatively barren, and remains so until spring, when conditions become favorable for growth and reproduction. The water of the eddy is by no means completely replaced at once, however. Much of it remains in the southern part of the eddy supporting a rich population of plankton that had grown up the previous summer and had become only moderately diminished by the adverse conditions of winter. In the spring and summer, when the inflow and outflow decreases, this held-over water starts moving northeasterly in the direction of the Bay of Fundy, engaging in a second circuit of the Gulf of Maine. Thus it enriches with plankton the northern part of the gulf during the late summer and fall. Thus, too, the gulf is largely self-supporting, and contributes to other areas as well. The distribution of the petrel, a plankton-feeding bird, corresponds in a striking way to that of the plankton. In June and July the birds are most numerous in the southwest part of the gulf; in August they are distributed more northerly; in September they are rather evenly distributed about the gulf.

Mackerel, which are plankton-eating fish, evidently also follow a similar pattern. In early summer, they occur along the southern shores of the Gulf of Maine. By late summer they have moved to the northern shores, including the Bay of Fundy. The distribution of mackerel fishermen fits the pattern too, for of course they follow the fish.

Animals of boreal origin may be carried into the Gulf of Maine eddy, and not survive there. Thus occasionally swarms of the planktonic mollusk *Limacina retroversa* invade the Gulf. Redfield, in discussing a study of one of these invasions, writes:

> The most conspicuous result of this study is the demonstration of the degree to which the occurrence of *Limacina* in the Gulf of Maine depends upon the circulation of its waters. Damas [6] in 1905 raised the question: How does the plankton of a given region maintain its character in the face of the continual circulation of the currents and how does a given species persist so as to possess a special geographic distribution? He concluded that there must exist a special zone or center of production in which adults abound and reproduce successfully and that to this region circulatory currents serve to bring back periodically a proportion of the individuals which become entrained and dispersed by the continual movements of the water . . . The observations on *Limacina* have not revealed the presence of a center of production in the Gulf of Maine. They point to the existence of such regions offshore to the eastward and are of interest rather in telling something of the fate of these animals, entrained in the movement of water, which are carried away never to return, yet for a while to occupy an important role in the ecology of other regions. Behind the geographical distribution of each species of plankton there must be a complex balance of biological and physical factors. Of the latter, flow of water appears to be paramount; its consequences too frequently neglected.[7]

Important though flow of water may be, however, other properties of environment besides motion evidently also affect marine life, and not all of these are known. Indeed there are many mysteries about the production of marine organisms that have eluded all efforts to understand them. On a small island close to Pensacola, Florida, the United States Fish and Wildlife Service operates a laboratory for studying oysters. There, oysters taken from a homogeneous stock and planted at opposite ends of the island, a distance of not more than 1000 feet, grow at significantly different rates and ultimately attain significantly different average size. At the same time, the growth rates in the two localities fluctuate simultaneously and in the same direction. The physical conditions at the two localities seem to be identical; at least two years of intense search have failed to disclose a difference in any measured feature of the environment.

Another example: Oysters live a brief pelagic existence during their larval stage. At length they "set"; that is, they settle to bottom, fasten to a solid object, if they happen to be lucky enough to find a suitable one, and remain there until death. The number of oysters that sets varies tremendously from year to year and from place to place. Nowhere in United States' waters has this been shown to be correlated with the number of spawners or with any of the characteristics of the sea water that have been measured in oyster beds. The degree of fluctuation itself varies. In some places, like the Thimble Islands in Long Island Sound, the oyster set is consistently good. In other places like New Haven Harbor, which is only a few miles away, it is consistently bad. Why this is so remains a mystery.

In the Limfjord of Denmark, on the other hand, scientists believe fluctuations in the set of oysters are definitely associated with weather. R. Spärck writes on this:

> The depletion of the stock of oysters on natural beds in the Limfjord . . . was not evenly distributed; in large parts of the fjord the decrease was even greater than 90 percent and it appears that in a few restricted areas the decrease was much less . . . in the period from 1925 to 1937 there was no oyster fishing at all on the natural beds in the Limfjord, so that the stock decreased only on account of natural conditions. There can hardly be any doubt that the fluctuations are mainly governed by the summer temperature since the periods of increase coincide with periods of warm summers (mean temperature in July of the surface water of the Limfjord about 18° C. or more) while periods of decrease coincide with periods of cold summers (mean temperature in July of surface water in the Limfjord 17° C. or less).[8]

The quantity of organic substances at times appears to play a most critical part in productivity of the sea. Thanks to the work of a few scientists in scattered places, evidence is slowly accumulating to foster a belief that the various organisms themselves may have important effects on each other's distribution and abundance, either by their mere presence or, more likely, by substances—ectocrines—which they impart to the water.

The literature contains many reports on the scarcity of fish in places of maximum phytoplankton concentrations. For example, R. E. Savage[9] found that *Phaeocystis,* an alga which reaches the height of its bloom in spring, sometimes seems to constitute an impassable barrier to the shoaling of herring on the usual fishing grounds. At other times, it may divert more herring to the fishing ground, depending on its position. Similarly, A. C. Hardy and E. R. Gunther [10] observed that in Antarctic regions euphausids and other animals of the plankton are relatively scarce where phytoplankton is abundant. They admitted that the euphausids, enormously abundant, widely distributed, and voracious as they are, must to some extent reduce the quantity of phytoplankton by grazing, a fact which can account for the observed inverse association. Nevertheless, they remarked that not only herbivorous animals of the plankton but carnivorous ones as well seemed to avoid dense patches of phytoplankton. Even the animals which were too scarce to affect the abundance of the phytoplankton appreciably by feeding on it seemed to avoid it. Hardy suggested a theory—"The Animal Exclusion Theory"—that some marine plants have properties repellent to animals and thus in effect exclude them by their presence. Biologists do not universally accept this theory, for they find it hard to believe that animals would be repelled by their food. [Concentration?]

To test this point Richard Bainbridge,[11] working at Plymouth and Millport, studied how zooplankton behave in the presence of different species of phytoplankton. His observation aquarium consisted of a transparent tube, held horizontally for some experiments, vertically for others, and divided into compartments by sliding doors. In a typical experiment, he would fill one end of this apparatus with filtered sea water and the other with water that had been enriched with phytoplankton. Then he introduced the experimental animals in each end of the tube, opened the sliding door, and watched the animals to see the direction and speed of their migration. Did they move toward the end with the greatest concentration of phytoplankton or away from it, or were they quite irresponsive? That was the question at issue. In the horizontal apparatus there was a significant movement of experimental animals into water enriched with cultures of four out of seven species of diatoms and five out of seven species of flagellates tested. The animals did not react to three of the diatoms or to two of the flagellates tested, and they migrated away from two species of flagellates that had given evidence of having toxic properties. In several, movement toward the enriched water seemed to be more definite among the animals that had been starved before the experiment than among those that had been well fed. These experiments demonstrate that animals of the plankton react variously to different species of plants, being attracted to those which presumably are nutritious, indifferent to those which are not, and repelled by some which are distasteful or toxic. Bainbridge concluded that phytoplankton could not remain abundant long in the presence of herbivorous animals. The suggested sequence of events is something like this: on locating a concentrated stand of plants a swarm of animals feeds until it has reduced it almost to the vanishing point; then it goes searching for another pasture. Thus plants can remain in dense aggregation only until animals find them, and thus the exclusion effect is produced. Bainbridge suggested that the positive or negative reactions which certain species of plants invoke among animals might be mediated by substances excreted into the water.

Scientists have known for a long time that sea water contains considerable quantities of dissolved organic substances.[12] These are presumably the products of decomposition of the dead bodies of plants and animals and of the processes of respiration, secretion and excretion of the living. For the past twenty-five years, biologists have accepted Krogh's [13] contention that these substances are not used as food in the ordinary sense, at least the metazoan animals do not seem to take up significant quantities of them. Yet a number of pieces of evidence from recent studies suggest that organic substances in sea water *are* biologically important to living organisms, if not actually used as food.

It is simple to make up an artificial sea water with the proper proportions of the various chemical constituents dissolved in distilled water. This can be enriched with phosphate, nitrate and iron, and its hydrogen ion concentration can be adjusted with carbonate, so that by ordinary chemical tests it is indistinguishable from natural sea water. Nevertheless, certain species of diatoms will not grow in it until some natural sea water is added; only a small amount is enough to start the plant culture growing vigorously. The same effect can be produced with a decoction of algae, or with soil extract, or with certain organic compounds. Not all natural sea water has this life-stimulating property. For example, water which H. W. Harvey collected near Plymouth in late summer and early autumn of 1937 and again in July 1938, lacked it, as evidenced by the fact that diatoms did not grow in it but formed spores which failed to develop and died in spite of the water's being fertilized with inorganic nutrients. On the other hand, two lots of water which Harvey collected in the same place in October 1937 and April 1938 proved to be fertile enough for diatoms to grow in without the benefit of organic additions. Harvey then concluded:

> The inference drawn from these observations on growth in natural sea water is that these two particular strains . . . require for continued growth, not only a supply of available nitrogen, phosphate and iron, but in addition, some

other accessory substance or substances, whose concentration in offshore sea water was less than the necessary limit during the summer of 1937 and 1938. In the autumn of 1937 either the accessories were re-formed or a body of water containing the accessories had moved into the area. This *"fertile water"* either lost its fertility or was gradually replaced during the early summer of 1938. Samples of offshore water collected during the autumn and winter of 1938 behaved in the same way as water collected during the summer—there was no return of "fertile water." [14]

These accessories are evidently a complex of substances which Harvey has divided into two groups, *A* and *N*. The biological effects of *A* substances on diatoms can be duplicated by adding *l*-cystine, glutathione, methionine, aneurin (Vitamin B_1), or biotin. There is probably some special biological significance to the fact that these compounds all contain divalent sulphur. Water rich in accessory *A* substances becomes infertile on standing and will not support diatoms until fresh *A* substance has been added. The effects of *N* substances can be duplicated in part by certain other compounds, among them *dl-a* amino-propionic acid, *dl-a* alanine, *dl* lactic acid, dextrose, and gluconic acid, all of which form complexes with iron and manganese. Diatoms will grow in sea water enriched with nitrate, phosphate, and iron, without any accessory substance, provided a small amount of manganese is present. They grow better if silica and trace elements are also present, but still better when accessory substances are added.

For many years the staff of the Plymouth Laboratory had measured the annual cycle of nutrients and of the resulting abundance of plankton and young fish in the English Channel near Plymouth. During the winter of 1930 there occurred a sharp drop in the concentration of phosphate, which was followed shortly by a drop in the abundance of plankton and young fish, and a disappearance of the herring that had formed the basis of an important winter fishery. At the same time, the composition of the pelagic fauna changed. Whereas for five years a certain arrowworm *Sagitta elegans* had been the more prominent of the two principal species of the group of animals which occurs in that part of the world, it was replaced by another species of arrowworm, *Sagitta setosa,* which has predominated almost continually ever since. Each of the two worms is associated with a particular environment, S. *elegans* with a body of water ("western water") coming from the direction of the open Atlantic, and S. *setosa* with the water of the English Channel. Under favorable oceanographic conditions, western water has pulsed seasonally into the channel carrying with it its characteristic fauna. Some scientists affirm (others disagree, or at least consider unverified) that channel water is favorable for a flowering of the diatom

Rhizosolenia, which in turn seems to repel herring. It is unfavorable to the survival of larvae of certain sea urchins and Polychaete worms. Under laboratory conditions these young animals developed abnormally when nurtured in channel water, but in water identified at sea as "western" and transported to the laboratory, they prospered and grew normally.

One of these bodies of water must contain some substance still unidentified which the other lacks. This substance may be necessary to the production of living organisms, and therefore a constituent of western water. On the other hand, it may be toxic and a constituent of English Channel water. Douglas Wilson has carried out experiments pertinent to this problem. He finds that worm larvae do not live in a jar of pure channel water; on the other hand, they do very well in a jar of western water. The addition of some western water to the jar of channel water evidently adds whatever is needed for the survival of the worm larvae. So it appears that the western water does contain some symbiotic substance.[15]

On the other hand, sea water also contains antibiotic substances which under some circumstances may be enormously important. To non-marine bacteria, sea water is curiously antagonistic. They cannot be cultivated on nutrient agar prepared with it. It kills 80 per cent of the organisms in sewerage within half an hour. The salt is not what kills the organisms, nor the osmotic pressure, as proved by the fact that after the water is heated bacteria will live in it almost indefinitely even though it is no less salty than before. Besides, they will grow on media made of artificial sea water. Evidently there is something in the natural water that has an antibiotic effect. What this something is has not yet been determined. It deteriorates on standing, some but not all of it is stopped by fine filters, and it is destroyed by heat. Its effect is strongest in fresh sea water collected in places where the population of marine bacteria is most concentrated. Among fifty-eight species of marine microorganisms which William Rosenfeld and Claude ZoBell [16] tested at Scripps Institution of Oceanography, nine were found to exert an antibiotic effect against non-marine forms.

B. H. Ketchum and others of the Woods Hole Oceanographic Institution observed the same effect in nature.[17] At Mount Hope Bay, Massachusetts, they found that the concentration of coliform bacteria discharged in domestic sewerage diminishes much more rapidly than can be accounted for by mere dilution with sea water. Again in New Jersey, Ketchum and his colleagues [18] studied the fate of coliform bacteria in the Raritan River and its tidal estuary. They began at a point where the bacteria, recently introduced into the river, numbered 115,000 per cubic millimeter, and they made comparable observations successively toward the mouth of the river until the concentration of cells reached 214 per cubic millimeter. Almost all of the diminution in concentration was accounted for by the joint action of dilution, antibiotic effects, and predation. In the river end of the estuary, the three were about equal in their effect, but toward the sea the bactericidal action gained ascendancy until at the end of the observations it was about thirty-five times as effective as dilution and about sixteen times as effective as predation in reducing the concentration of the bacteria.

In a review of the significance of organic substances in sea water, C. E. Lucas, of the Scottish Marine Laboratory at Aberdeen, Scotland, writes:

> Here may briefly be considered the possible mediation of "animal exclusion" in which it now seems reasonable to see the more or less passive avoidance of certain plant products [those typical of peak numbers] which in some instances may prove lethal if they cannot be avoided. . . . The widespread occurrence of antibiotics elsewhere makes highly probable the existence of such processes in the sea, and a diversity of processes may be anticipated. Some of them may only apply between some plants, and others only between some animal species, whilst "antibiotics" between some organisms may prove to be "symbiotics" between others. In the case of "animal exclusion" the observed effect is between plants and animals (i.e., the plants inhibiting the the animals, although it is by no means certain that instances of the reverse inhibition do not occur, in view of the known excretion by animals of substances of biological significance). The nature of the metabolite in "animal exclusion" is as yet quite uncertain; it is possible, however, to suggest one type of agency, although by no means the only possible one. . . . Phytoplankton organisms produce carotenoids and sterols within their bodies, and their flowerings are known to leave large quantities of the former and probably of the latter, by one means or another free in the water. . . . The comparatively well-established knowledge of the influence of sterols in life, and the growing appreciation of that of the carotenoids, immediately suggest their probable significance as free environmental agents. . . .
>
> Whilst certain carotenoids and sterols, at moderate concentrations, might well be beneficial to certain animals, at higher concentrations they might induce avoiding reactions or be lethal.[19]

Thus the abundance and distribution of any species in the sea, including those useful to man, are influenced in varying degree and in various ways by all the other kinds of creatures about them. Where there is a rich production of phytoplankton, there can be expected to follow a rich production of zooplankton and thence of higher invertebrates, fishes, and marine mammals. But these relations are evidently not so simple that they can be described in a system of formulations such as the gas laws. Some species of phytoplankters can prosper only in water in which other phytoplankters have preceded them. Other species are less demanding. Phytoplankters give off substances which have important physiological effects on animals, some favorable and attracting, others unfavorable and repelling, still others deadly poisonous (see Chapter 11). At least one species of animal, the American oyster, and therefore perhaps others, seems to be able to feed only when dissolved organic substances exceed a certain critical concentration.[20]

How important to the well-being of fishery stocks are these organic substances that have biological effects? What are the mechanisms of their physiological actions? What controls the rates of their formation? What is the geography of their distribution? These are questions which will be answered only with the accumulation of a great deal more knowledge than exists today about the biochemical and physiological intereffects of organisms. They are questions which might be most fruitfully studied by an environmental laboratory.

Thus a fishery stock in an environment is but one detail in a vastly intricate system. Biologists usually refer to the predator-prey relations in this system as "the food chain," evoking thereby an image of an orderly succession of linkages, connecting smaller fodder to feeders, that is, microscopic plants to herbivorous plankters to small carnivores to successively larger ones. Although this is a useful piece of jargon, the scheme of things in the sea cannot be adequately described as a chain. "The food pyramid" is an expression that is frequently used; "the web of life" is another, "cycle of life" still another. Whatever we call the system, however, the primary element in it is the array of microscopic organisms which fulfill many functions, of which the most obvious are the synthesis of carbohydrates by plants and the dissolution of dead organisms by bacteria.

Diatoms, flagellates, protozoa, and bacteria are the most numerous organisms in the sea and the groups about which least is known. Furthermore they are the least studied. This is less true of diatoms than of the other groups. Diatoms are easily collected, preserved, and identified, and their functions seem fairly clear cut. Ecologists in discussing the food pyramid emphasize the diatoms as the chief primary producers because they are the most familiar. At the same time, the naked flagellates, which photosynthesize, may be quite as numerous and as important. These organisms are exceedingly delicate; they disintegrate in preservative and therefore it is difficult to sample them quantitatively. For example, *Gymnodinium brevis*, a dinoflagellate, is killed within seconds if the collecting apparatus contains a trace of copper, to which it is particularly sensitive. Bacteria are affected similarly by metals, as may be species of flagellates other than *G. brevis.* Consequently present ideas of the abundance of these organisms may be based on gross underestimations.

What is the role of dinoflagellates in the sea? They photosynthesize, and under some circumstances they also ingest food. They can use extremely low light intensities in photosynthesis. Could it be that they are the chief primary producers in deep water? In this connection it may be especially significant that they can apparently live at lower nutrient levels than many other microscopic forms, such as diatoms.

Bacteria are widely distributed and extremely important in marine ecology. They too are closely involved with fundamental processes in the sea. Yet there are few scientists engaged in marine bacteriological research. ZoBell in his monograph on hydrobacteriology writes, "It has been necessary to rely largely upon personal judgment in recording the frequency of occurrence of bacterial genera in the sea. The descriptions of many marine bacteria are so fragmentary that it is difficult or impossible to ascertain the genus to which they belong." [21] The biology of microorganisms of all classes has been more neglected than any other subject of marine research. Work in this field should be greatly expanded to include laboratory physiological and biochemical studies as well as careful quantitative observations at sea.

How observations on characteristics of the environment might be integrated to evaluate the role of each element and to predict biological effects under given circumstances has been demonstrated by Riley, Stommel, and Bumpus in an analysis of data concerning a portion of the western North Atlantic Ocean.[22] They took into account measurements of solar radiation, temperature, vertical turbulence, transparency, and the concentration of phosphates in deep water; and they used these five environmental factors to estimate theoretical quantities of phytoplankton, herbivorous zooplankton, and carnivorous zooplankton. The quantities of plankton which they estimated for various parts of the western North Atlantic corresponded closely to the quantities which they actually observed during the brief period of their study. As more systematic data about environments accumulate, the accuracy of such estimates should improve. Furthermore, it might become possible to extend the methods to the prediction of the abundance of fishery stocks.

In the foregoing pages, I have tried to develop a case for setting up teams of scientists to concentrate their attention on the study of marine environments. It must be admitted that a considerable body of theory and fact on this subject has already accumulated for a number of regions. Indeed, it is not possible to carry on any serious marine oceanographic or fishery study without adding to knowledge about environment. A few scientists in scattered places devote all their time to integrating data in order to formulate a concept of environmental dynamics. Gradually, their efforts should become ever more rewarding and useful. Still, these people depend very largely on hand-me-down data. They have little to work with and little help, and their inclusion in oceanographic programs, while welcome, is often pointedly incidental to other activities. Consequently the growth of knowledge about sea environments is retarded.

The literature is full of comparisons between the productivity of the land and of the sea, between farming and fishing. There really is no adequate basis for comparison yet; we do not really know the sea as we do the land, and our knowledgeable use of sea environments is centuries behind that of land environments. If it were desired to expand knowledge about marine environments, where it is most needed, what would be the best way of going about it? The most obvious answer would seem to be this: Establish laboratories in maritime countries where they are now lacking. It would seem logical to give precedence to countries whose populations are densest, whose food problems are most serious, whose fisheries are still far undeveloped, and which are within practical cruising range of promising fishing grounds.

This seems reasonable enough. If there are so many laboratories in northern countries, they must be needed. If they were not beneficial or at least gave no promise of being beneficial, they would not continue to be supported as they are. If they are needed in one part of the world, why not also in another?

However, it is easy enough to say, "Put marine laboratories here and there." Some serious obstacles have to be faced. These institutions cost a great deal of money to establish and a great deal more to maintain. The laboratory building is only the beginning. There must ultimately be expensive equipment such as aquaria, scientific instruments, libraries, fishing gear, and sea-going vessels. There must be a well-balanced staff of scientists who are paid salaries high enough to keep them happily attached to the institution, and given enough expense money to make their research programs effective. It is better not to establish a laboratory at all than to give it poor equipment, inadequate support, and half-hearted backing.

Money, then, is the first problem. However, it is not necessarily the most difficult one. Recruiting the scientists might be harder.

These men should be well educated in their fields. The director of a new environmental research laboratory situated in a relatively unexplored area should have an exceptionally wide range of learning and experience. His team should be composed of men dedicated to applying their several fields of learning to the central goal of understanding the sea as a system of environments for living organisms. Drawn from many countries, they should be congenial and understanding of each other's cultures. Scientists willing to uproot themselves are not easily found. Apart from that fact, there are not enough qualified general marine biologists, fishery biologists, and physical oceanographers in the world to satisfy present demands. There is some hope that this situation will improve, since many countries are sending students to northern universities for training in aquatic sciences. Yet here another problem is introduced. These people go to long-established, well-equipped research centers for their education. They become familiar with advanced techniques. When at length they return home, ready to begin putting their learning to use, they often find nothing to work with—no suitably equipped laboratory, not enough money to finance a research program, a vessel perhaps, but no means to operate it, and worst of all, only half-hearted interest from their government. Sometimes a man returns home to find his job gone. These are the most frequent complaints of foreign students in northern universities. Probably it is unreasonable to expect large enough means to maintain an effective laboratory in every country. The alternative, of course, is to encourage two or more countries to cooperate in establishing and maintaining regional laboratories.

6

The Uses of Ecological Principles

Another View of Environmental Research

Management of fishery industries and conservation of fishery resources should have one common goal, namely, full use of marine environments. Research and thinking about environments, particularly in relation to philosophies of conservation, should be directed toward finding principles of ecology that will be helpful, if not essential, to achieving that goal. In this chapter a few principles that seem valid and pertinent to our subject are examined in comparison with some common misconceptions that are often responsible for the wasteful misuse of environments. The development of true ecological principles depends on long-continued systematic studies of environments. In general, ecological research in the past has not been continuous. Such progress as has been made in this field has resulted from spurts of transient, sometimes enthusiastic support usually ending with fits of impatience or starts of economy. Consequently, much of marine ecology is characterized by a quality of aimlessness, as though people concerned with it, lacking direction, devoted themselves to collecting odds and ends of unrelated data. What is needed for this field is a clear goal and a great deal of attention to the integration of *results with the formulation and rigorous testing of natural laws. Two general lines of work are indicated: (1) systematic, well-planned field observation, which would come within the purview of the laboratory of environment proposed in the previous chapter, and (2) assembling and analyzing information from all available sources to see how it can be applied to the direction of fisheries.*

The argument of the previous chapter was directed toward making environment the subject of research for the sake of learning the how's and the why's of the occurrence of the various kinds of marine organisms, regardless of their commercial value. Such research would enlarge knowledge of the mechanics of ecological systems and would be used as a basis of dynamic fishery management. This chapter will examine environmental research once again, this time from the viewpoint of application of its results to the development of a science of fisheries.

A few definitions will be useful: by a system, we mean an assemblage of natural elements which affect each other in various ways and are thus united by interaction or interdependence. "Ecosystem" is another way of saying environment (as I use the term in this book), but it connotes something more, namely, the environment in action.

Dynamic fishery management, an ideal to be striven for, is continuous direction of fisheries so as to take full advantage of the action of ecological principles in relation to current conditions of availability, density, abundance, and distribution of all the various usable species. That is to say, an industrial or governmental fishery manager having current knowledge about an area over which his fishery operates—the characteristics of the environment and the physiological requirements, and abundance, and distribution of the several species—would deploy the fishermen's efforts over time, over fishing grounds, and among species, so as to spread the harvests to promote on the average the most economical use of fishing time and equipment, and to encourage a desired balance of the populations.

The idea of dynamic fishery management differs from the concept of management which has long been orthodox among people concerned with exploiting the sea, in emphasizing the environment as a whole rather than a few popular species within it. It is based on the principle that the composition of every environmental system exists naturally in a state of constant flux, whether man is part of the system or not. Individual populations flow and ebb as shifts in the environment favor or do not favor their specific requirements. Any action disturbing one part of the system necessitates some reaction, however slight, in all the other parts. Thus readjustment toward a steady state goes on constantly.

Nevertheless, ecological systems seem never actually to reach a steady-state condition because the environment changes continually, within limits, just as do elements in large-scale geophysical systems such as the weather. The assemblage of species responds variously to these environmental changes as well as to each other's response to them, and there are time lags in these adjustments. Thus at best the species of a system are in a state of continual oscillation. The alternating waves of abundance of predator and prey species is one example. The lag between failure of one fishery and development of a new one is another.

As soon as fishermen begin exploiting a virgin stock of a species, they introduce a new factor into the system of which it is a member, disturbing thereby the pattern of oscillations in which they found it. Gradually thereafter, while the fishery grows, they reduce the stock to lower levels until a new pattern becomes established in the system, which now includes man among the predators. From then on it is difficult to study "the environment" or "ecology" without taking human affairs into account. Man's weight in the equilibrium is determined by such things as the number of fishermen, the efficiency of their gear, the wages that a fisherman is willing to work for, the price the public is willing to pay for the fish, and so forth.

People of fishery industries are often passive to these biological and economic mechanisms and tend to strike a let-nature-take-its-course attitude about its action. Taylor expresses this attitude perfectly in the following passage:

> [There is] a characteristic behavior of the fisheries under heavy exploitation that is often overlooked, namely, that as any one species of fish is pursued and its abundance diminishes (as a result of fishing or any other cause), the cost of producing it rises relative to the cost of catching other species; if the price does not increase to compensate, the fishermen discover the diminution of returns from this fishery and some of them take up some other, so that part of the pressure is taken off the "over-fished" species, a process which amounts to an automatic economic regulation of the intensity and distribution of fishing. The principle applies also to the fisheries collectively of a region operating in competition with other regions. If the fisheries reach a point of diminishing returns in one region, economic compulsion operates to relieve the pressure in favor of another.
>
> *It appears to be impossible to exterminate a species or a fishery for profit,* since the profit disappears before the fish is exterminated. Within the fisherman's freedom of choice to catch, and selectivity or nonselectivity of gear, each species or fishery tends to be fished to a point at which it just yields a wage to those engaged equal to what they could earn by fishing other species, or by working at some other trade ashore. Equilibrium would undoubtedly be estab-

lished at this wage level for each species if natural fluctuations did not occur in the supply of various species and if market conditions remained constant. *This operation of economic law is such as to distribute the total fishing effort over the total fishery resources of a region and to deliver a total of yield into the consuming market just sufficient to meet total of demand.*[1]

Even if this description were correct, the automatic mechanism, such as it is, is so far from smooth-acting as to be of little benefit to society. For a reduced fishery is rarely replaced by another in the same region—the same country, perhaps, but not the same region. Moreover, after a fishery has fallen to unprofitable levels, there is often a considerable time lag while the public cultivates new tastes, and while fishermen and others in the industry adjust their habits, apparatus, and techniques to new types of fishing. Thus the collapse of the Pacific pilchard fishery in 1947 has not yet been compensated for by the growth of another Pacific coast fishery of similar magnitude. During the lag period, men lose their investments and their savings, some of which are never recovered. Some fishermen change to other occupations, and their country loses them as links in a chain of tradition and becomes the poorer thereby. Burkenroad writes on Taylor's argument thus:

The phrase . . . *"it is impossible to exhaust a fishery for profit because the profit disappears before the fish does,"* is speciously employed. A fishery may continue profitable to fishermen even though exhausted to such an extent that effort is being wasted with the sole effect of reducing the catch. Such waste may be contrary to the public interest. . . . The quoted maxim is used as if it meant that self-regulating factors ensure use of fish-stocks in the manner most advantageous to society; whereas its only real meaning is that changes caused by most commercial fishing are likely to be reversible under appropriate conditions.[2]

A fishing industry can be strengthened by flexibility and diversification. One which depends wholly on a single stock is at the mercy of the vagaries of its abundance and availability. If the stock vanishes, the fishermen spend a few seasons hopefully searching for it—"surely this season they will be back." After that, they consider what other kind of fish to exploit. This is bad management. A conservation agency might consider only the vanishing stock, seek restrictive laws to reclaim it, and not consider how to redirect the fishery to other species. That, too, would be bad management. In both instances, people are unduly restricting their use of the environment's total produce. In other words, fisheries could be greatly improved if the people concerned with the business enlarged their idea of the sea's potentialities and came to think of their resource not so much in terms of a few well known species as in terms of the environmental systems in which those species live.

Environmental systems have mechanisms which operate according to principles, and these principles must be understood before a system can be manipulated scientifically. Textbooks of ecology often attempt to state principles controlling the relations of environments to their resident populations. It is hard to be precise about such statements. Hardly are they set down on paper before it becomes necessary to add a weakening, qualifying word; and hardly is that added before exceptions come to mind. Still there are a few statements of principles which seem approximately true and pertinent to our subject. It is probably true that:

The populations of organisms inhabiting a common habitat are in constant flux and react upon each other dynamically.

For each species there is a unique combination of environmental conditions which is optimal for its well-being.

A population tends to fill all the space in its system that meets its peculiar physiological and behavioral requirements, up to limits set by the abundance of food, predators, and competitors and by diseases and physical barriers.

With changes in the combination of environmental conditions in an ecological system, such as a fluctuation in climate, a shift in ocean currents, invasion by a new predator (man, for instance) or the sudden infestation of the dominant species by a disease, the species composition of the system changes.

The members of a population compete with each other for food and space.

The bulk of living organic matter is greatest in the plants which synthesize organic food, least in the supreme carnivorous animals which live off other carnivores. Among species between these extremes it decreases rapidly as dependence on animal food increases. Consequently, the farther away from the bottom of this "food pyramid" a fishery operates, the smaller is the maximum possible harvest.

The supply of food varies from time to time and place to place.

Generalizations more or less like these are taught in college courses in ecology. They are widely accepted as truth, or at the very least as rough approximations of truth, for there is a good deal of reason and some evidence to support them. These generalizations have been reached from studies on land and in fresh water rather than in the sea. If such principles do hold true in the sea as well, they ought to influence people's attitudes toward the exploitation of sea environments. As it is, they have rather little influence, for there are in existence some quite commonly held opposing ideas which have evolved by deduction from reasonable-sounding premises, and which are kept alive by tradition and sentiment. These principles are not often expressed; nevertheless they are clearly implied in many proposals of laws advanced for conservation purposes. They go about like this:

The number of offspring fish surviving to useful size is closely related to the number of spawners.

This idea seems so logical that the man in the street usually assumes it to be true without even questioning it. Yet no study of a marine fish has yet demonstrated a clear, consistent correlation. This point is discussed more fully on page 43.

It is more destructive to catch fish during the spawning season than at any other time of year.

This conclusion grows out of the belief that as long as the sex products are ripe they should be utilized. But the quantity of sex products is so vast that the proportion destroyed by taking spawning fish is negligible. Moreover, a fish caught in December instead of in the following June is thereby prevented from spawning in June and the effect is the same. Under some circumstances, however, the proposition may be true. If all the adults of a stock collect in one place to spawn, they will be particularly vulnerable to a fishery that converges on them at that time.

A species has but little effect on others that share the same environment. If one species declines, the space which it had occupied remains vacant until the abundance is restored to its former level.

This is an assumption which is often implied in policies of those concerned with commercial fisheries. Yet it is contrary to principles of ecology. If a valuable species declines, its space may be occupied by a species quite worthless from the commercial point of view, but it does become occupied. When a food species fills this space, fishermen should be encouraged to change their operations accordingly.

The only important cause of diminution or disappearance of a stock of fish is man. All other causes are, on the average, constant and relatively inconsequential. Being natural causes, "they have always been that way" and should not be altered. Indeed, they cannot be altered. Therefore there is little practical value in studying them.

This idea is becoming less prevalent among people interested in fishery problems than it was a few years ago. Its persistence in some quarters adds to the difficulty of gaining support for ecological research.

An unregulated intense fishery will always exterminate a stock eventually.

This is one extreme view and probably unsound. It can reduce the volume and value of the annual yield, but is not likely to extinguish the stock.

Direction (i.e., regulation) of a fishery is useless for various reasons, for example, because natural factors alone control abundance or because economic factors alone control fishing rates.

This is another extreme view, and probably also unsound.

If there is not enough knowledge about a stock to provide a basis of scientific regulation, it is better to regulate by judgment or common sense than not to regulate at all.

This is a dangerous idea because it *seems* right and is hard to refute. Actually such a regulation might be of no benefit to the stock and harmful to the fishery. Where an unsupported regulation is absolutely necessary, it should be carried on as an experiment, its biological effects carefully measured.

For the most part these statements are inconsistent with principles where facts are available to support principles, and they are inimical to the most profitable management of the resources. How backward agriculture would be if it were conducted with such a restricted viewpoint! An educated cattle rancher seeks to run his business in accordance not only with sound economics but also with principles of scientific land use and of animal husbandry. He recognizes that the two sides of his job, the one having to do with human affairs and the other with the ecology of his property, are inseparable. Fishery entrepreneurs on the other hand, though attentive to business, are often passive to husbandry, leaving the job of fishery management wholly to government. Since they expect this management to take the form of restriction to prevent overfishing, they often oppose it automatically. Government interest in this kind of management usually does not begin until a fishery gets into a distressing situation. I have written elsewhere on this as follows:

> A species may appear to be in danger of extermination through overfishing; or fishermen operating two types of gear may dispute as to whether one of them is unduly destructive; a population of shellfish may suddenly vanish without trace; an epidemic may break out or masses of dead fishes may wash up on the beaches, the stench of their rotting bodies driving tourists away. But whatever the occasion, it is generally the disturbing condition, preferably a disaster, that arouses people's interest. They hope the Government will solve the problem quickly by acting, say, to stop dumping ammunition at sea, or by passing legislation providing a size limit, or by enacting a law to stop

all commercial fishing for a species, or to abolish purse seining, or to abate pollution. The Government usually holds hearings over such questions, which usually bring out such diverse and conflicting opinions on the issues that it becomes necessary to gather some pertinent, objectively gathered facts before reaching a decision. Thus the Government starts an investigation of a species, or a fishery, or a particular situation.[3]

This is a pattern which has been repeated in various localities to solve special problems during the whole history of our biological fishery research. There develops an anomalous condition (often diminution of fish stocks which people remember as having once been much greater). An interested special group of people requests that the condition be investigated, and after due legislative procedure, scientists are assigned to the problem. To understand the cause of the undesirable condition, the scientists first try to establish facts about the time when the condition was satisfactory (i.e., the normal pattern), but because records are nearly always fragmentary or lacking, this effort usually proves fruitless. Then, because they are expected to devise a remedy for the condition in a reasonable time, they make deductions and recommendations from the data they can assemble. Such an investigation may not be conducive to learning much about the normal, being bound by too many limitations, for the anomalous condition is usually sharply delimited in scope. It is limited in time to the memory of the current generation, often even to such a short period as a season or two. It is limited ecologically to the affected species which are of most economic value.

The net effect of our preoccupation with problems of this kind is that we neither cover enough ground in our research programs nor make fast enough progress toward the ideal goal of full utilization of marine environments. What can we do to speed up the rate of progress? We can be sure that the most dramatic events—the undesirable situations, the anomalies—will continue to generate public support for special investigations and we will have to continue conducting them. But at the same time, we must try by every means to get better support for the systematic, less spectacular studies of normal conditions, which in the long run will provide us more systematically with what we need to know about the anomalous situations.

Very little systematic marine biological research has been devoted to the dynamics of ecological systems. There is a plenitude of descriptions of communities and catalogues of animals and plants collected in surveys. Although these have reference value to zoogeographers, taxonomists, and others interested in what is often called natural history, they tell very little about the history of nature. A list of species resulting from a survey, even one made with proper statistical technique, shows only what composed a community at one moment in its history. It is like a single frame of a motion picture in its relation to the continuity of a drama. A second survey made of the community ten years after reveals that the flora and fauna have changed. Nothing more. What caused the change? Did an intensive fishery remove an important predator, permitting species lower in the food pyramid to accumulate? Or did it remove a key fodder fish, causing predators to starve to death or to leave for richer grounds? Had a change of climate resulted in a rearrangement of distribution? Had epidemics destroyed some of the populations? Had cycles, resulting perhaps from the numerical relations of predator and prey, arrived at a different part of their periods? It is not possible to understand causes of changes in the composition of an ecological system without watching them happen, and that requires the drudgery of systematic, long-continued observations of the system in its natural setting. The following is an example to illustrate that changes do occur:

F. M. Davis surveyed the Dogger Bank area of the North Sea during 1921–1923 to measure the relative quantities of the various bottom-living organisms that his gear (Petersen grab) collected.[4] Twenty-seven years later Erik Ursin of the Danish Commission for Fishery and Sea Investigations made a similar survey in the same grounds. In comparing the numbers of animals in the samples which he took in the central and western parts of the Dogger Bank with those which Davis had taken, Ursin found that a remarkable change in faunal composition had occurred in the intervening time,[5] as shown in the following table:

	Number per Square Meter	
	Davis (Oct. 1922)	Ursin (May 1951)
Spisula subtruncata	272	5
Mactra corallina	11	1
Other species of bivalves	4	43
Polychaets	4	70
Echinoderms	4	28
Other groups	8	65
Total	303	212

Among miscellaneous species not listed above, the most numerous was *Tellina fabula* of which there were 22 specimens per square meter in 1951 as compared with 0.5 per square meter in 1922. Ursin also found fairly large quantities of a few species which apparently had been absent in 1922. Notable among these were *Echi-*

nocyamus pusillus, Myriochele heeri, and *Cerianthus lloydii.* Ursin writes on this:

> What brought about the changed composition of the fauna is still an unsolved question because we know very little of the stability of marine animal communities. In fact, it is not known whether the difference observed between the composition of the fauna during the two periods of investigation is indicative of a fairly constant change from one state of balance to another, or whether it merely indicates the degree of fluctuation in the said area under relatively stable conditions of environment.

There is still another possibility. Ursin made his survey in the spring, Davis in the fall; and the differences in faunal composition might reflect seasonal rather than annual differences, since the mollusks in question are short-lived.[6] This points up the importance of carrying on surveys like this all the year round, as well as year after year.

It would be appropriate now to give an example to illustrate changes in fish fauna, but as far as we know, no one has yet followed the history of an entire ecological system completely enough or long enough to observe how the various species of fishes oscillate and interact. This is partly because of the difficulties of sampling several species of motile organisms of differing habits, and partly because such a study requires continued financing and persistent work over many years before results can emerge. Fortunately, at least one example is available to show how one species *may* affect another. Scientists of the Danish Biological Station made periodic surveys of the Limfjord from 1903 to 1927, fishing with a fine-meshed otter trawl throughout the fjord.[7] This trawl consistently took at least one kind of fish in proportion to its abundance, the eelpout (*Zoarces viviparous*). Presumably the other species were variably elusive. The eelpout fluctuated during the twenty-year period in three waves. At the same time, the commercial catch statistics of the area show that the stock of codfish also fluctuated. Periods of scarcity were followed by periods of abundance when good year broods appeared in the fjord, as they do at rather rare intervals. When that happened, the young cod fed voraciously on the accumulated stock of eelpout and gobies, which they quickly reduced to levels that remained low until fishermen had caught off the cod.

Here is another suggestive example:

Within the short span of eight years, the total southern New England catch of yellow-tail flounder plummeted from 60 million pounds to only 10 million pounds. This evidently reflected a decline in actual abundance. Fishermen say that all the while this was happening the quantity of miscellaneous species of lesser commercial value which they call "industrial fish" was steadily increasing. (Fishermen originally called them "trash fish," but later agreed to change the name because these miscellaneous species do have value as raw material for fish meal.) They had always returned these unmarketable odds and ends to the sea, but beginning about 1947 they brought them into port to supply the growing demand of animal feed producers. Thus in five years, the landings of "industrial fish" from the area that had formerly been flounder grounds, rose from zero to over 55 million pounds. More than 90 per cent of it was composed of red hake, eelpout, skates, whiting, sculpin, goosefish, toadfish, sea robin, sea raven, and dogfish.[8] Did overfishing reduce the stock of flounders to low ebb, or were other causes responsible? Did the reduction in flounders itself bring about the alleged increase in "industrial fish," or was it changes in the climate of the environment that did it? No one knows. Scientists were studying the yellow-tail flounder, but before they could get to its ecology the work was discontinued. Consequently no one knows what, if anything, happened to the environment, or how, or to what extent the fauna changed; and there was nothing by which to advise fishermen how they might have taken most profitable advantage of the changes that were occurring, or how they might even have directed their fishing so as to control the faunal composition. As it is now, flounder fishermen, on purely circumstantial evidence, blame the industrial fishery for the decline of the flounder resource.

Enough has been said about environment as a whole—the ecological system—to emphasize the scientific and practical value of making it the focal subject of special research. Enough has been said, too, to show that environment is a peculiarly amorphous and elusive subject to study as well as to discuss. It is far beyond the range of any one man's education, for it involves many fields: among the biological sciences—zoology, plant and animal physiology, histology, cytology, taxonomy, anatomy, comparative physiology, bioassay and biochemistry; and among the physical sciences—organic, inorganic and physical chemistry, soil analysis, trace element analysis, geology, hydrography.

The greatest danger of environmental research is that it will fail to track. Each of the people engaged in it can easily find some detail of environment overwhelmingly diverting, and pursue it "for the sake of science." Of course an environmental laboratory needs such people. It also needs others who have the patience to conduct the necessary systematic observations year after year. And above all it needs scientists who are devoted to integrating all sorts of information in order to find such principles as it may disclose.

7

Behavior

Most people who have thought about the matter agree that even in the most advanced countries, fishing, as compared with other food-producing occupations, is still at a low level of development. Fishermen are like hunters and gatherers in primitive societies. Their techniques and apparatus—hook-and-line, traps, nets—are essentially the same as they have always been. This is not to say that they are as good as they could be. Fishing is everywhere a difficult occupation; and although fishermen in a few special situations are sometimes prosperous, most of them are perennially poor. The processes of fishing are slow and costly, with the consequence that fish is too expensive to solve protein deficiency problems. Thus fishing is less profitable than it should be, fish is more expensive than it need be. How could these conditions be improved? Experts generally agree that fishing could be made more economical if the techniques and apparatus were more effective than those now used. Perhaps entirely new methods need to be devised, radically different from anything that has ever been used. These are most likely to be achieved if based on principles of the behavior of marine animals. Research to discover those principles is fundamental to developing any science of sea fisheries. This chapter suggests questions which need to be studied, and examines various research techniques. It concludes that a special laboratory for studies in marine animal behavior should be established in an area where local conditions are favorable.

In the previous chapter it was suggested that one of the most valuable activities of an environmental laboratory would be the continuous systematic study of faunas. This would give information about the existence, abundance and oscillations of populations of organisms, including those having fishery potentialities. While this research was in progress, a fishery research agency (perhaps governmental) could test, by experimental fishing, the possibility of exploiting such potentially valuable stocks as were discovered, and later could determine appropriate harvesting rates by statistical analysis of fishermen's catches. Thus would come answers to the following questions about any environments that were studied: What is there? How much is there? How much can be taken each year?

There is another question that bears on the full utilization of the sea's biological resources: What is the most efficient and economical way to harvest a given environment? The approach to answering that one is to develop a science of the fishing process itself. As it is now, fishing all over the world is too cluttered with orthodoxies to be scientific. At best it is much more an art than a science, governed not so much by principles as by agglomerations of lore. True, much of this lore is sound, having evolved through centuries of observing the habits of fishes and trying various apparatus, tricks, times, and places to catch fish. Very little of this lore has been systematized, however. What fishermen usually do is draw conclusions and make generalizations from impressions rather than from organized facts; and thus they fall short of a useful degree of accuracy. There is a large element of luck in fishing; fishermen, like gamblers, tend more or less unconsciously to attach special significance to chance association between exceptionally good or bad fishing and quite unrelated events that happen to occur at the same time. Landsmen have many comparable notions, as, for example, that Friday the thirteenth, a black cat, a broken mirror, and an unfortunate arrangement of tea leaves in a cup are all inauspicious omens. Fancied associations like these are continually invented, and although most of them are short-lived, a few persist. Fishermen in many parts of the world go through various actions whose obscure purposes they themselves do not understand. They do these things simply because they were taught to do them. Some of these actions result from pure superstition and must have had their origin in episodes very far back in the past. A boy born into a fishing family grows up steeped in all such lore. It becomes part of him, like a language, so that by the time he is on his own it affects his response to every situation at sea.

Thus an aura of mystery has evolved about fishing, which sets it apart from the more prosaic activities of man. Moreover, it is much more hazardous than most occupations, financially as well as physically. Whether or not a fisherman makes a living at all depends very much on the success of his judgments, which in turn depends on his store of real knowledge. At best his income is unstable. Not only is he subject to the same economic ups and downs that affect people in other occupations, but he must contend with sharp fluctuations in fishing luck that range from glut to famine.

Fishing need not be so unstable. It need not be such a blind gamble, for the element of luck largely is proportional to the amount of ignorance. If fishing were completely scientific, a fisherman would know what species it would be most profitable for him to take at a particular time. He would know exactly where to find it and at what depth; he could herd not merely the species but the sizes he wanted, repelling those he wished to avoid; he would capture his quarry and get it aboard his vessel quickly and with a minimum of labor. All this would require very great improvement in the ways of fishing, including the invention of new apparatus and techniques. However, this should be attacked not by trial and error, which is a wasteful and unnecessarily slow way to advance, but by application of principles.

Perhaps the most fundamental subject of research to bring forth such principles is the psychology of marine organisms. That is to say, if we are to develop the most efficient ways to catch fish, we must first find out what they *do*. What are the strong and weak points in the patterns of their behavior? How can these be used to the advantage of fishermen?

For example, how do fishes feed? Do they detect food by sight or by smell, or by hearing? Do they go about actively seeking and selecting their food? Do they stalk their victims, or do they lie in ambush for them? Or do they behave like living plankton nets, sieving out of the water whatever food organisms happen to get caught in their mouths? Do they feed only when they are hungry, or whenever food is available? What are their enemies? How do they elude their enemies? How otherwise do they protect and defend themselves? What are their spawning habits? Do they exude their sex products into the water at random, or do they pair off and go through some kind of mating activity? Do the males and females ever gather into separate aggregations, and if so, under what circumstances? Do they sort themselves out by sizes to spawn in different areas? How do they distribute themselves and move in relation to each other? What do they perceive in the water? What attracts them? What repels them? What brings them together? How does an individual that has become isolated find its own species? What causes a school to disperse? To concentrate? What are the patterns of the diurnal rhythms in their behavior? How do they react when confronted with a situation new to their experience, like the sudden appearance of a net, the disturbance made by a propeller, bright lights at the surface of the water, or high-frequency sounds sent down by echo instruments? What compels them to migrate? How do they find their way over the courses of their migrations? How far can fish see? What shapes and sizes of objects and what colors can they discriminate? What part does motion play in their vision? What are the thresholds of light intensity that they can perceive?

All these questions have to do with fishes. They are equally pertinent to any other marine animals of interest, from the largest mammals down to the smallest invertebrates. It adds enormously to the difficulty of this line of research that patterns of behavior differ so profoundly among species that knowledge concerning one cannot ordinarily be applied to another. Even for a single species, behavior patterns usually change seasonally, and therefore must be followed through the course of a year. They also change with age, as a result of experience, and must be followed through a complete life cycle. On this, E. S. Russell writes:

> . . . a very important characteristic of much behaviour, the significance of which is apt to escape the sophisticated observer, intent on analysis . . . is the fact that behaviour is often part of a long-range cycle of events, in which one action prepares for and leads on to the next until the end term is reached. Each stage in the chain or cycle is unintelligible to us except in its relation to what has gone before, and, more particularly, to what is yet to come. Such cycles have a temporal unity, extending often over months of time, just as a simple coactive action has unity of short temporal range.[1]

We agree, then, that it is worthwhile to study behavior of marine animals. How shall we proceed? The idea that comes immediately to mind is to experiment in aquaria. Subject captive fishes to various stimuli and observe how they respond. A few scientists have engaged in such research. However, they have used for subjects mostly animals that do well in small aquaria, like tide-pool fishes. These show such remarkably distinctive behavior patterns as to make one wonder what larger animals would do. There we run into an extremely difficult problem, for capturing large sea animals without injury and transporting them alive to a shore base poses a complex of formidable problems. Keeping them alive in a tank, even a very large one, and inducing them to feed and carry on their normal life habits without being conditioned by the artificial environment to the point of uselessness as experimental animals poses another set of problems. Russell makes the following comments.

> One of the great practical difficulties about the study of animal behaviour is that it does not lend itself readily to laboratory work; it is necessary first of all to study the animal in its natural surroundings, to become acquainted with its normal mode of life. Without such knowledge we may easily go astray in our interpretation of behaviour in the unnatural conditions of a laboratory experiment; we may easily devise experiments which are meaningless, and, from the animal's point of view, stupid.
>
> Work in the field then—good old-fashioned natural history observation—should precede experimental work in the laboratory. This is often a difficult task, requiring the expenditure of much time and energy.[2]

This statement represents an opinion that is widely held among biologists. It should be taken as a warning, not against attempting laboratory experiments, but against putting too much reliance in them.

There is a circle here. Field studies are needed to learn enough about the natural environment to reproduce it artificially. Experimental studies in the laboratory are needed to learn what elements of the environment are biologically critical. Ideally, the two should proceed together, each benefiting by advances of the other.

Scientists at the University of Hawaii have demonstrated that large, delicate, active, pelagic fishes like yellowfin tuna, dolphin, and jacks can be kept alive in large outdoor tanks.[3] Their experience is worth recounting to show the kinds of problems that are involved in such research. It was virtually impossible to transport skipjack tuna successfully; either they bled at the gills during their violent struggles on deck or they killed themselves by dashing against the sides of the live well. With other species the shock of capture and transportation killed from 40 to 99 per cent of the specimens and the subsequent mortality in the tanks was probably much higher than under normal, natural conditions in the sea. Even so, a few specimens did become adjusted to living there and survived long enough to permit several months of study.

P. B. van Weel conducted experiments on two specimens of yellowfin tuna (*Neothunnus macropterus*) and five of little tunny (*Euthynnus yaito*) in a concrete tank about 33 feet long.[4] His object was to determine whether these fish could detect food by smell or taste alone. To do this he tried several clear, colorless, and therefore invisible, extracts of supposedly attractant substances, introducing them carefully below the surface through a tube. The fish, cruising leisurely round and round the tank, would show a reaction by increasing speed and circling closer to the opening of the tube. The tests showed that both species responded strongly and positively to extracts of flesh of tuna and of marlin, but not at all to water in which bait fish had been living ("conditioned" water) or to extracts of bait fish or of squid. In general, the reactions of the tunny were more pronounced than those of the yellowfin. Further tests showed that it was the protein, rather than the fat, fraction of the tuna flesh extract which contained the attractant principle.

During the next two years Tester and others [5] continued these studies with much greater success in establishing yellowfin and little tunny both in the tank and in a large pond about 360 feet long, 75 feet wide, and averaging about 6 feet deep. Several of the fish survived for at least five months. Yellowfin loss was high, but this was ascribed to poachers who took advantage of the "tame" fish. Of the tunny, which were much less "friendly," two survived in the tank for about a year and two more lived in the pond for over two years. Tester attributes his success to the presence of these survivors, which acted as leaders of newly introduced fish. Eight of the little tunny survived at least five months; all of the yellowfin died within two months. The captive fish were fed squid, shrimp, and fish flesh, and their reactions to a large number of clear extracts of natural foods and suspensions of chemical materials were observed in a series of carefully conducted experiments. The fish responded positively to extracts of various kinds of fishes, squid, and shrimp, and not to any of the chemical substances. However, Tester could not evaluate the extent to which these results must have been influenced by conditioning, a factor which severely limits such tank experiments. The tuna became so accustomed to being fed dead material that they ignored the live bait in the pond to which they readily respond in live bait fishery. The cut-up food evidently gave off juices which were similar to some of the experimental extracts; consequently, the subjects associated the savor of these extracts with the act of feeding.

The first line of research which these results indicated was to test whether extract of tuna flesh could be effective in luring fish to a boat working in the open sea. The next would be to identify, isolate, and manufacture the essential principle into a bait. An artificial bait, if practical, could revolutionize tuna fishing by obviating the collecting of live bait, which requires days or weeks of each voyage before fishing for tuna can begin. The tests with extract of tuna flesh revealed that there was an intermediate problem. Whereas the attractant effect of the juices had been impressive in the tank, it was unappreciable in the sea. Evidently taste alone was not enough to attract and hold the fish. Perhaps what was required was a visual stimulus. Pieces of aluminum foil, strips of tin, and other such objects were suggested as possibilities. They shine like silvery fish. However, when tried they attracted tuna only momentarily.

The addition of extract had no apparent effect, suggesting that vision plays a greater part in feeding than the sense of smell. Something else is needed besides appearance and savor; that something probably is the motion of a living animal such as a tuna is accustomed to eating. The desideratum now is to develop and produce in mass quantity a cheap artificial bait, with a fish-like shape and color, emitting an attractive flavor, and moving automatically in a lifelike fashion long enough to hold the interest of tuna and keep them at the surface where fishermen can catch them.[6] Whether such a contrivance is mechanically, economically, and biologically feasible has yet to be demonstrated.

The experiments to test the reactions of the captive tunas to food extracts were performed during the noon hour of the day. After dark, Sidney Hsiao observed the reactions of the same specimens to artificial light.[7] He illuminated the tank constantly with two 60 watt bulbs, and then cast additional light in a beam horizontally from one end of the tank to the other. In one series of experiments he used an arc lamp, in another, a projection lantern, and in a third, electric light bulbs. Both the yellowfin and the tunny were attracted to white or colored light of intensities ranging from 70 to 450 foot-candles. They did not react to weaker light, and they were repelled by stronger light. Systematic observations of this sort might lead in time to a more knowledgeable and effective use of lights in night fishing.

The tank studies revealed the kind of pitfalls to be watched for in laboratory experiments with large wild fish. The scientists had only one fish to work with at first, a yellowfin. When later they added another specimen of yellowfin and five tunny to the tank, the two species tended to swim in separate aggregations and to show different reaction patterns. When one of the two yellowfin died, its fellow joined the tunny, and although normally a slower swimmer than that species, it tried to keep up with those in the tank. Consequently its speed of reaction increased and was no longer comparable to what it had been earlier. Next, four of the five tunny died, and the survivor swam with the yellowfin, which took the lead; and reactions of the surviving tunny became slower than had been those of the school. These changes in behavior suggest that a great deal of work will have to be done before one can generalize about the reactions of schools or of individuals of these two species.

Captivity seems to increase susceptibility to disease, with consequent aberration of behavior. This is a problem which is very troublesome in aquaria, and which would always plague tank experiments. "Yellowfin number 1," the subject of most of van Weel's experiments, was brought into the tank on June 20, 1951. It started feeding twelve days later and remained in what appeared to be excellent health until the end of October. Then it took less and less food until it finally stopped feeding and its skin became whitish and distended. Late in December and early in January the fish regained its desire to feed, and although it would snap at food, it invariably missed its target. When it died in mid-January, its body puffy and swollen, it was found to be blind in one eye. The five tunny, introduced at the end of August, began to feed within one to three days, and remained in excellent condition until the end of October. Then they became listless, fed only occasionally, lost their bright color, and died during November and December. This experience probably results from the fish's being much more susceptible to disease in captivity than in their natural environment.

Large, circular tanks, 70 feet in diameter, 30 feet deep, more or less, have come to be a feature of several commercial establishments called oceanaria which have been built during the last few years in several places in the United States. The very size of these tanks makes it possible to approximate natural conditions in the sea so that if artificial intervention for the sake of showmanship were omitted, it might be possible for many species to behave as though they were in their normal environment. However, even as they are, with the crowds of people staring through the windows, and in spite of the spectacular acts that some of the animals have been taught to perform, and the unnecessary conditioning that has affected all the captives, the oceanaria are still useful for some kinds of scientific studies.

At the oceanarium in Marineland, visiting scientists have studied the noises which these animals make under water. The bottlenose dolphin, for example, produces sounds ranging from low growling or groaning, through barking noises, to shrill whistles. Since they make noises, can they also hear them, and if so how do they react to them? To study this question, W. N. Kellogg and Robert Kohler,[8] of Florida State University, subjected twelve specimens at Marineland (ten bottlenose dolphin, two long-snouted dolphin) to artificial sounds made with an oscillator having a frequency range of 20 to 200,000 cycles per second. The normal behavior of the captive animals was to cruise about the tank day and night in groups of two to six, generally in a clockwise direction against the current. They did react immediately to the sounds which the experimenter's instrument produced, by increasing the vertical movement of their horizontal tail and lunging forward with an increase in swimming speed. This burst of speed continued for several seconds after the end of the stimulus. Thus it transpired that these animals heard and responded to sounds ranging from 100 to close to 80,000 cycles per second. The lower tones, from 100 to 400 cycles per second, disturbed the animals much more than the higher ones, causing them to break up their swimming formation, at times to leap out of the water, and at other times to charge or attack the sound-making instrument. These studies demonstrated not merely that dolphins hear, but that they are sensitive to sounds far outside the range of man's hearing. This may mean that they can produce ultrasonic vibrations. Perhaps, like bats, they detect objects by the echoes of their own sound waves. Perhaps they locate food thus, and since they swim as fast as they do, navigating at night and in murky water, they might use this natural sonar, if they possess it, to avoid striking objects like submerged rocks.

Other kinds of marine animals may also depend heavily on hearing for their perception of the environment. People had long thought of the sea as a great world of silence. Now we know it is nothing of the sort. The intensity of sound is reduced by a factor of 1,000 to 1 at the interface between air and water in passing from one medium into the other. Consequently, all but the loudest of undersea noises are inaudible to us. People acquired the means of observing them only after the hydrophone was developed. With this instrument, Marie Fish, of the Narragansett Marine Laboratory, has tested many fishes of the western North Atlantic. Among sixty species studied, all but six made sounds which the hydrophone detected. Fishes have several sound-making mechanisms. The most important of these is the gas bladder, which is caused to vibrate and thus to produce sounds that are usually "low pitched, guttural, vibrant and drum-like . . . variously described as thumps, grunts, groans, growls, knocks, thuds, clicks, boops or barks." [9] Some fishes make rasping, scraping, scratching, or whining noises, by scraping their teeth together, vibrating bones, or rubbing the pectoral fins against the body. Among crustaceans tested were six snapping shrimps, one squilla, three spiny lobsters, a crab, and the white shrimp of the Gulf of Mexico. These all make stridulatory (high-pitched, creaking) noises. Barnacles are reported to make weak cracklings.

Probably many if not most of these sounds have some biological significance. Some attract members of the same species or serve to keep members of a community together. Others repel enemies. Croakers engage in choruses during their spawning migrations. One sound which the toadfish makes appears to serve as a mating call;

another is a threatening growl which tends to drive intruders away from the spawning nest. Hiyama [10] has recorded noises associated with all sort of activities of marine animals, some to repel enemies, others to attract their own kind, and still others made incidental to swimming, feeding, breathing (by mammals), and struggling (against being caught).

Here is a great subject for research. What are the functions of all these noises? How would marine animals respond to reproductions of their own sounds? Research on this aspect of behavior might lead to using sounds for inducing certain species to congregate in places where it is most convenient to catch them, and for driving others away.

Primitive fishermen in various parts of the world apparently use such a principle. In Indonesia, a boy clinging to a bamboo float, his head close to the water, cries out a long monotonous wail over the surface. This noise attracts a certain kind of fish, the black pomfret, which gathers around the singer, where other fishermen are waiting with a net. In the Natoena Islands fishermen attract sharks by making a noise with a rattle. In some Oriental countries, tuna fishermen heighten the frenzy of feeding fish by spraying drops of water on the surface of the sea. Skipjack fishermen of Hawaii do the same thing.

Perhaps fishes hear—perhaps identify—the low frequency sounds which swimming motions of other fishes generate, and from these they may locate their prey. Perhaps too, they somehow orient themselves by using sound. Donald Griffin, working at the Woods Hole Oceanographic Institution, analyzed sounds that had been recorded at sea. In the course of these studies, he observed a loud noise which an unidentified animal had made, followed by a fainter repetition of the noise. Griffin concluded that the second sound was an echo, which was probably audible to the animal producing the original sound. He writes:

> It is thus plausible to infer that at least one abyssal fish estimates its distance above the ocean floor by echo sounding. But we cannot pass beyond the level of speculation without further data concerning the occurrence of such sounds, their correlation with the presence of fish or other marine animals, and the quantitative sensitivity of their hearing.[11]

C. M. Breder has made many studies on fishes in aquaria and tanks. At the Lerner Marine Laboratory at Bimini, Bahamas, he studied the structure and behavior of schools of the small fish, *Jenkinsia,* in a circular pond 12 feet in diameter. At the same time he observed schools of wild fish from the laboratory dock, and so was able to integrate experimental work with natural history observations. *Jenkinsia* may never become a commercially valuable species, and the patterns of its mass psychology may be very different from those of such fishes as herring and mackerel. Yet Breder's studies demonstrate that schools can live in a tank—he had as many as 1,000 individuals at once. They demonstrated further that a great deal can be learned about behavior of a captive school and that there are distinctive mass reactions to stimuli. For instance, schools of *Jenkinsia* always form clear spaces around dark objects. They will not approach solid objects closer than a certain distance. They go nearer to light objects than to dark ones. The temperature of the water in fractions of a degree determined the location of the school in the tank.

> Certain temperature gradients acted to confine these fish as well as would a solid wall. No amount of frightening caused them to pass this temperature barrier.
>
> As the water entering the circular pool was naturally cooler than that near the outlet of the pool, because of the heating effect of the sunshine on the shallow basin of water, a nice gradient occurred across the tank. The critical temperature appears to be about 30°C., the fish consistently refusing to enter water of this temperature. . . . They simply could not be driven by nets or shadows from the area of tolerance.[12]

Concerning the behavior of individuals in the captive schools Breder writes:

> A second-to-second check shows that there is a considerable variation in the behavior of any one individual fish. It is as though any given fish were acting individually, but because of the large numbers of others present, each with its sphere of influence, that individual is continually thrown back from what would have been an independent course of action, giving the whole group the appearance of unit action. The spacing of individuals is also not so regular as might be supposed. . . .[13]

Kenneth Norris, Director of the California Oceanarium, finds that it is not possible to get an accurate conception of the shape of a school by observing from above; it is necessary to observe them frontally also; and this can be done effectively through the windows of his deep tank.

Large open tanks permit the captive animals a good deal of swimming space and thus to some extent simulate natural conditions. At the same time the animals are subjected to such complexes of influences, some natural, others not, that it is difficult to isolate one of them in order to determine its contribution to the sum of effects. This, of course, is a problem that good experimenters continually keep in mind.

An entirely different technique of studying behavior in an aquarium is practiced by H. O. Bull, who experiments on conditioned reflexes of marine fishes under very close confinement in a small laboratory, to learn how they respond to individual stimuli. His work, carried on at the Dove Marine Laboratory, Cullercoats, England, necessitates a specially constructed, sound-insulated building, with tanks designed to preclude all extraneous stimuli from affecting the subject under observation. In a personal communication, Bull writes:

> This special building enabled me to concentrate on factors which are important from the fisheries' standpoint. Emphasis was shifted from academic problems to such purely technical ones as keeping fishes (especially the major food fishes) alive and healthy in confined spaces for long periods, and of isolating the particular stimulus being investigated. None of these was complicated in the sense that a radar set is complicated, but to ensure the purity of the stimuli was not easy.

He first conditions his subjects to associate the presence of food with a change in a single element of the environment—say temperature. Then he determines what degree of change the subject feels and responds to by the threshold at which it performs a complex task to get food. Thus a cod is conditioned to associate food with a change of temperature. It is kept in a specially constructed tank with floor inclined so that one end is deep enough to provide an inhabitable living space and the other extends out of the water. The food is introduced into a chamber at the upper end of the inclined floor of the tank. Gradually, over the many days that the conditioning process goes on, the subject cod learns that food is in the chamber when the temperature of the water increases. As this association becomes more and more firmly established, the subject fish becomes conditioned to move up the inclined plane. At the same time the food chamber is gradually moved upward, day by day, ever farther out of the water. At last the fish learns to go quite out of the water, to wriggle into the food chamber, and to wait there practically high and dry until food is given, which it then seizes sharply and splashes and swims back to its normal position. There is no mistaking the response. If the cod detects a change of temperature, it goes through this remarkable performance; otherwise, it does not.

With such experiments, Bull has demonstrated that under some circumstances sea fishes react purposefully to changes in temperature of 0.03°C., and in salinity of 0.2‰. These figures are close to the limits of accuracy of hydrographic instruments. This fact must be taken into account in designing programs to bring out relations between oceanographic conditions and biological effects; and observations at sea, such as readings of instruments, must be made with much more attention to precision than is generally realized.

Experiments with these conditioned-response techniques are probably the only way to determine sensory thresholds of fishes. They must be planned and controlled with extreme care, however, to avoid conditioning the subjects to the wrong stimulus. This precaution has been very much neglected in the past. Between 1887 and 1920, at least thirty papers were published describing results proving or disproving that fishes discriminate colors. Most of these were meaningless because their authors had failed to control brightness in the experiments.

Many of the troubles that plagued earlier scientists experimenting with these techniques have at last been overcome by improved measuring instruments. Useful as these experiments are, however, they are no magic key to understanding all the mysteries of animal behavior. They tell us about sensory capacity but nothing more. For example, we might train a fish to respond to very low concentrations of various chemical substances in the water. From these studies we could conclude that the olfactory apparatus is functioning well, and we might even establish a measurement of its sensitivity. But we cannot tell how the subject uses smell in analyzing its environment. This problem might best be attacked with a different type of experiment, based essentially on unconditioned rather than conditioned responses and designed to mimic natural situations as closely as possible. But this is exceedingly difficult.

Many kinds of marine organisms seem to have exacting and mysterious environmental requirements which we do not yet understand and therefore cannot yet duplicate. A deep-water species, such as some of the rockfishes (*Sebastes*), might never prosper in artificial enclosures, no matter how large the tanks. And even if, by very clever effort, a few specimens were acclimated to live in an aquarium, it seems doubtful that much could be learned about their normal behavior in so abnormal an environment. However, if we cannot have them in the laboratory, we can at least try to study them in their native environment. So long as we do so systematically with clearly formulated questions in mind, and not just to accumulate more anecdotes about behaviorisms, we can learn a good deal in the field, especially since there are now new instruments which make it possible to penetrate the marine environment with our senses of hearing and sight. Echo sounders, sonar, underwater cameras, television, and bathyscaphe are new and still in the developmental process. Consequently biologists have hardly begun to use them, and have yet to learn how to give full scope to their potentialities. When they do, such instruments will probably be the means of revolutionizing both marine biological research and fishing.

Although the echo sounder is older than the other instruments, it is only in recent years that scientists have begun to adopt it as a research tool. This instrument was invented to measure the depth of the water automatically and continuously as the ship plows ahead at full speed. It sends a beam of high frequency sound waves into the water, receives the rebounding echoes, translates the intervening time into fathoms, and with a stylus draws on a moving strip of paper a graphic picture of the sea bottom. Recently developed instruments are built to send the beam horizontally as well as vertically, and can detect objects as far away as 2,200 feet. They record not only the bottom, however, but anything that can deflect the sound and send back echoes, which means anything whose density is in contrast to that of the surrounding medium. Fishermen have been using echo sounders for several years to locate fish, and so have saved themselves untold time over the older method of blind scouting. They are even learning to identify the fish below from the characteristics of the traces on the bathygram.

Fishermen locate schools with the echo sounder, but scientists, whose skill it is to arrange and collate data so as to bring out otherwise obscure patterns, can make much more from the records than just that. One example of a fishery biologist's studies of bathygrams will suffice to illustrate the point:

By continuous use of the echo sounder, I. D. Richardson, of the British Ministry of Agriculture and Fisheries was able to keep a research vessel over a school of sprats in the Thames Estuary from mid-afternoon of one day until mid-morning of the next.[14] In the afternoon, the school was in shallow water, packed in a dense mass close to the bottom. About an hour before sunset, it started to rise. By 4:55 p.m. it had reached eighteen feet from the surface, and in the next twenty minutes as the light of the sun left the sky, it rose until the noise of the fish breaking the water could be heard. The school moved about, into areas that were deeper, but stayed near the surface until dawn, when it descended again towards the sea floor.

He went on further to observe the diurnal movements of herring schools off North Shields, off the Yorkshire coast, off East Anglia, and off Cape Gris-Nez on the French coast. Herring evidently behave differently in different places. The echo tracings showed that in the North Shields area they formed less tightly packed schools than off Yorkshire or East Anglia, perhaps because in the one region they were schooling for feeding, while at the other two they were gathering before spawning. Although there was a good deal of irregularity about their vertical movements, the schools of herring tended to be nearer the surface of the sea during hours of darkness and farther down during the day. Off North Shields the schools came to within about five fathoms of the surface at midnight, on the average, whereas off Yorkshire they never got closer than ten fathoms, and at Cape Gris-Nez six or seven fathoms.

At East Anglia herring seem to rise suddenly and rapidly from the depths. These episodes, which fishermen call "swims," generally occur at night, though occasionally also during the day. After a swim, the schools remain near the surface for a very short while, and then descend to deeper water. Swims are very important to East Anglian fishermen, for it is then that schools strike the drift nets suddenly and fill them with bumper catches. On analyzing a large number of echo tracings, Richardson was not able to adduce any evidence to support fishermen's long-standing belief that a swim results from a fast, sudden vertical movement. When he statistically analyzed the tracings from all places where echo soundings had recorded herring, it transpired that the level which schools take is determined by the intensity of light; and that varies from place to place and time to time, depending on the quality of daylight and the turbidity of the water. A rapid swim certainly does occur at East Anglia, for fishermen's nets do on occasion fill up suddenly and fast, but it has yet to be explained.

Why herring seem to respond to light as they do also has yet to be explained. The logical first supposition is that the fish rise or descend not because the light intensity changes, but because they are pursuing food organisms which migrate diurnally. But it can hardly be that, since herring make the same vertical migrations during periods when they are fasting as when they are feeding.

Richardson performed some interesting experiments with an electric searchlight which he directed vertically over the side of the ship. As soon as he switched on the light over where the echo sounder had recorded a school of herring, the fish descended to deeper levels, and remained there until he switched off the light. Then they rose again to their normal level. Pilchard, on the other hand, reacted differently. When the light was switched on, they descended just like the herring. But after a minute and a half, they rose towards the light, a few specimens even breaking at the surface.

They remained there until the light was switched off and then returned to their former level.

Scientists on board ships have performed other light experiments which demonstrate how changing some quality of a stimulus can alter the response. Although sunrise and a bright searchlight repel herring, causing them to move to deeper levels, people often use lights to attract them. The difference in intensity between a 100 watt bulb and a 200 watt bulb hung over the side of the ship is enough to reverse the reaction; that is, herring rise toward the surface when the weaker light is turned on, but move downward in response to the stronger. It thus appears that a certain light intensity exists above which herring are photonegative and below which they are photopositive. In the afterglow after sunset, they rise and move westward. In the pre-dawn glow they move eastward. At sunrise when the light becomes bright they descend.

Studies on the responses of marine animals to artificial stimuli in their natural environment obviously have important practical application in fishing. They can go farther, however, when they are backed by fundamental research into the microscopic anatomy and the physiology of the sense organs. This is a field of research that has been very much neglected by marine scientists and should be a starting point in any serious effort to build up a science of behavior.

It is an old story to fishermen that commercially useful demersal animals like flounders, rockfishes, lobsters, and crabs are not scattered randomly over continental shelves, but are concentrated in rather definite areas. The locations of these areas shift about with a certain amout of regularity, but also with enough irregularity to make them undependable. To understand such vagaries in distribution, it would be useful to know the habits of all the other creatures that share the environment with the commercially valuable species. How do the animals space themselves in relation to their own kind and to other species? What are the geological characteristics of the ground which they occupy? Until lately, scientists could answer such questions only by sampling the bottom with dredges and mechanical grabs, then analyzing the composition of the collections. That was the only means they had. Qualitatively it was not very satisfactory, and quantitatively it was worthless because there was no way of knowing what had escaped from such gear, and no sure way of reconstructing from the heaps of intermingled specimens, rocks and mud, the arrangement in which these organisms existed in the bottom communities from which they were taken. That need no longer be a troublesome problem, because the bottom can at last be photographed, and its ecology examined as it actually exists.

An automatic undersea camera was introduced in 1940, which can be operated down to depths of over 2,000 feet and can take pictures which show the organisms clearly enough to permit identification and counting.[15] It is a superb, relatively inexpensive instrument for systematic ecological studies on an area like a bank, but so far its use for that purpose has not been fully exploited. Henry Vevers, of the Marine Biological Laboratory at Plymouth, England, has given a fair sample of the kind of information the camera can yield.[16] He took a large number of photographs each of a square meter of ground, along transects over the bottom off Plymouth, following sampling methods used in surveying land vegetation. Just as expected he found patchiness in the bottom fauna. In some places there were very few animals, in others clumps of bryozoans, which served as shelter for crabs and mollusks. Most astonishing, though, were the masses of brittle starfish which he found concentrated in some areas, completely covering the bottom and piled on top of one another. He counted as many as 500 on a square meter, and estimated that over large areas of the sea bottom in that part of the ocean, there were 250 million brittle stars to the square mile. He thought they might concentrate thus only during a certain season of the year, perhaps for spawning. But no, continued observations proved that they remain so all year round, packed together even when there is apparently vacant space nearby.

A laboratory study has shed much light on the reasons for this behavior. W. C. Allee,[17] working at Woods Hole on *Ophioderma,* a related inshore species, found that this brittle star would form just such aggregations in glass aquaria but not in their normal summer habitat which is among the leaves of eel grass. Aggregated animals consumed more oxygen than isolated ones, and their survival was better. This effect persisted when Allee substituted twisted glass rods in the aquarium for some of the starfish. The starfish would then twine themselves amongst the rods, not forming the typical clusters found in otherwise empty aquaria.

Do fishes avoid these grounds that are so infested because brittle stars are not very nourishing, or in response to some other mechanism? In any case, such grounds are useless for fishing. It might be worthwhile to trawl out the starfish in order to make room for something more valuable. That brings up the question of whether fishes would actually move in to take up the space thus vacated, and whether the job would cost more than the return.

Automatic cameras can provide answers to many questions, but their use is a blind operation and they do not afford continuous observation. For that, a television camera, adapted for underwater research, is ideal. After several years of development the apparatus is still expensive, good equipment costing in the neighborhood of $20,000. Less sensitive yet very useful equipment can be bought for around $5,000. Underwater observation with television has been shown to be a wonderfully effective instrument for studying the deep sea environment and its occupants.

H. Barnes, one of the pioneers in developing this equipment and in using it for undersea studies,[18] has demonstrated its effectiveness in bottom surveys for estimating sizes and numbers of sedentary and slow-moving animals. He watched for several hours at a time the behavior of lobsters and crabs with traps. He observed that most crabs entered the traps through the opening on the side facing down tide. Evidently they were reacting to material carried down current from the bait. Once inside the trap the crabs made straight for the bait, sometimes fought rivals for a piece of bait, fed vigorously for about twenty minutes, then retired to a corner and remained inactive for a while. Then they moved around to explore the trap, sometimes escaping through the top netting. Barnes also observed and identified plankton organisms and even counted those passing before the lens at different levels.

He points out several disadvantages. For one thing, the biological material is only seen, not brought up for examination. Therefore, television cannot be used quite independently of classical techniques of zoology and botany. On the other hand, information gained through television should be helpful in making collections. Another disadvantage of television at its present stage of development is that it is costly to operate as well as to buy, for it is necessary to have a full-time technician to service it. No doubt further improvement of the apparatus will bring about considerable simplification. Clarity of water is a limiting factor; in turbid water the haze resulting from light scattering reduces the quality of the image. When artificial light is used, animals do not behave normally, a fact which the observer must take into account in assessing the results.

Barnes also points out the advantages of underwater television in undersea studies. It yields information on the bottom fauna and the relations of one set of organisms to another. The observer can watch a scene continuously on the viewing screen, making records all the while. He can adjust the apparatus by remote control mechanisms so as to get the best view and focus of a given scene. With television biologists can safely and comfortably study ecology at great depths. In discussing the results of his studies, Barnes writes:

> We have had many hours' viewing and it is neither necessary nor desirable to describe in detail the many things which have already been seen. Rather we must attempt to assess the potentialities. The instrument is undoubtedly of importance for the study of the epifauna both biologically and in its relation to the physical environment. If the species present in an area are known, it is not difficult, after practice, to distinguish between them—and if in doubt animals can be lowered with the camera for practice recognition. Dense colonies of Ophiuroids, *Luidia ciliaris* preying on them and seeming to sweep whole areas clean, have been observed. The behavior of animals can be watched—the fighting of crabs, the behavior of bottom-living creatures in relation to their burrows—all come within this category. Physical features of the bottom—aggregation of shells of fixed orientation, sand ripples, traces left by animals dragging over mud surfaces—have all been investigated.
>
> All these are stationary or sluggish subjects. With fast moving animals such as fish the technical difficulties become greater. When close up and easily recognizable they are quickly out of the field of view and when far away they are recognized only with difficulty.

Already a good many of the disadvantages described by Barnes have been overcome by recent advances in underwater television development. A group of fishing gear experts at the United States Fish and Wildlife Service laboratory at Coral Gables have developed a small, compact vidicon television chain. This equipment has proved effective in studying fishing gear in operation in the clear waters of Florida. Observers have studied a moving trawl by lowering the television camera from a following boat and towing it in various positions around the net. Remote controls enable the operator to direct the camera toward the particular parts of the net under investigation. The great possibilities for the use of television in gear improvement work are apparent.

The advantages of vidicon equipment in simplicity and compactness are offset to a considerable degree by lack of sensitivity. This shortcoming may be of little importance in clear tropical waters, but can reduce the usefulness of television greatly in the turbid waters of more northerly seas.

Biologists at the United States Fish and Wildlife Service laboratory at Woods Hole, Massachusetts, have recently developed a television chain which combines compactness and high sensitivity. The image-orthicon equipment used is sensitive enough to produce a usable image with only one foot-candle of light. This television chain requires, in addition to the underwater camera, deck gear in the form of a power supply unit and a camera control unit, each about the size of a living room television set. These units are connected to the camera by a 28 conductor, ¾ inch, water-proof cable.

The camera unit is housed in a streamlined cylindrical case, 10 inches in diameter and slightly over 5 feet long, which contains sufficient air space to afford neutral buoyancy. This housing can withstand pressures to 1,000 feet of depth. Controls on the deck units permit the operator to change focus, select one of three lenses and adjust the iris opening. Signalling systems warn of leaks in housing or cable and of excessive heat in the camera unit.

The remarkable sensitivity of the image-orthicon equipment permits viewing in depths of over 120 feet in the normally turbid waters off the New England coast. Thus relatively deep-water species can be studied in their natural environment without affecting their behavior, for artificial illumination is unnecessary. Although it is still not possible to observe closely the activities of fast-moving, wild fishes on the underwater plains over which they range, many exciting possibilities suggest themselves.

The Woods Hole biologists have been able to secure the camera inside a trawl which they have dragged at 3.5 to 4 knots over the bottom. Thus they have been able to prove that small fish of many species really do escape through the distended meshes of the cod end (thereby refuting fishermen's assertions to the contrary), and they have watched the impounded larger fish swimming along in the same direction as the net was dragged, evidently not panicked by the surrounding webbing.

A direct and inexpensive way for the field observer to get into the same environment with marine animals is by free diving equipped with a scuba (self-contained, underwater breathing apparatus), consisting of a face mask, compressed air apparatus to permit underwater breathing, and skin covering for protection against cold. Free diving is the best means of studying marine life and the reactions of animals to various stimuli, for the animals seem generally indifferent to the presence of a human being. Occasionally a curious fish approaches to investigate him but most animals ignore him. Thus he is able to observe their normal behavior in their own environment. He can peer into caves, dig in the bottom, collect specimens of particular interest, and can experiment with lights, sounds, chemicals, and objects. These things cannot be done by the operator of a television camera or a biologist sitting in a bathyscaphe. On the other hand, a Scuba diver is severely restricted by depth, air supply, and other limiting factors.

An excellent instrument for observing at deeper levels is a steel diving chamber. The first of these was the bathysphere, which Otis Barton invented more than twenty years ago, and in which he and William Beebe went down 3,028 feet into the deep water off

Bermuda. Through the fused quartz windows, 3 inches thick, they peered at such wonders as had never been caught in net or on lines, and so had not been seen by anyone else. Beebe wrote, "Every descent and ascent of the bathysphere showed a fauna rich beyond what the summary of all our 1,500 nets would lead us to expect. Bermuda is in the Sargasso Sea, which is accounted an arid place for oceanic life, but my observations predicate at least an unsuspected abundance of unknown forms." Other such craft have been built since. In 1953, Auguste Piccard and his son descended into the Tyrrhenian Sea almost two miles in a "bathyscaphe." This diving vessel was lowered a short distance by a cable, then freed, sinking with the help of two steel balls held in place magnetically. Two small electric motors permitted navigation. The vessel was raised by cutting the magnetic field which allowed the steel balls to drop off. Thus the diving vessel was free to cruise about independent of the surface tender. The first descent of the bathyscaphe established a record for depth. The observers saw plankton, looking like "the milky way during a beautiful summer night." [19] At 1,200 feet they saw shrimp, jelly-like blobs, small medusae, and a number of kinds of fishes, including some that looked like anchovies, and small eels. At 3,300 feet the abundance of organisms increased considerably. There were shrimp, squid, unidentifiable creatures, and many sharks. The bottom at 4,040 feet was "blistered with innumerable big mounds pierced by small holes." Animals burrowing into the bottom indicated an intense underground life. A bathyscaphe would be superbly useful for studying life on the slopes of continental shelves and in canyons where the ordinary gear of fishermen does not reach, for learning the direction of migrations, and for locating stocks that have moved out of the range of a fishery (i.e., become "unavailable").

A research submarine chamber has recently been built in Japan. It is 3.15 meters high, 3.7 meters long; the observation chamber is 2.2 meters high and 1.48 meters in its outside diameter. It has one window in front which is 150 millimeters in diameter, besides three on the sides and rear and one on the bottom, all 100 millimeters in diameter. Lights required for photography and illumination, including a strobe flashlight, although outside, can be controlled from within the observation chamber. The apparatus carries two people; it can descend to 200 meters and stay there for ten hours. In case of emergency, it can be raised immediately by manipulating a special device, or if this should fail, by casting off weights attached to the lowering platform, and thus increasing buoyancy. An advertisement says of this instrument:

> With this we can study the spawning grounds in deep sea areas, the ecology of fishing grounds, the characteristics of the bottom on which fishes live. We can observe fishing gear in actual operation. We are now carrying on a survey of coastal resources, which we consider a most important undertaking. We are firmly convinced that this is really an epoch-making research enterprise.

I have emphasized in this chapter the difficulties inherent in laboratory studies. Bringing the animals from their native habitat to a laboratory subjects them to a severe trauma. They are given too little space and are frightened; they become malnourished, diseased, and they die. If we could take the laboratory to the animals, as we could with a diving vessel, these technical problems could be solved. There would be other problems, of course, but we would at last surely be studying natural behavior. Biologists using this instrument would have the chance to answer many questions that have been puzzling us. For example, how do bottom-living fish behave? What are the diurnal rhythms of animals? What stimuli trigger their responses? How do animals space themselves in relation to each other? How do predators attack their prey? How do the various species protect themselves against each other? How do they cooperate? In short, what do animals *do* in their own environment? People to whom the behavior of land animals is commonplace knowledge because they have seen it with their eyes, do not realize the vastness of our ignorance about behavior of marine animals. The original bathysphere still exists, others have been built in France and in Japan, and one is being planned in the U.S.S.R. Unfortunately, these are costly to buy as well as to operate; they are cumbersome and they can accommodate few observers at a time. For these reasons the chief hope of making a submarine observation vessel generally available to biologists in a region would be for several neighboring laboratories to join forces to acquire one and keep it in continual operation.

In the main, it is not lack of techniques and instruments which hinders research into the psychology of marine animals, but lack of interested scientists. How can research on behavior of marine animals be encouraged? To begin with, it is necessary to seek scientists who are more interested in that subject than in anything else and who have prepared themselves for it by a suitably broad education. Research must always begin there, with men who are excited by a particular mystery in nature, and are driven by an irresistible will to explore it. To study behavior effectively, these men need something more than a pair of rubber boots, a bucket, and a portable glass aquarium. They must have a proper place to work, including large, deep tanks with facilities for underwater observation and laboratory rooms especially constructed for perfect control of experimental conditions. There must be equipment for free diving, for undersea photography and television, and, if possible, a submarine such as a bathysphere or bathyscaphe. For behavior studies, the characteristics and equipment of the base of operations are more important than for most other kinds of laboratory marine research. The base of operations must be in a place where the surrounding water is clear enough for field observation and where there is a good supply and variety of marine forms for study. It might be in such a place as Bermuda, the Gulf of California, the Mediterranean, or Hawaii. It should be part of an environmental laboratory attached to an established research institution, providing the obvious advantages of a good library and a staff of scientists working in related fields.

8

The Dream of Harvesting Plankton

The largest volume of marine life is in the plankton, that is, the communities of all kinds of organisms that drift more or less passively in the water. Whales, whale sharks, and tunas feed on plankton and grow rapidly to great size thereby. Massive populations of herring, sardines, and anchovies are supported by plankton. A few distinguished scientists have speculated on the possibilities of magnifying the ocean harvest by fishing directly for plankton, and in this chapter some of their proposals are described and assessed. All evidence makes the prospects look discouraging. Even where plankton is most abundant, it is still too diffuse to support a profitable fishery. The question is not quite closed, however. As knowledge about the distribution and abundance of plankton is enlarged through the researches of marine laboratories, the basis of a definitive opinion should become firmer.

Marine scientists generally agree that the sea is not a very rich medium for life. It does not produce more living material than the land, indeed perhaps even less. Its produce is distributed over a vastly greater space. Nevertheless, the fact remains that we are getting only one thirtieth as much produce from the sea as from the land. This seems too small a portion. How might it be very substantially enlarged? People who seriously consider this question usually reach the conclusion that the only way of accomplishing that end is to exploit at a lower level of the food pyramid, where the mass of organisms is many times that of fishes. This implies fishing for plankton.

Plankton is distributed unevenly and often diffusely and it varies enormously in quality. Therefore, the chief problems of utilizing it would be first to find ways of concentrating and collecting it, then of controlling and standardizing the products. Long ago, people solved these problems simply and directly, perhaps in the only way feasible, by exploiting the work of whales and such plankton-eating fishes as herring, pilchard, and menhaden. These animals are very efficient in concentrating plankton and transforming it into their own flesh which, for any one species, is a product of comparatively uniform quality. However, it does take at least ten pounds of plankton to make a pound of whale or of herring. Could we do better? Is it likely that we could invent a mechanical apparatus, a sort of artificial whale that could be used to harvest plankton more cheaply than whales or herrings do it, and thus open up vast new sources of protein? This is not a new idea. Many times in the past people have considered the feasibility of capturing plankton and preparing it for human or animal consumption. One of the first articles on this subject described eight yachtsmen who made breakfast by cooking marine copepods in Norway in 1891.[1] Shortly before World War II the German State Biological Institute at Heligoland investigated the possibility of harvesting plankton as a new food source for the German market. In 1941 Sir John Graham Kerr wrote a letter proposing that a special committee of biologists investigate the possibility of obtaining food directly from marine plankton. A month later A. C. Hardy[2] published an article suggesting that plankton could serve as a source of food in England during the wartime food shortage.

In more recent years, reports of oceanic voyages in rafts of various sorts have mentioned utilizing plankton for food. Thor Heyerdahl in *Kon-Tiki* says "and these, the tiniest organisms in the sea [the plankton], were good eating."[3] In speaking of individuals who have starved to death at sea, Heyerdahl believes "if, in addition to hooks and nets, they had had a utensil for straining the soup they were sitting in, they would have found a nourishing meal—plankton." In a *Life* magazine article, Dr. Alain Bombard, reporting on his trip across the Atlantic in a raft, mentions that he varied his diet with plankton caught with fine nets. "It tasted like lobster, at times like shrimp and at times like some vegetable."[4]

These popular accounts are by no means the results of exhaustive scientific experiments. But, taken at their face value, they do demonstrate that some people have found plankton to be palatable.

From time to time, chemists have analyzed samples of plankton.[5] As would be expected, the organic content varies according to species composition, as shown in Table 8-1.

TABLE 8-1. ORGANIC CONTENT OF PLANKTON
(dry weight)

	Protein %	Fat %	Carbo-hydrate %	Ash %	P_2O_5 %	Nitrogen %
Copepods . . .	70.9–77.0	4.6–19.2	0–4.4	4.2–6.4	0.9–2.6	11.1–12.0
Sagittae	69.6	1.9	13.9	16.3	3.6	10.9
Diatoms	24.0–48.1	2.0–10.4	0–30.7	30.4–59.0	0.9–3.7	3.8–7.5
Dinoflagellates	40.9–66.2	2.4–6.0	5.9–36.1	12.2–26.5	0.7–2.9	6.4–10.3

SOURCE: Johannes von Krey, "Eine neue Methode zur quantitativen Bestimmung des Planktons," *Kieler Meeresforschungen*, VII (1950), 58–75.

It is evident from this table that if one were fishing for oil and protein it would be better to attack the zooplankton rather than the phytoplankton, not only because the oil and protein content is in general higher, but the ash content (including silica) is considerably less. Any processing would then only have to take account of the chitin. These figures, however, show the ranges of values over a season and it is probable that peak values of a particular component are sometimes higher. Thus diatoms under certain unusual conditions produce large quantities of fat.[6]

If it ever proved feasible to fish for plankton, oil might be the most important product, especially during periods of world fat shortages such as develop in times of stress. The oils of plants and animals of the marine plankton vary widely in properties from species to species, and therefore conceivably could serve a considerable variety of industrial uses.

R. S. Wimpenny, of the Fishery Laboratory at Lowestoft, and Dr. K. Kalle, of the German Hydrographic Office, suggest[7] that large quantities of oil might be obtainable from the patches of the diatom *Coscinodiscus concinnus* that occur sporadically on the surface of the North Sea in summer after a fortnight's fine weather in late May when there is a thermocline. There the oil might simply be pumped off the surface of the sea and the water separated off. No doubt there are similar situations in other parts of the world. Experimental pumping at the appropriate season in an area where these patches occur and chemical analysis of the material collected would be necessary in order to assess the quantity and values of oils that could be obtained from this source.

Although carotenoids are generally distributed among plankters, Vitamin A is particularly notable in the Euphausids.[8] It is concentrated in the eyes. As much as 12,000 international units of Vitamin A per gram, dry weight, of body tissue occurs in some species of Euphausids (as compared with 70 international units per gram, dry weight, in mammals). Other pertinent data are given in Table 8-2.

TABLE 8-2. CAROTENOID AND VITAMIN A CONTENT OF ZOOPLANKTON

	Vitamin A		Carotenoids	
	i.u.*/g animal	i.u./g oil	μg †/g animal	μg/g oil
Meganyctiphanes norvegica	15	680	42	1,900
Thysanoessa raschii	32	495	33	500
Pandalus bonnieri	2.1	89	24	1,000
Spirontocarus spinus	1.0	22	27	950
Crangon allmanni	0.4	30	5	390
Crangon vulgaris	0.2	21	5	550

SOURCE: S. K. Kon and S. Y. Thompson, "Preformed Vitamin A in Northern Krill," *Proceedings of the Biochemical Society,* XLV (1949), 31–33.

* International unit
† Microgram

Moreover, phytoplankton organisms of fresh water and presumably also those of the sea contain Vitamin B,[9] riboflavin,[10] niacin, and biotin.[11] There is no question that plankton is rich in food materials, especially protein, and in certain accessory products. Nor is there any question that plankton is abundant in certain areas (Figure 15). Certain whales, sharks, and many kinds of fishes feed on plankton almost exclusively. A blue whale, which lives chiefly on euphausiids, can grow from 25 tons to about 87 tons in the two years between weaning and maturity. Probably most of this growth takes place during two summer seasons (about 12 months) in the Antarctic.[12] This rate of growth would require at least 110 quarts of plankton per day. When the respiratory requirements are added, the total daily ration becomes 740 quarts. One basking shark caught off the west coast of Scotland was reported to have 1,000 quarts of copepods in its stomach. One year's catch of 550,000 tons of sardine off the coast of California (during the era when the sardine was abundant there) represented perhaps one half of the total population. It must have taken around 15 million tons of zooplankton a year to support that population. In the North Sea about 2 million tons (wet weight) of herring are based on from 50 to 60 million tons (wet weight) of zooplankton annually. The standing crop of zooplankton in the North Sea has been calculated to be at least 10,080,000 tons wet weight.[13]

Thus it appears that plankton is not only nutritious, but that the

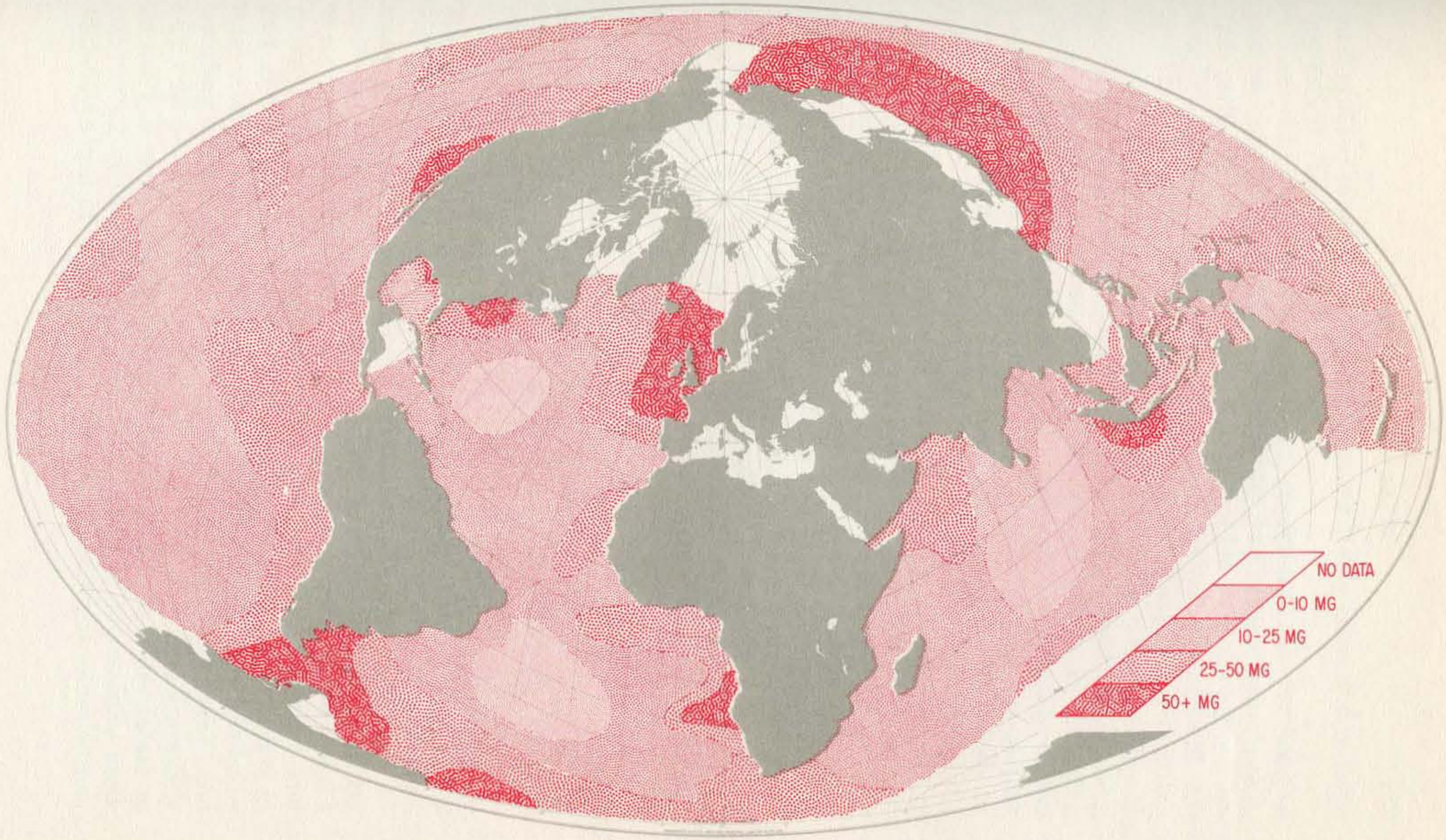

FIG. 15. Biological productivity of the seas. Density of shading is roughly proportional to the degree of biological productivity as measured by the amount of organic matter (in milligrams) produced annually per cubic meter of sea water. Estimates given by Cushing and Corlett, Fishery Laboratory, Lowestoft, England.

mass of it in the sea is large. Can it be profitably harvested in large quantities? That is the question.

Except in a few isolated instances, plankton has so far been of interest only to scientists. They study its distribution, composition, and drift in connection with oceanographic and biological researches. Hence, their aim is not to collect a large amount of material but merely samples representing what is in the sea. Nevertheless, their experience should give some inkling of the feasibility of catching commercial quantities of plankton. The classical collecting apparatus which scientists use is a cone-shaped net made of bolting silk or of stramin, usually about 1 to 2 meters in diameter at the mouth, and about 4 or 5 meters long. They lower it to the deepest level to be sampled, then haul it vertically or tow it horizontally or obliquely at a speed of about two knots for as long as an hour.

George Clarke [14] of Harvard University, in discussing plankton as a food source for man, based some pertinent calculations on such a net. He assumed that a rich area of the sea should yield an average of 0.1 grams (dry weight) of plankton per cubic meter of water. He assumed further that the stramin net is 20 per cent efficient. Then a normal, conical net with a round opening 2 meters in diameter would require about 3¼ hours to collect a little over 1½ pounds (750 grams, dry weight). In 24 hours of continuous operation, which is feasible if two nets are fished alternately, a 2 meter net would collect about 12 pounds (5.5 kilograms, dry weight) of plankton. The largest conical tow-net which has been fished successfully is the 4½ meter net used on the research vessel, *Discovery*.[15] This net was of coarser mesh than stramin. Even so, using Clarke's assumptions, it would collect 61 pounds (27.5 kilograms, dry weight) of plankton in 24 hours of fishing.

Table 8-3 shows the daily yield of dry plankton per day by various methods tested by scientists, on the assumption that one cubic meter of sea water contains on the average 0.1 grams dry plankton, and that stramin nets are 20 per cent efficient.

Philip Jackson [16] estimated the probable costs of plankton fishing in this way: He assumed (a) an average population density of 0.1 grams (dry weight) per cubic meter for mobile harvesters, and 0.01 grams (dry weight) per cubic meter for "fixed" harvesters in tidal estuaries, (b) 2,000 hours harvesting per year, (c) 200 hours traveling to and from harvesting areas (where applicable), and (d) a 20 per cent straining efficiency for large tow nets (probably on the low side) and 90 per cent for small nets or filter fabric in non-towing methods where a finer mesh can be successfully used. Allowing a cost of £3,600 for operation of a 60-foot motor fishing vessel, the cost of producing a dry ton of plankton by the various methods which have been suggested would be from £1,800 to £3,000 ($5,040–$8,400).

TABLE 8-3. ESTIMATED YIELD OF PLANKTON BY VARIOUS COLLECTING DEVICES

Method	Reference *	Dry Plankton Per Day Kg.	Lbs.
Plankton collecting ship	Hardy	125.0	275.6
Passenger liner condenser	—	28.8	63.5
Swing net	Hardy (1941)	26.7	58.9
4-½ meter net	Marr (1938)	27.5	60.6
Heligoland larva net (towed)	—	13.5	29.8
Harvester (2nd model)	Shropshire (1944)	16.0	35.2
Harvester (1st model)	Shropshire (1944)	3.2	7.0
2 meter stramin net	Clarke (1939)	7.2	15.9
Heligoland larva net (vertical)	—	4.4	9.7
Centrifuge	Juday (1943)	0.002	0.004

* *References:*

A. C. Hardy, Private letter to David Cushing and John Corlett.

A. C. Hardy, "Plankton as a Source of Food," *Nature*, CXLVII (1941), 695–96.

James W. S. Marr, "On the Operation of Large Plankton Nets," *Discovery Reports*, XVIII (1938), 108–20.

R. F. Shropshire, "Plankton Harvesting," *Journal of Marine Research*, V (1944), 185–88.

George L. Clarke, "Plankton as a Food Source for Man," *Science*, LXXXIX (1939), 602–3.

Chancey Juday, "The Utilization of Aquatic Food Resources," *Science*, LXLVII (1943), 456–58.

Cushing and Corlett have compared the amount of effort spent in catching fish and plankton: [17]

In the North Sea in 1948, fishermen caught on the average 58.6 tons of herring in 100 hours. To collect plankton equal to that quantity of herring, it would be necessary to strain over 57.5 million tons of water! Indeed, the herring must do much more than that. They work very hard at it and it takes three or four years of feeding before they come to useful size.

None of this evidence offers an encouraging prospect for a profitable plankton fishery. It looks as though plankton harvesting must be left to the sea creatures best fitted to do it, namely, whales, herrings, and the like. Is the evidence enough to settle the issue? I was interested to know what other scientists think about this and related matters and circulated a questionnaire among Americans and Europeans (through Messrs. Cushing and Corlett). Here are the questions and summaries of the answers:

(1) *Do you think that any material can be made more efficiently from marine plankton than from other sources?*

Probably not. The task of quality control of the products would in itself probably make the cost prohibitive. Anyhow, too little is known about the biochemical composition of plankton to answer this question with certainty.

(2) *What sort of products (not necessarily food products) could be manufactured from marine plankton to make up deficiencies in supplies from other sources?*

Animal feedstuffs, proteins, amino acids, vitamins, and various oils might be extracted from plankton. Before manufacturing feeds, however, it would be necessary to determine the nutritional effects of the various components of plankton organisms, as for example, the waxes in the fatty constituents, the chitinous "shells" of arthropods, the silicious skeletons of diatoms. It would also be necessary to guard continually against introducing poisonous organisms like certain dinoflagellates into feedstuffs. Probably many vitamins and growth factors will always be more cheaply producible by synthesis than by extraction from marine organisms.

(3) *Where in the oceans would you expect to find the greatest standing crops of plankton?*

The greatest standing crops would be found in the arctic and antarctic seas and the regions of upwelling associated with the Humboldt and Benguela currents and with the equatorial current systems. Although temperate latitudes might be less spectacularly productive than higher latitudes, they would probably yield more in the long run because of their longer season. Pilot experiments to develop and test methods of plankton harvesting could best be carried on near centers of oceanographic research, that is, in the North Sea, on the New England Banks, off southern California, Puget Sound, or a number of other areas.

(4) *What are the probable yields and what is the course of the annual productive cycle in those areas listed in the answer to Question 3?*

There is no sufficient basis for answering the question. For that it would be necessary first to carry on year-round, sytematic, quantitative observations in those areas.

(5) *What is the most likely method of (a) catching plankton? (b) processing it?*

The consensus of opinion was that probably no mechanical device of man will ever equal the efficiency of whales and fishes. Nevertheless, a few scientists thought the question of the feasibility of plankton harvesting has not been settled. Dr. Hart suggested the use of a "mechanical whale," that is, an apparatus that would engulf water and press out the plankton, simulating the manner of a whale taking in mouthfuls; Mr. Rae suggested a factory ship with open collecting channels in its hull; several others, a combination of pumps and filters. Most frequently mentioned was pelagic nets, fished near the surface at night. Dr. Havinga suggested that nets used less energy than other apparatus, because water did not have to be displaced, but Mr. Rae thought them much too slow.

The method of processing depends on what products are required. For feedstuffs, maceration and steam extraction were suggested. The chitin of the zooplankton was generally recognized as being a nuisance. Drs. Marshall and Orr suggested that this indigestible substance might find use in the plastics industry. At the same time it was recognized that some animals might be indifferent to chitin, as they are to lignin.

(6) *Can you give an opinion as to whether the possibilities of developing a profitable commercial plankton fishery are hopeful enough to justify setting up a pilot project?*

Professor Hardy and Mr. Wimpenny thought that the question of profitable plankton harvesting is not yet settled. Wimpenny, Friedrich, and Rae thought it would be desirable to spend money on a pilot experiment if only for the useful scientific information about plankton that would be obtained. On the other hand, Jackson [18] concluded that "plankton harvesting could not be economically feasible unless and until areas of greatly increased population density can be either located or produced by artificial means or a radically novel and cheaper method of harvesting becomes available."

(7) *If you had to decide on a research program relative to a possible plankton fishery, in which directions would you guide it?*

One of the most important things to do, perhaps *the* most important, is to find out just what useful substances plankton contains. For this, systematic biochemical analysis of plankters, species by species, is necessary to assay their chemical composition and follow the seasonal and geographical variations. At the same time, industrial chemists should develop and test useful products made of the various materials extracted from plankton.

Meanwhile, it is necessary to devise methods of accurately estimating the quantity of harvestable plankton. Then it would be necessary to apply these methods in making year-round surveys in areas that are believed to be fertile, but which are still unexplored. Year-round surveys require intensive sampling at points close together in time and space. Therefore, to get meaningful results in a large area such as the Indian Ocean would require a whole fleet of research vessels working steadily. This is quite out of the question.

Perhaps the world could be adequately covered with year-round plankton surveys without research ships by utilizing ocean-going liners. The Hardy plankton recorder would be useful for that purpose. This is a collecting device equipped with an automatic slowly revolving spool of fine silk. A small opening about a centimeter square admits water continuously, which strains through a small segment of the silk. One of the ship's officers is paid a small fee to take care of the device. He attaches it to a line at the beginning of a voyage, according to instructions, and hauls it to deck to change spools at stated intervals during the voyage. Thus a small but continuous sample is obtained along the whole course of the voyage. At the end of the voyage, the spools are sent to a central laboratory for analysis of the material collected.

Another means of sampling large areas without resorting to special expeditions might be to use condenser intakes on ocean-going liners. For this, special apparatus would have to be invented in order to provide continuous collections that could be identified with time and place of capture.

Several biologists suggested establishing facilities for cultivating plankton on a large scale, to harvest it either directly, or indirectly by feeding it to fish and shellfish reared for commercial purposes in salt water ponds (see Chapter 9). This would require research into the physiology of the plankton organisms to be cultivated, to learn how to control their growth and mortality and hence their production.

In reckoning about the possibilities of plankton fishing, people tend to give little consideration to the fact that plankters swarm. Yet swarming is one of the most characteristic features of their behavior which may make it feasible to fish for them profitably. Perhaps we are on the wrong track in thinking about fishing passively for plankton. Perhaps the only way to make the enterprise successful would be to hunt for swarms of particular species as fishermen now hunt for schools of pelagic fish. No one fishes blind for sardines, putting nets out at random in the hope of striking a school. Why should we expect better luck fishing that way for copepods or euphausiids or any other swarming creatures? Hunting for plankton, however, would not be as simple as hunting for fish. It would take special techniques which would have to be developed. For this it would be necessary to study the characteristics and behavior of swarms of plankters.

In short, a science of plankton fishing would have to be developed, based on knowledge about the organisms. Until we have that knowledge, it will not be worthwhile to spend a great deal of money on fishing apparatus for trial-and-error experiments. Meanwhile, general knowledge about plankton, including its abundance and behavior, should be one of the many useful products of research on environment (Chapter 5) and on behavior.

9

Farming the Brackish Waters

Probably the only parts of the sea which can be farmed are in inshore waterways and estuaries which are well protected from the open ocean. Although such areas are farmed in a few countries, they are completely neglected or even badly used in many parts of the world. Yet, when properly manipulated, they can produce larger quantities of animal protein than can farmland. This chapter discusses the fertility of brackish inshore waters, describes the species which are most suitable for cultivation in them, and suggests lines of research which should lead toward yields and profits in aquiculture.

There are long stretches of coast about the world where land and sea are not so sharply distinct as they are at rocky shores; where, instead, the two merge gradually in an irregular and sometimes intricate edging of estuaries, sloughs, lagoons and mud flats, brackish swamps, and fringing islands. This transitional area where the land reaches out into the sea and the sea into the land is one of the most interesting of all marine ecosystems, and perhaps from a fishery viewpoint potentially the most valuable. In some places it is richer than the richest farm country, for it is lavishly fertilized with inorganic nutrients which the land is continually pouring into it.

Something about these brackish waters seems to be peculiarly necessary to many marine animals, something beyond the ordinary nutrient salts. What this essential principle or complex of principles is no one knows. Various lines of evidence point to organic nutrients which might be imparted to a large extent by the brackish flora of delicate, filamentous green and blue-green algae, which provide the niche and the nourishment for many kinds of organisms from bacteria and protozoa up through herbivorous fishes and large invertebrates.

The brackish area is the habitat of valuable mollusks like oysters and clams. It is a kind of crossroads for fishes that divide their lives between fresh water and salt. Anadromous species like salmons and shad pause for a sojourn there before going out into the open ocean or on returning from the sea before going upstream to spawn. Many kinds of animals of the open sea are transient visitors there, entering and leaving at random in the course of their constant searching for food. Others, such as striped bass, spend much if not most of their lives there, and though they do go to sea annually to make excursions along the coast which probably increase in distance with age, they have to return for spawning. Still others, such as prawns, which are spawned only in the open sea, must go to the inside waters early in life. They are evidently carried thither during larval stages as the passive cargo of currents and tides, and if they fail to find an entrance they perish. Those that do get inside, reside there until time for their spawning migration.

Thus the brackish area is not only the home of its own fauna of year-round permanent residents, but is also a spawning ground for some species that come in seasonally, a nursery for others that drift in during planktonic stages, an occasional feeding ground for others that wander in and out at random, and a thoroughfare for still others that are migrating between river and sea destinations. With all this flow of life, the biological content of the brackish area is extraordinarily rich. And, being conveniently close to land, shallow, and well protected from the open sea, it is the most likely part of the sea to subject to cultivation.

True, hundreds of thousands of acres of these areas *are* cultivated in various parts of the world, mostly in Indo-Pacific countries. At the same time there are millions more that are not cultivated, or at least not developed to their full potential for the production of food. In many regions, fishermen treat the brackish inshore waters just as they do the open sea, hunting and gathering only the wild stocks. In doing this, they are making just as foolish use of environment as ranchers would if they were to use rich farmland for range country, or range country only for hunting wild game. In densely settled areas, people turn their sloughs and mud flats into unsightly dumping grounds for their rubbish. This is neglect of opportunity. What may be worse, because irrevocable, they often regard these areas as wasteland, to be filled in and thus "reclaimed" for agriculture, industry, or living space. This destruction of the unique brackish environment in order to create a relatively small piece of land is not usually evaluated. Undoubtedly the need for land is important, but the consequent loss from devastation of marine animal protein resources may in some instances far exceed the benefits of the new land.

We might best judge the potential value of brackish waters by comparing the experience of peoples who have cultivated them with the experience of farmers. A good standard of comparison would be the production of domestic animals per unit area of farm land. Unfortunately, it is difficult to find suitable data because wide variation in the productivity of different soils and in the circumstances of production reduce the significance of averages. Statistics on production in brackish water ponds are even more elusive. At best, the available agricultural and aquicultural statistics can give us only a very rough basis for comparison, and as we shall see, they are not directly comparable. We need to know how much land it takes to feed the various kinds of farm animals. In other words, to what extent do they compete with human beings for food and space? How much do our meat and other livestock products cost, in terms of feed? How much space is required to produce that feed? The answers to those questions might best be derived from these estimates:

Under average agricultural conditions in the United States, the grain produced on one acre will feed enough livestock to yield around 21 pounds (dry weight) of protein food in a year.* In comparing this figure with what is obtained from a brackish environment, we have to remember that a landsman has an advantage over a sea farmer in having behind him a tremendous accumulation of research in all the fields of science that touch his occupation—genetics, entomology, microbiology, biochemistry, and agronomy, to name only a few. What has the sea farmer that is comparable? Almost nothing. He is centuries behind the land farmer, and the results of his labors should be judged accordingly.

In many places the sea farmer does essentially little more than corral some animals into a prepared enclosure and hold them during a suitable growing period without feeding or fertilizing. Thus he allows them to be nourished by what comes naturally in the water. Although this passive treatment is called "culture," it is at best a primitive sort of culture, and of course the yields are not spectacular.

In the United States oysters are the only marine species which are grown commercially. Here, yields of 100 or 150 bushels an acre

* This is about 37 per cent of the dietary allowance of protein recommended by the Food and Nutrition Board of the U. S. National Research Council for a moderately active American male weighing 70 kilograms (154 pounds).

are fairly common. These are 1.5 to 10 times as much as can be obtained from wild stocks on public grounds. Even so, they are only a fraction of what they might be when the science of oyster farming becomes further advanced.[1]

In places where marine aquiculture is practiced, yields vary widely according to location and types of soils, but perhaps mostly according to the amount of work and investment put into the enterprise. A good demonstration of what a brackish enclosure can yield with minimum labor and without special management has been made in an experimental pond at Bears Bluff Laboratory in South Carolina, U.S.A. Here Robert Lunz [2] found a stock of one species of fish (a drum, *Pogonias cromis*) to increase in weight 21-fold in nine months, and of the shrimp (*Penaeus setiferus*) to increase 14- to 15-fold in two months. He did not plant these animals, nor did he make much of any attempt at management, but admitted to his pond whatever entered naturally when he flooded it and gathered what was left when he subsequently drained it. On several drainings he harvested as shown in Table 9-1.

TABLE 9-1. HARVEST FROM THE BEARS BLUFF EXPERIMENTAL POND

Date Drained	Elapsed Time Between Drainings	Pounds of Fish Per Acre
8/29/47	6 months	147
7/7/48	10 months	162
8/24/49	13 months	194
4/28/50	8 months	83
11/27/50	7 months	20 [a]
5/17/51	6 months	180

SOURCE: G. Robert Lunz, "A Salt Water Fish Pond," *Contributions from Bears Bluff Laboratories, No. 12* (Wadmalaw Island, S. C.: 1951), pp. 3–12.

[a] Killed by cold.

In addition to the quantities given in the table, Lunz also gathered prawns and crabs, but owing to lack of help was usually unable to weigh them. On one occasion (May 1951) he measured 48 pounds of crabs per acre; on another occasion, over 40 pounds of prawns.

In Indonesia,[3] and also in the Arcachon Basin, France, commercial brackish ponds yield from 100 to 450 pounds of fish an acre (whole, wet weight). In Formosa, by contrast, they yield 800 to 1,200 pounds.[4] This wide difference may be attributed largely, if not entirely, to the fact that Formosans fertilize their ponds, and feed their stocks (whereas the others do not) and they cultivate much more intensively. Perhaps the ponds of Formosa come closest to achieving maximum production and are therefore the best basis of judging the potentiality of under-utilized brackish areas (Table 9-2).

It is not reasonable to draw from these data or from any of the literature on pond culture precise generalizations for universal application. However, this much it seems safe to say:

A properly constructed artificial brackish water enclosure can be handsomely profitable. At the very least, it will yield many times more pounds per acre than fishermen ever get from free fishing in the natural environment. With minimum care, taking whatever animals enter naturally, without fertilizing the water or feeding the stock, a brackish pond can yield more than half as much animal protein as an average acre of farmland supports. With the same kind of care that the farmland requires, that is, careful selection of stock, removal of predators, and fertilizing and feeding, a brackish pond can produce better than three times as much flesh as can an acre of land. This is by using present information. What might result if as much research were put into brackish farming as has already gone into agriculture, no one can say.

TABLE 9-2. PRODUCTION IN BRACKISH PONDS

Country	Pounds Per Acre				
	Milkfish	Prawns	Other Species	Total	Total Edible Protein (Dry Weight) *
Java (a)					
West	120	25	15	160	8.6
Central	100	25	15	140	7.6
East	180	70	30	280	15.1
Sumatra (b)	500	100	150	750	40.5
Celebes (b)	430	75	108	613	33.1
Lesser Sunda Islands (b)	414	69	138	621	33.5
Formosa (c)	958 †	?	?	958	51.7
India (Malabar Coast) (d)	—	—	—	900 ‡	48.6
Singapore	—	70–1,000 †	—	70–1,000	3.8–54.0
Philippine Islands	300 †	—	—	300	16.2
Cochin	—	1,200–1,500	—	1,200–1,500	64.0–81.0
France (Arcachon)	—	—	270	270 ‡	14.6

SOURCES: (a) W. H. Schuster, *Fish Culture in Brackish-Water Ponds of Java,* Indo-Pacific Fisheries Council Special Publication No. 1 (Bangkok: Indo-Pacific Fisheries Council, 1952). (b) Hasanuddin Saanin Sutan Larangan, *Aspects of the Inland Fisheries of Indonesia,* Indo-Pacific Fisheries Council Special Publication No. 2 (1953), 41–43. (c) Tung-pai Chen, *Milkfish Culture in Taiwan,* Chinese American Joint Commission on Rural Reconstruction, Fisheries Series: 1 (1952). (d) B. N. Chopra (ed.), *Handbook of Indian Fisheries,* prepared for the third meeting of the Indo-Pacific Fisheries Council, Madras, February, 1951.

* Allowing 5.4 per cent of the weight of the whole fish. † A small volume of other species is included in this figure. ‡ Mostly mullet.

The heart of the job of brackish water fish culture is to control the ecosystem so as to improve the yield of desired species. Techniques of doing this must be adapted to the local fauna and environmental conditions and to local economics and sociology. However, they always begin by closing off and improving a part of the environment. In the following paragraphs I shall quote brief descriptions of these operations as carried out in various parts of the world, in order to show what processes are involved.

In Arcachon on the Bay of Biscay there are about 600 acres of marine fish ponds which were artificially created by excavating and embanking suitable places in salt marches. They are flooded with sea water or brackish water controlled with sluice gates. Hickling [5] describes these ponds thus:

These appear as pleasant lakes and canals set in green meadows, separated from the Bay of Arcachon by a wide and strong embankment, pierced by numerous sluice gates. These were originally put up for the manufacture of salt; but it was soon noticed that fish, and especially mullets, which entered with the water, flourished and grew fast in the ponds. So salt making was gradually superseded by fish raising. The secret of full production in these ponds is the correct working of the sluices. Fish, and especially in this case the fry of mullets, and eels tend to swim against a current. Therefore, at neap tides, the sluices are opened very slightly so that a slow current of water flows out of the ponds. Fish fry are attracted by this current, and collect in the sluice gates. Then a fine meshed grill is placed in the gate to prevent their escape, and on the rising tide the small fish are swept into the ponds by the rush of water. This rush of inflowing water, of course, is also a signal for the larger fish, already growing in the ponds, to try to escape, but they are prevented by a long sleeve of netting, which is attached to a wooden frame fitting into the sluice, and through which the water is passed.

In Java, marine fish ponds, called *tambaks*, are built on estuarine low-level coastal flats, usually in places where the level is below that of the local mean spring tide. Schuster describes these as follows:

A tambak in its simplest form, common in West and Central Java, consists of a square or oblong sheet of water with an area of about 6 acres, from 1 to 4 feet deep. A small wooden or bamboo gate controls the in and outflow of the water. Since there is tidal movement in those parts of Java, dikes 5 to 7 feet high are sufficient to protect the ponds against flooding.

Tambaks such as this are generally constructed by first digging a broad, shallow ditch along the sides of the plot, using the soil thus removed to build the embankment. Frequently, large quantities of soil are piled in ridges and hills in the centre of the pond to save the trouble of carrying the soil to the sides. Because of this practice ponds often are not simply an open sheet of water, but are divided into complicated patterns of strips of water and elevated parts by the long ridges of piled soil. If there is later a need to reinforce or heighten the embankment, soil is cut from the ridges, but only slow progess in bringing the ponds into correct shape is made in this way.

In other districts the ponds have been made so narrow that the removed soil could be deposited on the dikes without making use of a canoe or a raft. In this way, wide sites of oblong ponds have been built with a length of a mile or more, but a breadth only of ten to twenty yards.[6]

Fenton Carbine writes of the Philippines ponds thus:

They are often built simply by surrounding suitable areas with dikes. Peaty clay and colloidal clay are considered the most desirable soil for pond bottoms and for building dikes; Nipa palm land is considered next best. Mangrove swamps are extensively used, but are expensive to prepare, for the trees must be removed and the wood is hard to cut and the stumps tenacious. Even so, the wood once cut, is in great demand for firewood and the bark for *cutch*, a product used for tanning fish nets and leather. The bottom of a pond is always higher than in mean low tide so that the pond can be completely drained.

All construction work is done by hand labor. In digging mud for building dikes, and in excavating or filling, a small spade-like instrument is used and the soil in the bottom of the pond, river, or estuary is removed in blocks. These are placed in a canoe, paddled to the construction area, and laid by hand in the spot where needed. Dikes are always built in a series of layers, each of which is about 2 feet thick. Each layer is allowed to dry for several days before the next layer is placed on top. Mangroves and Nipa palms are sometimes planted along the exposed sides of dikes to prevent damage by wave action, current, and other types of erosion. The bottom of a pond is prepared so that it drains readily toward the outlet, and large ponds may have several channels to facilitate drainage. Dikes vary in height, depending upon the tidal variation at each particular location.

Sluice gates, to control the inflow and outflow of the water in each pond, are usually built of concrete, although stone and wooden gates are still in use in many places.[7]

In Formosa, milkfish ponds, called *wun*, are built in series of 3 or 4 to 20 or 30, to serve various purposes, as water supply canals, nursery ponds, rearing ponds, and wintering ponds. Tung-pai Chen describes these as follows:

The water supply canal is of one to several meters in width and runs the length of the wun either on one side or between two rows of ponds. A sluice gate connects the canal with the sea, and other gates connect it with the ponds in the wun. In some wun of comparatively high elevation, mechanical pumps are set up on the dike for pumping water into the ponds to maintain the proper water level.

The nursery ponds are small ponds of less than one foot in water depth. The area of each is usually 100 to 200 square meters.

The rearing ponds are 3 to 4 feet in depth of water. They are in the shape of long ditches, with a width of about 10 to 20 feet. A bamboo windbreak is set up on the windward side (northeast) to ward off the cold wind during the winter.[8]

Like everything else about sea farming, designs of enclosures have evolved through generations of imperceptible steps resulting from occasional successes among many brave trials. In some regions the rate of this evolution has been held back by firmly established orthodoxies. Therefore, the designs in use are not necessarily the best that could be devised. Among questions that deserve special study are these: What sizes, shapes and depths of enclosures would be optimal with given qualities of climate, soil, and water? How could sluices be made so as to control most effectively the biological content of an enclosure? Such problems should be put up to first class engineers to solve in collaboration with biologists. The design of ponds is of course an important subject for research. One which presses more immediately, however, concerns what goes into the ponds.

One of the most critical steps in brackish water farming is the proper selection of stocks. Very few species are suitable. Most marine animals could not survive the close confinement or the sharp fluctuations in weather that affect shallow water. Nor could many marine animals fully satisfy their own peculiar food necessities, some of which may be for organisms that occur only in the depths of the sea. Some species that could thrive in a brackish enclosure grow too slowly to provide frequent enough paying crops; others are too predaceous, will eat only fishes, including their own young, and therefore, even though fast growing, could not produce large enough crops for profitable farming. The value of a species for aquiculture depends on the extent to which it can meet the following qualifications:

1. Ability to feed, keep healthy, and grow in a brackish enclosure; tolerance of a relatively wide range of environmental conditions, particularly temperature and salinity
2. Fast growing, reaching a size suitable for market fast enough to produce frequent crops
3. Edible, fleshy, not so full of bones as to be troublesome to eat; fine flavored, marketable
4. Nonpredaceous, feeding on algae or on plankton
5. Breeding naturally in or near the brackish areas
6. Disease resistant

Animals which have proved to meet these requirements most perfectly are mullets (*Mugil* spp.), milkfish (*Chanos*), prawns, and oysters.

Mullets (Mugilidae) are among the most widely distributed of shore fishes. They occur on all coasts in the Pacific, Atlantic, and Indian Oceans, from South Africa, South America, and Australia northward to the British Isles, Cape Cod, Monterey, and northern Japan. There are more than 100 species in all; 13 of these are recorded from South Africa and 26 from India. Although most mullets have rather limited distribution, one form, the common grey mullet (*Mugil cephalus*), occurs all about the world in the tropics and subtropics and even penetrates into temperate zones, an occasional specimen turning up as far north as Halifax, Nova Scotia. This species is pre-eminent among the few mullets which are suitable for cultivation.

Mullets are creatures of brackish or even fresh water. At maturity, however, they must go out into the open sea for their spawning season. The fry, produced at sea, find their way into the inshore environment, perhaps simply by passive drift, or perhaps by constant exploration along shore for openings and passages. It is in these passages that they are easily and cheaply collected in large quantities for stocking ponds.

Mullets are not carnivorous, but feed on organic material contained in the bottom mud or suspended in the water and on detritus of animal and plant origin. They grow to be about 30 inches long. They are particularly good subjects for fish farming because they are cheap to produce. They are farmed in the New Territories of Hong Kong, in Bengal, in Cochin, in the paddy fields of the Malabar Coast, and in the Arcachon Basin in France.

The milkfish (*Chanos chanos*) also is widely distributed, the only species known occurring along all coasts in tropical and subtropical latitudes of the Indian and Pacific Oceans, from southeast Africa to Australia, from New Zealand to southern Japan, and from Chile to the Gulf of California. Its environmental tolerances are considerable, though somewhat less than those of mullets. Milkfish is primarily a marine species. Although some individuals enter brackish and fresh water, they are not impelled to do so, and they seem never to enter voluntarily during their early youth. Consequently to farm milkfish it is necessary to capture the fry in the sea, a slow, difficult, expensive job. Once transplanted into an enclosure they do very well in their new environment in spite of the rigors of transportation in small earthenware jars, in which they suffer from heat and from oxygen depletion, and in spite of the sharp change of salinity which would be fatal to many other sea fishes.[9]

In the Philippine Islands there is a special fishery for milkfish fry, which are available almost all the year round in various regions. Some people rear the fry until they are 3 to 5 inches long, then resell them to other pond owners, who thus are able to produce three to four crops a year.

Milkfish grow fairly fast in ponds. In Indonesia, for example, they reach 1 to 1.6 pounds in eight months, and a stock of fish at that size is ready for a succession of croppings which extends over three or four months. If left alone, they grow to be at least 3 feet long. Like mullet, they are not carnivorous. The fry feed on an organic substance called *tai-aic* or *lab-lab*, consisting of decayed algae, diatoms, protozoa, and bacteria. All this packs together in a mass having a jelly-like consistency, which lies as a layer on the bottom or floats in cakes at the surface. It is nutritionally rich, easily digested by the small fish, and its production and the regulation of its abundance constitute a most important part of the processes of milkfish culture wherever it is practiced. As the fish grow larger they feed upon somewhat coarser fare, which nevertheless continues to be composed of decaying algae, detritus, zooplankton, and diatoms.

Milkfish are probably more extensively cultivated than are mullets. In many parts of the Orient milkfish are an essential dish for ceremonial parties and often bring a very high price.

Of shrimp and prawns there are several genera and many species. They occur from the Arctic Ocean to the antarctic and in all types of environments from brackish swamps and creeks to the deep sea. They have great diversity of habit. Some shrimps live among sea grasses in inshore protected waters, others browse over the muddy bottom of deltas or on offshore banks. Some are wholly pelagic. Although relatively few species of shrimps are large enough, accessible enough, or abundant enough to be attractive commercially, those few can be exceedingly valuable.

Shrimp culture is highly successful in many parts of the Orient. In six test ponds in East Java the yields of prawns in pounds per acre per year came to 41, 330, 380, 470, 830, 230, and 250. This was in addition to the normal crops of milkfish. In Cochin, 1,200 to 1,500 pounds of prawns per acre are often harvested in addition to the rice crops.

The prawns of greatest interest for pond culture are the tropical and subtropical species belonging for the most part to the family Peneidae. What gives them this particular interest is their habit of entering brackish inshore waters during infancy and remaining there for several weeks, which makes them conveniently accessible during that period. They feed low in the food pyramid, on plankton, decaying flesh, and organic detritus. As they approach maturity they return to sea for breeding. They are short-lived animals, most of them probably not surviving a year or two.

Prawns make a very profitable addition to a pond containing milkfish or mullet. It is not necessary to collect the larvae for planting since they enter incidentally when the pond is filled. Schuster says, "Millions and millions of larvae must enter . . . to secure a normal yield. Overstocking a pond with prawns is hard to imagine." A maximum number can be induced to come in by clever manipulation of the gates to the sluices for two or three days after filling.

In the Philippine Islands, fishermen collect prawn larvae by tying bundles of grass to a long heavy cord about 6 to 8 feet apart, which they string out at the edge of a mangrove thicket. At half-hourly intervals they lift out each bundle with a dip net, which collects the larvae that have gathered there. They put these into jars and sell them at the end of each day to pond owners for three centavos each. The larvae grow to catchable size within six weeks after entering a pond. Beginning about that time an urge to go to sea impels them to seek constantly for a way out, and since they can get through very small holes, many escape. Consequently, to get the maximum crop, a pond owner must harvest his stock of prawns early and intensively.

The success of prawn culture depends first of all on the supply of young, which varies greatly from one locality to another, certain rivers or channels consequently receiving more larvae than others. This may result from peculiarities of the current in the outside waters, which in large measure must direct the destination of the drifting larvae. Beyond that, the characteristics of the various rivers and creeks—rate of flow, fertility of the water, quality of the bottom soil, and the flora of the shore—must all exert some influence as to which of several directions the infants may take under such powers to navigate as they possess at that age.

Oysters are excellent subjects for pond culture. They are creatures of inshore environments, generally occur in depths shallower than 40 or 50 feet, and tolerate a wide range of saltiness from nearly fresh to almost undiluted sea water. There are many species of oysters, of which only certain ones are suitable for human use. They are distributed over the world in temperate and tropical latitudes. Some species are oviparous, other viviparous, but either way they spend their infancy as free swimming creatures, transported by tides and currents until they have developed to the point where they must settle to bottom. Then they cement themselves to the substrate and live out the rest of their lives permanently thus fixed. They filter large quantities of sea water through their gills, straining out their food, which consists of microscopic organisms. Oysters are peculiarly amenable to cultivation. Wild stocks are overcrowded, full of misshapen, stunted individuals, jammed with commensals, parasites, predators, and competitors. When fished intensively they quickly become depleted. On the other hand, if seed is carefully selected, planted in a protected environment with due consideration to proper spacing, and with periodic removal of predators, and if the adults are harvested at a proper rate, production can be sustained at a relatively high level. Although oyster farming is profitable where it is practiced, there are large areas where people fail to take advantage of the opportunity which their oyster resources afford. The fishermen, not knowing their great value, sometimes ignore them or merely gather from the wild stocks.

Tilapia is a genus of tropical fish, of which there are several species, native to Africa, belonging to the family Cichlidae. Since 1930, it has been introduced into ponds and paddy fields in Indonesia, Sumatra, Siam, Burma, Malaya, Formosa, the Philippine Islands, and the West Indies. Although *Tilapia* is a freshwater fish, it is included in this book because it is cultivated in brackish as well as in fresh water, and also because it serves as an excellent example of an exotic species which people have introduced with great enthusiasm without sufficient thought of the consequences. During the early stages of its introduction it did look like the perfect fish for tropical ponds. It lives peacefully with other species, feeding on algae, detritus, and plankton. Under favorable circumstances, individuals grow to weigh 30 ounces in a year. They mature at about three months of age. One writer said of them "All a farmer has to do is pour a can of *Tilapia* fingerlings into his pond and he is in the business as a fish farmer . . . The fish eats like mad, grows like mad and spawns like mad." It is that "mad spawning" which probably spoils *Tilapia* as a pond fish for human food, for populations tend to become so overcrowded that the members become stunted. This is so serious that the Food and Agriculture Organization of the United Nations no longer recommends it for pond culture. On the other hand, experiments in the Honolulu laboratory of the U.S. Bureau of Commercial Fisheries (Fish and Wildlife Service) show promise that *Tilapia* may be a suitable species to cultivate as bait for high seas tuna fishing.

Any research program about pond culture should make provision for seeking and testing other species which might be suitable. It does not seem likely, however, that many would be found and probably the center of interest would continue to be on mullet, milkfish, prawns, and inshore-dwelling mollusks, and on the environments which those species occupy.

True, brackish water farming has developed to a high level in oriental countries; but it is still practiced essentially by rules handed down from one generation to another, bound by tradition, and kept from advancing by the fact that there are wide gaps in knowledge about the animals, particularly about their life in the sea, and about the ecology of their inshore environment. No doubt these gaps would become narrowed with more centuries of experience, but they can be closed reasonably fast only by scientific research.

Part of this research would deal with a complex of problems regarding the spawning requirements of mullet, milkfish, and prawns. These animals must all leave the inshore waters at maturity and go to sea for spawning. Why? What elements of the open sea, what chemicals, what qualities of water, what light intensity, what quintessential foods are critical for their maturation and spawning? Could they possibly be induced, by some economical means, to spawn in a pond? Solving this problem would open the way to selective experiments and the development of strains of animals having particularly desirable qualities. All these questions demand physiological research under rigidly controlled conditions of a laboratory situated beside experimental ponds.

Another line of research should follow the natural histories of these animals, which are very poorly known. Where are the spawning grounds? What features of hydrography influence the subsequent distribution of eggs and larvae? What vagaries of environment affect their survival?

Here, the study of the sea habits of young milkfish is particularly important, for it should lead to improving means of locating fry, and of utilizing peculiarities of their behavior to attract and concentrate them. All this would have great practical value to brackish water farmers because collecting fry and transporting them is now laborious and expensive. It is hazardous, too, because people lose many fry while carrying them to their ponds in small earthenware jars. In Formosa, two men fishing steadily during two tides of one day will gather 50 to 70 fry, sometimes as many as 100, but seldom more. Because Formosans cannot supply their needs in this way, it is necessary for them to import from Indonesia and the Philippine Islands, where milkfish fry seem to be more abundant or at least more accessible. This too is expensive, adding greatly to production costs. Not only in Formosa, however, but wherever milkfish farming is carried on, people speak of the difficulty and cost of obtaining fry.

The search for spawning grounds and the study of the sea habits of the young fish require working in the outside waters on a seagoing research vessel. This vessel should also be engaged in determining how the various conditions and movements of the water affect spawning and the drift and survival of eggs and larvae. It should be fully equipped with instruments for making oceanographic observations, for collecting plankton, and for fishing, and its program should be supervised by a staff of competent oceanographers and biologists.

Oysters differ from other marine animals which are farmed in that they spend their entire lives in the inshore environment. Nevertheless, the problems involved in their cultivation are similar to those of the fishes and prawns. What influences the survival of their young, the production of seed, the rates of growth and mortality of oysters, and the abundance and habits of the predators? Oysters would make an excellent addition to a properly stocked pond, and these questions must be solved if there is to be a science of oyster culture.

There are many fundamental problems concerning the biology of the ponds. The Indo-Pacific Fisheries Council has posed one of the most important of these as follows: "It is highly desirable to evolve techniques for the assessment of the carrying capacity of ponds since a mistake along this point leads to high mortality and to the possible production of inferior quality fish. It is possible that this problem may be attacked on the basis of availability of food and space and such other criteria as may be found feasible." [10]

How do the various elements of environment influence the production of filamentous algae, flagellates, protozoa, and bacteria, and what conditions favor the formation of *lab-lab*, the substance on which milkfish, mullet, and perhaps also prawns feed? The fertility of ponds declines rapidly with continuous and prolonged use. How can it be replenished? Is it economically feasible and profitable to fertilize ponds? Could cheap, easily procurable artificial feeds be developed to supplement the natural supply?

What species are predaceous? How can they be kept out of ponds, or at least their numbers minimized? This is a problem which is particularly hard to solve in a marine pond, and therefore is usually neglected. It is equal in importance to the problem of keeping bears and wolves out of a cattle ranch. The research involved in predator control should begin with the biology of the predators to determine the weak points in their life history, and the peculiarities in their behavior of which advantage might be taken in devising control measures.

Pond culture research requires a laboratory. This must be located in a place where experimental ponds can be built, and which has easy access to the open sea. It ought to be in a country where there are extensive brackish water areas that are undeveloped, where there is a large population of people, and where a shortage of animal protein food is serious and appreciated. It could in fact be an environmental laboratory such as was discussed in Chapter 5, established in a tropical setting. It ought to begin on a small scale, centering its attention at first on studying the environments of the brackish inshore area and of the immediate offshore vicinity.

10

The Role of Disease

*One of the most serious gaps in our knowledge of marine ecology in the study of diseases. To what extent do pathogenic bacteria, fungi, viruses, and other groups affect populations of plants and animals? For this chapter I have assembled a number of examples to illustrate that epidemics * are common occurrences in marine environments, and sometimes have devastating consequences. They may be an important cause of fluctuations, and should therefore have a prominent place in research programs.*

Most scientists agree that understanding of the biology of a marine organism can come only by studying it as a component of an ecological system. This means taking into account the physical characteristics of its environment and the action and interaction of all the competing predaceous and prey organisms composing the system. This is what ecology is and what ecologists seek to understand. However, one aspect of marine ecology which has been peculiarly neglected is disease.

It is true that when biologists draw up ideal programs of ecological research they mention diseases and parasites, but always far down on their list of things-to-study-if-opportunity-permits. And opportunity does not permit. It is an exceptional marine laboratory that provides for a pathologist or epidemiologist on its permanent staff. Marine microbiologists, of whom there are precious few, do

* Strictly speaking, "epidemic" refers to diseases affecting people, and is therefore not properly used in this text. However, it has the advantage over "epizootic" and "epiphytotic" of being a familiar word, and I have therefore indulged in the license of using it in referring to diseases of animals and plants.

not often focus attention on pathogens because most microscopic animals and plants are not pathogenic. Moreover, disease is such a highly specialized subject that one can study it profitably only if he gives it full-time continuous attention and has certain special equipment which marine laboratories usually lack. Hence, the intellectual atmosphere is not very encouraging to the study of marine diseases. Nevertheless, during the past seventy years a few scientists have described a number of pathogenic organisms incidentally to their other studies. They have recorded enough epidemics to suggest that disease might be a much more potent factor in marine ecology than it is usually assumed to be, perhaps as destructive to the animals and plants in the sea as it is to those living in fresh water and on land. If this is true the failure to include disease within the scope of marine biological researches might explain why fluctuating abundance continues to be a mystery.

In the following pages I shall give a few examples to illustrate that diseases do exist in the sea, that they are distributed widely over the world in different classes of organisms, that some of them are deleterious to their hosts, and that they occasionally devastate whole populations.

An example of a well-documented disease is that due to the fungus *Ichthyosporidium* which infects several kinds of fishes in the North Atlantic Ocean. It is endemic to the herring of the western side of the Atlantic, but apparently does not affect the other stocks of that vastly abundant species. American fishermen recognize it by the black specks it makes on the skin of the fish, from which they give it the name "pepper-spot disease." They will tell you they have always known about it, and so had their fathers and their grandfathers before them. They find that the disease is always present. Because the disease sometimes affects the quality of fish to such an extent that canners must cull out infected ones, government biologists have had occasion to keep records of the incidence of infection. The percentage of sick fish fluctuates from year to year and from place to place. It is higher in winter than in summer. It never goes below 1 or 2 per cent, and it may reach 70 to 80 per cent during the height of infection in a season. Certain other fishes, for example the alewife, the winter flounder, and the mummichog, catch the same disease apparently where they frequent waters inhabited by infected herring.

The disease organism is suspected of gaining entrance through the intestine, presumably carried there by some infected food organism or by another kind of parasite. Flatworms may introduce the spores with their borings into the intestinal wall of the fish. By whatever means the fungus gets in, it sends forth thread-like processes which produce strong enzymes that break down the proteins of the host tissue on which the fungus depends for its existence. Thus the plant dissolves its way throughout the body of its host, through kidneys, spleen, blood vessels, brain, muscles, and skin. It is inconceivable that a fish so overwhelmed could long survive. During severe epidemics, fish caught in the herring traps skim about at the surface in circles, on their sides, as though intoxicated. When they are in that condition, other kinds of fishes, gulls, and seals find them easy prey.

On the European side of the Atlantic, the same fungus, or at least a closely related species, infects mackerel, hake, sea snail (a fish), flounders, cusk, cod, and haddock, and in lakes on the European continent, trout and other fresh-water fishes! [1] In the mackerel, the disease organism seems to be limited to the viscera, particularly the kidney and spleen. It rarely attacks the muscles as it does in the American herring. Nora Sproston, studying this disease in mackerel at Plymouth, England, in 1940, 1941, and 1942, found the incidence in samples to fluctuate between zero and 100 per cent. Of all the specimens she examined during those three years, the percentages infected were 70, 38, and 69, respectively. She wrote, "The disease is a very serious one, showing no signs of abatement." No one knows what proportion of the mackerel population this disease kills. In any event it is a nuisance to fishermen because the proteolytic enzymes produced by the fungus cause infected specimens to become centers of putrefactive bacteria soon after death, so that the presence of even one in a barrel will quickly spoil the others.

Haddock of the western side of the Atlantic seem to be free of this fungus disease—at least no cases have been reported—while those of the eastern side are not. In them it causes such a discoloration of the muscles that infected fish must be condemned as unfit for human food. Fishermen are familiar enough with them to apply such special names as "spotty haddock," "greasers," "smelly haddock," and so forth.

What transmits this disease is a mystery. Fish do not seem to catch it from each other, at least not immediately, for healthy herring have been kept in tanks full of infected ones for an entire summer and in tanks full of spores of the fungus without becoming infected.* Perhaps the disease is transmitted in food, but no massive infections have yet been observed among the organisms on

* Leslie Scattergood and Carl Sindermann are studying the etiology of this disease at the United States Fishery Station, Boothbay Harbor, Me.

which herring and mackerel feed. Moreover, the experimental fish were fed mysids which had been injected with spores, and copepods which had been exposed to them, and still no symptoms of the disease developed by the end of the summer. The possibility that food is the carrier remains open, however, for the fungus *Ichthyosporidium* has been provisionally identified in a few specimens of copepods in the Mediterranean (in *Acartia*), and in the Clyde Sea area (*Calanus*), showing that it might occur among plankters.[2]

Ichthyosporidium has not yet been reported in the Pacific; but Miss Sproston at Plymouth found in a can of California sardines some particles that looked very similar to spores of the fungus which produces the Atlantic mackerel disease. A primitive aquatic phycomycete, probably related to *Ichthyosporidium*, caused a heavy mortality of rainbow trout in a commercial hatchery in Washington.[3] And a herring packer of Alaska described to me an occasion in 1945 when Pacific herring obviously had something the matter with them, for they swam round and round at the surface as though quite mad, which is what Atlantic herring do when severely infected with pepper-spot disease.*

It is difficult to be certain about the taxonomy of *Ichthyosporidium*, for the plant body varies in form with different hosts. Is it really only one species that attacks the various kinds of fishes in the North Atlantic, as well as trout on the continent of Europe and copepods in the Mediterranean, or are there several species? This is an open question, probably to be most profitably attacked by a team having competence in both biochemistry and microbiology.

Another fungus, belonging to a different group (Saprolegniaceae) was identified with an epidemic disease of a copepod (*Eurytemora hirundoides*) in the northern Baltic in August 1950. Apparently it had not been observed there before. Sten Vallin wrote about it as follows: "Where the mould came from, and why it appeared first in the Bay of Sundsvall, are questions to which we have no answer . . . Probably high water temperature favors the mould. The optimum temperature for the related crayfish disease fungus is 20–25° C., though it can also be virulent in the winter."[4] The disease killed a large though unknown proportion of the local population of *Eurytemora*, which sank to the bottom in large enough quantities to foul fishermen's nets with the sticky substance of the decomposing bodies. The disease recurred in the same area the next year, and though it again killed many *Eurytemora*, the destruction was not so widespread as it had been in 1950. During the summer, *Eurytemora* is normally the commonest copepod in the surface waters of the

* This is a symptom of many other diseases of fishes, however.

central Baltic; and since it is an important constituent of the food of plankton-feeding fishes, any diminution in its numbers probably adversely affects the abundance of herring, among other species.

Parasitic marine fungi must be exceedingly common and widespread. F. K. Sparrow, an American mycologist working at Woods Hole during two summers (1934 and 1935), distinguished seventeen species, two of them new, and described two new genera. Of the seventeen, all but one were parasitic or saprophytic on various species of algae, and one was parasitic on the eggs of a microscopic animal, probably a rotifer.

Sparrow had previously found seven of these fungi on the other side of the ocean, in the Kattegatt, and other mycologists have recorded several in the arctic, the North Sea, the Baltic, the Gulf of Naples, and the Adriatic.

The commonest fungus in Sparrow's Woods Hole collection, *Ectrogella*, is parasitic on certain diatoms * to such an extent that during one month (July, 1934) 88 per cent of these plants were infected. Sparrow describes the importance of the disease thus:

> At no time during the process of disintegration of the host cell could the presence of any other type of organism be detected. . . . The fungus had apparently so completely absorbed the available nutriment that even after infected cells had become broken or had fallen apart, bacteria and protozoa were seldom seen feeding on the residual material.
>
> It was very evident that not only could the fungus initiate the infection, but once inside, could bring about, unaided by other agencies, the almost complete disintegration of the contents. Further, the thallus, derived from a single zoospore at maturity, became transformed into a myriad of swimming spores, each of which was potentially able to infect another diatom.
>
> . . . a closer examination of this disease might reveal that, in some instances, it is responsible for the partial or complete disappearance of the diatom from a locality. . . . It is not known whether similar epidemics may be produced by *Ectrogella* among pelagic species. In this connection, certain of the peculiar rhythms of "flowering periods" of pelagic diatoms which have been noted in the past and which cannot be attributed to changing physical factors might well be considered from the standpoint of the presence of parasites. Due to the importance of diatoms in their role of "producers" in the sea, such a disease as that caused by *Ectrogella* should be examined in all its aspects, even though at the moment it appears to be confined to littoral algae. Further, it would be well in the future to give closer attention to the examination of plankton samples for evidences of parasitic organisms, especially during the decline of a "flowering period." [5]

Notwithstanding Sparrow's very pertinent exhortation, the only evidence that anyone gave attention to fungus parasites of algae during the next fifteen years is a few pages of brief notes scattered through the scientific literature. Then in 1950 an Egyptian mycolo-

* *Licmophora* and *Striatella.*

gist, A. A. Aleem, reported observations which he had made at Banyuls in the Mediterranean during one September, which were comparable to those of Sparrow at Woods Hole.[6] He found eleven species of fungi parasitic on diatoms and algae, not only along shore but also in deep offshore water. Three of them gave evidence of damaging their hosts, the commonest of these being *Ectrogella*, which was in several species of diatoms. Regarding the importance of these marine fungi, Aleem says:

> . . . . It is clear that the marine Phycomycetes are a very widely distributed group, capable of activity, able to survive great variations in physical and chemical conditions. Their tolerance to variations of salinity and temperature is shown by the presence of the same species simultaneously at Banyuls and on the Scandinavian coast. The role which these organisms play in the organic decomposition in the sea cannot be over-estimated. . . . Moreover, they produce great numbers of zoospores, but these are so minute that people have given them little attention. Yet they may be very important as food among the microfauna. While examining algae under the microscope, I have on several occasions seen them devoured by rotifers and other animals which live with the algae.*

A primitive fungus, *Labyrinthula*, is credited with responsibility for the pandemic of a wasting disease which, in 1931 and 1932, all but destroyed the eelgrass (*Zostera marina*) of the North Atlantic.[7] This marine flowering plant lives close to shore from North Carolina to southern Labrador, in Hudson Bay, in Greenland, and in Europe from northern Scandinavia to the Mediterranean. In the Pacific it occurs from Lower California to Bering Strait, and on the Asian side southward at least to southern Japan.

It is exceedingly important as a check to bottom erosion, as a niche to several species of larval and small fishes, shellfishes and other aquatic organisms, and as a food to aquatic birds, which feed on its seeds, underground root stocks, and leaves. People use eelgrass in various ways for insulating, packing, and upholstering material, and for fuel and fertilizer.

The pandemic started along the American Atlantic coast in the summer of 1931. The first symptoms were a peculiar streaking and blackening on the leaves of the eelgrass, usually down near the roots. Soon the blackened area disintegrated, the leaves broke off, the roots died. By the end of the first year of the pandemic, this wondrously abundant plant which had formed vast meadows along our Atlantic shore was virtually wiped out, and the beaches were piled high with windrows of dead leaves that had washed ashore. Soon

* A free translation.

after it started in America the disease appeared in France, England, and Scandinavia, with almost equally disastrous effect.

The conclusion of this devastating episode was by no means as abrupt as its beginning. Time and again the eelgrass would seem well started towards recovery, only to be struck down again. After more than ten years of such ups and downs, the stands eventually have again grown to their former state of abundance and well-being. It is puzzling that *Labyrinthula* still lives among the eelgrass, but now apparently as a harmless commensal. It might be that *Labyrinthula* has lost its virulence, or that the eelgrass has gained in resistance. Or it might be, as some authorities think, that it really was not *Labyrinthula* at all that did the damage, but some other organism still undiscovered—a bacterium, perhaps, a virus, or another fungus.

Late in the 1930's eelgrass became affected on the Pacific coast. The disease might have been carried there with eastern oysters, which are regularly planted in California bays, or with the water ballast of ships coming from the Atlantic. By whatever means the disease was introduced into the waters of California and Oregon, eelgrass declined very gradually beginning about 1938 until by 1940 only 25 to 40 per cent of the normal stand was left in some bays.[8]

The ecological effects of the disappearance of eelgrass from the Atlantic coast were severe. Shore birds which depend on the grass, notably the brant, became greatly reduced in numbers. It is also often asserted, but unfortunately without quantitative evidence, that certain coastal fishes and mollusks, crustaceans, and other small invertebrates also diminished in numbers. The effects on the Pacific coast were less striking than on the Atlantic for the disease was not so widespread or so devastating, and birds were evidently able to find other food during the time of scarcity.

In October 1938 an epidemic broke out among sponges in the Bahama Islands, rapidly spread throughout the West Indies and thence to the northwest coast of Florida, to Mexico, and to British Honduras. The orderly geographic progression of this disease corresponded strikingly with the prevailing system of currents, suggesting that the whole epidemic started from one point. Within two years, the disease killed 30 to 90 per cent of the adult populations of commercially valuable sponges. Such worthless species as loggerhead and mumjack remained unaffected, while in some places velvet, grass, and yellow sponges were almost completely wiped out. The disease organism was a fungus, tentatively identified as *Spongiophaga.*

> The symptoms of the disease were identical in all the varieties of sponges, the first visible sign of it being a bald patch on the jet black horny skin of the affected specimen. On cutting such a sponge, a considerable portion of it was found to be already dead, the tissues rotted away and often of a greenish color. In many instances only a thin core of living tissue remained of a large wool or velvet sponge, the interior of which was still occupied by the skeleton. . . . After the peak of the mortality had passed, specimens were often found with large lesions showing the inroads of the malady.[9]

People engaged in the sponge fishery were aroused for a while to encourage research into the origin and nature of this blight which affected their livelihood, but their interest subsided as the sponges showed signs of recovery.

Fungi also parasitize eggs of marine animals. ZoBell has found malformation in eggs of Pacific sardine to be often attributable to fungus infection.[10] This might be a significant cause of failure of sardine crops.

Eggs of the blue crab in Chesapeake Bay become infected with the fungus *Lagenidium callinectes* and either die or hatch into abnormal larvae which fail to develop further. This fungus penetrates the eggs while they are being carried by the mother. Fortunately it affects only those eggs near the surface, and rarely goes deeper than a few millimeters into the egg mass before the eggs hatch and are scattered. This mechanism may prevent the fungus from ever overwhelming the population of crabs, unless the fungus can also attack the free swimming larvae. Unfortunately no one has studied the ecology of this disease enough to examine that possibility or to measure the annual fluctuations in the incidence of the disease and determine its contribution to the causation of fluctuations in abundance of the crabs.

It requires a rather elaborate procedure to establish the etiological role of microbes, particularly bacteria and viruses. It is necessary to isolate bacteria, which are often highly fastidious, from the infected fish. However, this is a difficult thing to do because many kinds of bacteria are normally present on fish; and though they are not normally pathogenic, they may act as secondary invaders. Most of them grow on ordinary culture media, and unless the laborious testing to fulfill Koch's postulates is carried out to conclusion, these harmless organisms can easily be confused with the actual agent of the disease in question. Proof of the pathogenicity of a fungus also depends on laboratory infection of lots of fish and the exclusion of bacteria and other possible agents.

Marine epidemics are attributed more often to fungi than to any other type of organism. This need not mean that fungi are the most destructive pathogens of the sea, but only that they are the easiest for a nonspecialist to detect. They generally are relatively large and often have a peculiar form that readily distinguishes them as fungi. Other microbes require special stains and tests which must be based on their morphological, physiological and biochemical characteristics. Unfortunately these characteristics have been studied for only a few species, and therefore there is very little in the literature on which to base diagnoses. Some microbiologists think fungi are usually only secondary invaders, attacking after an infection of protozoan, bacterium, flagellate, or worm has weakened the host. Certainly there are enough records in the literature to prove that those organisms occur in the sea. It would be most peculiar if there were not many more than we know about, and if they had no influence on mortality rates of fishes, and if their virulence did not fluctuate.

People notice that an epidemic is in progress when the symptoms are startlingly obvious. They do not report it until large numbers of fish have died; then they send a few specimens to a fishery laboratory. By the time the specimens arrive, they have become so full of putrefactive organisms that it may be impossible to determine what killed them.

Let us turn to a few examples of pathogens other than fungi. There is a large group of protozoans having the form of stalked cysts, which attach themselves to certain appendages of copepods. These seem to be harmless. There is another group of protozoans, however, belonging to the Cnidosporidia, a subclass of the Sporozoa, which are not harmless. These are parasitic only on invertebrates and cold-blooded vertebrates, and often produce epidemics among commercial marine fishes. Nigrelli [11] has observed more than 700 species of Cnidosporidians in more than 1,000 species of fishes during the course of his work at the New York Aquarium (see Table 10-1). He found various species infecting the skin, connective tissue, muscle, bone, cartilage, eyes, gills, heart, nervous tissue, body cavity, gastrointestinal tract, liver, gonads, spleen, kidney, air bladder, gall bladder, and urinary bladder.

Fish become infected by eating infected fish, or by ingesting the spores of the parasites, which have been released into the water with intestinal or urinary wastes. Some of these parasites have been found infecting fish eggs.

These parasites produce all sorts of symptoms, which vary with species and according to the degree of infection. They may cause no more serious reaction than formation of connective tissue cysts; or they may cause an acute or chronic disease similar to cystitis, ne-

TABLE 10-1. SOME MYXOSPORIDIA AND MICROSPORIDIA FROM MARINE FISHES

Host	Parasite	Site
	Myxosporidia	
Alosa finta, thwait shad	*Mitraspora caudata*	Kidney
Anguilla vulgaris, eel	*Myxidium giardi*	Kidney
Atherina hepsetus, silverside	*Letotheca hepseti*	Gall bladder
Bairdiella chrysura, silver perch	*Myxoproteus cornutus*	Urinary bladder
Brevoortia tyrannus, mossbunker	*Chloromyxum clupeidae*	Muscle
Clupea harengus, herring	*Chloromyxum clupeidae*	Muscle
	Ceratomyxa sphaerulosa	Gall bladder
Clupea pilchardus, sardine	*Ceratomyxa truncata*	Gall bladder
	Sphaeromyxa balbianii	Gall bladder
Cynoscion regalis, squeteague	*Myxidium glutinosum*	Gall bladder
Gadus morrhua, common codfish	*Myxobolus aeglefini*	Cartilage, bone, cranium and eye
	Myxidium oviforme	Gall bladder
	Zschokkela hildae	Urinary bladder
Hippoglossus hippoglossus, common halibut	*Unicapsula muscularis*	Muscle
Melanogrammus aeglefinus, haddock	*Myxidium gadi*	Gall bladder
	Myxobolus aeglefini	Cartilage
	Zschokkella hildae	Urinary bladder
Merluccius merluccius, European hake	*Ceratomyxa globulifera*	Gall bladder
	Leptotheca elongata	Gall bladder
Merluccius capensis, South African stockfish	*Chloromyxum thrysites*	Muscle
Microgadus tomcod, tomcod	*Zschokkella hildae*	Urinary bladder
Molva molva, ling	*Myxobolus aeglefini*	Bone
	Leptotheca informis	Gall bladder
	Sphaeromyxa hellandi	Gall bladder
Mugil cephalus, mullet	*Myxidium incurvatum*	Gall bladder
Mugil chelo (?), mullet	*Myxobolus exiguus*	Stomach, spleen, Kidney, etc.
Oncorhynchus keta, chum salmon	*Henneguya salminicola*	Under skin
Oncorhynchus kisutch, silver salmon	*Henneguya salminicola*	Under skin
Oncorhynchus nerka, red salmon	*Chloromyxum wardi*	Gall bladder
Paralichthys albiguttus, gulf flounder	*Ceratomyxa navicularia*	Urinary bladder
	Leptotheca glomerosa	Urinary bladder
	Sinuolinea brachiophora	Urinary bladder
Paralichthys dentatus, fluke	*Ceratomyxa drepanopsettae*	Gall bladder
	Ceratomyxa navicularia	Urinary bladder
	Sinuolinea capsularis	Urinary bladder
	Leptotheca lobosa	Urinary bladder
Pleuronectes platessa, plaice	*Sphaeospora platessae*	Otic capsule
Pollachius virens, pollack	*Myxidium gadi*	Gall bladder
	Myxidium bergense	Gall bladder
Pomolobus aestivalis, summer herring	*Chloromyxum clupeidae*	Muscle
Pomolobus mediocris, hickory shad	*Chloromyxum clupeidae*	Muscle
Pomolobus pseudoharengus, alewife	*Chloromyxum clupeidae*	Muscle
Pseudopleuronectes americanus, winter flounder	*Ceratomyxa acadiensis*	Gall bladder
	Myxobolus pleuronectidae	Muscle
Scomber scombrus, mackerel	*Leptotheca parva*	Gall bladder
	Leptotheca renicola	Kidney

TABLE 10-1. SOME MYXOSPORIDIA AND MICROSPORIDIA FROM MARINE FISHES (*Continued*)

Host	Parasite	Site
	Myxosporidia	
Sebastes viviparus, redfish	*Leptotheca macrospora*	Gall bladder
Sphaeroides maculatus, common puffer	*Ceratomyxa navicularia*	Urinary bladder
	Sinuolinea capsularis	Urinary bladder
	Zschokkela globulosa	Urinary bladder
Tautogolabrus adspersus, cunner	*Chloromyxum clupeidae*	Muscle
Thrysites atun, snake mackerel	*Chloromyxum thrysites*	Muscle
Urophycis chuss, codling	*Ceratomyxa acadiensis*	Gall bladder
Zeus capensis, John Dory	*Chloromyxum thrysites*	Muscle
Zoarces americanus, eel-pout	*Ceratomyxa acadiensis*	Gall bladder
	Microsporidia	
Acanthocottus scorpius, European sculpin	*Plistophora typicalis*	Muscle
Callionymus lyra, dragonet	*Glugea destruens*	Muscle
Clupea pilchardus, sardine	*Glugea cordis*	Heart muscle
Lophius piscatorius, goosefish	*Nosema lophii*	Nervous system
Macrozoarces americanus, ocean pout	*Plistophora macrozoarcidis*	Muscle
Melanogrammus aeglefinus, haddock	*Nosema branchiale*	Gills
Osmerus eperlanus, Baltic smelt	*Glugea hertwigi*	Intestine
Osmerus mordax, American smelt	*Glugea hertwigi*	Intestine
Pollachius virens, pollack	*Glugea punctifera*	Eye muscle
	Plistophora spp.	Muscle
Pseudopleuronectes americanus, winter flounder	*Glugea stephani*	Intestine

SOURCE: Ross F. Nigrelli, "Cnidosporidiosis in Marine Fishes" (unpublished manuscript, 1952).

phritis, hepatitis, or enteritis such as occur in warm-blooded vertebrates. Others may induce tumors of the infected organ or surrounding tissue. Still others may cause hyalin degeneration of the tissues (see Table 10-2).

Cnidosporidia are responsible for the condition known as mushy or wormy halibut and the milky disease of Australian barracuda. The halibut fishery of the eastern Pacific has been subject to a considerable annual loss because a large percentage of the fish are so badly infected as to be unmarketable. Apparently no figures have been compiled to indicate the frequency of this disease. In Australia, 5 per cent of the barracouta (*Thrysites atun*),[12] and in South Africa,[13] 76 per cent of the John Dory (*Zeus capensis*) and 70 per cent of the stockfish (*Merluccius capensis*) taken in trawls have all been found infected with the same species of Cnidosporidian, namely, *Unicapsula thrysites*. About a quarter of the catch of John Dory has been in such bad condition that the fish were unfit for filleting. Nigrelli comments as follows on these diseases.

No determination of what role they play in the mortality of fishes under natural conditions has yet been made. There can be no doubt, however, that affected fish become susceptible to secondary invaders, such as fungi and bacteria, and that the hosts succumb more readily to changes in the physical and chemical conditions of the water, e.g., to sudden changes in temperature, pH, salinity, or to pollution.[14]

There are parasitic dinoflagellates which live in the body cavity or in the gut of copepods. Parasitologists seldom examine copepods —that is to say, not more than half a dozen have reported doing so in the last 50 years—but when they do, they find these organisms. Thus they have recorded their presence in the Clyde Sea area, in the

TABLE 10-2. CAUSES OF DEATH FROM PARASITIC AND INFECTIOUS DISEASES OF FISHES IN THE NEW YORK AQUARIUM

	1940	1941
Diseases of skin and gills		
Bacterial	8	23
Oodinium (Dinoflagellate)	11	—
Trichodina (Ciliate)	20	24
Myxosporidia (Cnidospordia)	—	3
Epibdella (Trematoda)	99	2
Microcotyle (Trematoda)	44	14
Diplectanus (Trematoda)	2	—
Argulus (Copepoda)	2	—
Livonica (Isopoda)	1	—
Diseases of skin and internal organs		
Lymphocystis	9	—
Diseases of digestive system		
Enteritis and Stenosis due to Acanthocephala	5	5
Diseases of circulatory system		
Pericarditis due to Echinostome infection	—	1
Total	201	72

SOURCE: Ross F. Nigrelli, "Causes of Diseases and Death of Fishes in Captivity," *Zoologica,* XXVIII (1943), 203–16.

North Sea, in the English Channel, in the Mediterranean, and in the Arabian Sea.[15] Specimens of 25 species of copepods in the Arabian Sea and 16 in the Mediterranean were found infested with several kinds of dinoflagellates of the genus *Blastodinium.*

Some parasitic dinoflagellates spend the first part of their life cycle in the water as free-living flagellates. When one finds a suitable host, it penetrates the body and there changes into an amoeba-like form having several nuclei. At that stage it is called a plasmodium. With *Peridinium,* one of the more pathological dinoflagellates, the plasmodium is a delicate network of protoplasm which gradually spreads among and over the organs, pushes its way between the body muscles, and goes deep into the nervous tissue. When the parasite has filled all available space, it gathers into one or two spherical masses which penetrate the gut and leave the host through the anus. In the sea they transform to flagellate spores, and the cycle begins again. This type of parasite may completely destroy the sex glands of its host or at least upset the balance of sex hormones so profoundly as to cause hermaphroditism or sterility. Not only that, but the egress of the parasite is nearly always fatal to its host. If it does not break the body of its host into pieces, it leaves it enfeebled beyond recovery.

There are records of dinoflagellates infecting tunicates, diatoms, pteropods, siphonophores, annelids, and the eggs of copepods. One species, *Oodinium ocellatum,* lives on the skin and gills of several kinds of marine fishes, with consequent dermatitis and suffocation. This disease has been a frequent cause of death in the aquaria in London, San Francisco, and New York. In London, the disease seems to originate among specimens from Bermuda, in San Francisco, among Hawaiian fishes, and in New York, among those from Sandy Hook Bay. Many kinds of fishes are susceptible—jacks, pilot fish, bluefish, striped bass, porgy, weakfish, spot, croaker, puffer, boxfish and sea robin.[16] A similar disease, evidently also caused by *Oodinium,* affects pink salmon in Puget Sound.[17]

Bacterial diseases have been observed more often in aquaria than among feral populations of marine fishes. Tuberculosis caused by acidfast bacteria is the most fully described. It is also relatively easy to diagnose, thanks to well-established specific staining techniques. This disease causes tubercles in the spleen and liver, sometimes also in the gills, kidneys, roe, pericardium, eye, and intestine.[18]

A bacterium belonging to the genus *Gaffkya* was responsible for an epidemic disease of lobsters in the summer of 1946 along the coast of Maine and the maritime provinces of Canada. The symptoms were a diminution in number of blood corpuscles and in viscosity of the blood. From 20 to 50 per cent of the lobsters held in ponds and tanks died. In some provinces in Northumberland Strait losses approached 100 per cent.[19] The same disease appeared in the Netherlands in 1955 and again in 1957, causing numerous deaths among lobsters held in ponds.

In the early 1930's a dermatitis caused by the bacterium *Achromobacter ichthyodermis* broke out in the laboratory aquarium at Scripps Institution of Oceanography. Killifish, blennies, gobies, smelt, and other species of fishes became infected. At the same time, several specimens of killifish (*Fundulus*) sick with this disease were observed in the sea. The effect on the wild populations was not determined, but in the laboratory, mortality reached close to 100 per cent.[20]

There is a good deal of visible evidence that kelp on the Pacific coast of America is parasitized, but the diseases of these valuable plants have not been given much study. Sometimes, when water temperatures become abnormally high, extensive acreage of kelp off southern California and in the adjacent Channel Islands region is destroyed by a disease called "black rot," which is believed to result from a bacterial infection.[21]

Erling Ordal of the University of Washington has studied fish diseases at the State Department of Fisheries Station at Bowman's Bay. There he has observed several diseases of salmon in sea water. He writes of these in a letter (1957):

> Some studies have been carried out on diseases of fish from sea water. Particular attention has been given to salmon in sea water at the State Department of Fisheries Stations at Bowman's Bay and Hoodsport.
>
> One of the most striking of the diseases occurring in young salmon in sea water may be characterized as a hemorrhagic septicemia. Outbreaks of this disease have occurred many times at Bowman's Bay and Hoodsport and heavy mortalities have sometimes resulted. The pathology in affected fish is strikingly similar to that reported by Foerster in the course of a disease of unknown etiology in pilchards along the shores of Vancouver Island some years ago.[22]
>
> Similar disease in pilchards with very heavy mortalities had been noted in American waters shortly before the Canadian outbreak occurred.[23]
>
> More recent studies have shown it to be endemic in herring in lower Puget Sound. Outbreaks of the disease in herring with characteristic pathology occur almost every year in this area. Bacteriological studies have shown that a number of marine vibrios, which can be distinguished serologically or culturally, are responsible.
>
> An outbreak of disease characterized by initial destruction of the eyes followed by septicemia and death occurred in salmon, cod, and bottom fish held in sea water. Again a marine vibrio was found to be the etiological agent. It is possible that this disease is identical to "Augenkrankheit" which was found in cod in the North Sea by Bergman.[24] Earlier, Bergman had shown that "red disease" of eels in the Baltic Sea was due to a marine vibrio which was given the name *Vibrio anguillarum*.[25]
>
> Several marine myxobacteria have been isolated during outbreaks of disease in young salmon held in sea water at Bowman's Bay and at Hoodsport. One particular type, which has been isolated several times, produces a disease which resembles "columnaris disease" in fresh water. However, the etiological agent is different and is a highly fastidious, halophilic myxobacterium.
>
> Another disease occurring in three year old silver salmon held at Bowman's Bay was characterized by muscular boils and abscesses. The disease was slow and chronic but ultimately killed the entire population. The agent in some respects resembled the diplobacillus of kidney disease, but was easily cultivated and gave entirely different symptoms on experimental infection of several lots of fish.

In addition, during the past few years we have been investigating kidney disease, primarily in chinook salmon. In the course of these investigations we have taken various lots of the fish to Bowman's Bay for study of the disease in sea water. We found that it persisted in sea water and the majority of the fish were eventually lost, though the mortality rates varied in different lots of fish. One lot introduced into sea water in January was lost by the end of August. In another experiment we found that the mortality rate was reduced when the fish were fed a full natural diet, but the disease persisted and eventually most of the fish perished. The stocks of Columbia River origin suffered a higher mortality rate than those from the Green River Station.

During the summer and fall of 1952 further studies were carried out on kidney disease of salmon in the Columbia River stocks of salmon. As part of our study we looked for evidence of it in adult salmon migrating into the river from the sea. A considerable number of salmon taken at Bonneville, Oregon showed gross lesions of the kidneys. Upon microbiological investigation we found enormous numbers of tubercle bacilli in the lesions. Many of the tubercular fish were smaller than normal fish. Some tubercular females, though normal in size, showed partially developed ovaries. The question then arose as to the source of the tuberculosis. Were the fish originally infected before going to sea, were they infected in the marine environment, or did the infection occur after they again returned from the sea? Upon examination of salmon taken in the commercial fishery near Astoria, it was found that considerable numbers of fish were tubercular. This finding coupled with the disparity in size of some of the tubercular fish makes it unlikely that the fish were infected on return from the sea. Much more work needs to be done before it can be established with certainty that the disease was contracted in the sea, during the initial period in fresh water, or in both habitats.

Pathologists suspect that viruses are very destructive to fresh-water fishes. At least one, the lymphocystis disease, occurs in the sea. This is characterized by the fact that connective tissue cells in the victim grow to gigantic size and become surrounded by a thick transparent membrane. The disease has been recorded among flat fishes in Europe, perch in the Baltic Sea, *Sargus* in the Mediterranean, striped bass in Connecticut, New York, and New Jersey, angelfish and hogfish from Key West, Florida, and orange filefish from Atlantic City.[26]

Worms—flatworms, roundworms, and leeches—as well as crustaceans, parasitize all kinds of marine animals. These have not been studied much, but being quite visible to the unaided eye have been more frequently noticed, named, and recorded in scientific literature than have the microscopic pathogens. In general the metazoan parasites seem not to destroy their hosts. They reduce their vitality, they sterilize them, they emaciate them, and they make them susceptible to other diseases. But there are no accounts of mass mortalities attributed to them.

I will end this collection of evidence bearing on the importance of diseases and parasites in marine ecology by telling of the natural history of one copepod parasite to illustrate how it links the life conditions of two very diverse groups of fishes:

This copepod, *Lernaeocera branchialis,* begins life as an independent, free-swimming member of a plankton community. It moults several times in the course of growth. When it reaches a point of development at which it must take up its parasitic life, it seeks a flounder, and if chance favors its coming upon one, it goes into the mouth and attaches to the inner wall of the gill cover. Hundreds of young copepods may live thus in a single fish, doing what damage no one knows. Presumably they inhibit its respiration to some degree. In any case, in the flounder they mature and fructify, the male dies, and the fertilized female grows in size about threefold. Then it leaves the flounder, lives a free-swimming existence for a short period while seeking another fish, this time a member of the cod family. There, as in the flounder, it takes up residence in the gill cavity. But whereas there had been hundreds of infant *Lernaeocera* in the first host, there are never more than three, and usually only one, in the second. Now an extraordinary change takes place. The female copepod, which so far has looked enough like a crustacean to be easily recognized as such, develops into a grotesque object, a mass of growing tissue bearing no resemblance to its free-living relatives. Leaving its posterior part exposed in the gill cavity, the parasite eats its way and grows through the flesh of its host towards the heart, sometimes actually reaching the pericardium. This activity stimulates the formation of tumors in the host tissue that probably impede circulation and may contribute to shortening the life of the host. Even after the host dies, the female copepod continues to live until the eggs hatch. Then the cycle of generation of the parasite begins again. In Cuxhaven in 1949 and 1950, the percentage of infected fish among samples of fishes examined were: haddock, 10 per cent; whiting, 80 per cent; and cod, 20 per cent. Infected fish were below normal in weight, whiting by as much as 23 per cent, cod and haddock by 5 to 15 per cent.

Now to attempt some conclusions:

Marine animals and plants, at all stages of life from egg to adult, are hosts to a large assortment of disease organisms, which vary in their effects from mild irritation to deadly virulence. The resulting diseases often occur in epidemics which may be limited to particular localities or may travel around the world. Some disease agents are severely fastidious, held by their physiological constitution to living on a single species; others have a much greater nutritional tolerance. Diseases in the sea come and go as mysteriously as do those on land. Apparently it is not merely fertility of the water or population density that controls them, for there are examples of epidemics in poor as well as in rich areas, and among stocks of fishes at low levels of abundance as well as among those at high levels. Apparently epidemics occur in cycles of rather long period, on which are superimposed irregular fluctuations and seasonal cycles. Very likely they, too, are subject to diseases which may occur in cycles. Thus, epidemics seem to be controlled partly by climate, but much more by something else. That something else may be a complex of fluctuating influences, including fluctuating virulence in the pathogens, or fluctuating resistance in the host species. What mechanisms control these influences is a mystery.

A very large proportion of marine biological research programs is devoted to measuring abundance of fishery stocks and determining how this is affected by rates of mortality and replacement. "Mortality" is the resultant of death from man's fishing and death from natural causes. "Replacement" refers to restoration of a fished stock by growth of survivors and by addition of new generations. The interrelation among all these quantities should be, and sometimes is, one of the most important considerations in designing regulations for conservation purposes. Unfortunately, mortalities and replacements are so very elusive and difficult to measure that fishery administrators often cannot wait for the determinations. Behind fishery administrators' policies is often the unconscious assumption that natural mortality at the commercially useful ages is always negligible compared to fishing mortality.

Behind fishery research programs is this line of reasoning: Natural mortality is highest during the infancy of a generation; it probably reaches its peak soon after the larvae have absorbed their yolk and must begin to find their food supply in the water. It then declines rapidly to a relatively low level where it remains stable for the rest of the life of the generation. As a consequence of fluctuating infant mortality, the number of survivors in broods of fish varies from year to year, and this greatly affects abundance and therefore the fortunes of fishermen. It would be valuable both to administrators and to fishery industrialists to predict the size of generations as far as possible in advance of their entrance into fisheries.

The commonest assumption about infant mortality is that it results chiefly from unfavorable hydrographic conditions which are lethal to the brood or to its food organisms. Biologists therefore attempt to associate changes in various features of the environment with changes in distribution and size of broods of fish, and with the density of plankton. They sample the water and its contents as thoroughly as the speed of their ships and their equipment permit, measuring such qualities of the sea as are likely to prove useful—temperatures, salinity, oxygen content, phosphates and nitrates, and turbidity. This has been going on for years in many parts of the world with few, if any, persistent correlations so far. Could it be that they are examining only a part of the environment and overlooking one of its most important features?

If diseases did weigh heavily among causes of infant mortality, fishery biologists would hardly ever know it, because they do not usually search for diseases of eggs and larvae. They preserve their plankton samples in formalin sometimes for months before they examine them to identify and tabulate their contents. It would be close to impossible to detect bacterial or virus infection in such material! Nor can any very useful progress be made toward exploring this field until scientists are attached to marine laboratories for the particular purpose of conducting continuous research into disease-producing organisms and their effects on the marine world. This is not a job for the jack-of-all-trades. A laboratory interested in establishing a pathology unit should not be content with less than a team consisting of a bacteriologist, a mycologist, a parasitologist, a virologist, a pathologist, and a biochemist.

11

Poison

In assaying the potentialities of marine animals for human use we must recognize that not everything that lives in the sea is edible. A few species are poisonous, some all the time, others only occasionally and in certain areas. Fish poisoning seems to be confined to the tropics. In those latitudes it discourages using many species that are usually safely edible. Its cause has not yet been discovered and it is a subject deserving special study. Poisoning affects not only fishes but marine invertebrates, reptiles, and mammals as well. Under some circumstances which are not fully understood, some dinoflagellates become poisonous and cause mass mortalities of marine animals. Others cause mollusks which ingest them to become poisonous to human beings. This chapter reviews the subject of poisonous marine organisms, emphasizes its importance, and suggests pertinent marine research.

Poisonous Fishes

There are large quantities of shore and reef fishes living throughout the tropical latitudes which are relatively little known and little exploited for human use. Special methods would have to be developed to catch these fish, and the problems of concentrating, preserving, storing, and transporting the catches would be formidable. However, a much more serious condition that must be understood before anyone should attempt to revolutionize fisheries on the shores or the reefs of the tropics is that many kinds of fishes there are sometimes poisonous to eat. This fact is well known throughout the tropics and is the origin of certain food taboos. In some places as many as 15 per cent of the species that are usually edible become toxic from time to time, enough so to make people who eat them become violently and sometimes fatally sick. This is not the consequence of the known bacterial food poisonings associated with putrefaction or of pollution of the water but of some toxic substance in the flesh of the living fish. The identity of this substance probably varies geographically and from one group of fishes to another.

There is a voluminous literature to document the existence of fish poisoning, its widespread occurrence, and its seriousness.[1] What causes it remains a mystery. The symptoms begin from within one to ten hours after eating the fish. They may include any of the following: nausea, vomiting, acute diarrhea; metallic taste in the mouth; tingling sensations of the face, fingers, soles of the feet, and toes; cramps in the extremities, aching muscles and joints, scalding urination with albumin, granular casts, and mucus in the urine. Cold objects may seem warm to the senses and warm objects may seem cold. There may be convulsions. Temporary paralysis of the legs may occur and last a day or two to several weeks. Between 2 and 3 per cent of the cases are fatal. Death has been known to occur within seventeen minutes after eating a poisonous fish. It is impossible to say how many cases of fish poisoning occur annually, owing to the unreliability or nonexistence of health statistics in areas where poisoning occurs.

There is striking geographic variation in the incidence of this condition and in the degree of toxicity of the affected species. Judging from published records of actual observations or of conversations with natives, the Marshall Islands are remarkable for the frequency and the potency of poisoning. The Marianas, on the other hand, have fewer susceptible species, and their toxicity is relatively weaker. In the Carolines poisonous forms are abundant about the western islands, but evidently absent from the eastern islands. Barracudas from the Marshalls and Marianas become poisonous; those from the Carolines do not. At Christmas Island only the lagoon has a bad reputation. In the Caribbean, both at Grand Turk Island and at Cuba, fish on the north side are said to be more dangerous than those on the south side. At St. Thomas, fish near Sail Rock and Peter Island are particularly feared. At Puerto Rico the dangerous area runs from Salinas Playa on the south to Fajardo on the east.

At least twenty families of fishes contain species that have records of sporadic toxicity. Among them are such ordinarily excellent and well known food fishes as the snappers (Lutianidae), sea basses (Serranidae), barracudas (Sphyraenidae), anchovies (Engraulidae), pompanos (Carangidae), surmullets (Mullidae), and such less familiar families as surgeon fishes (Acanthuridae), triggerfishes (Balistidae), butterflyfishes (Chaetodontidae), porcupine fishes (Diodontidae), snake mackerels (Gempylidae), wrasses (Labridae), anglers (Lophiidae), filefishes (Monocanthidae), moray eels (Muraenidae), trunkfishes (Ostraciidae), demoiselles (Pomacentridae), parrotfishes (Scaridae), puffers (Tetraodontidae).

TABLE 11-1. OCCURRENCE OF RECORDED FISH POISONING CASES IN THE CARIBBEAN AREA

Month	Number of Outbreaks	Species of Fish Responsible					
		Sphyraena barracuda	*Seriola falcata*	*Scomberomorus cavalla*	*Caranx* spp.	*Epinephelus morio*	Unknown
January	0	0	0	0	0	0	0
February	5	0	2	1	2	0	0
March	1	0	0	0	0	0	1
April	2	0	0	0	1	1	0
May	3	2	0	0	0	0	1
June	1	0	1	0	0	0	0
July	2	0	1	0	1	0	0
August	3	1	0	0	2	0	0
September	4	1	0	1	2	0	0
October	3	1	0	0	1	0	0
November	2	0	0	0	1	0	1 *
December	0	0	0	0	0	0	0

* This case involving 15 individuals was reported caused by an assortment of fish consisting of amberjack, king mackerel, and snapper.

Puffers and porcupine fishes are dangerous wherever they occur, even in temperate latitudes. In the Philippines all fourteen species of puffers are considered poisonous, and in Hawaii a law prohibits the sale of one species (*Tetraodon hispidus*). In Japan about twenty people die from eating puffers every year. In some puffers the poison seems to be concentrated in the skin and viscera, and the flesh, if carefully removed and thoroughly washed, is edible. Indeed, in Japan puffer flesh is a delicacy.

Halstead describes the Japanese preparation of puffer flesh thus:

> The Japanese government passed a law that cooks preparing fugu (i.e., puffer) for public consumption must pass rigid examinations regarding the identification and preparation of these fishes. There are certain species which are said to be strongly toxic at all seasons of the year and it is difficult to remove the poison, hence they are usually not used for food. If the candidate passes the test, he is then designated as a licensed fugu chef and is permitted to advertise as such. As you enter the restaurant there is usually a sign over the doorway calling your attention to the fact that this is a licensed establishment. . . . The fish is carefully prepared by first removing the viscera under running tap water, with care being taken not to rupture the gall bladder. As much of the skin and blood is washed off as possible. The fish is skinned and the meat removed from the bones, cut into thin slices and then placed

in running tap water for about 3 hours, at which time the poison is leached from the flesh. The fish is then ready for consumption.[2]

There are plenty of theories to explain fish poisoning but no facts. In some species toxicity seems to be associated with the spawning season. Certainly among puffers the poisonous factor is most potent in the gonads; in the California cabezone the roe has been found, on at least one occasion, to be poisonous. Nowhere, however, has anyone made systematic observations to measure seasonal variations of toxicity. Arcisz[3] tabulates the occurrence of twenty-six recorded outbreaks in Puerto Rico and the Virgin Islands (see Table 11-1). These data are not sufficient to justify concluding that December and January are months when it is safe to eat any of the listed fishes.

It seems reasonable to suppose that poisoning results from some sporadically occurring component of the food of the affected fish. Dinoflagellates cause poisoning among mollusks. Could they also affect fishes? So far no evidence has appeared to show that they or any other organism, for that matter, are involved. Fish and Cobb summarize theories on causes of fish poisoning thus:

> Regional variations in toxicity occur in both herbivores and carnivores and are frequently attributed to diet, but this has so far been difficult to prove. Hiyama[4] concluded that a relation exists between the nematocysts (sting cells) of coral polyps and poisonous fishes because in his field investigations he found toxic species concentrated for the most part about isolated tropical islands where clear water favors reef coral, and sparse or absent in areas of heavy terrestrial outwash not conducive to coral growth. Smith also suggests that since surface-feeding fish taken offshore are not known to be harmful, the poison evidently originates in the food of reef and lagoon species. This is hardly conclusive evidence, however, because some edible fishes also feed on coral polyps, and at least one sizeable Japanese jellyfish, *Rhopilema esculenta* Kishinouye, well provided with nematocysts, is sold as a delicacy for human consumption in Nagasaki.
>
> Norman believes that forms like the wrasses (Labridae) and parrotfishes (Scaridae) derive their toxic properties from poisonous mussels, echinoderms, polyps and other invertebrates which themselves contain alkaloids. A similar opinion has been expressed by Jordan who found that, although there are no known poisonous marine foods in the Apia area of Samoa, it is reported that fishes sometimes eat poisonous deep-sea growths which appear after storms. These are said to make the flesh poisonous and sometimes kill the fishes themselves. One of the forms which becomes poisonous at times in this area is a large species of *Gymnothorax* known to the natives as "pusi." The fishes that poisoned many persons and domestic animals on Fanning Island in 1946–47 are said to have been nonmigratory species taken from areas in which the American Army had dumped war materials in 1945. The symptoms, however, appear to have been much the same as in cases of fish poisoning elsewhere. Fishermen of Saipan and Tinian believe that fishes in those waters feed on poisonous algae but Matsuo concluded that the alkaloids are more likely derived from echinoderms or crabs, although he could find no trace of any

of these forms in stomach contents. Feeding experiments on Saipan proved equally inconclusive. Intestinal contents, consisting of both animal and vegetable matter, produced no symptoms of poisoning when fed to dogs.

Toxic potency increases with age in some fishes; in fact it has been reported that when young most poisonous species, if at all toxic, are only mildly so. According to Hiyama, *Caranx sexfasciatus* becomes toxic in the Marshalls at 25 cm. (dangerously so at 50 cm.) and *C. ascensionis* at 30 cm.; in New Caledonia *Lethrinus mamlo* is said to be poisonous when larger than 80 cm. The barracuda, *Sphyraena barracuda*, is generally considered to be deadly poisonous in the Marshalls, although some of the other members of the genus do not become inedible until they reach large size.[5]

Arcisz made an extensive bacteriological study of forty-six specimens representing eight species of fishes collected near St. Thomas in areas where poisoning is frequent. He concluded that ". . . some of the fish may be infected with enteric pathogens. A more intensive active research program is needed to determine the cause. . . ."[6]

Wherever fish poisoning occurs it produces the same symptoms. Yet the nature of the poisonous factor remains unknown. Several writers have referred to it as an alkaloid, but as far as I can learn from literature, this is pure supposition. The only properties of the substance, apart from poisonousness, which seem well established, are that it is heat-stable and soluble in water and in alcohol.[7] One specimen, for example, remained toxic after being broiled for twenty minutes and baked for two and one-half hours. A mildly poisonous specimen can be made safe, as well as tasteless, by soaking it in water overnight, then pounding the flesh and rinsing it thoroughly in water.

Every year fish poisoning strikes a few hundred or perhaps thousands of people and kills in the tens or perhaps hundreds. It is thus insignificant as a cause of human morbidity and mortality. At the same time it is serious enough to stop many people from eating fish in the tropics or from promoting fishery industries, and therefore is of the greatest importance to our study. Moreover, the very fact that known species are occasionally poisonous makes one hesitate to recommend exploiting unutilized species anywhere.

The most useful goal of research on fish poisoning is to find a way of making it safe to eat fish whether they be initially poisonous or not. This might be accomplished by adding to the fish during the preparation or cooking process a chemical which would nullify the action of the poison, or at least reveal its presence. Or it might be accomplished by learning what conditions in the sea are associated with the poison, so that people could tell when they must avoid eating fish. Whatever the method of control it must be based on chemical and biological knowledge, not on opinion.

To reach this goal these basic questions must be answered: What is the identity of the poisons which occur in fishes? What are their properties? Where, when, and how do they originate?

These problems should be studied in a place where poisoning is frequent, such as St. Thomas or Palmyra. We might start with the hypothesis that fish poisoning originates with some microscopic organism which swarms sporadically. That would require systematic study of the plankton, with isolation and experimental culture of suspected forms in the laboratory and testing of their effect on fish. The minimum staff of a laboratory devoted to these studies should be a general physiologist, a zoologist who knows how to identify marine organisms accurately, a microbiologist, and two assistants. The most obviously essential and costly piece of equipment is a vessel about 60 feet long, with gear for fishing and collecting plankton, and with laboratory facilities for treating material immediately. In addition, of course, there must be a station ashore suitably equipped for physiological, biochemical, and systematic studies.

Fish poisoning is important enough around the world to deserve establishing a special project to investigate it. On the other hand, it is only one facet of a much larger problem, as we shall see further in this chapter, and a team of scientists studying it should be attached to a laboratory having a more comprehensive interest in the biochemistry of marine organisms.

Other Poisonous Marine Animals

Poisoning is not confined to fishes. Sea turtles are sometimes affected. Cases of poisoning from eating the flesh of hawksbill sea turtles (*Chelonia imbricata* and *C. japanica*) have been reported from Arabia, the Malay Peninsula, Malay Archipelago, Australia, Formosa, Samoa, Guiana, the Bahamas, and Guatemala. Poisoning from eating leathery turtle (*Dermochelys coriacea*) has been reported from the Cape of Good Hope, the Indian Ocean, New Zealand, and the Solomon Islands. Symptoms, which may start immediately to a week later, consist of diarrhea, boils, fever, hallucinations, debility, nausea, vomiting, sore throat and lips, and irresistible somnolence. Coma and death may occur within twelve hours after ingestion, or death may be delayed as long as two weeks.

Among marine mammals, flesh of the lion white seal (*Neophoca cinerea*) of southern Australia and the bearded seal (*Erignathus barbatus*) of southern Greenland and Iceland is at times poisonous; so also is the liver of the polar bear (*Thalarctos maritimus*). According to Rodahl and Moore, the liver of bears and seals is rich in vitamin A. The toxicity is associated with the concentration of this vitamin. In feeding experiments, one rat died with lesions specific for hypervitaminosis A.

Among invertebrates, the horseshoe crab of the estuaries of Malaya and Siam (*Carcinoscorpius rotundicauda*) and of Japan (*Tachypleus gigas*) is sometimes poisonous. The flesh and eggs of *Carcinoscorpius* can be fatal.[8] Nigrelli[9] found a sea cucumber (*Actinopyga agassizi*) in the Bahamas which produces a substance (holothurin) which is extremely poisonous to fish and to other invertebrates. The poisonous principle is contained in the "pink gland." A dilution of 1 to 100,000 of a suspension from this gland killed killifish in twenty-three minutes. A dilution of 1 to 1,000,000 killed the same species after several hours. Death was due to breakdown of the capillaries. Mice into which Sarcoma 180 had been implanted were given nonlethal doses of holothurin subcutaneously. Autopsies of the specimens, sacrificed six days after the injections, showed the sarcoma to be considerably reduced and necrotic. Here then is an example of one poison from a marine organism which may eventually prove to have therapeutic value.

Mollusk Poisoning

The dinoflagellates compose a very large class of microscopic primitive organisms, distributed widely throughout the world, with many genera and species and a great variety of characteristics. They have attributes both of plants (they photosynthesize) and of animals (they ingest food). They are almost if not quite as numerous as are diatoms and as important in the sea economy. They enter into the diet of a multitude of invertebrates and small fishes. The great majority of dinoflagellates seem to be benign all the time, but in certain parts of the world a certain few species occasionally burst into a dense flowering called a "red tide" and then give off substances into the water which are deadly to many kinds of marine animals, causing terrible mass mortalities (page 175). In certain other parts of the world, a certain few species which occur near shore are ingested by sea mussels, clams, mole crabs, and other animals of the intertidal zone. And although they seem not to harm these animals they make their flesh poisonous to human beings.

Mollusk poisoning evidently occurs in several regions, notably in Japan, North America, and Europe. The most severely affected region is the Pacific Coast of North America from Southern California to Alaska. In the Atlantic it occurs on the American side in the Bay of Fundy, occasionally southward as far as Cape Cod, and on the European side in Germany, Scotland, Ireland, England, Wales, and Norway.

In Japan, the causative organism has yet to be determined. From California to Alaska several species of the genus *Gonyaulax* are associated with poisoning. However, one, *G. catenella,* is so overwhelmingly predominant that researchers have felt justified in ignoring the others in their studies. In eastern Canada, *G. tamerensis* is the guilty organism. In Northern Europe, it is *Pyrodinium phoneus.*

The dangerous season varies geographically. In Japan, the incidence of poisoning is low in summer and fall. It starts to rise in January, reaches a peak in February and March and declines in April;[10] in Alaska it occurs all year round with fluctuating and evidently irregular intensity which seems to be highest between February and August; in California the dangerous period extends from May to December; in the Bay of Fundy from late summer to early fall, and in Northern Europe from August to December.

All mollusks and some crustaceans, including mussels, clams, oysters, and crabs, become poisonous in the vicinity of an affected area. On the Pacific Coast of America and in the Bay of Fundy, it is generally the shellfish inhabiting the open unprotected shores rather than those in enclosed bays which become infected. In California, the mussel *Mytilus californianus,* which is an open coast form, becomes poisonous, while *Mytilus edulis,* which inhabits bays, never does. In Europe it is the other way round. There the causative organism is a form characteristic of brackish water rather than of the open ocean. Consequently, most of the outbreaks of poisoning have resulted from eating shellfish of estuaries, inner harbors, and small enclosures like canals. In Maine the poison has been found in strongest concentrations in the mollusks and in the mud of the tidal waters of rivers or brackish bays at considerable distances from the open ocean.

Normally these dinoflagellates are yellow green or golden. As they become poisonous, however, the color of most individuals takes on a reddish brown or orange brown cast. When this happens the mollusks in the vicinity become affected very quickly. In one observation, where *Gonyaulax catenella* was flowering, the toxicity of mussels increased a hundred-fold in twelve days. The poison becomes concentrated in the liver of mussels, scallops, and most clams, in the siphon of the butter clam, in the gills as well as the liver of the bar clam and soft-shell clam. When the dinoflagellates go into their non-poisonous phase, the shellfish excrete their stored-up poison into the water and thus purify themselves in a few days.

People who study mollusk poisoning measure the degree of toxicity in mouse units. A mouse unit is the amount of poison contained in one milliliter of alcoholic acid extract dissolved in water, which, when injected intraperitoneally into a white mouse weighing 20 grams, will cause death in fifteen minutes. In one analysis made at the Hooper Foundation in California, 240 kilograms of whole mussels contained 58 mouse units per gram. The poison which *Gonyaulax catenella* produces is soluble in water, methyl and ethyl alcohols, acetic acid and acetone; it is insoluble in ether, chloroform, ethyl acetate, butyl alcohol, and toluene. It breaks down on heating, also with increasing alkalinity. It seems to be a nitrogenous base. It has not been isolated but its hydrochloride is said to have the empirical formula of $C_9H_{17}N_6O_4(HCl)_2$. It is one of the most toxic substances known.

Biochemists have detected more than one poison in California marine invertebrates. One they called P-I. In mice this causes central paralysis, severe spasms, heart block, and death, all within twenty minutes.

Another, less potent poison referred to as P-II, may be caused by something different from *Gonyaulax catenella.* This can be demonstrated only when P-I is absent and not interfering with the test, in other words, only in late fall and winter. It causes symptoms similar to those resulting from tetramethyl ammonium salt (which has been found in certain sea anemones)—that is, motor paralysis and feeble heart beat. Symptoms begin from several minutes to several hours after administering the poison, and death may occur from five minutes to several hours after the onset of symptoms.

A third poison, P-III, does not begin to show any effect in mice until six to thirty hours after it has been administered. This was observed only in mussels and sand crabs in La Jolla in May, 1933, when *Prorocentrum micans,* a dinoflagellate, increased in abundance to 200,000 per liter of sea water. This poison causes trembling, incoordination, tetanus; and death occurs in eight to ninety hours. It took a large dose of this to kill a mouse—no less than 30 milligrams of crude extract.

A fourth poison, P-IV, was detected in samples of plankton collected from a pier at Halfmoon Bay, California. This affected mice much like P-I, but caused no heart block, and therefore presumably originated in some organism other than *Gonyaulax catenella.*[11] It may be identical with a poison produced in the Japanese clam *Venerupis,* and called by Japanese scientists "venerupin." [12]

People vary in sensitivity to shellfish poisoning. Evidently the toxicity varies too with differing species of dinoflagellates. Sommer, who studies mussel poisoning, remarked (in a conference at Washington, D.C., in 1946) that people can take a few thousand mouse units at a time without noticing any ill effects. He considered 40,000 mouse units to be the beginning of dangerous levels.

On the other hand, Canadian scientists, working in the Bay of Fundy, record sixty cases of people taking estimated doses of 300 to 17,000 units without ill effect, but 28 other cases of people taking estimated doses of "1,000+" units up to 36,000 units showed varying degrees of intoxication from mild to extreme. The scientists concluded that some people have a natural tolerance to the poison. Those living in shore communities who eat shellfish regularly may acquire a tolerance to doses which would produce severe symptoms in unconditioned persons.[13]

TABLE 11-2. OCCURRENCE OF RECORDED MOLLUSK POISONING CASES AND MORTALITY FROM POISONING IN SELECTED AREAS

Country	Year	Number of Cases Reported	Number of Deaths
Japan	1889	81	54
	1941	6	3
	1942	334	114
	1943	16	6
	1948	11	1
	1949	67	3
U.S. (Calif.)	1927	102	6
	1929	62	3
	1932	40	1
	1933	22	1
	1934	12	2
	1936	3	2
Germany	1887	3	1
England	1888	3	1
Ireland	1890	7	5

Symptoms depend on the poison present. They can begin almost immediately or as long as twelve hours after eating the affected mollusks and may include feelings of prickling, numbness, or constriction about the lips, tongue, pharynx, and face; prickling sensation of hands or feet; sensation of lightness and the impression that objects have no weight; patients may believe they can fly. The pulse rate may quicken to a frequency of as high as 160 per minute, the pupils of the eyes may become dilated and reactionless, and patients may hold themselves in an upright position with great pain. Urination may be painful and difficult. There may be headache, backache, dizziness, nausea, vomiting, and difficulty in breathing. Various muscles may become temporarily paralyzed for hours and remain weak for several days after recovery.

It is impossible to know the mortality rate from mollusk poisoning, since many cases go unreported. However, Table 11-2 gives sample pertinent statistics.

Governments provide for research about mussel poisoning wherever it is frequent and serious enough to endanger human welfare. Thus scientists in Canada, California, Oregon, and Washington, and in Japan have followed its occurrence and some of them have worked to isolate and identify the poison principle.

In our study we are looking toward fuller utilization of the ocean resources. That might mean doing something with plankton. If some of the organisms of the plankton secrete harmful substances, we should learn all we can about them. This requires studying them, primarily with the aim not of preserving public health, but of learning about their life processes. Before considering what studies ought to be undertaken to achieve this aim, let us consider some other cases of toxicity among marine organisms.

Red Tides

It is puzzling that fishes and mollusks should become deadly poisonous to warm-blooded land vertebrates without becoming affected themselves. Could it be that the marine animals have grown immune to the poison through long conditioning, whereas the land animals have not had the same opportunity? This would seem a logical explanation were it not for the fact that there are other kinds of marine microorganisms which go through a phase when they give off substances that intoxicate and kill fishes and invertebrates, but which may have no noticeable ill effect on warm-blooded land vertebrates. In fact in some places people regard these marine catastrophes as opportunities to gather the dying fishes, crabs, and shrimp for market.

For one possible example, a very mild form of mass intoxication of fishes is a common though sporadic event in Mobile Bay, Alabama. It occurs during summer, not every year, but some years several times, generally after a period of excessive rainfall accompanying a shift of winds. These conditions make for a diminished salinity in the Bay and a dead calm sea. Then some quality of the water, perhaps merely a diminution of oxygen, but perhaps instead swarming organisms which the tide has brought in from the sea, has a curious and rather sudden effect on the fauna of the Bay. For hundreds of yards or even for several miles blue crabs leave the deeper water to gather in masses close to shore, some of them even emerging onto the beaches; others jam together on pilings while all sorts of fishes, especially flounders, catfish, sting rays, and eels, and also shrimp, congregate close to shore, and lie in the shallows, moving about sluggishly, aimlessly, as though intoxicated. While all of this is going on, crowds of people gather close to shore to spear the helpless fish by the hundreds and with scoop nets take in crabs by truck loads.

This massing of fishes and crabs, which is locally called a "fish jubilee," may break up within a few minutes, or it may last a few hours until the tide goes out. Then the animals disappear into the depths to return to their normal habits. These episodes are characteristic of the eastern shore of Mobile Bay, but rarely happen on the western shore.

For a more clear-cut example, at Malabar, India, there is a frequent, perhaps annual, blooming of flagellates which devastate marine life with their poison.[14] These episodes happen after the rainy season is over and the southwest monsoon has subsided. Then, with a week or so of calm weather and a slackening of the coastal current, conditions are favorable for a red tide. At first there may be a swarming of the harmless organism, *Noctiluca*, densely enough to color the sea bright red. This the Malabar people regard as presaging the poison water.

Within a few days the flagellate *Euglena*, may have succeeded *Noctiluca*. Now the water becomes brownish, and the first sign of the poisoning shows when fish and crabs move sluggishly towards the shallows as though in a state of exhaustion very much as in the Mobile Bay "jubilees." And just as in the jubilees, men and boys crowd down to the shore, and with spears and nets make great catches for market. As time goes on the color of the water gets redder and gives forth a "horrible stench," probably of hydrogen sulfide. Then fish of all sorts that have not left the poison area at the beginning of the bloom die and are cast up on shore. Those that suffer the heaviest losses are bottom-living fishes such as soles, catfish, and croakers, and invertebrates such as hermit crabs, rock crabs, mole crabs, spiny lobsters, clams, mussels, and other bivalves, and alcyonarians. At infrequent intervals sardines may be trapped in the poison water, and when that happens the sea may be covered for miles with dead or dying sardines "in enormous multitudes." The poison water may persist for several days until a freshening wind disperses it.

In the Walvis Bay region of Southwest Africa, poison water is a common visitation. It generally occurs during December or January, but may extend into March. It may appear four or five times in a season, nearly always killing some fish, and occasionally it devastates the whole area of its marine life. Here the mechanism seems to be more complicated than in most other places where mass mortalities occur, for it may involve bacteria as well as dinoflagellates. An azoic zone extends for about 200 miles along that part of the African coast and seaward for 25 or 30 miles. The bottom there, almost destitute of animal or plant life, is composed of a diatomaceous ooze which gives off hydrogen sulfide when any of it comes to the surface. This happens from time to time in a curious way. Islands of mud, sometimes measuring several thousand square feet, rise to the surface, remain perhaps an hour or even several days, and then vanish without trace, leaving the bottom as deep as it had been before. During their short existence, they give off a stench of hydrogen sulfide which people can smell 25 miles away. The water around them is turbid, and full of bubbles. Dead fish float about. Sometimes what people describe as steam issues from these islands, but there is no noticeable heat either on the islands or in the surrounding water.

Occasionally, bubbles of hydrogen sulfide gas rise to the surface accompanied by clods of mud. Once a large ship stirred the bottom mud while berthing. Shortly afterward there rose to the surface hundreds of dead soles, which the people gathered and ate without any ill effect.

According to Copenhagen,[15] the gas is generated in this way: The oxygen content of the water in the "azoic zone" diminishes towards the bottom to zero. Thus sulfate-reducing bacteria (*Desulphovibrio desulphuricans*), which can exist only under anaerobic conditions, thrive there. Part of the year the cold Benguela Current flows over the azoic area. This is an extraordinarily fertile body of water, full of plankton, and with large populations of pelagic fishes. During the summer, a shift of winds from north to west, diverts or retards the Benguela Current, whilst warm, highly saline tropical Atlantic water invades the coastal area and usually raises the temperature five or six degrees centigrade, but occasionally as much as ten or eleven degrees. These sudden changes, when severe enough, are destructive to the Benguela fauna, killing masses of animals among the plankton and fish, whose dead bodies enrich the azoic zone and stimulate growth of the sulfate-reducing bacteria. But the hydrogen sulfide is also destructive, for it depletes the water of its dissolved oxygen and moreover is toxic enough so that when meteorological conditions cause the bottom water to rise to the surface, it kills pelagic fish that happen to be there.

Quite apart from the role of hydrographic changes and of sulfate-reducing bacteria in causing mortalities of marine life at Walvis

Bay, poisonous dinoflagellates bloom there sporadically during the summer. The Danish research ship *Galathea*, visiting in 1950 a few days after a fish kill, found the surface of the sea in and about Walvis Bay, down to a depth of about a meter, khaki colored, and densely populated with a dinoflagellate subsequently named *Gymnodinium galathea.*[16] Moreover, many accounts of mass mortalities at Walvis Bay refer to the sea being blood red and soupy-thick with a dinoflagellate identified (probably erroneously) as *Noctiluca.*

Frequent as are the mass mortalities at Walvis Bay, evidently no one has yet had the opportunity to make the year round systematic hydrographic and biological observations which would be necessary to observe all the sequence of events leading to the mortalities. Until that is done, no one can weigh the relative contributions to the mortalities by hydrographic changes, by sulfate-reducing bacteria, and by poisonous dinoflagellates.

Red tides occur at irregular intervals on the west coast of Florida. Outbreaks in the winter of 1946 and spring and summer of 1947, reached such spectacular proportions that the United States Congress passed a special appropriation to investigate the phenomenon. Galtsoff [17] estimated that somewhere between 100 and 200 million pounds of fish were destroyed. At one time masses of dead fish extended along the coast offshore for 120 miles in a band 20 miles wide. All kinds of animals died, turtles and porpoises among them, pelagic fishes as well as bottom dwellers, and invertebrates, including crabs, barnacles, oysters, and clams. About 80 per cent of the edible oysters grown on piles were killed. This destruction was associated with the occurrence of large streaks of discolored water which ranged in hue through shades of green, yellow, amber, brown, and red. As fish entered these patches, they would come to the surface, whirl about crazily, then turn on their sides, float a while belly up, and then sink to the bottom. The plankton within the discolored area included several species of diatoms, copepods, cladocera, and lamellibranch larvae. The predominant species was a dinoflagellate, *Gymnodinium brevis,* which occurred in concentrations up to 56 million per liter. At the same time the water was slimy with a mucous which was apparently derived from broken bodies of this organism.

People ashore were affected too. With the onshore wind and breaking of the surf, particles of the dinoflagellate borne into the air in a mist gave a burning sensation to the nostrils, eyes, and throat, and made people cough, sneeze, and suffer symptoms of heavy colds or hay fever. The economic consequences of red tide were serious, for both local fisheries and tourism were hard hit.

There is little doubt that *Gymnodinium brevis* is the cause of the mass mortalities in the red tides. When it is swarming, there are red tides and mass mortalities; when it is absent, there are none. Fish put into laboratory cultures of various species of phytoplankters, including *Gymnodinium splendens* (a closely related dinoflagellate), remain unaffected, but in a culture of *G. brevis* they die quickly, just as they do at sea.[18] Collier, Wilson, and Ray, of the United States Fish and Wildlife Service, have succeeded in cultivating *G. brevis*, thus creating red tides under artificial conditions. In this way they have been able to learn much about the mechanism producing it. It appears that this dinoflagellate is peculiarly sensitive to the ions of heavy metals, even in the minute amounts in which they occur in sea water. Under the conditions which normally prevail, *G. brevis* evidently persists in a non-swarming, benign phase along the shore. Among the factors which make it possible for this organism to live are sulfides, chiefly hydrogen sulfide, and organic matter, such as detritus, large quantities of which occur in the organically rich soils of the nearby swamps. When this material comes into contact with the metallic ions in the sea water, it enters into union with them, taking them out of solution. Thus the metals, which are a natural barrier to *G brevis* (there may be others) are removed. The mechanism of the process is only partly understood. Perhaps normally the balance between the material from the swamps and metal ions is such as to hold the numbers of the organism down to a low level. Occasionally, however, under certain circumstances, abnormally high quantities of it may accumulate along shore. Besides taking the metal ions out of solution, the sulfides seem to have a direct physiological effect on the dinoflagellates, further contributing to the swarming stimulus. In the ordinary course of events, with normal intermittent rainfall, run-off from the swamps, wind, and sea currents, the sulfides carried down to sea are dispersed. When rainfall is abnormally high and prolonged, an abnormal amount of fresh water is carried down from the land. If this coincides with a period when winds retard the dispersal of this sulfide-rich water, and when surface temperatures are peculiarly favorable (probably around 26° to 28° C., judging from laboratory experiments) *G. brevis* is released from its usual barriers, bursts into a swarming phase, and poisons the water. As fish die, their rotting bodies generate sulfides, and a vicious circle becomes established, the sulfides taking more metallic ions from the water and thereby enlarging the area favorable to red tide. This horrible sequence continues until the circle becomes broken; then *Gymnodinium brevis* retreats to its usual habitat, and the red tide disappears. Fortunately severe episodes are not frequent (1854, 1878, 1880, 1882, 1883, 1908, 1916, 1946, 1947, 1953, 1954, 1957).

The records of mass poisoning of marine organisms, exasperatingly fragmentary though they are, show that there must be considerable variation in the characteristics of red tides from one part of the world to another. A few circumstances appear in the records often enough to suggest a common pattern.

These episodes occur in areas which are well fertilized by nutrients usually brought to the surface in the process of upwelling or carried from land down to the sea by rivers. They occur when anomalous meteorological conditions hold the enriched water mass stagnant long enough to allow certain microorganisms to accumulate up to some critical level of abundance. Under these circumstances their physiological processes change, as evidenced by their explosion into "blooms" and by their secretion of poisonous substances. Meteorological conditions which seem to be often associated with red tides in areas where fertility and topography are suitable are heavy rainfall, followed first by a shift of the normally prevailing wind, and then by an abnormally calm sea. The red tide always disappears when the water mass is dissipated. This may happen with a change of tide or with a freshening and change of direction of the wind. In some places, as at Walvis Bay and in the Black Sea, where anaerobic sulfate-reducing bacteria flourish at the bottom, the bodies of animals killed by a change of surface temperatures or more probably by poisonous dinoflagellates may feed the bacteria, thus increasing the production of hydrogen sulfide. The hydrogen sulfide contributes to the lethal influences, perhaps through its action on trace metals such as copper.

Poison in fishes and mollusks discourages the full use of sea food resources in certain areas. Red tides are destructive to sea life. There are good practical reasons for giving special study to these phenomena. Governmental research agencies do study them in various places, with the idea of understanding them, predicting them, and perhaps controlling them. There is another viewpoint, however, which has not been considered. Food is not necessarily the only biological resource of the sea. Substances which are deadly poisonous in some circumstances may be beneficial in others. For example, opium, strychnin, caffein, quinine, camphor, atropin, and digitalis are all products of land plants, which though poisonous, nevertheless have great medical value when properly used. The possibilities of deriving medicinal or industrial products (insecticides, herbicides, poisons for chemical fishing) from marine plants and animals have hardly been touched.

Concerning the possibilities of obtaining pharmacologically active substances from the sea, Emerson and Taft say:

> The lack of application of substances from marine sources to medicine, aside from those materials which have proven their worth over the years (I, Mg and Br compounds, agar, fish oils), is due more to lack of study of the highly potent agents available and search for others than to a paucity of pharmacologically interesting substances from the sea. There is little doubt that if the chemical isolation of insulin had been more difficult to perfect, fish would constitute a major source since their islets are readily obtained essentially free of acinar tissue. The search for antibiotics more satisfactory than penicillin has not, to our knowledge, been extended to marine forms, although *Chlorella vulgaris* and *C. pyrenoidosa* yield an antibiotic.[19]

This is a field of research that is wide open and not likely to be explored much by government scientists, because the need, the promise, and the ultimate application are not clearly evident. Moreover, there are precious few men available to do such work. The sea may occupy 71 per cent of the earth, the majority of species may inhabit the sea, and they may have an infinitude of unknown properties; nevertheless, the number of scientists in the world studying the biochemistry of marine organisms is negligible. Few laboratories have any provision for such scientists.

12

The Improvement of Fishing Vessels and Gear

Fishing vessels and gear all over the world have evolved by processes of trial and error. In some regions they have come to be very well adapted to local conditions and requirements, in others they are grossly inadequate and are retained only by the forces of tradition and ignorance. Very small changes in the equipment of fishermen in primitive countries could increase production manyfold. An example in point is the addition of outboard motors to dugout canoes. In advanced fisheries, the design and layout of fishing vessels as well as the mechanisms of propulsion could all be improved to good effect. This chapter reviews various fields in which improvements are indicated. A special laboratory for the design and testing of vessels and fishing gear is suggested. This should be integrated with a laboratory where research on behavior and on environment is being conducted.

Obviously there are many ways to enlarge the harvests of the seas. None of these alone can bring about a brave new world in which people will be nourished largely by marine organisms. Any great total increase must come through the sum of many actions—through the development of new fisheries, the proper application of husbandry, the control of predators and diseases, the scientific balancing of different fisheries so as to direct the weight of fishing pressures among different species. Chapter 7 stressed the importance of studying behavior of marine animals to provide a basis for improving fishing and techniques. Several of these measures imply the necessity of improving the efficiency, speed, capacity, and safety of fishing vessels. That alone could result in great increases in the production of sea foods, especially in primitive areas where fishing is still conducted on the level of a folk culture.

To peoples of northern countries the phrase "great fisheries" evokes an image of vast fleets of otter trawlers, purse seiners, tuna clippers—vessels which sail far out over the ocean with mechanized equipment and large crews, bringing back catches of many tons to canneries and filleting plants or to refrigeration centers for reshipment far into the interior. It brings to mind ports like Gloucester, Hull, Grimsby, San Pedro, Tokyo, San Sebastian, and Murmansk. Actually, a large part of the world's fisheries are not like this at all, but are conducted by thousands of individual men scattered along lonely coasts working in tiny boats out of settlements that could hardly be called ports, for they have neither harbor nor anchorage.

Such a fisherman may live in a small village. He gets up at dawn every day that the weather is good enough for his work. He goes down to the beach and meets his fellow fishermen. Together they load a dugout canoe with gear, drag it down to the water, push off, and paddle out to their usual fishing grounds. In some places such men will fish with hook and line, in others with spears, in still others with nets, depending on the tradition of their region. After a few hours they must return with their day's catch, rarely consisting of more than a dozen or so shorefishes, which must arrive in good condition, preferably alive, and in good time for the day's market. No one knows how much fish is handled in this way throughout the world, for it is impossible with present facilities to collect meaningful statistics. The quantity probably is very high, for hand-powered craft are the principal types of fishing vessel along all the coastal countries of Middle and South America and Africa, and of all the countries of the Indian Ocean and the western Pacific. If these little boats are widely used, it is because they offer distinct advantages. The boats are simple enough that a man can make one himself. He might even buy one, for they are cheap compared with motorized vessels. They are easily handled, require no important special equipment and, most important of all, cost nothing for upkeep—no docking expenses and no mechanical repairs. In short, they are the kind of vessel that a poor man can possess and operate.

On the other hand, there are disadvantages to these small craft. Fishermen cannot paddle far enough to find the most productive grounds. They dare not go beyond the narrow range of their familiar areas for fear of being caught in bad weather or of staying out too long and thereby spoiling their catch and missing their market. Fishermen can overcome this problem by using sailing craft to extend the range of their operations. This is the maximum reached in propulsive power in a large part of the world's fisheries. Sailing, however, has serious limitations, too. Fishermen can operate effectively only when winds are optimal. In a study of Malayan fisheries, Firth [1] found that about 5 per cent of possible fishing days were lost because winds were too light for fishermen even to reach the fishing grounds. Besides that, there was a much higher percentage of good fishing time lost because of the slow passage to and from the grounds.

Poor wind conditions also reduce the opportunity to scout for fish on the grounds and impede effective handling of gear. Even a little motor power would expand the time of these fishermen tremendously—time which they could use for preparing gear, baiting hooks, handling catch, maintaining boat and equipment, exploring for new fishing grounds, and traveling to more distant areas than hand propelled or simple small sailing boats afford. Such a seemingly minor change, if widely accepted in the many parts of the world where fishing is still at a primitive level, could increase production of sea food tremendously. This has been demonstrated in India, where Setna [2] has compared the performance of vessels variously powered. Sailing vessels fishing for threadfins can operate 60 to 75 drift nets. During five months of 1953, their average catch of these large fish was 485. Powered vessels, on the other hand, can operate 100 to 110 nets. For this reason, and also because of their greater fishing range and speed, they averaged 2,000 fish during the same season.

Such a change in so ancient a craft as fishing can have a very profound effect on a conservative society, introducing many problems that ramify throughout the intricacies of the economic and social structure. Here I shall touch only on the mechanical problems, which are formidable enough.

Perhaps the simplest innovation in a fishing community that depended on dugouts would be an outboard motor. How about outboard motors? Most of them are designed for relatively light-duty work in waters where corrosion is not a great problem. Available types of outboards, of which there are many, would need to be thoroughly tested and certain types recommended for particular purposes. Probably, special motors would have to be designed to stand heavy work and abuse, and manufacturers would have to be encouraged to build them. The Food and Agriculture Organization has initiated such tests to help solve the motorization problems of the dugout canoe.

Ziener [3] describes difficulties encountered with outboards in a study of the motorization of Chilean fishing craft. Since Chilean fishermen must import motors from foreign countries, the necessary parts for repair are often not locally available, and at best it is usually a lengthy and difficult process to obtain them. The outboard motors themselves corrode rapidly, wear badly, and require frequent repair. Among 330 motors in operation on the Chilean vessels studied, 307 were of a model produced by one manufacturer, which proved to be the only one that could stand up well under extreme wear and corrosion. But this is still not an ideal motor. An even better type could be produced if designed especially for this type of operation. Traung suggests (in a personal conversation) that a small diesel engine might be the solution to the present difficulties of outboard motors, but that has yet to be developed.

That is only one of the problems of mechanization. There are others. Outboard motors can sometimes be adapted effectively to the existing craft. But in many instances a new type of boat would have to be introduced to make motorization possible. The new boat must be designed with an eye to the fact that local boatyards must be able to build it and of materials locally procurable. Moreover, they must be able to sell it at a price which fishermen or their entrepreneurs can afford to pay. And finally, the fishermen themselves must favor the new type of vessel over those of the old style.

Designers would, of course, think of benefits other than mere speed. Craft which can be paddled or sailed effectively usually are narrow of beam and are not optimally safe or seaworthy. These faults could be corrected in a power-motored vessel. At the same time, designers must not lose sight of local necessities. For example, in many primitive fisheries, harbor facilities are not available and the boats must be operated from the beaches. Consequently, the new craft should be so constructed that it could be easily launched in the surf and beached and hauled up away from the reach of tide and waves.

Culture, tradition, and religion, which are very important in certain primitive fisheries, must be considered and respected in the design of boats, or motorization may not win favor with the fishermen. A background of tradition has been built up around the special types of boats used in many fisheries, involving special features of construction and adornment. The fishermen may not readily accept the improved types of boats unless these special features, superfluous though they may seem, are carried forth in the construction of the new craft.

With better boats fishermen could advance their means of catching fish. The expanded range of the boats could carry the fishermen to places where greater quantities of fish are available and perhaps concentrated into dense schools. Here the old traps, drift nets, and hooks would probably in some places be superseded by gear more effective for catching pelagic schooling species. The extra power and maneuverability of the motor boats would make it possible to use a round haul seine with which whole schools could be encircled and caught. This sort of fishing would probably be conducted by a group of boats, one of which would be a large and sturdy craft to handle the net. The behavior of the species involved and their reactions to the nets would have to be studied in order to provide a net of the maximum efficiency for their capture. Fishermen would have to be trained to construct, operate, and maintain these new nets.

Perhaps the greatest impediment to motorization will be in the lack of modern shore facilities. Procuring fuel would by itself introduce a complex of problems, necessitating the construction of docks, storage tanks, roads, and distribution centers. Shops would have to be established to repair the motors. A supply of new parts and new motors would have to be maintained. Mechanics would have to be trained especially to do the repair work and fishermen would have to be taught to operate and take care of the motors. With greatly increased quantities of fish landed, means must be provided to preserve and store them, to sell them, to transport them to distant inland markets.

A great expansion of the fisheries in primitive fishing communities would change the whole economic structure. Change in the social structure would undoubtedly follow. The rather extensive ramifications of these changes are very well stated by Firth, as follows:

> Any radical change in the fishing industry will almost certainly lead to far-reaching changes in the way of life and social institutions of the fishermen. To take only two aspects. Attempts have been made together with the introduction of power boats to get the fishermen to remain at sea for several days in succession instead of returning to shore each evening (or morning if they are engaged in night fishing). This has proved difficult. The fishermen are disturbed at the prospect of leaving their wives and families for so long, and if the period lasts seven days or more they miss the break from work on Friday, the Muslim Sabbath, when they normally attend the mosque, and then repair and dye their nets. Any system of deep-sea fishing which kept them away from their villages for more than a week at a time would involve changing these established patterns of behavior. Again, the introduction of power boats, with their greater capital outlay, would tend to change the existing pattern of economic relationships in the community. The common practice of lending boats would become less simple because of their greater value, greater liability to damage in unskilled hands, and the less general knowledge

of how to handle them. Capital would probably have to be found in new ways, the increased costs would demand a rearrangement in the established systems of distributing earnings, and there would be more likelihood of the gap between wealthy and poor fishermen being widened. A special group of power-boat owners with superior economic status to the ordinary fishermen might even be created. Since in these communities economic relationships are closely bound up with other social relationships, from kinship to recreation, the structure of the peasant society itself would be affected.

In brief, substantial changes in the fishing industry mean substantial changes also in the kind of society in which the fishermen live. Experience has already shown in Africa and elsewhere how peasant societies have reacted to modern technological and economic changes: the traditional structure has tended to become disrupted and community ties loosened, the old system of social values loses much of its force and the new values are apt to lack that cohesive quality for individual behaviour which gives strength to communal activity. Change in the structure of these peasant societies is not a new phenomenon. For instance, it took place in Malaya and parts of Indonesia with the coming of Islam. But it was then mainly the religious and social structure that was affected; the economic foundations remained much the same. The new influences of the last half-century or so have been responsible for economic modifications which, when fully developed, will be more radical in their effects than anything that has gone before. There can be no question of repressing these changes. The problem is to understand them, to try and predict their effects, to safeguard and to stimulate those community ties and values which give meaning to individual and social life and give a basis for cooperation. Much of the traditional social structure will doubtless long remain, and some of its elements at least will serve as rallying points. But the rather narrow concepts of the old peasant community will have to be built up into something wider. It will be necessary to create additional bases of loyalty, new foci of interest.[4]

It need not be assumed that improvement must always carry the threat of dire economic and social consequences for the fishermen. Quite the opposite may be expected and must be striven for.

It should be apparent, however, that fishery development programs must be preceded by extensive economic, sociological, and technological research and thorough scientific planning. Furthermore, fisheries improvement must be evolved gradually and executed systematically. Overly ambitious expansion programs are bound to fail and the memory of failure is long lasting and detrimental to further efforts.

The literature is full of warnings against the danger of too rapid expansion. For instance, Qureshi and others, quoting Chapelle, write that "it would be very wise indeed to motorize and otherwise improve the small primitive types of fishing boats (rather) than to introduce European and American launches, draggers, seiners and trawlers."[5] In another instance, Bergius concludes, "The main lesson learned from the story of the Scottish fishing industry is that a start should be made in a modest way and every endeavor made to encourage the fisherman to build up slowly and surely and so retain his independence. The main aim should be to help the fisherman to help himself."[6] Osorio-Tafall warns, "For any immediate increase in fish supplies it would, perhaps, be advisable to carry out a number of small, less ambitious but economically sound projects which, in the aggregate, would considerably increase production. For each Latin-American country, the nationwide development of fisheries must be a slow and gradual process, of the evolutionary type, because any hurried spectacular measures are bound to fail. The pace of development will largely depend on the training and experience of the personnel engaged in the fishing industry."[7] Zimmer states, "Development must, on account of the human element, be gradual, and the main problem is the persuasion and education of the fishermen."[8]

The type of boat used in each fishery has gradually evolved through generations of trial and error. This process has produced some excellent craft which are perfectly adapted to local conditions. It has also produced others which are poorly constructed, unwieldy, unsafe, or otherwise completely unsatisfactory.

The first step in any program to improve fishing boats should be thorough investigation and testing of the existing types. It is necessary to understand why and how each type of boat has evolved, and why certain materials and methods of construction have been used. Boats must be tested for seaworthiness, sea-kindliness, stability, hardiness, speed, and general suitability for the kind of fishing operations involved.

Such a survey might conclude that present boats are perfectly adequate as they are, or would be with a few modifications. On the other hand, it might be found that new designs need to be developed. The survey would make available to the architect information concerning the special vessel characteristics in present types which specific conditions of local weather, sea, and fisheries require.

Fishing vessels fall roughly into about five size categories, each identified by certain characteristic features and each with its own individual set of problems: (1) small open boats propelled usually by paddles, oars, sails, or in some cases by outboard motors; (2) larger craft, usually open, powered with small, often air-cooled, inboard motors or large outboard motors; (3) lightly constructed craft of shallow draft usually partially decked and with partial shelters, often with converted automobile engines, running up to about 40 feet in size; (4) ocean-going, fully decked craft with enclosed shelters, large fish holds, marine engines, crew accommodations, usually of wooden construction, and having a size of not less than 40 feet; (5) larger, all-steel, fast moving vessels with heavy duty engines built for long range, distant operations and of large carrying capacity.

Improvement possibilities for the smallest boats have been covered in a general way in preceding pages. There is need for research, guidance, and development for larger sizes as well. Modern methods employed by naval architects and engineers could be used to advantage in the design of fishing boats. Usually small fishing boats are constructed by individual boat builders without benefit of naval architect. Prepared plans are usually either very rough or entirely absent. Choice of lines, general arrangement, engine and propeller, deck layout, material, fastenings, and so forth are made on the basis of tradition, sometimes of whimsey, but rarely of scientific knowledge.

The approach to improvements in hull shape through preliminary testing of scale models developed by Froude over eighty years ago has been used mostly in the development of large ships. The techniques developed could readily be utilized for designing of fishing craft and thus minimize the errors in the design of the boats. Detailed objective measurements of the important characteristics can readily be made from studies of the action of models.

Tank studies are conducted in the following way: [9] From a provisional plan of the ship's hull a model is constructed for study under experimental conditions. It is subjected to all sorts of tests. For example, it is towed in a tank while the resistance is measured at various speeds, and observations on the wave patterns are made to discover possible defects in hull shape. Self-propulsion tests can then be made with installed electric motors; at the same time torque and thrust measurements are made. The model can be modified and the tests repeated until the optimum shape is achieved. Further tests can be conducted to study such features as maneuverability, rolling, and general seaworthiness. The histories of the ships actually constructed are subsequently followed to provide comparisons of test results with actual operation in order to improve future testing. The ship model facility thus becomes a center of knowledge and experience in this particular field. The value of a ship model testing installation exclusively for fishing boat studies becomes apparent. Such a center, specializing in fishing boat studies, could greatly reduce the expense of trials and would build up a background of knowledge and experience from which boat designers and builders the world over could benefit.

Traung [10] has written of the special problems of predetermining the speed of fishing vessels. He says:

> There is seldom time or money enough, after the completion of a fishing boat, to carry out trials to investigate the true speed at different engine loadings. It is therefore difficult to get any reliable data about fishing boat speed; published data from trials and tests made at time of delivery are often exaggerated. . . . Complete and reliable tests take time.

Traung describes one of his own experiments, financed by a research grant, thus:

> Three models were used in the experiments and every model was altered several times in order to study the effect of single alterations. The ships were tested in several displacements corresponding to (a) light ship (b) ship "ready to go to sea" with full bunkers and ice and (c) ship homebound with cargo. The following results are taken from tests in the "ready to go to sea" condition, which was done with a displacement of 115m^3 (corresponding to 118 tons).
>
> First a design was chosen of a 68-foot boat, considered good by many fishermen. The boat was carefully tested in full scale trials. The stability and the datum waterline, and thus the displacement or hull weight were investigated. Then a model, designated 250, was made and tested in the tank at Göteborg. The results were compared with the full-scale tests and were in full agreement. . . . In order to study the effect of sharpening the forebody, the model was sharpened twice. The half waterline angle was first 36°, then 33°, and finally 28.4°. The biggest sharpening in the datum waterline on each side was 0.1 m. the first time and then 0.2 m. or a total sharpening of 0.3 m. The resistance decreased, which means that fuel consumption will be lower or the speed higher.
>
> Some tests had been made for another purpose with a model of an icebreaker tugboat, called 258a, which had shown especially good nondimensional values. The boat had a long overhanging cruiser stern, which made the model somewhat longer than the 250 model. . . . It was decided to try to adopt this type as a fishing boat. The long cruiser stern would not be suitable for fishing so it was simply cut away and the stern was finished with a transom, the transverse section of which was "V" shaped as in the cruiser stern, and the model now was called 258b. The resistance increased somewhat. Then the stern was sharpened to a cruiser stern, as similar as possible to the stern of fishing boat model 250, and called 258c. The resistance increased considerably. . . . The next step was to replace the sloping icebreaker stem with a stem profile similar to the fishing boat model. This causes a slightly higher resistance.
>
> The altered tugboat model now had the same profile, beam, and displacement as the fishing boat model, but the resistance was lower. With the transom stern, however, it should be still lower, especially in the loaded condition, and it was decided to investigate whether a fuller cruiser stern would be better than the fishing boat shape. The stern was made as full as construction in wood would allow, and the model was called 258e. In the light condition, the result was a considerable improvement but, surprisingly, the fuller cruiser stern was still better than the sharper one in the loaded condition. The result was a boat with much lower resistance than the original fishing boat model.

. . . At 9 knots the resistance was 26 per cent less in the "ready to go to sea" condition and 29 per cent less in the loaded condition.

These studies illustrate how much time can be saved and how many frightfully costly mistakes can be avoided by such testing.

The performance of a vessel in a seaway is determined by the skill of the crew and certain features of the design and construction of the boat. Much of the information needed to study and improve the qualities of stability, seaworthiness, and sea-kindliness must be studied at sea during actual operations. Data must be collected during running and fishing in all types of weather, including icing, for various stages of loading and trim.

Möckel [11] had the opportunity to conduct such a study aboard five German trawlers. As a result of his scientific collection of data, he learned that certain characteristics of a boat govern its loss of speed in rough weather. He determined when fishing had to be discontinued because sufficient power to maintain towing speed in rough weather was lacking.

He accurately determined the amount of power necessary to overcome air resistance, as well as the combined effect which loading of fish, distribution of weight, and consumption of fuel and water have on stability and sea-kindliness. He studied the behavior of the boat in rough weather. As a result of his observations, he made recommendations for operating a vessel under stress and listed the following points for consideration in the design of trawlers:

1. Sufficient reserve buoyancy, particularly forward. A good freeboard should be aimed at, though this is unpopular with many fishermen because they consider it makes handling of the trawl difficult. Well flared sections above the water line in the foreship and as large a forecastle as possible also contribute to extra buoyancy.
2. In calculating stability, the shipping of considerable quantities of water should be taken into consideration. To keep rolling acceleration low, heavy equipment should be arranged towards the ship's sides, if possible, as this will increase the radius of gyration without decreasing GM (i.e., the metacentric height).
3. Scuppers must be large enough to allow the water to run rapidly off the deck.
4. The superstructures astern must be built over the entire breadth of the ship, as is sometimes done on modern trawlers, for protection against overtaking waves.
5. The stern above the water line must be as full as possible, to provide extra displacement and to adapt itself easily to the waves coming from astern.
6. According to experienced trawler skippers, a GM of about 2.8 feet

at departure, and one of 1.65 feet at arrival is considered to be very good.

7. To obtain a satisfactory damping of rolling, it is not desirable that the floor rise and bilge radius be too great.

Möckel summarizes as follows:

> Model tests can give practical results only if they are correlated to the data collected on board ship showing the behavior of the ship in all conditions of service. Such research on large cargo boats has been carried out in several countries, but little information is available concerning fishing vessels.

The following passage illustrates the benefit of developing superior hull shapes:

> The shape of a fishing boat's hull is important in relation to efficiency and running costs. It has been shown that even well designed fishing boats can be improved to such an extent that the fuel consumption is reduced by 30 per cent without sacrificing speed, seaworthiness or carrying capacity. If the fuel cost is about 15 to 20 per cent of the boat's total expenses (including depreciation) the total saving is therefore around 5 per cent. It has been considered satisfactory if a fishing boat can give about 5 per cent profit. A saving of 30 per cent on the fuel account would correspond to an amount which is almost equal to this profit.[12]

The question of V-bottom versus round bottom construction is a matter of some controversy. Experts disagree as to whether V-bottom boats can be produced more cheaply than conventional fishing boats and whether they have as good qualities of sea-kindliness and seaworthiness. Authorities also argue over the relative merits of stern types—cruiser sterns, transom sterns, and so forth. The limited results of studies published are not convincing in either direction. These are two specific examples of current controversy which could be settled by model studies combined with full scale trials.

The whole question of vessel construction requires investigation. People disagree on the merits of wood and of steel construction. Many authorities claim that wood greatly limits the possibilities of design and construction, and that vessels made of wood are much more costly to maintain and are shorter-lived than those of steel. Others take a contrary view. Size seems to be the determining factor at present. Smaller boats are wooden, larger boats are of steel, and intermediate sizes may be of either material. The optimum strength of fishing vessels must be related to economy of construction. If a vessel is too heavily constructed, it becomes unnecessarily costly. If it is too weakly constructed, it is unsafe and therefore also too costly. Japanese researchers in the field of vessel design have begun a program of deliberately breaking fishing boats to determine their points of weakness. At the same time they test the scantlings to study their properties and to improve their design.

The local availability of materials has governed the design and construction of boats in all fisheries, but particularly in the more primitive areas. The many difficulties of structure and design might be solved by using new materials. New synthetic materials are constantly being developed and improved and should be tested for vessel construction. Such materials might be molded into hulls. As a matter of fact, fiberglass is used for that purpose now.

The use of laminated beams in vessel construction appears to be particularly promising. These can be made stronger than solid members and can be produced in a greater variety of shapes and sizes than solid pieces. The opposition to laminated construction usually stems from the use of inadequate glue and poor control of the moisture content of the wood. These seem to be simple technical problems for which solutions ought not to be difficult.

Another important and particularly promising field for research is in the development of improved fastenings, that is to say, the dowels, nails, screws, lags, and so forth that hold the boat together. The types of fastenings and the methods of using them in wooden construction have much to do with strength of the vessel. Improving the fastenings increases the strength, or it makes possible the use of lighter members to obtain the equivalent strength, thus reducing the weight, the cost, and the power required for propulsion, and extending the life of the boats.

There are special problems concerning the design and construction of beach-landing craft. Many fisheries are carried on in areas where natural harbors are not available. The building of artificial harbors is generally prohibitively expensive, and in some areas they are not feasible because of unfavorable physical conditions. Consequently, where there can be no harbors, boats must be built that can be operated from the beach. They must have special qualities of seaworthiness which will enable them to be launched in heavy surf. They must be very light so that they can be easily hauled across the beach, strong enough to withstand the exceptional abuse to which they are subjected and give years of useful life. The bottoms must be designed in such a way that the boats will remain upright when beached and hauled. The propeller installations must be constructed so that the propeller will not be damaged by beaching.

Many types of beach-landing craft have evolved throughout the world, most of which could be improved through research into design and construction. This is of particular importance in relation to mechanization of primitive craft which are now propelled by oars or sails.

Zimmer [13] recommends considering some recent improvements in the construction of lifeboats, which were based on extensive research. This research has resulted in the development of superior hull types, which might be applied in the construction of fishing boats. Various types of jet propulsion have been tested. Improved launching methods have been developed. Hulls have been constructed of novel materials such as laminated moldings, various types of metals, double diagonal wood, and plastics. Further research should be conducted into the specific problems involved in the design and construction of beach-landing fishing craft, however, because of their entirely different function.

One of the important tasks in vessel improvement is to increase the efficiency and reliability of propulsive power. To do this requires very advanced and specialized engineering research, whether the problem concerns the smallest outboard or the largest high-powered diesel engine. Let us consider a few of the opportunities in this field:

The difficulties associated with the use of such a simple machine as the outboard motor have already been discussed. Ziener also recounts problems involved in inboard installations of engines. He states that the lack of progress and poor results of the motorization of the Chilean fishing fleet are due to technical and economic difficulties "the origin of which nobody has bothered to discover." [14] These difficulties are caused by factors far beyond the fisherman's influence. Vessel problems in Chile are worth discussing at some length, because in many ways they typify those which people in a number of underdeveloped countries experience.

In the absence of proper guidance, Chilean fishermen have usually bought engines unsuitable to their requirements, that is, a lightweight gasoline engine which is very expensive to operate, or a high-speed diesel which is very expensive to maintain. Fishermen are now being encouraged to buy semidiesel engines which, though costly to buy, are economical to operate and maintain. The efficiency of propulsion (the proportion of power produced by the engine transmitted by the propeller) is a serious shortcoming in Chilean boats. Ziener states, regarding conversion ratios, that "the average for the whole fleet may be estimated at 30 per cent, but several boats work with no more than 15 to 18 per cent." Since 50 to 55 per cent is possible, there must be a waste of as much as three quarters of the fuel. Ziener cites an example in which a 25 horsepower, 3,600 rpm gasoline engine was replaced by a 10 horsepower, 800 rpm semidiesel with a suitable propeller. For the same speed the fuel cost was reduced to one fifth the former amount.

Maintenance problems for the Chilean fleet are great. Engine repairs are expensive, parts are hard to obtain, and in many instances engines that are out of order are discarded when they could perfectly well be repaired. The frequent breakdowns are often due to faulty installation. Crankshaft breakage is common owing to misalignment of bearings, torsional vibration caused by improper propellers, deficient reversing gears, poor engine adjustment, propeller posts that are too heavy, improper propeller shafts, and so forth. These troubles result chiefly from lack of knowledge, training, guidance, and technical assistance.

Obtaining proper diesel fuel is another serious problem which troubles Chilean fishermen using motorized vessels. With improper fuels such as are often supplied, carbon residues build up so fast that in many cases engines have to be dismantled for cleaning every twenty-four to forty-eight hours of running time.

Electrolysis also causes much trouble. If metal parts are not properly installed and protected, galvanic action proceeds very fast with disastrous results. In some cases, iron fittings on brass cooling tubes were eaten away in less than two weeks, resulting in flooding of the motors and boats. Ziener cites one extreme case of improper design and faulty installation of engine and propeller:

> . . . a new-built boat of 40 ft. length, 10 gross register tons, should, for a speed of 9 knots, have had a motor of about 60 h.p. at 600 r.p.m. and a propeller with 28 in. diameter and 24 in. pitch. Instead, on recommendation of the motor-importing firm, a motor of 90 h.p., 3600 r.p.m., direct drive, with a propeller of 13 in. diameter and 13 in. pitch, was installed. In sheltered water the boat did not exceed 5 knots and outside the breakwater, under average weather conditions, less than 4 knots. The maneuverability was dangerously bad even in sheltered water. The small propeller of 13 in. hidden behind a sternpost of 7 in. width, worked with an efficiency estimated at 13 per cent. The lack of slipstream impaired the rudder action. The boat was useless for its purpose and the motorization proved a complete failure. Generally, such cases can be remedied by the installation of a reduction gear and a bigger propeller, but it was not possible in this instance because the stern was built too small to accommodate a normal propeller.

Several lines of engineering research are indicated for improving propulsive power. For example, efficient jet propulsion might advantageously be adapted to certain types of fishery vessels. Eliminating propellers and bearings would solve many of the propulsive problems of beach-landing craft. It would obviate the trouble caused by sand in stern bearings and bushings. With the necessity of protecting rudder and propeller removed, the design and construction of a vessel would be much simplified. Launching in heavy surf would be much easier with jet propulsion because power could be applied much sooner. A type of jet system is now available, but because the power is supplied by a high-speed gasoline engine which is expensive to operate, it is not likely to be widely accepted by fishermen.

Electric systems have been considered for fishing-boat propulsion but have not been very successful. Research may result in improvements and demonstrate these systems to have advantages under certain circumstances.

Various modifications of standard propulsion methods are already available. A rather recent development is the use of "father and son" systems. In this arrangement, two engines of different power are installed. The larger engine is the main propulsion unit, assisted when required for extra speed or power by the smaller unit. The smaller unit is used to power the winch, pumps, electrical system, and so forth. The smaller engine can be connected alone to the shaft to propel the boat in emergencies. This system has the advantage of great flexibility and improves efficiency of operations. It also adds to safety and reliability by providing a reserve engine for propulsion in the event of breakdown of the main engine. This type of system would be of greatest benefit to larger boats.

The Kort nozzle has proved advantageous for certain boats. Essentially, the Kort nozzle is a metal shroud over the propeller, which reduces the amount of power required for a given amount of thrust. The fact that these systems have won popularity with tugboats indicates their desirability for net towing operations such as otter trawling.

The conventional type of propeller is a compromise between efficiency of running and efficiency of towing. A controllable pitch propeller increases efficiency, for it can be adjusted by a simple control in the pilot house to give the best pitch either for running or for towing, whichever is desired. Their effectiveness has been demonstrated by widespread successful use in such countries as Sweden. Those made in countries other than Sweden are delicate and expensive, and therefore not widely used on fishing vessels. Engineering studies are needed to make them more rugged and cheaper.

Vibration in fishing boats is usually considered to be an unavoidable source of discomfort. Actually, discomfort is the least of its effects. Much more important is the fact that vibration can cause serious mechanical troubles.[15] For example, it leads to breaking of the propeller shaft. This sometimes happens in rough weather, with the consequence that the vessel becomes helpless and sometimes founders. Excess vibration can also damage the structural parts of the vessel by loosening rivets and fixtures. Vibration is avoidable, but constant study is necessary to determine how and where to reduce it. There may be a number of remedies, such as a proper choice of propeller, shaft, engine, and mountings, proper engine and shaft installation, and proper hull construction.

A fertile field of research is in the development of improved types of deck gear. The efficiency of all mechanized fishing operations depends upon the capability and reliability of the deck gear. For the most part this means winches of all kinds, from the small power gurdies used to haul line trawls to the massive winches which haul nets aboard the large trawlers. Although at least one winch is on every mechanized fishing boat, it is rarely completely suited to its job. Breakdowns occur frequently and power conversion is often poor.

Winch types, like boat types, have evolved gradually, under various circumstances, and the effectiveness of different designs is extremely variable. The steam winch was reliable and successful in the days of steam propulsion but now has become outmoded. Most fishing boat winches are operated through mechanical linkage to a power takeoff from the main engine. Severe strains affect the whole system, causing frequent mechanical breakdowns. Clutch, brake, and speed controls are often troublesome. Electric and hydraulic winches, which eliminate many of these mechanical shortcomings, have not been generally accepted, partly because of the cost of installation. The more extensive use of these better winches depends on further research and development and testing of models suited to various operations.

Deck gear problems may become the most important in the mechanization of primitive fisheries. There has been no evolution of types of gear to provide a basis of experience for the design of such equipment. Not only must deck gear be designed, but methods of handling the fishing gear will have to be developed.

Setna comments further on his example of increasing catches with mechanized vessels as follows:

> The performance of the mechanized boats would have been still more remunerative if they had possessed small winches. It is realized that mechanization will not be fully complete without the use of mechanical equipment aboard. At present, power is used only for propulsion; it can profitably be employed to perform work which engages the tedious and exhausting labor of a number of hands. For instance, power vessels using drift nets carry 7 to 8 men for setting and hauling the nets. Similar work is, in other countries,

done by four men through the use of winches driven by the engines. This economy can be achieved in India also and the problem of installing winches in mechanized craft is now before the Department of Fisheries. This will lead to an increase in the number of boats as crews will be smaller and there will be more fishermen available to man new boats and, consequently, increased supplies of fish made available.[16]

Included in the field of vessel design is the art of devising the proper layout of boats for maximum convenience, comfort, safety, and economy. The general layout of a vessel is often established more by tradition than by practical considerations. Fishermen and boat builders are usually content to follow the accepted standard rather than attempt any novel departures. This is owing in part to general conservatism but mostly to the fear of expensive modifications after the boat is built. Neither the fisherman nor the small boatyard has capital enough to experiment properly with expensive fishing boat construction.

There are many questions about the internal and external layout of fishing vessels which require engineering research before they can be answered authoritatively. The positioning of winches, bollards, gurdies, poles, tanks, and other deck equipment has great influence on the efficiency and safety of fishing vessel operations. For example, the development of bait storage facilities on American Pacific tuna clippers came by a process of trial and error.[17] The error resulted in loss of life and ships. As faster and larger boats were built, bigger and bigger bait boxes were carried on deck. Designers tried carrying part of the bait in wells in the hold so as to improve stability. However, this arrangement not only limited capacity, but it was unhandy for transferring bait to the deck boxes and for handling the ice and the catch. Consequently, the owners built additional boxes on deck, thus making the boats very tender and topheavy. Eventually two of these vessels capsized while a third was lost with all hands. Of course more attention was paid to improving stability after these disasters.

There is a good deal of controversy concerning the location of engine, fish hold, crew's quarters, storage space, pilot house, and galley. Layouts vary widely geographically and from one fishery to another. Small Pacific salmon trollers have pilot house, engine, galley, and bunks forward and the hold aft. Small Atlantic draggers have the galley and bunks forward, engine and pilot house aft, and hold in between. Tuna clippers have galley and crew's quarters on deck, engine forward, and hold aft. Large Atlantic draggers have the galley aft of the pilot house on deck; below they have the crew's quarters forward and aft, the engine aft, and the hold in between.

Layout in fishing boats is in large part determined by the type of fishing done. In trollers and draggers on the Pacific coast of the United States, fishing is carried on from the stern; therefore, the hold must be aft to be easily accessible. This necessitates placing the engine and pilot house forward. The layout of Atlantic trawlers is influenced by the arrangement of the sailing schooners and beam-trawlers from which they developed. With the hold amidships, the pilot house had to be placed aft and fishing was done from the sides. The engine was placed aft to shorten the shaft, control linkage, and solve other mechanical problems, thus leaving the crew forward. Fishermen believe that having galley and crew's accommodations aft is most conducive to comfort when bucking into heavy weather and to convenience and safety, for this arrangement minimizes movement about the deck, an important consideration in stormy weather. Tyrrell,[18] in discussing Irish fishery boats, cites further advantages of having the engine forward and the crew aft. He gives these arguments: trim is unaffected by loading, since the hold is situated about the center of buoyancy; and full use can be made of the stern space, permitting the aft bunks to extend to the rudder. Forward installation of engine permits a convenient drive to the winch, which is placed forward. The engine is in a completely accessible position and is always clear of bilge water.

On the other hand, Tyrrell also points out disadvantages of this layout: The length of the propeller shaft with its support bearings becomes much increased. Mechanical controls over the considerable distance to the wheelhouse aft are complicated. The weight of the engine forward makes the vessel heavy forward. This tends to increase pitching in head seas, perhaps also to broach in following seas. Thorough research into these matters would probably provide the means of correcting such faults. Special shafts and bearings could be developed, as well as methods of precise alignment. Mechanical controls might be improved, or hydraulic or electric systems developed instead. Hull types could be designed which would reduce the heavy pitching and the tendency to broach. Here again, model tests would be of great benefit.

As was brought out in Chapter 5, fishermen would profit by diversifying their activity in response to seasonal changes, fluctuations in abundance or availability of species, and market conditions. However, to catch different kinds of sea animals requires different equipment and techniques. Each type of equipment requires a special deck layout. Each fishery usually employs a type and size of vessel which is more or less peculiar to itself. This may be culturally picturesque, but it is not economically feasible to operate a boat for only a few months and tie it up for the balance of the year. A fisherman desiring to diversify his fisheries must have a boat which he can adapt easily and quickly to any of several kinds of operations. Until recently little thought had been given to such a possibility. Attempts to modify specialized vessels for multiple use have met with only limited success. The boat designer must consider each type of fishing to be done, and then design a new vessel which strikes a happy compromise among the important features required for each. There can be no universal combination boat. Hull form is not the only problem involved in designing multi-purpose boats. It is necessary to develop special winches and winch positioning to provide maximum efficiency for the various operations. Many other factors must be considered such as the deck and interior layouts, kinds of propulsive and supplementary power, and methods of handling different kinds of sea animals.

In recent years a trend toward building combination boats has developed in some areas. For instance, Hanson [19] describes a type of combination fishing vessel developed for the Pacific coast of the United States which can be arranged for tuna fishing, purse seining for salmon and herring, longlining for halibut, dragging for groundfish, and trolling for salmon. Most of these are seasonal fisheries which could not individually justify the investment but collectively could provide for successful year-round operations.

The heavy capital investment required for a boat is a serious obstacle to expansion of fisheries. A major factor contributing to the high cost is the diverse nature of the boat-building industry. Fishing craft are for the most part constructed individually in small yards. Each boat is built according to the whims of designer, owner, and builder. Very few attempts have been made to introduce mass production methods into fishing vessel construction. There is great diversity of opinion, however, as to whether this would make very good sense at present.

Hardy concludes that mass production of fishing boats would be possible if "designs were frozen." [20] Traung argues that the adoption of a world standard fishing boat would be impractical because of the multiplicity of special local requirements and the diversity of boat-building facilities. He feels that small individual yards would still be able to produce boats more cheaply than great factories.[21] On the other hand, Ringhaver has shown that mass production is practical, at least in the United States. Since his boatyard shifted from conventional construction of individual shrimp boats to a mass production method, there has been a constant demand for his standard 60-foot shrimp trawler. By mass production operations combined with a financing system, his output has more than tripled to the rate of ten vessels per month.[22]

The solution may not lie in the development of a "world standard" fishing boat, but rather in a family of standard types, each suitable for certain types of operations and operating conditions. With minor modifications these could be adapted to any particular situation. The standard types would be suitable for many if not most purposes. At the same time, it is likely that some vessels would continue to be built to individual order for special purposes.

Standardization of boat types is progressing at present in varying degrees on a regional scale. Zwolsman,[23] for instance, reports some progress in standardization of Dutch fishing boats. Three types of cutters were developed after considerable investigation into design, construction, upkeep, propulsive power, and other features. The difference between the three types of boats is mainly one of size, the boats being of 55, 60, and 65 feet in length.

The standardization of part of the Irish fishing fleet was made possible through the development of multiple-use boats which represent the best compromise between the requirements of various types of fishing. A 50-foot boat is being built for fishing with driftnet, seine net, longline, and trawl. Various modifications can be quickly made, such as the relocation of engine and winch when the vessel is to be used for seine netting only. In addition, a 60-foot boat, which is being built for seine net fishing and trawling only, can haul larger nets in deeper water than has been possible with smaller boats. Because the larger vessels will be using deeper harbors and can have more draft, there is much opportunity for improving their design.

Setna [24] proposes the development of two standard types for Bombay, India. One is of shallow draft and flat bottom to harbor in shoal water inlets and creeks which dry up at low tide. This type would be about 35 feet long and would make only day trips. The other is larger, capable of making extended trips even during the less severe parts of the monsoon season. Provision would be made for minor variations to fit the boat most suitably for its particular operations. This standardization would enable fishing boats to pass easily the required government certification.

Boavida [25] mentions another advantage of the development of standard types. As a part of a motorization plan for small Portuguese fishing boats, investigations are currently being made to provide the information needed to establish standard types. When the investigations are completed and standards developed, fishermen will be able to obtain loans to build boats of these accepted types. It is apparent that well designed, thoroughly tested and accepted standard types of boats would encourage both private investors and governments to provide capital for building fishing craft. There would be other advantages. These boats would be designed for safety as well as efficiency; consequently, insurance costs, which are a major factor in the economy of many modern fisheries, could be reduced.

The present stage of development of electronic equipment is largely the result of research supported by the military during the past war. Fishermen need inexpensive, reliable models of all types of electronic equipment, and indeed, such are being developed. For instance, intricate radar sets developed for the Navy have evolved into much simpler types that are within the financial means of the larger boat owners. Perhaps further simplification could lead to production of an inexpensive short-range set which the smaller offshore boats could afford.

In the past, depth finders have been too expensive for the average small boat operator. Consequently, manufacturers have resorted to rental plans in order to make the expensive sets available to fishermen. However, depth finders have become simpler and cheaper so that now a type of shallow range set is available at well under $200. Some highly sensitive sets are being made specifically for the fishing industry. These are primarily fish locating devices. The presence of fish can be observed and an experienced operator can recognize species or even sizes of fish by the characteristic of their trace. Individual fish have even been spotted on these locators. Types are being developed that can be operated through a 90 degree angle vertically from bottom to surface. Others will provide an extended horizontal sweep. With these modifications it will be possible to explore the waters in any direction from the vessel. One model has been specifically developed for the use of whalers. With this finder a whale can be tracked through the water so that the boat can be ready for the kill when it surfaces.

Perhaps the most significant recent development for offshore fishing boats is the loran position locating system. Unfortunately, loran is very costly equipment. For a while after the war, United States fishermen were able to buy cheaply sets which were surplus property of the Air Force. As this source of supply has diminished and as demand has expanded, the need for a simple inexpensive loran instrument has grown apace. Manufacturers in various parts of the world are developing instruments to meet this need and are gradually bringing the price to a level that fishermen might be able to reach.

Radio receivers, transmitters, and radio direction finders are all necessary equipment for offshore fishermen. However, the combined cost of all the separate electronic aids needed prevents the average fisherman from being fully equipped. Compact, moderately priced combinations of radio transmitter, receiver, and direction finder have been available for some time. It may be possible to go even further and produce various simplified combination sets including most or all of the electronic aids needed—sounding machine, loran, simplified radar, radio receiver, transmitter, and direction finder. Such a unit or units should sell at a much lower price than the collection of individual items and be more adaptable to shipboard installation and operation.

Improvement of fishing vessels should be aimed toward increasing safety and comfort and toward reducing operating and maintenance costs and the time required to reach fishing grounds. Electronic equipment helps to find the grounds and the fish. There remain to be considered the problems of improving the means by which the fisherman actually captures the fish. Here a new type of specialist must appear. It is hard to prescribe the exact education and background he must have, particularly since his is a science which has yet to be developed. The fishing gear expert must be imaginative and at the same time practical. He must be able to study like a scientist, design like an architect, build like an engineer, speak like a fisherman, and think like a fish.

Thanks to recent advances in submarine photography and diving, we will now be able to watch and photograph his gear in operation. He can observe how the fish react to its action. The lens of the underwater television camera can penetrate beyond the depths which man can safely explore with his frog's feet and bottles of compressed air. A less spectacular, but economical and perhaps more fruitful way to study the action of trawls is by towing models in tanks (which need be no larger than an ordinary swimming pool), observing their action under controlled conditions and experimentally altering their design. Such studies are carried on at several laboratories in Japan (at the Tokai Regional Experimental Station in Tokyo, for example), and in Germany.

The opportunities for improving fishing equipment seem endless. To suggest a few ideas:

There has been much discussion in recent years about the possibility of capturing fish with electricity.[26] Electricity is used extensively in fresh water to guide, attract, repel, and paralyze fish. If it could have similar effect in the sea, it might reduce tremendously the labor and time required to concentrate and catch fish.

Unfortunately there are technical difficulties to overcome which have seemed formidable enough to discourage developmental research in sea fishing by electricity. Because the conductivity of sea water is very much higher than that of fresh water, and because there are no natural boundaries in the sea to contain an electric field as there are in a stream or a shallow lake, the amount of power required to produce a field which could control the movements of fish in the open sea is theoretically too great and costly for practical purposes.

Dickson, reviewing these difficulties in 1954, wrote:

> . . . there remains the possibility of using electrical fishing apparatus as a marine research tool and even as a commercial gear in particular circumstances, and these possibilities seem worth exploring.
>
> Better results could be anticipated using electrical fishing apparatus in conjunction with a trawl or other gear. It has been observed that the reaction of some species of fish to an electric field is more marked when they are facing the cathode, and that they do not remain in such an alignment. This gives rise to the possibility that, even without the field being strong enough to impel a fish towards the anode, its normal escape reactions to a trawl can be upset in a manner that increases the efficiency of the trawl. In mid-water trawling, where the fish have so much more possibility of escape, this could be particularly important.[27]

That electricity already has practical applications in sea fishing is shown by the fact that German fishermen use it to shock large tuna after they have caught them by trolling with a hooked lure which is also an electrode. The other electrode dangles a short distance behind the lure. After the fish are hooked they are electrocuted to make them easier to handle, thus speeding the operation of bringing them into the boat.

Otis Smith, a fishery industrialist in Delaware, has experimented for several years with electricity in menhaden fishing. He persisted through the discouraging early stages of his work, when it did appear to require a tremendous amount of power to generate the amount of electricity that was needed. He has overcome this problem to the point where relatively negligible amounts are required. He has not only demonstrated the practical value of electrical fishing when the apparatus and process are properly designed, but he uses it throughout his fleet. After the menhaden have been impounded in the usual way with the purse net, the current is turned on to raise the fish in the net and attract them to the opening of a hose, the bell-shaped end of which is made of copper and functions as an electrode. This method is so successful that Smith is encouraged to continue his developmental research with the aim of eventually abandoning nets entirely in favor of electricity alone for menhaden fishing. His optimism should encourage fishery people all over the world to experiment along similar lines.

Not all improvements in fishing equipment need be installations of large costly machines. Sometimes a very small thing can be enormously effective. For example, a simple device is an artificial fishing bait made of rubber and shaped like a worm. This idea is not new. Baits had been made of rubber for years, but were not successful until recently when new materials and shapes were developed in Norway. Many of these artificial baits are connected to a single line so that the struggles of one captured fish set the rest of the bait into tempting motion.

There is room for an infinite number of other inventions, small and large, to reduce the time, labor, and cost of fishing. There is an infinite number of questions to study about all the processes of fishing. To suggest a few: What are the engineering principles involved in the successful operation of a net? Why do slight modifications in the way a net is hung make very large differences in catches? Which new synthetic materials are most suitable for nets and lines? What are the most effective ways to prepare baits? How can the handling of a catch be reduced so as to get it into the hold most quickly in a most nearly perfect condition? What are the most efficient layouts for dock and wholesale market facilities? Such matters can best be attacked by a staff of appropriately educated people—probably chiefly engineers, all-around scientists, time-and-motion specialists, naval architects—working full time, devoting themselves wholly to the ideal of making the exploitation of the sea scientific. They should not be temporary project employees, but permanently attached to a research center especially built and equipped for their work. This should be an adjunct of a laboratory of marine research where studies of behavior of fishes are a prominent feature of the program. Several such units should be established in various parts of the world to serve differing cultures, climates, sea conditions, and fisheries. The size of a unit must depend on the degree of advancement of the area where it is established. A naval architect, a marine engineer, an expert in fishing methods, perhaps two or three apprentice-technicians, and draftsmen could form the nucleus of a unit.

The theme of this book is research. What kind of research is needed to provide knowledge for expanding the use of the seas' biological resources? That is the principal question being examined. However, we must not lose sight of practical applications. Learning how to exploit the sea scientifically is one thing; inducing fishermen to accept your advice is quite another. Fishermen everywhere are more or less conservative; in primitive places they are excessively so. Suppose that a research center were established in an undeveloped area, complete with all the facilities suggested in the preceding chapters; then as information accumulated, means should be provided to teach it to fishermen so that they could profit by it. The scientists should not be expected to assume this duty. Rather, special teachers should be trained for the purpose. In other words, a school for fishermen should be founded close by the research center. Here young fishermen from many countries in the area would gather for training in navigation and the safe handling of boats; in the operation, maintenance and repair of engines; in the general principles of vessel design and construction; in the construction and repair of fishing equipment and the techniques of fishing; in the proper handling, preparation and preservation of their catch; in natural history; and in the ideas and principles of conservation.

People conducting such a program would have to be supremely patient. Years might go by before the results of their labors would even begin to show. Beever says on this:

> New techniques or the use of superior equipment must be taught in a similar fashion and must be adapted to the capacity of the fishermen to absorb instruction. Revolutionary changes of craft and techniques may alarm and repel, while too many changes all at once usually confuse the fisherman. It is usually more profitable to introduce changes one at a time, so that the characteristic features are retained. A fisherman who successfully tries out a new craft or a new engine on his familiar grounds with his own methods is more likely to cooperate in further improvements than one who is introduced simultaneously to new grounds, different working hours, new equipment, new craft and so on. That is one of the more important lessons learned from past efforts at development.[28]

II

THE RESOURCES OF THE SEA

The marine animals and plants have been neither exhaustively surveyed nor fully described. There must be many species, and even some higher orders in classification, which zoologists and botanists have missed during their expeditions, and many which they have collected but have not yet identified or described. At the very least, however, we can say that the sea's faunas and floras have been thoroughly enough sampled that there is little likelihood of discovering many, if any, large populations of organisms which are not closely related to those that are already known. We can expect an occasional startling discovery such as that of the coelocanth a few years back, but as far as we can see, these are not likely to affect fisheries very profoundly.

What is true on land is true in the sea: only a few of the thousands of species have actual or potential direct value to man; and of those that do, only a small minority are abundant enough or valuable enough to support great fisheries to supply established uses. At the same time, we must not assume that all the possible uses of marine organisms have been discovered. New products might emerge at any time from researches in many different fields, and these would stimulate new demands and generate new fisheries.

The following five chapters are devoted to a general survey of the principal groups of animals and plants which have value in human affairs. They point out gaps in our knowledge about these groups and suggest lines of research needed to fill in those gaps.

13

Invertebrate Animals

The commercial value of invertebrate species cannot be judged wholly by catch statistics. Peoples of the coastal areas take large quantities of food with rather little effort from shallow lagoons, estuaries and bays. Much of this they use for their own subsistence. Some they dry or otherwise preserve for future use; the rest they sell immediately near the place of fishing. Government officials find it difficult to get much information about such casual fisheries, and consequently knowledge of the consumption of invertebrates is even less accurate than that of fishes. However, it is certain that they are much less important to us than fishes for they contribute only 16 per cent of the total production of all sea food. Around four million metric tons of marine invertebrates are caught during a year.[1] Of this amount, as well as one can guess from published statistics, in which figures on invertebrates other than crustaceans and mollusks are combined with those on sea turtles, shells, lampreys and frogs, about 68 per cent are mollusks, 22 per cent are crustaceans, and the rest are sea cucumbers, sponges, worms, and jellyfishes (see Table 13-1).

More than 90 per cent of the mass of animal life in the sea is composed of invertebrates. Although there is a great variety of genera and species of which some occur in enormous numbers, few meet the requirements for usability as defined on page 227. Nevertheless, in some parts of the world, there still remain invertebrate resources which could contribute importantly to the food supply.

The food invertebrates consist now, for the most part, of oysters, clams, scallops, lobsters, shrimps, and squids. In general, people do not know about other forms, or if they do, are repelled by their strange appearance.

TABLE 13-1. CATCH OF CRUSTACEANS AND MOLLUSKS, 1953
(thousands of metric tons)

Country	All Fishery Organisms	Crustaceans	Mollusks
Africa			
Angola	222.4	0.0	0.1
French Morocco	128.0	0.5	0.7
S.W. Africa	274.8	10.3	*
Spanish Morocco	10.8	0.1	†
Union of South Africa	353.4	13.6	0.6
America, North			
Canada (excluding Newfoundland)	661.4	21.1	15.6
Newfoundland	263.3	2.0	5.2
United States	2,385.2	187.8	465.0
America, South			
Argentina (1952)	78.7	3.0	2.4
Chile	107.2	2.1	16.2
Asia			
Ceylon	25.5	0.7	2.8
Japan	4,576.5	73.4	939.9
Pakistan (1952)	126.7	6.8	*
Philippines	311.9	6.1	5.0
Europe			
Belgium	74.4	2.6	0.6
Denmark	342.8	1.6	19.9
Finland	62.1	0.1	‡
France (including Algeria)	520.3	15.7	30.9
Germany, Western	730.4	40.2	7.8
Greece	46.0	0.7	2.0
Ireland, Rep. of	19.0	0.3	3.1
Italy	213.6	6.3	23.4
Netherlands	343.3	16.9	58.4
Norway	1,505.5	6.4	0.1
Portugal	392.4	2.6	4.4
Spain	634.7	16.8	31.5
Sweden	210.0	2.8	‡
United Kingdom	1,121.6	8.0	18.1
Yugoslavia	24.4	0.2	0.2
Oceania			
Australia	51.6	8.9	4.0
New Zealand (1952)	35.3	3.4	8.5

SOURCE: *Yearbook of Fishery Statistics, 1952–53: Production and Craft.* Rome, F.A.O., 1955.

* Not reported.
† A negligible amount.
‡ Included with crustaceans.

Many species which are not edible might be good for fertilizer. Some which are poisonous might have pharmaceutical value. However, few if any, systematic technological studies are carried on to test these possibilities. Few efforts are made to arouse public interest in utilizing unfamiliar sea organisms.

In the following pages, I shall discuss the principal types of commercially valuable invertebrates and their uses.

Sponges

Sponges occur in all seas in a great range of depth and in a wide variety of forms and sizes. Although there are thousands of species, hardly more than a dozen of them have commercial value. These are characterized by skeletons composed of an organic substance called spongin.

Sponge fishing, once a substantial industry, is a victim of the technological age. In 1938, the annual world production of sponges was about 2.5 million pounds. Within ten years it had dropped to a third that volume. Production in the United States is now less than 6 per cent of what it was in 1936.[2] The development of synthetic sponges has been chiefly responsible for the downfall of the fishery. In addition, a wasting disease has at times (1938–39, 1947) plagued the grounds off Honduras, the Bahamas, and in the northern part of the Gulf of Mexico;[3] and divers have severely overfished the grounds. Chances for the recovery of the sponge industry to its former status seem slight, and natural sponges will be replaced gradually by synthetics unless some new valuable use can be found for them. If that is ever accomplished, sponge farming might be developed into a profitable venture, for these animals can be cultivated.

Sponge farming had a promising start in the Bahamas and British Honduras before the epidemic of 1937–1938 ruined the enterprise, and Japanese attempts to cultivate sponges in Caroline and other mandated islands under the Japanese occupation were promising.[4] However, it seems unlikely that artificial cultivation of sponges can be profitable on the present market.

There are some kinds of sponges which are very abundant, for which no commercial value has ever been found. For example, the loggerhead sponge of the Gulf of Mexico grows to huge size, and is a nuisance to shrimp fishermen, for it impedes trawling operations. The commercial possibilities of such species have never been thoroughly explored.

Biochemical study of the composition of sponges has disclosed the presence in some of large quantities of iodine in an aromatic amino acid contained in the skeleton, identified as 3:5 diiodotyrosine. In the red sponge (*Microciona prolifera*) it amounts to 0.3 per cent of the total dry weight. The method of accumulation of this element, present in an extremely minute quantity in sea water, still is a mystery of much scientific interest. Several organic compounds have been extracted from sponge bodies. *Crypototethia crypta*, a sponge growing in abundance around Bimini[5] contains, among other substances, the nucleosides "spongothymidine" and "spongosine." *Spheciospongia vesparia* contains metanethole, an odoriferous product responsible for the odor of many sponges.[6] Chalinasterol is found in *Chalina arbuscula*, a common sponge of the coastal waters of New England[7] and availability of this compound makes possible the preparation of the C_{24}-isomers of ergosterol and of its irradiation products. Sponges are one of the best sources of fatty acids of high molecular weight.[8] These substances are all of scientific interest to biochemists. Continued systematic chemical studies of the composition of these and other species might result in discovery of chemical compounds having medicinal or industrial value.

Coelenterates[*]

The coelenterates offer no great source of food, although one jellyfish is eaten in Korea, Japan, and China. In the Mediterranean countries and in Japan red corals are fished extensively for manufacture into jewelry and ornaments. And throughout the tropical and temperate countries various species of corals are always present in the shops which sell shells. Sea anemones are eaten in France and in some of the Pacific islands. Coelenterates possess stinging cells and some of the large jellyfishes of tropical seas and some of the siphonophores, such as the Portuguese man-of-war, are highly poisonous and contact results in serious burns. In some areas jellyfish are seasonally a nuisance to bathers. Systematic biochemical studies to identify and determine the properties of the toxic compounds in coelenterates may be of value. Although sea anemones and other coelenterates occur in vast quantities close inshore as well as on the high seas, in many parts of the world, we do not know their constituent chemicals or their potential uses.

While it does not seem probable that jellyfishes could become the object of great fisheries, nevertheless certain of them are among the most valuable animals in the sea, for they give shelter to the young of a number of species of fishes, such as hake, haddock, cod, horse mackerel, butterfish. These little fish travel with their host in the plankton, feeding around it within a radius of a few feet, darting to safe shelter beneath its umbrella when threatened by enemies. They continue this mode of life as long as it is advantageous to them, until they are ready to become independent. This association may be an essential stage in the life cycle of some fishes; that is to say, if they fail to find a jellyfish within a certain time, they probably perish. In spite of the probable importance of this relation, it is astonishingly neglected in research programs.

Echinoderms

As a source of food the echinoderms are of relatively little significance. Only a few species of sea cucumbers (trepang or *bêche de mer*) are extensively fished in the Orient. These belong to the families Stichopidae and Holothuriidae. Several species are used as trepang. At least one (*Stichopus chloronotus*) is used for fertilizer. Another, *Cucumaria minata,* sometimes finds its way into soup as an important ingredient, if not the principal one, in clam chowder on the west coast of America.

In Japan, one species of sea cucumber, *Stichopus japonicus,* is raised on trepang farms and research is in progress to develop methods of artificial propagation from larvae.[9]

The trepang will continue to be popular in the Orient, but it seems doubtful that sea cucumbers are abundant enough to be of major importance. Not all species are edible. Many are too small to be useful. At least one species is deadly poisonous.

The ripe gonads of sea urchins are frequently used for food, but are scarcely of great importance as a food resource. The importance of sea urchins as a material for scientific research, however, far exceeds their usefulness as food. *Arbacia* of the North Atlantic coast and several species of *Strongylocentrotus* and the sand dollar *Echinarachinius* are used as experimental animals in studies of cellular physiology, biochemistry of ova, fertilization processes, and experimental embryology. Eggs of these species, and particularly those of *Arbacia,* continue to be the most desirable material for research in many marine laboratories.

Most, if not all sea urchins have poison glands, but in only a few is the quantity of poison great enough to be serious to man. Sometimes, for instance, large quantities of the common green sea urchin *Strongylocentrotus dröbachiensis* become caught in trawls; and then the handling of such large numbers is an irritation to fishermen.

The species of *Toxopneustes* found in East Africa, Fiji, New Caledonia, Japan, and from the Gulf of California to Colombia have powerful poison glands in their large and numerous pedicellariae. These sea urchins are much dreaded by fishermen, for occasionally they cause fatalities.[10] The spines on *Diadema* and one species of Echinothrix are very poisonous. So are the spiny projections of the starfish *Acanthaster.* Here again, pharmacological and chemical studies of echinoderm toxins are desirable, not only from the viewpoint of human safety, but also because those animals might prove to be a valuable source of new and physiologically important chemical compounds.

Mollusks

Among all major groups of invertebrates, mollusks probably offer the greatest opportunity for expanding the harvest of seafood resources. The shores of all countries are populated with sedentary mollusks, some crawling about the bottom, others buried in the sand or mud, still others attached to such solid objects as rocks or the shells of their forebears or the roots of mangrove trees. Most of them are easily and cheaply harvested, for they can be picked up by hand during low tide or grabbed with simple gear such as tongs, from small boats working in shallow water. Nevertheless, many of these are not utilized, often because people are ignorant of their value. Other mollusks, notably squids, are not sedentary but behave like fish, traveling in the open sea in dense schools. These can be caught with purse seines like herring, and where they are exploited, they support large and profitable fisheries. Mollusks are not universally appreciated, and in places where they are appreciated they are often improvidently harvested, with consequent depreciation of their productivity.

OYSTERS. Many species of oysters, of which there may be a hundred or more, are widely distributed in temperate, subtropical and tropical regions, mostly between the forty-fifth parallels north and south of the equator, but also, thanks to the moderating influence of the Gulf Stream, as far north as about the sixty-second parallel on the European side of the Atlantic. In North America, Europe, and in parts of Asia, they are exceedingly valuable. In the United States, for instance, the annual harvest brings more than 32 million dollars to fishermen. In many regions, particularly in the southern hemisphere, oysters seem to be far underexploited; indeed, little is known about their distribution, abundance, or commercial potentialities. It is reasonable to expect that explorations and studies along the coasts of Brazil, Peru, Chile, and the east coast of Africa would disclose valuable latent oyster resources and perhaps stimulate new industries in those countries.

In many areas wild oysters are gathered from natural bottoms without any effort to maintain the productivity of the stock. About a third of the harvest in the United States waters is obtained in this way. It is a foolish and destructive method, leading to unnecessary dimunition in the profitableness of the resource, as exemplified by the decline in production on the Atlantic coast of the United States. The most promising way to sustain the yield of oysters is to farm them, as is done in some areas of the United States, and in Japan, England, France, Italy, the Netherlands, Denmark, Australia, and the Philippines. Even where oyster farming is most advanced, however, a great many problems must be solved to minimize variation in production and quality, to control the many diseases, parasites, and predators which plague oysters throughout life, and to improve the fertility of the grounds.

As practiced today, cultivation depends largely on the ability of the oyster grower to place at the right time and place sufficient quantities of clean, hard material for the attachment of free-swimming oyster larvae.[11] To accomplish this it is necessary to determine in advance and with accuracy the expected time and intensity of setting. Work in this country and in Europe has developed some practical schemes which make it possible to anticipate the time of setting. It has not, however, attained any degree of success in predicting the survival of oyster larvae and frequent failures of oyster sets remain unexplained. Every theory so far advanced to explain the setting behavior of oyster larvae seems applicable only to some particular case and becomes untenable when applied to other situations. The apparent preference of oyster larvae to set in certain localities in a rather narrow zone of tidal flats is particularly mysterious. Large concentrations of newly attached oysters are often observed at a level of 1 to 2.5 feet above mean low water, while in other locations such selectivity in vertical distribution of setting is lacking and young oysters are more or less uniformly distributed on the bottom from low water mark to depths of 20 feet or more.

Oysters and other shellfish are subject to wide seasonal fluctuations in the chemical composition of their meats. A yield from a bushel of oysters gathered from the same location at different times of the year may be as low as 2 pounds of meat or as high as 8 and 9 pounds. Total solids may vary from 10 per cent in poor oysters to more than 20 per cent in good ones. Changes in the total solids are accompanied by corresponding fluctuations in the content of tissue-bound water. Total carbohydrates, particularly glycogen, vary, depending on the season and location of grounds, from less than 0.5 to about 8–9 per cent of wet weight.[12] Likewise, there are conspicuous seasonal and geographical differences in the content of copper, manganese, zinc and iron. The control of such variation is one of the principal subjects of research needed for the improvement of oyster farming. Another is oyster genetics. This cannot go forward for any species until a reliable and practical method of voluminous artificial propagation of seed oysters is developed. When that problem is solved, it should be possible, by selective breeding and hybridization, to produce strains characterized by rapid growth, high glycogen content, thin shell, disease resistance, and other features that may materially improve the quality of commercial oysters and increase their yield.

MUSSELS. Several species of mussels (*Mytilus*) are widely used for food in all European countries and to a lesser extent in North and South America, Australia, and South Africa. Probably fairly large quantities of mussels are eaten in the Orient, but production statistics are not available.

Mussels are extraordinarily fertile, and the productivity of mussel grounds far exceeds that of the best oyster bottoms. They are capable of forming in a short time large, thickly layered beds covering the bottom. Demand for them in Europe for food and bait at one time was so great that natural mussel beds were inadequate to supply the fishery and much attention has been given since to mussel culture, especially in France and Italy, where the ancient system of "bouchots" or fences made of twigs set in shallow water for the attachment of mussel larvae is still in use. Because of the prolonged reproductive season and very rapid growth of mussels in the Mediterranean Sea, the cultivation of mussels is a continuous process. Each generation becomes mature within sixteen to nineteen months and new generations are well under way when the old one is harvested. French mussel growers report that about 150 kilograms of mussels may be taken from each linear meter of "bouchot." In the Bay of Taranto, Italy, where mussel culture is highly developed, the productivity has averaged 1,215 kilograms per 100 square meters, or 49 metric tons per acre.[13]

Mussels have relatively thin shells and consequently the edible portion of their bodies is relatively greater than that of the oyster. According to Atwater and Bryant (1906) the waste material comprises only 46 per cent of the total weight of mussels while it constitutes more than 90 per cent in oysters. Much more food material may be obtained from the sea by growing mussels than from any other edible shellfish.

Improvement in the production of mussels requires research to develop methods of controlling parasites, diseases, and predators and, where farming is practiced, of propagating seed. In certain areas, mussels are occasionally infected by poisonous dinoflagellates and then are dangerous to eat. Where this happens, the possibility of controlling the sporadic blooms of the poisonous organism, perhaps by chemical means, should be thoroughly explored.

CLAMS, SCALLOPS, COCKLES, AND OTHER LAMELLIBRANCHS. Clams of many species and genera are used for food all over the world.

They are exceedingly nutritious, easily reached and cheaply gathered. If harvested at a proper rate, under regulations based on biological information, clam beds can be highly productive. Otherwise they are particularly vulnerable to overfishing. Clams are also vulnerable to a considerable assortment of predators, of which the most terrible are boring snails and crabs. Unfortunately the crabs are usually too small to have commercial use. Clams are among the animals that can be profitably cultivated; in fact that is the principal means of production in Japan. By growing clams under protected conditions it is possible to minimize predation by pests, and to harvest them as the market demands at their most profitable size. The same kinds of research problems apply to clams as to oysters, namely, methods of artificial cultivation, selective breeding, methods of controlling enemies, and methods of improving the fertility of beds.

In the United States several species of clams are the object of important fisheries on both Atlantic and Pacific coasts, and intensive research programs are aimed particularly toward designing regulations for rational conservation, and toward the control of predators.

In the tropical zone of the Pacific the giant clams, *Tridacna,* and the related genus *Hippopus,* a horse-hoof clam, which live either embedded in coral reefs or lie unattached on the surface of reefs, are regularly used for food.

The utilization of the window shell, *Placuna placenta,* in the Philippines deserves special attention both because of the extensive use of this mollusk in home construction and the success in its cultivation in Manila Bay where the high yield of the fishery is maintained primarily by extensive farming methods. *Placuna* is widely distributed through the Philippine Archipelago. It inhabits the bottom from the littoral zone to a depth of 300 feet. For centuries its thin semitransparent shells were used in oriental countries as a substitute for glass. At one time about half of the houses in Manila had *Placuna* shells in their windows. This city still uses several million shells annually, while large quantities of them are exported to India, Ceylon, and China.

Placuna farming, practiced in the Philippines, consists in gathering the young from their natural beds and planting them on suitable ground. They thrive on muddy bottoms and grow very rapidly. The meat of *Placuna* is palatable and is frequently eaten, although it is usually not sold in fish markets. The yield from a good *Placuna* farm is said to be twice as much as that from an oyster farm of the same size. Frequently both oysters and window shells are grown on the same grounds. Periodic mortalities strike *Placuna* populations. Filipino fishermen frequently report finding large numbers of shells buried in mud. Like many other mortalities of marine populations the cause of this one has not been determined.

Many species of scallops and cockles (*Pecten* and *Cardium*) are widely distributed throughout the world, from the arctic to the tropics. Their habitat extends from shore to at least 450 fathoms.

Although scallops are able to swim, by a peculiar rapid clapping of their valves, they seem not to migrate very far and usually remain within a relatively limited distance of their beds. As a rule they prefer hard and sandy bottoms but occur also on mud and among rocks. Some species of scallops live in shallow inshore waters and are easily caught with rakes and light dredges operating from small boats; others live offshore in greater depths, and require heavier gear and larger vessels. Bay scallops may be particularly vulnerable to overfishing. To guard against this the rate of fishing must be regulated to produce the highest sustained yield.

Scallops are particularly appreciated in the United States. On the United States Atlantic coast, 24 million pounds are caught in a year, worth about 13 million dollars. Much smaller quantities are caught in the United Kingdom, Ireland, France, Oceania, and Japan. Elsewhere scallop resources are quite neglected.

The scallop has provided material for the study of many interesting physiological problems. Gill epithelium, adductor muscle, and eyes have received special attention. No other organ of mollusks has given rise to more discussion than the complex scallop eyes. Since their discovery over 150 years ago these remarkable organs, arranged in a row on the edge of the mantle, continue to excite the interest of zoologists, anatomists and physiologists. The gill epithelium of scallops is a favorite object for study of the physiology of ciliary motion. The search for the nervous control of ciliary beat is a problem of wide interest because ciliary motion is involved in physiology of vertebrates (including man) as well as of lower animals.

The use of cockles (*Cardium*) is limited. Although gathered for food in Europe and in some oriental countries they are almost completely neglected in the United States. Fisheries for cockles, as for many other kinds of mollusks can be materially expanded in many areas with the help of market development programs.

The principal source of pearls is a lamellibranch mollusk of the genus *Pinctada* which differs from the true oysters by the presence of a byssus, by which pearl oysters attach themselves to the substratum. The mother-of-pearl fishery is of considerable economic importance, providing raw material for buttons and decorated articles for which there is a fairly stable market. Commerce in pearls, on the other hand, is much affected by the fluctuations in price and market demands.

It is doubtful that new, rich pearl oyster grounds can be found, since for centuries all waters likely to contain them have been searched intensively. Important fisheries are located in the Red Sea, Persian Gulf, Ceylon, Sulu Archipelago of the Philippines, Australia, west coast of Mexico, Panama, Venezuela, Hawaiian Islands, and the Gulf of California. The Japanese pearl fishery occupies a unique position because of the highly developed cultivation of pearl oysters and artificial induction of pearl formation.[14] All pearl oysters are edible; their use for human consumption is gradually increasing and meats formerly discarded as refuse are in some places preserved by canning or drying.

SNAILS. Marine snails can be utilized for human needs to a much greater extent than is generally known. In North America they are almost completely neglected; in Europe a few forms such as periwinkles, whelks, and limpets are used for food. In the Orient many more species are eaten, including large whelks and conchs. In the Philippines small fresh-water gastropods are fed to ducks on the many duck farms near Manila. The principal product of the farms is not the duck meat but duck eggs, which are permitted to develop nearly to a hatching stage and are then preserved by boiling and sold as "balut." Parasitological study of the snails used to feed the ducks as possible vectors of various trematode diseases of man and domestic animals is of importance because of the known role of gastropods in transmitting schistosomiasis and other diseases.[15]

Large marine gastropods of the family Trochidae are important sources of material for button manufacture and other shellcraft. In Australia *Trochus* shells are extensively used for jewelry, and *Trochus* meat is used for food throughout the area of its distribution in the tropical seas.

There are many species of carnivorous marine snails which live by boring holes in the shells of other mollusks, particularly oysters and clams, and feeding on their flesh. In this way they inflict terrible damage in commercially valuable areas all over the world, in the tropics as well as in temperate latitudes. Control of such pests would do more than anything else to improve the productivity of shellfish grounds. This is an exceedingly difficult problem to solve, however, for these animals are prolific, hardy, and widely distributed. Detailed studies of the habits, reactions, growth, reproduction, diseases, and enemies of these snails are needed to develop methods for their control. Commercial uses should be sought; for some of them are not only edible but palatable, though rarely eaten and not sold in the markets.

ABALONES. The abalones (*Haliotis*) are one kind of gastropod which is extensively used for food. These animals, of which there are several species, are fished on the Pacific coast of North America, as well as in China, Japan and Korea, and to a lesser extent in the Union of South Africa and in southern Peru. They tightly adhere to rocks under water and can be dislodged only by divers using crowbar or chisel. These mollusks are highly appreciated wherever they are fished. It does not seem likely that there are many accessible unfished stocks which could add significantly to the world's food supply.

CEPHALOPODS—SQUIDS, CUTTLEFISH, OCTOPUS. About 1,800,000 metric tons of mollusks are harvested annually in the world, which is over 70 per cent of all the invertebrates harvested. More than a quarter of these are squids. There are many species of these animals; they range in size from pygmies of a few centimeters to giants of over 15 meters. They are widely distributed, horizontally along shores as well as on the high seas, and vertically from surface down to great depths. They are evidently exceedingly abundant, as shown by the fact that squids are one of the important fodder animals of fishes. Even the giants, which are rarely seen by man and then generally only as dead specimens washed upon beaches, are probably also abundant, for they are one of the principal foods of the great whales. Squids are highly predacious themselves, feeding on fishes and pelagic invertebrates. Hence they are competitors of fishes in the economy of the sea. The species which are most familiar to fishermen grow to be 20 or 30 centimeters long and are pelagic, traveling in large schools at the surface. They seem to be enormously abundant and are nutritious and palatable.

Recently squids have become important in neurophysiological research because of the presence of giant nerve cells which greatly simplify experiments in neuromuscular transmission. Demands for live squid have become so great that it is difficult to satisfy the needs of experimental laboratories and organizations engaged in this research. Neurophysiological studies of the nature and mechanism of nervous impulses contribute to the advance of human physiology and have broad application in medicine.

Cuttlefish are similar to squids but differ in having a heavy calcified internal shell or bone, as contrasted with the thin "pen" of the squids. They, too, are caught for food and bait. In addition, their internal shell is manufactured into a powder for polishing and other industrial purposes and for dentifrice. The whole shell in "cuttlebone" is sold for feeding cage birds. The ink sac of cuttlefish is a source of the natural brown pigment called sepia.

Octopi are much less abundant than squids. They are shore-dwelling animals, occurring around sea coasts all over the world. They are caught with traps and used extensively for food in countries of the Orient and in southern Europe. Elsewhere they are not appreciated and almost completely neglected. They could add something to the world's food supply, but not very large quantities.

People who have never tasted squid, cuttlefish, or octopus generally look on them with abhorrence. This prejudice is the first obstacle to starting fisheries for these animals. It could be overcome by market development programs, by advertising, cooking demonstrations, and most important of all by the development of attractive marketable products.

Before the war the Japanese squid fishery took 75,000 to 150,000 tons annually; in recent years, their catch has grown to a peak of 600,000 tons. In North America where squid stocks may be equally large, less than 6,000 tons are caught, most of it on the Pacific coast. Southern European countries, chiefly Spain, Portugal, Italy, and Yugoslavia, take about 20,000 tons. The rest of the maritime countries take inconsequential amounts. Thus squid might be one of the most promising of the unutilized fishery resources. In Japan and in western United States squid are sold fresh, dried, and canned, and are also used as bait. They might be a good raw material for protein meal. In Europe and western America they are caught by encircling nets, and in Newfoundland and in Japan they are snagged on hooks. In Japan, squid are fished at night, being attracted and concentrated by the use of lights. Since they swim in schools, come close to shore, and can be easily caught with simple equipment, they are the object of a very intense fishery conducted by coastal dwelling families operating small boats in the southern part of Hokkaido (northern Japan). There squid constitutes as much as 60 per cent of the total catch of sea food. As fisheries for squid and octopus developed, it would be important to study the ecology, life histories, behavior, and migratory patterns, to measure the rates of birth, growth and mortality, and to determine the effects of fishing on abundance of the stocks.

Crustacea

Of many thousands of marine crustacea only a few species, belonging mostly to the order Decapoda, are of economic importance now. The lower groups, immensely abundant in the sea, for the most part are only indirectly concerned in human economy either as food for fishes or as such nuisances as the organisms fouling ships' bottoms (barnacles) or those boring into wooden hulls and piling (wood-boring isopods).

PRAWNS AND SHRIMPS. Of all the edible decapods, prawns and shrimps* are by far the most important. They occur in estuaries, in fjords, in areas of continental shelf that are nourished by rivers, and sometimes on offshore banks. The greatest fishery for prawns is in the United States, where (called shrimp) they are the most valuable of all the sea foods. The annual catch in the South Atlantic and Gulf states, where the principal fishery is carried on, is now around 250 million pounds.

At least 22 species of shrimps and prawns are fished commercially. There are important fisheries for these animals in the United States, West Indies, coastal European countries, along the central American and South American coasts, and throughout the Indo-Pacific area.

Perhaps in many areas where they occur, shrimp and prawns are underutilized. This is a possibility which can only be tested by experimental fishing. Exploratory fishing and development of new gear and fishing techniques are important activities for future investigations. Efforts made so far in these directions have had some promising success judging, for instance, from the discovery of populations of northern shrimp, *Pandalus borealis,* along the New England coast,[16] of the pink shrimp (*Penaeus duorarum*) near Key West, Florida, and of the "royal red shrimp," *Hymenopenaeus robustus,* in 200 fathoms off the Florida coast.[17] Further exploration may result in discovery of untapped shrimp populations which may materially add to our food resources.

Prawns and shrimps tend to live in parts of the sea that are fertilized by land drainage, such as estuaries, fjords, and bays. A pattern of life history, which is common to many of the species (perhaps to all peneids), is this: They enter the inshore waters and estuaries at very young stages; for a few months they live in these nursery grounds while they grow very rapidly. Just before maturity they migrate to sea, where they spawn. Perhaps they die after spawning; at any rate they do not return. Thus they are short-lived fast-growing animals, a fact which gives them special value as a food resource, for it makes them less vulnerable than other species to intense fishing (see also pages 45 ff.). Perhaps the most useful line of prawn research would center about the inshore nursery areas. What controls their productivity? What are the competitors

* The large species, mostly belonging to the genus *Penaeus,* are prawns.

and predators of the young prawns? What is their food? What are the optimum densities of prawn stocks? Why must the prawns go to sea to spawn? Could they be induced to spawn in enclosures? Would artificial culture be a profitable enterprise?

LOBSTERS. These crustaceans are the object of fisheries in Europe, America, the West Indies, South Africa, Australia, and Japan. They are probably not vastly abundant anywhere, but they are much appreciated and high-priced wherever they occur. The principal species are the true lobsters, *Homarus americanus* and *H. vulgaris;* and the spiny lobsters (crawfish or crayfish)—*Panulirus argus* (Florida, the Caribbean area, the Atlantic coast of South America, *P. interruptus* (Southern California), *P. rissonii* (western Mediterranean and West Africa), *P. japonicus* (Japan and Hawaiian Islands), *P. inflatus* (west coast of Mexico and Hawaii), *Jasus lalandei* (Australia, Juan Fernandez Islands, New Zealand, and South Africa), *J. verreauxii* (southern Australia and New Zealand), *Palinurus elephas* (Europe), *Panulirus penicillatus* (Indo-Pacific and Korea), *P. longipes* (western Australia); likewise the deep sea shrimp or Norway lobster, *Nephrops japonicus* (Japan and Korea), and *N. norvegicus* (in deep water off the coast of Norway).

Several unsuccessful attempts to introduce the Juan Fernandez lobster to the coast of the mainland have been made. Expansion of the spiny lobster fishery in Australia and New Zealand is likely to continue for some time and unexploited populations may be found along the coast of Chile and Peru. Although it is doubtful that the yield of the American lobster can be increased, spiny lobsters seem to be underutilized. This is a possibility that could be tested by exploring likely fishing areas near Mexico, Central and South America, and the islands of the Pacific.

Artificial propagation of lobsters attempted by government agencies does not seem to be promising. The post-embroyonic development is complex and slow, and the rate of infant mortality in captivity is discouragingly high. Furthermore, the growth rate is so slow that raising them in captivity to maturity would probably be a prohibitively expensive undertaking. It seems better sense to support the lobster populations on their own natural grounds by controlling fishing rates. This necessitates measuring the rates of growth, birth, and death, the size of stocks, and the effect of fishing thereon.

It is very difficult to do this with crustaceans, for they molt in growing, and in doing so, often throw off any tag that has been applied to their shell. How, then, can we learn their routes of migration or measure the size of their population and their rates of growth and replacement? Another difficulty is that they do not record their age on parts of their body as fishes do. Consequently, special methods must be developed to permit analysis of the age composition of samples, which is an essential part of population dynamics studies. The development of such techniques must be the object of special research. This is true for crabs as well as for lobsters.

CRABS. There are many species of crabs used for food but only a few of them are taken in quantities large enough to be recorded in statistics. Among the most important species are the blue crab of the Atlantic and Gulf coasts of the United States (*Callinectes sapidus*), Dungeness crab of the Pacific coast (*Cancer magister*), the giant crabs of Alaska, the Bering Sea, Japan, and Kamchatka (*Paralithodes camtschatica, P. platypus,* and *P. brevipes*), the red crab, (*Chionectes opilio*), and the blue crab (*Neptunus tritubercu-letus*) of Japan.

It seems likely that some of the crab resources of the Americas are not fully utilized and that new fishing grounds may be located by exploring the continental shelf and the inshore waters. Information about crabs in the Indian Ocean, Philippines, Australia, and South Africa is too meager to encourage any speculation regarding their potentialities.

BARNACLES. The principal fouling organisms on ships' bottoms and on floats of hydroplanes, barnacles make for costly maintenance throughout the world. Antifouling measures, scraping and repainting of ships' hulls, and the use of antifouling materials cost millions of dollars annually. There is, however, a species of large sessile barnacle, *Nalanus psittacus,* common on rocks of the coast of Chile which Darwin described as "universally esteemed as a delicious article of food." Another edible species is the goose barnacle, *Mitella pollicipes,* used for food along the coast of Brittany, Spain, and the Mediterranean. Economically these species are of little significance.

TUNICATES. These organisms are widely distributed in the ocean and flourish in tropical and subtropical seas. On an evolutionary scale tunicates occupy a unique position as predecessors of vertebrates. One of the characteristic anatomical features of tunicates is the presence of a tough tunic made of the animal cellulose tunicin. The body inside the tunic is soft and watery.

Tunicates are of slight if any economic importance. Free-swimming forms like Appendicularidae and ascidian larvae are eaten by fish and therefore indirectly contribute to the supply of human food. Sedentary ascidians are edible and occasionally are used by people living in tropical islands. Species of the family Cynthiidae are fished for food in various parts of the world, for example, Japan, China, Siberia, and southern France.

Tunicates are unique in several respects. One of their most interesting features is the ability to concentrate in their bodies the rare metal vanadium, which is found in the sea water in low concentrations (0.2–0.3 milligrams per cubic meter).[18]

14

Fishes

Among all the biological resources of the sea, fishes have always been the most important. Compare them with marine mammals—whales, porpoises, and seals. They are much more abundant, more widely distributed, and less elusive. The average fisherman in most parts of the world with his modest vessel and apparatus stands a far better chance of catching a few tons of fish in a day's fishing than an equivalent quantity of mammals, and the fish are generally easier to dress, preserve, and market.

Compare fishes with the familiar commercial invertebrates like shrimps, crabs, lobsters, oysters, and clams. They are more densely concentrated in volume, and yield more pounds per unit of labor. A tuna boat takes around ten or twelve tons in a day's fishing; a shrimper does well to take one fifth of that quantity. Thus even the expensive varieties of fishes are cheaper than most invertebrates, which for the most part are too costly for anything less than the luxury trade.

Consequently, when people concerned with world food problems consider means of expanding the use of ocean resources for the humbler human needs, it is fishes on which they set their great expectations. They count on increasing greatly the quantities which fishermen now harvest and market. For purposes of this discussion, let us minimize the human problems involved in accomplishing such an increase. Let us presuppose unlimited supplies of skilled labor for fishing, unlimited capital for buying equipment, unlimited markets, unlimited demand, and unlimited preserving, storage, and transportation facilities. Economics, technology, and sociology are not the province of this chapter. In this section we are concerned with the fishes—cold-blooded, aquatic, backboned animals with gills and fins, excluding such other marine animals as mammals, mollusks, and crustaceans. If the exploitation of the sea is to be increased, where could the additional quantities of fish come from?

In searching for answers to these questions it is necessary to keep in mind the rather exacting limits of human needs and fishing capabilities, for not every kind of fish is usable. The total commercial value which a species contributes to a country's economy depends on the extent to which it possesses the qualities listed below:

Abundant, i.e., voluminous, in the sense of being capable of yielding large volume

Aggregated in dense concentrations, or easily concentrated

Regular enough in their habits that fishermen can depend on finding them year after year at about the same places and times

Accessible to fishermen; that is to say, not so deep as to be beyond range of fishing vessels and their gear, not inhabiting unworkable ground, not so elusive as to make the cost of catching prohibitive

Accessible for a long enough season to permit attractively profitable returns for the necessary investment in vessels, gear, and labor

Comestible, palatable, and nutritious

Aesthetically acceptable

Firm-fleshed, and therefore well-keeping during the time of transportation from fishing grounds to port

Amenable to preservation by such methods as salting, pickling, smoking, freezing, canning, or keeping alive in tanks until needed *

These qualities are not absolute. They must change with the technological advances and according to economic conditions and human tastes.

In general (there are some localized specific exceptions such as the ipon fishery of the southern Philippine Islands, which depends on the fry of gobies) the foregoing requirements severely limit the range of choices of fishes that may be exploited largely for human use. Indeed, they rule out at once the majority of species. They rule out most of the kinds of fishes that are too small to be worth anything, like the little blennies and sculpins that live in tide pools; many queer-shaped, slender, relatively fleshless ones like sea horses, pipe fishes, and snipe eels; some poisonous ones, like porcupine fish; all those that live permanently beyond fishable depths, like the grenadiers; and many fishes that evidently do not school and, as far as anyone can tell, are rare.

Thus it looks as though only a few kinds of fishes can be used. As it is, out of all the sea fishes which are known in the world, not

* See note 1, page 307.

more than 6 per cent are ever used, and not more than 2 per cent are used very much. The great majority of commercial species are in less than a dozen of the three or four hundred families. About a third of the total catch of all sea fishes reported in catch statistics of the world are herrings and their relatives (sardines, menhaden, and anchovies); about a quarter are cods and their relatives (hakes, haddock, and pollack); about 9 per cent are mackerel and their relatives (bonitos and tunas); and about 3 per cent are flounders. The remainder, almost a third, is made up of rockfishes, basses, snappers, weakfishes, and a miscellaneous assortment of other groups.

Fishermen have arrived at this narrow selection by generations of experience at catching and marketing fish. The machinery of their industries, creaking and cumbersome though it may be, is geared to dealing with those kinds of fishes which they have learned how to catch regularly and in large quantities, and which the public has become accustomed to seeing and therefore conditioned to accepting. Were markets now to change radically, calling for enormous increases in catch, existing fisheries could not produce them without changing in some way. What might they do? They might intensify exploration of the relatively unknown regions of the sea and subsequently generate fisheries for such bizarre creatures as they found which people had never before known. Or they might expand their fishing radius to include distant grounds which, although fairly well known, have so far remained almost untouched. Or they might harvest the less valuable species which they have hitherto avoided—familiar enough species living on or near the old, well worked-over fishing grounds. Or finally, they might advantageously manipulate rates of fishing, and the times, places, and techniques of fishing in order to enlarge the harvests of stocks which they already exploit.

The most hoped-for among these possibilities is to find and exploit something completely unknown. This would be difficult, for during the course of many scientific expeditions over the past hundred years or so, ichthyologists have collected specimens the world over with all sorts of gear ingeniously contrived to take fish wherever they occur and whatever their habits may be. However, it must be admitted that their sampling has been spotty. It has been most thorough where there are well-developed fisheries and fishery research laboratories and nearby university or governmental museums having study collections of fishes and competent curatorial staffs. Elsewhere, it has depended mostly on sporadic collecting expeditions. Thus, ichthyologists know a great deal about the species of fishes living on the plateaus of most of the shelf areas of north temperate latitudes, less about those living on the steeper slopes, and very little about those living on large stretches of shelf in equatorial and southern latitudes. They know least about the fishes of the deep sea.

Knowledge of the relative quantities of a species usually is in some proportion to the size of the fishery for it. Where knowledge depends on specimens brought back from expeditions, as it does for most species of fishes, its quantitative value is negligible. Thus, in general, ichthyologists are not in a very satisfactory position to offer authoritative a priori advice as to what kinds of fishes will yield large returns in underdeveloped areas, and therefore as to how much money people ought to hazard in new fisheries.

Up to now ichthyologists have collected and named more than 25,000 species. Judging from the rate at which they are discovering new ones, this number comprises a large part of the total; and judging from the kinds of discoveries which they are making, it probably includes most of the species of large populations. Thus it seems unlikely that many large stocks of fishes remain unknown to scientists. Scientists, however, usually communicate their discoveries only to other scientists, and in their own specialized language. Thus their knowledge about fish faunas is not easily available to average fishermen. But is it possible that fishermen, even with their very specialized gear, know more about fish faunas than their landings indicate? It would look as though their knowledge must be severely circumscribed. Most fishermen cannot go far from shore in search of new fishery stocks. They are more or less tied to the land, for the distances which they can travel and the things they can do are limited by the small size of their vessels, the simplicity of their equipment, and the driving necessity of earning a continuous living. Fishermen of highly advanced mechanized fisheries, on the other hand, are able to go much greater distances, but even they are not so independent of land as it would seem. Fishermen balk at spending long periods at sea unless they are exceedingly well paid. Moreover, it is not good economy to spend more time at sea than is absolutely necessary to get pay-loads. Such factors limit the range of oceanic fisheries and selection of fish to a few species like cod and tuna, which have special qualities that bring a high enough price in the market to make such fishing profitable.

While fishermen cannot often afford to explore far afield, they do cover ground which many fishes inhabit or visit, and they see many kinds of fishes which they do not catch and in some regions catch many kinds which they do not bring to port. Indeed, many more species of fishes than are exploited occur within the orbits of fishermen. Thus, about two thirds of all the known seafishes, that is, something like 17,000, live on continental shelves in depths of less than 100 fathoms. Continental shelves being narrow, for the most part, the majority of species of marine fishes live within twenty miles of land. Moreover, there is a tendency among shelf fishes to move into shallower water and toward shore in summer. Not only is this true of sedentary bottom-dwellers, but also of many pelagic, surface swimmers which, on the whole, never see the bottom during most of their lives. Some species of shelf fishes move in toward shore to spawn; others move offshore for that function. With either pattern, however, the young of certain species (particularly herring-like fishes) spend the first months of life close to the beaches, in estuaries or sloughs, and even far up in fresh water. As they grow larger they go out to sea, but not many species of these sea spawners go far beyond their continental shelf, for the spawning grounds are located in such relation to currents as to provide for transport of the young to their shoreward nursery grounds. Some of the pelagic fishes, notably the tunas and spearfishes, are not bound to the coastline as are the shorefishes, but occur on the high seas wherever temperature conditions are favorable. Nevertheless, they too, often touch inshore zones to feed.

Thus have fishermen had ample opportunity to acquire at least some acquaintance with many kinds of fishes that represent a much larger area than is encompassed by the limited radius of their small local fisheries. They may see only an occasional specimen belonging to a very large stock; they may not know where to seek the main body of the stock or be equipped to reach it. They may even have no name for these occasional visiting species, but from long-continued fishing experience, they do know of their existence.

Since generations of fishermen have thoroughly explored their coasts in the course of day-to-day work with many kinds of gear, they have had ample time and opportunity to learn what is there. Thus it seems unlikely that there could be many stocks of coastal fishes which are quite unknown to them. There are several that are underfished, certainly, but few that are unknown.

If there were to be any extraordinary increase in production of sea fishes, it would have to come partly by stepping up the rate of fishing the known species and partly by exploiting some of the seven thousand species which roam far below the surface of the sea outside the present range of fishermen.

While most of the familiar species occur near coasts, there are probably no parts of the sea except perhaps in the deepest depths (below 7,000 meters) which are quite devoid of fishes.[1] On the other hand, no species is found in all oceans or at all depths. Most marine fishes have more or less restricted ranges, and it is the exception rather than the rule to find identical species on the coasts of such widely separated regions as New Jersey and France.

Temperature is the most important factor determining the distribution of fishes, but it is not the only one. Depth and geology of bottom are others. One bottom-living species, for example, may be restricted wholly to coarse sand, another to mud, still another to broken shells, and another to rocks. Some species may be found only in the intertidal areas, in tide pools, while others may range from surface to bottom in open water. Wherever biologists have been able to observe the activities of shorefishes in their native habitat, as modern diving apparatus permits, they find that fishes, like land animals, occupy particular situations. A species may be absolutely confined to a habitat as restricted, for example, as an area in which are found colonies of a certain species of coralline alga, but only between the depths of 15 and 30 feet and only where the temperature never goes above 63° or below 55° F. Temperature and depth barriers may limit the fish to only a fraction of the range of the alga while colonies of the same species of alga in somewhat shallower or deeper water may harbor a closely related but quite distinct species of fish. Judging from such studies as have been made on fishes in their natural habitat, the occurrence of many species, perhaps of most of them, may be peculiarly and severely restricted, and often by a complex system of factors. Obviously, knowledge of such influences must have great bearing on where, how, and for what men fish.

Fishes vary greatly in size, from tiny gobies, adult at half an inch, to swordfishes of 14 feet or more. Sharks reach a far greater size, the basking shark to 25 or 30 feet and the whale shark to 50 or 60. However, most fish species are small. If we could average the adult length of all existing kinds of fishes we would probably arrive at an "average fish" of about 6 or 7 inches.

The saying, "big fish eat little fish," is generally true. Some commercially caught fishes, such as the herrings, sardines, and menhaden, feed directly upon plankton, but the majority of fishes, including food fishes, prey upon smaller fishes and other organisms which may themselves be one or two food-steps away from a basic plankton or plant-feeder.

It has been pointed out in previous chapters that in a simple ecological food pyramid, the ultimate predator is usually the largest species in individual size. He feeds upon a smaller species, the latter upon a still smaller one, and so on. Each step down on this "pyramid of numbers" means not only smaller size but also more individuals. Still more important in relation to the productivity of the sea, each step down means a tremendous increase in total bulk or weight of protein. In other words, with each ascending step towards the ultimate predator, there is a tremendous loss of protein. To produce one adult sea bass takes many times his weight of small fishes.

Those familiar with terrestrial food-chains may remark that this system does not hold so neatly for land animals, among which many large species, such as cattle, antelope, deer, and elephants, feed directly on vegetation, while the natural predators of these large herbivores (wolves, lions, leopards, and so forth) are often smaller than their prey.

However, as shown in Chapter 5, the ecology of the sea differs sharply from that of the land in many particulars, perhaps the most important being the distribution of vegetation. Light penetrates the sea for only a short distance, and plants need light. They live only near the surface of the oceans, and the great bulk of sea plants are microscopic, unicellular organisms such as diatoms. Although the zooplankton feeds on them, there are few truly herbivorous fishes. These are mostly specialized forms living on attached algae along shore. Most plankton-feeding fishes eat diatoms, but most of them also depend to a still larger extent upon animals for food. Few plankton-feeding fishes reach more than 12 or 15 inches in length and the majority are under 10. The only very large fishes in the seas which live directly and wholly on plankton are the two largest sharks, the basking shark and the whale shark. Practically all the large true fishes are active predators on smaller fishes. The ocean sunfishes, which are believed to feed principally on jellyfish, are the principal exception.

It is clear, therefore, that most kinds of fishes must be small. It is also clear that there is a much greater bulk of small fishes than of large. Yet most of the fishes utilized as food by man in Western Europe and North America (where high industrialization of the fisheries is accompanied by an effort to maintain the yield at high levels) are larger species, reaching from 10 or 12 inches to a yard in length.

If we except the plankton-feeding sardines, herrings, and menhaden, most of the food fish we consume are larger predators. This means, by and large, that we are losing the tremendous amount of protein that disappears with each step up the "pyramid of numbers."

Another phase of fish abundance is both directly and indirectly correlated with temperature and latitude. Observers familiar with the vast quantities of herring, cod, and other fishes on northern continental shelves have remarked on the absence of such tremendous numbers of fishes in tropical areas. Moreover, it is well known that the cooler, murkier waters of the north are considerably richer in all sorts of plankton than the clear waters of the tropics. As richness of plankton has proved to be an excellent indicator of richness of fishes in these northern waters, it has been quite generally assumed that sea fishes are simply less abundant in the tropics than in cold waters.

However, one cannot be certain on this point, for no satisfyingly quantitative comparisons have yet been made. Moreover, there are certain facts to consider that are often overlooked: on approaching the equator from the poles, the number of fish species increases prodigiously. On cold North Atlantic coasts there may be no more than 50 to 200 species at any one locality, while at Amboina, in Indonesia, it is probable that 1,500 to 2,000 will eventually be recorded from one small area.

Evidently tropical species can seldom be as abundant individually as cold-water species. Possibly, however, some continental shelf areas in the tropics produce as great a total weight of fish life as an equal area of, let us say, the North Sea. This may seem like rank heresy to marine biologists, but it may still be true. For one thing, the extreme diversity of the fishes in the tropics and the nocturnal or cryptic habits and small size of so many may easily mislead even a trained biological observer.

However, the most abundant of all fishes do not seem to be confined to the continental shelves at all. The discovery that pelagic organisms concentrate in layers (the "deep scattering layers") throughout all oceans at depths of 150 to 450 fathoms and rise toward the surface at night, gives point to some known ichthyological facts. Towed within the depth limits of the scattering layer, plankton nets bring up an abundance not only of small shrimps and other invertebrates, but also of small fishes. Many of these are lanternfishes (Myctophidae) of diverse species, some of which are already known to make vertical migrations toward (or quite to) the surface at night. But the most abundant of all fishes in these nets are a few very small, transparent, luminescent fishes of the bristlemouth family (genus *Cyclothone*). These fishes apparently occur by the billions within the depth limits of the deep scattering layers. The few species (chiefly *Cyclothone signata* and its close allies) must be the most abundant of all fishes—certainly in numbers and quite possibly in weight.

In general, mankind uses the fish resources of the sea poorly. Only on the coasts of western and northern Europe and on the north temperate coasts of North America and Asia are the sea fishes exploited according to modern knowledge and practice, and these areas form but a small part of the seas of the world.

Elsewhere, with the exception of only a few small areas, the marine fishery resources do not appear to be exploited to anything near capacity. Generally, only a small proportion of the more easily caught fishes are taken, the kinds obtained depending principally on primitive local fishing methods available and on local tastes and prejudices.

However, information on the extent of utilization of fishes in any area is peculiarly difficult to obtain. For some areas we have more or less reliable catch records but almost nowhere do we have accurately quantitative information on the *abundance* of the species caught, to say nothing of those that are not caught or that are discarded. We can piece some of this information together if we are familiar with the species representation at a given point and know something about the usual abundance of similar or identical species in other areas, but this is only a poor substitute for firsthand local knowledge. The truth is such information does not exist for nine tenths of the coasts of the world, let alone for offshore areas.

We know that there are long stretches of continental shelves, rich in fishes that could be easily caught, that are but lightly fished. One such area is the relatively broad shelf off the Atlantic coasts of Uruguay and Argentina, another is the west coast of Africa from Angola to French Equatorial Africa (see Figure 1, page 15).

We know that the bathypelagic fishes (and indeed all the deep water species) are untouched, for no one has yet devised a method of catching these animals in large quantity, or of sorting them out of the mass of planktonic invertebrates, some of which may be inedible or even poisonous. If such methods are devised, a supply of fish protein unrivaled by any existing fishery might become available.

We know that the offshore bottom faunas on the deeper parts of the continental shelves are rich in edible fishes, and that fisheries for these kinds are few and scattered (off Cuba, Portugal, the Azores, Japan, and South Africa).

We know that the more extensive coral reef areas of the world support large populations of many of the finest edible fishes, but that methods of catching them are difficult to devise and seldom very efficient.

We know that tunas and other pelagic fishes must occur in quantity in many tropical parts of the oceans, for example, in the South

Atlantic, Indian, and the mid-Pacific where there has not until recently been any important fishery for them, and the mid-Atlantic.

We know that sardine-like fishes are found in enormous numbers around almost all continents, and that far greater numbers could be caught of most species than are now obtained.

However, we also know that local customs, prejudices and economics often have far more effect on the utilization of these fishes than does knowledge of their existence, of their availability, or of means of catching them.

A study of the geography of fish distribution discloses an order from which it is possible to predict about what species may be expected to occur in any given locality. For, like other classes of animals, fishes fit into a distributional pattern in which may be distinguished several major zoogeographical regions, delimited by hydrographic and land barriers. Within each region there is an essential homogeneity of fish genera and families, and although a number of species range throughout an entire region, most of the included ones do not. Rarely does a species of shorefish occur in more than one of the major regions. In considering how and where to increase exploitation of the fishery resources, therefore, it is essential to take these patterns into account.

From a fishery-scientific viewpoint the *Indo-Pacific* is the most important of these zoogeographic regions, since more kinds of fishes live there than in any of the others. This zone extends from the Red Sea and Madagascar eastward half way round the world to the Marquesas and Tuamotu Islands. Its northern and southern boundaries are rather close to those of reef-forming coral. It reaches northward to southern Japan and Hawaii and southward to southern Queensland and the southern boundaries of Polynesia. Not only are the species numerous in the Indo-Pacific region—more than a third of all known sea fishes occur there—but they are remarkably unvarying and widely distributed. Many of the larger species of shorefishes—jacks, snappers, sea basses, and surgeonfishes, for example—occur throughout this vast region and nowhere else. No rule can be written about this, however, for some species are very restricted in their range. Myers has called the Indo-Pacific the "great mother fish fauna of the tropics." [2] Other tropical regions are only minor, relatively poor segregates of it, defined principally by the Indo-Pacific families and genera which they lack.

The other tropical regions are the *West African,* extending from Senegal to Angola; the *West Indian,* extending from Key West and Yucatan to Bahia or Rio de Janeiro; and the *Panamanian,* reaching from the Gulf of California to Ecuador and including the Galapagos

Islands. In kinds of fishes, all of these regions are far poorer than the Indo-Pacific. The West Indian is richest of these smaller regions, the Panamanian next, and the West African poorest of all. Each of them has a homogeneous shorefish fauna, which is almost totally different in species from all the others. Nevertheless, these faunas are more similar to each other than to any of those of the temperate regions to the north or south.

The two polar regions are poorest of all in species. However, we still know relatively little about them. The limits of the *Arctic* region differ considerably depending upon what criteria one employs. Dunbar in 1951 defined arctic marine areas ". . . as composed of arctic water only . . . subarctic areas as composed of a mixture of arctic and non-arctic water . . . and boreal or temperate areas as bounded to the north by the line south of which there is no admixture of arctic water." [3]

Arctic water masses possess many characteristics inherent to high biological productivity and these factors seem to be limited only by low temperatures. As a consequence, at the northern subarctic border or where arctic water mixes with other water masses, part of this temperature barrier is removed and high productivity results. The arctic marine fish fauna contains few species, and in fact is most easily distinguished from that of the subarctic by what it lacks in comparison.

The *Antarctic* region, bounded on the north by the 6° isotherm, consisting of the waters surrounding the antarctic continent and a few of the most southerly island groups, has a poor fauna, which is dominated by a single family of large-headed, rather sluggish, bottom-living fishes called Nototheniidae. Among 76 species of fishes in one collection from the Antarctic, 68 belong to this family; 6 are eelpouts (Zoarcidae), and 2 are sea-snails. In addition there are one or more species of the flabby, gelatinous member of the cod family, *Muraenolepis*. Most of the Nototheniids are rather small, growing to lengths between three and nine inches. A few reach larger sizes up to an extreme of about five feet. Although most of them live on the bottom, a few are pelagic or semipelagic.

One of the most striking features in the economy of life in the antarctic seas is that few fishes have the form and swimming powers to utilize krill (planktonic crustaceans) as a source of food. The evolution of pelagic types of nototheniid fishes has been limited, and it is the warm-blooded animals, the whalebone whales, crab-eater seals, and penguins, which make most use of krill. In oceanic circumpolar waters, a number of small bathypelagic fishes feed particularly on krill and are often to be found with the latter in the stomachs of whalebone whales. These fishes, however, would hardly repay commercial exploitation.

The bottom-living species feed largely on crustaceans (especially on amphipods and isopods), polychaete worms, small lamellibranchs and fishes. While Dr. Marshall was stationed at the Falkland Islands Dependencies Survey base at Hope Bay, Graham Land, over 1,000 nototheniids, mostly of one species, were caught by line through holes cut in the ice, or at the ice edge. Even in the winter months the stomachs of these fishes were nearly always packed with freshly eaten and partially digested isopods and amphipods together with small fishes, mollusks, and pieces of seaweed. Further indication of their bottom-living habit is the fact that the fishes would not take the bait until it had touched, or was very close to, the bottom.

Knowledge of the abundance of the coastal fishes of the antarctic continent is sketchy. The National Antarctic Expedition led by Captain R. F. Scott set fish traps at McMurdo Sound and caught up to 105 fish in one haul. The Australasian Antarctic Expedition (1911–1914) from time to time caught nototheniids by hand line. Part of the Swedish South Polar Expedition stranded at Paulet Island near the northeast coast of Graham Land fished through holes cut in the ice during the winter months. A day's catch could amount to about 100 small fishes and over 14,000 were caught in this way. Dr. Marshall writes that when he was at Hope Bay, Graham Land, he baited lines with pieces of meat, fish, or bunting, and from June until September fresh fish (mainly *Notothenia coriiceps*) of excellent flavor and weighing ½ to 2 pounds each were a frequent part of the diet. The fish could be caught quickly, the rate being set by the time required to take a fish off the hook and rebait and lower the line.

The cool-water *North Pacific* region, extending from northern Japan to the Bering Sea and Puget Sound, is exceedingly rich in endemic species and genera of sculpins, rockfishes, eel-blennies, and other related groups. Large flatfishes abound, and anadromous salmon which mature at sea and spawn in fresh water form a conspicuous and important element.

The cool-water *North Atlantic* region, reaching from New York to Iceland, to the English Channel, and Scandinavia, has fewer shore species than the North Pacific. It lacks the great variety of sculpins, rockfishes and eel-blennies of the North Pacific, as well as some endemic Pacific groups. There are a few more true cods than in the Pacific. Otherwise the two faunas are similar although few species occur in both regions.

The areas between the North Pacific and North Atlantic and the tropical regions to the south of them are, in general, transition zones. The coasts of North America between New York and Florida, and between Puget Sound and Lower California, are excellent examples. Many species and some genera are confined to these transition zones, but most of the shore fishes present are related directly to either more northerly or more southerly types. In the eastern Atlantic, there is more reason to delimit a major intermediate region because of the Mediterranean, which has a recognizable group of fish genera and species of its own. These extend north to the Atlantic coast of France and south to Morocco.

South of the tropical areas, fishes are less well known and the regions harder to define. The best marked one is the *South African* region, containing a large number of cool-water shore fish genera and species found nowhere else, and many others that appear elsewhere only on the coasts of southern South America and Australia. The South African region extends from just south of the southern boundary of Angola around the Cape perhaps as far east as Port Elizabeth.

The *South Australian* region probably has more species than the South African, but its limits are less easy to define. It is a relatively cool-water fauna that shows its nature best in Tasmania and the South Island of New Zealand.

The *Patagonian* region, south of Chiloé in Chile, and extending up an unknown distance on the Atlantic side, is very poorly studied. We have little knowledge of its extent or size, and only a general idea of the composition of its fish fauna.

We know too little about the vast area of the *deep sea* to divide it into geographic regions. The sea cools rapidly with depth. Below 2,000 meters it varies within a narrow temperature range—between 4° and —1° C., from the equator to the polar seas. Thus the deeper water fishes meet fewer temperature barriers than do the shore fishes, and some of them range widely over most of the oceans. These being the most difficult fishes to reach, they are the ones we know least about. We know little of their habits, the characteristics of their environment, or of the barriers that limit their distribution.

The deep pelagic fishes are mostly small, but some of them, as remarked above, such as the bristlemouths, of which little is known, are the most numerous of all fishes. Somewhat larger than the bristlemouths, but still small, are the exceedingly abundant lanternfishes, which also are obtained at present only with plankton nets. These are remarkable for their oil content, owing to a most interesting specialization. The lanternfishes possess the hydrostatic "air-bladder" typical of bony fishes, but many species of them make nightly vertical migrations, often to the surface, undergoing a change of pressure which would rupture a bladder filled with gas. The air-bladder is completely full of fat, thus retaining its hydrostatic function but without the dangers of an expansible gas. About 24 genera and about 175 species of lanternfishes have been named, varying in adult size from about an inch to over a foot. The average species reaches about 3 or 4 inches. They are characterized by luminous organs along the lower part of the sides arranged in patterns which vary with species, and which, in some species, differ with sex.

The opinion that bristlemouths and lanternfishes are abundant is based on the fact that marine biologists catch them everywhere in their deep plankton nets. Furthermore, lanternfishes are one of the most important items in the diet of fur seals feeding along the coast of Japan, and of tunas in the counter equatorial current of the Pacific.

Other bathypelagic fishes are legion, but the two groups already mentioned are the most numerous and possibly the only ones save the macrourids that would repay any efforts to utilize them for food.

The deep-sea fishes of the sea bottom are mostly found so deep that the efficient working of gear to catch them in large numbers imposes great obstacles to economic exploitation. The most important group are the grenadiers (Macrouridae), deep-sea relatives of the cods. The numerous species of this family range in length at adult size from 8 inches to 3 feet. A few occur in shallow enough water to be taken in some of the deep offshore, continental-shelf trawl fisheries. These are the only ones likely to be within reach of commercial fishermen.

The oceanic currents, typified by the Gulf Stream, the Kuroshiwo, and the counter equatorial currents, provide environment to tunas, dolphinfish, swordfish, and certain of the larger mackerels and jacks. These valuable pelagic species occur in two types of faunas. One, characterized by yellowfin tunas, skipjack, and dolphinfish, lives in the tropics; the other, characterized by bluefin tuna, swordfish, and albacore, lives in temperate waters. These seem to be more independent of land masses than any other species of marine food fish. Several of them are said to belong to world-wide species. However, these species are probably composed of many relatively small, more or less genetically independent stocks of overlapping distribution.

It is not possible to learn from published statistics how each of these regions contributes to the world's catch. Fishery statistics are obtained in various ways, sometimes from the complete, honest recording by literate fishermen in their log books, sometimes by divination. Consequently, accuracy of published catch data varies from near perfection to zero. It is highest for countries of the North Atlantic and North Pacific, and for a few in the southern hemisphere such as Australia and South Africa. Tables 14-1 and 14-2 suggest how the world catch of fish is probably divided among the various geographic regions.

TABLE 14-1. ESTIMATED CATCHES OF MARINE FISH BY GEOGRAPHIC REGIONS, 1956

Region	Millions of Metric Tons
Coastal Forms	
Indo-Pacific	2.8
South Australian	0.1
North Atlantic (combined with Atlantic Arctic)	10.3
Northeast Atlantic—Transitional	1.5
Northwest Atlantic—Transitional	0.6
Southwest Atlantic—Transitional	0.1
Patagonian	0.1
West African	0.6
South African	0.6
West Indian	0.2
Panamanian	0.7
North Pacific (combined with Pacific Arctic)	5.5
Northeast Pacific—Transitional	0.2
Northwest Pacific—Transitional	1.4
Oceanic Pelagic Forms	
Eastern Pacific	0.2
Western Pacific (exclusive of Indo-Pacific)	0.4
South Australian	<0.01
Indo-Pacific	0.6
Eastern Atlantic	0.4
Western Atlantic	<0.01
	26.3

Of all the great geographical regions, the North Atlantic and North Pacific are the most intensively fished, the most heavily exploited area being around Japan. Here alone almost all the kinds of fish that can be caught by existing methods are used by man. However, Japanese fishery conservation is still in a relatively early stage of development and little control is put on the industry. Indeed, much opposition must be expected to such control, for Japan produces little meat, gets most of its animal protein from fish, and has a great over-population problem.

In the North Atlantic, the North Sea continues to support a heavy fishery, and can probably continue to do so indefinitely, largely because of the regulations fostered by the bordering nations through the Permanent Commission. The western Atlantic is heavily fished but also will probably sustain its maximum productivity as a result of conservation action agreed upon by the nations belonging to the International Commission for the Northwest Atlantic Fisheries.

Outside the North Atlantic and North Pacific regions, the areas of the continental shelf which support very intense fisheries are small indeed, although for many reasons exact information is peculiarly hard to get and more difficult to evaluate once obtained. For example, in New Zealand some local areas are said to be highly overfished while others within reach are barely touched, the difference being due mostly to refusal of the fishermen to work more distant or "difficult" bottom, despite the much more lucrative returns to be gained. The relatively secure economic position of the fishermen and wages set by law at a high level operate here to determine the

TABLE 14-2. PERCENTAGE DISTRIBUTION OF FISH CATCHES BY GEOGRAPHIC DIVISIONS, 1956

Geographic Division	Percentage
Asia	39
Europe	30
North America	16
South America	3
Africa	5
U.S.S.R.	7
Northern Hemisphere	89
Southern Hemisphere	11
Pacific Ocean	41
Atlantic Ocean	54
Indian Ocean	5

pattern of fish resource utilization. Again, in the vicinity of Rio de Janeiro, in Brazil, certain local species and areas, as well as several quite distant ones, seem to be overfished, while intermediate localities and fish supplies lie relatively untouched. This is the consequence of a complex of prejudices among fishermen and the general public. Areas adjacent to Cape Town and other South African ports, to Sydney in Australia, to Singapore, to Buenos Aires, to Shanghai, and to other large metropolitan centers are said to be very heavily fished, while other nearby areas lie relatively fallow.

Although specific local information is lacking in most points, it seems likely that the catch of fish on continental shelves of most of the world could be increased with standard fishing methods of one kind or another. In some areas there would be special difficulties to overcome, as in the tropics, where the abundance of coral would preclude trawling and the diversity of species might necessitate devising new gear.

Almost everywhere in temperate and tropical seas we have enough information to say that there will be found, on the deeper parts of the continental shelf, a rather diverse assemblage (exact composition still to be discovered) of usable fishes, many that can be trawled and many others that can be fished with long lines. This assemblage is fully exploited in only a few areas.

About smaller islands and on many coasts, coral reefs form a rather narrow fringing area fairly close to shore, and although their length may be great, their width is not, and the total area is therefore small. In other places, notably on the coasts of Queensland and New Caledonia (the Coral Sea), the width may be great and the area large (see Figure 16). Near Nouméa, for example, one can sail for hours over water 10 to 50 feet deep where the bottom is covered with growing coral. This coral is not uniform, but occurs in patches of differing species or groups of species. The immediately observable fish population is very large, even though we know that but little of it is visible at any one time, especially during daylight hours. The abundance of fishes varies widely from one spot to another in a reef area. As Vernon Brock's surveys in Hawaii have shown, quantities range from 7 to 2,118 pounds per acre.[4] But the tremendous variety of fish species, each requiring a somewhat different catching technique, the obvious difficulty or impossibility of working normal fishing gear (even hooks) in such places, and lack of knowledge of the edibility of the species make utilization of coral reef fishes a rather complex business. Nevertheless, in some places, for example Hawaii, reef fishes have long been heavily exploited, perhaps even past the point of optimum utilization. Elsewhere, however, reef fishing techniques are adapted for the most part to catching only a few of the larger fishes in commercial quantities, and careful exploration of the means of catching large quantities of the other species has not been made. Nor is it likely that these means will be developed by fishermen steeped in traditional northern fishing methodology. A more promising line of attack would probably be to improve native fishing methods, or perhaps to utilize electronic, chemical, or other modern technological means of enticing fishes out of the impenetrable maze of coral.*

Meanwhile, little is known about the fish faunas in most of the coral reef habitats in the world. Few such habitats have been intensely explored ichthyologically. One of them is a small area at Dry Tortugas, Florida, which W. H. Longley studied for many years.

* At the same time, it must be remembered that reef fishes seem to be nonmigratory; some of them are believed to be slow growing and they may be particularly vulnerable to overfishing.

Another is in Hawaii where Vernon Brock conducts quantitative surveys. A third is at Bikini Atoll, where Vernon Brock, Earl S. Herald, and Leonard Schultz have collected extensively under water.[5]

Great tropical river estuaries, such as those commonly found in Indonesia, often support much larger fish populations than the rivers themselves or equal areas of the non-estuarine coast nearby. That this is due at least in part to the nutrients brought down by the rivers is unquestionable, but aside from the fact that such places do support extensive fisheries for certain types of brackish-water or mud-bottom fishes, we know comparatively little about them. Croakers, threadfishes, and many others are especially abundant in such places (see Chapter 9).

While there is no doubt that the fishes of the world can supply a greater amount of human food than they do now, it is peculiarly difficult to say exactly how and where. There is neither enough dependable information recorded about the fisheries or about the fishes. Knowledge of the fisheries comes mostly from fishermen who are usually untrained as observers (see page 64) and from fishery scientists and fishery officers who are trained, but whose opportunities for extensive observations are often limited. Much of this knowledge never becomes recorded in print. For some very small parts of the seas, such as the North Sea, the North Atlantic Banks, the Sea of Japan, and the Pacific coast of North America, our information is relatively abundant and well recorded. For most areas, it is astonishingly and exasperatingly scanty and undependable. Special scientific studies of habits, ecology, and life history have been made on relatively few species, even in the best known areas, and on none in most places (see Figures 17–19).

Hence, any attempt to evaluate the production or potential production of the fisheries of the world is very difficult, if not impossible, except in the most general terms. For even though existing knowledge of fish and their general distribution may enable us to give probable answers to some questions, the almost complete lack of knowledge of the abundance of any one kind at any one place for most of the world makes a precise answer impossible.

It seems obvious that any program designed to increase the contribution of the fisheries to the food supply of man must be based upon much more secure and exact information than is now available. No conference of fishery men, steeped in the traditions of their own homelands and differing profoundly in outlook and understanding, can produce that information. The only solution would appear to be to permit a group of men, with a united viewpoint, harmonious understanding of the needs, and broad knowledge of the world's marine animals, to examine the world's fisheries and fishery records at first hand in sufficient detail to permit answers to specific questions.

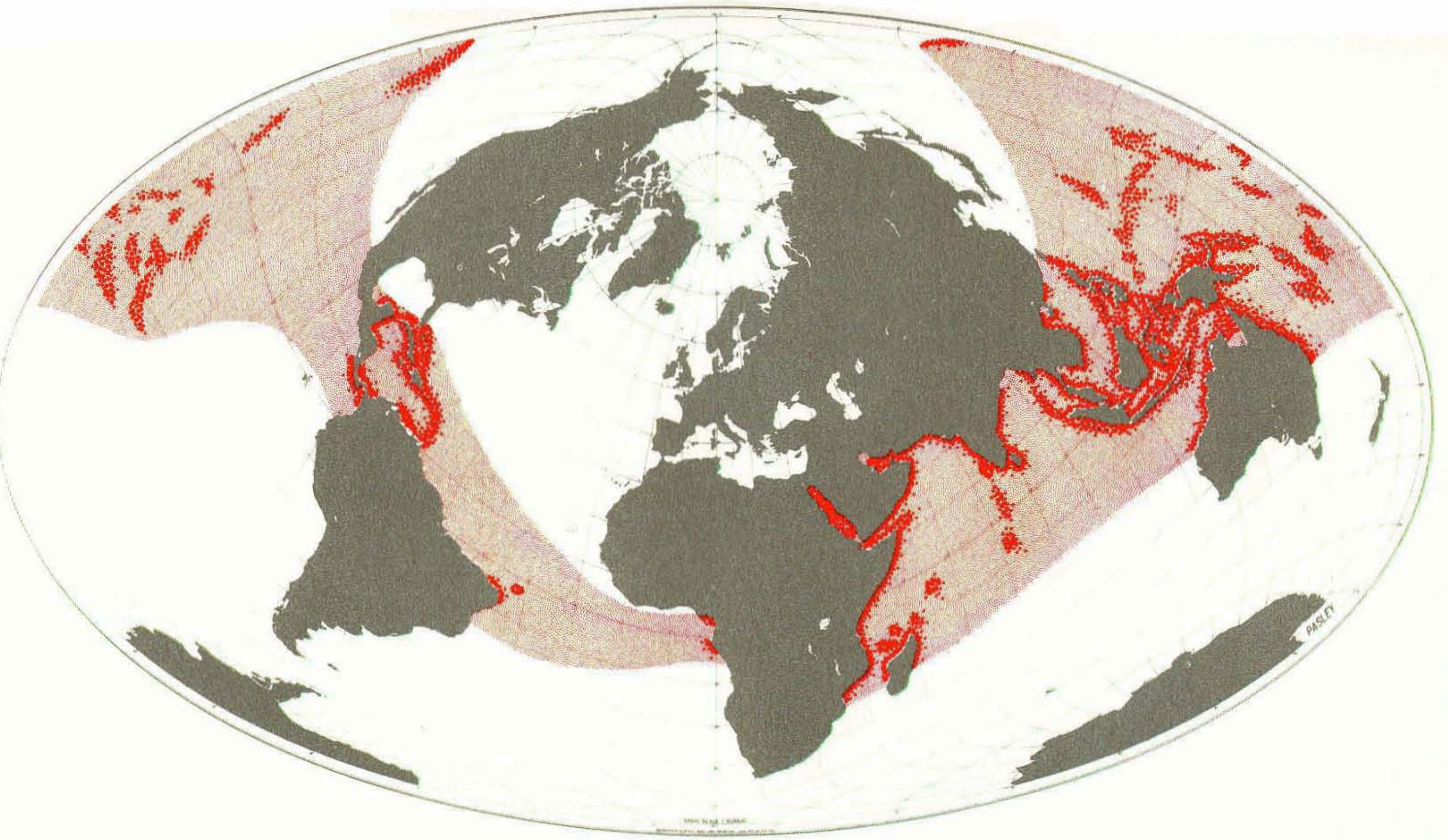

FIG. 16. Reef coral. Extensive coral reefs, of interest because of the important associated fishery resources, occur within the lightly dotted zone. The principal areas occur along the coasts and around the islands marked with larger dots. Data given by George S. Myers.

Discussion of Figure 17

Figure 17 is essentially a map of ignorance. It began with a survey of the world's marine fish faunas, some of the first very rough results of which, for the Pacific, were presented by George S. Myers in 1940.[6] It continued with an estimate of the total number of known species and, by a process of extrapolation, of the still unknown species of each of these areas and of the world. To this had to be applied a general knowledge of the rough ecological classification of the species into littoral, shore, pelagic, bathypelagic, and benthonic divisions.

A large number of geographical points were then selected. The number of species recorded from within each quadrant having one of these selected points as its center was then plotted against the total number of species to be expected in that quadrant, and the result expressed as a percentage. The areas between points were then filled in by careful judgment of the extent of knowledge of them as compared to the main points.

The result is a rough but probably reasonably accurate assessment of existing knowledge of the occurrence of marine fishes within any 10,000-square-mile quadrant of the sea. The principal error will be in regard to smaller bathypelagic species found at greater depths than 100 fathoms (roughly 200 meters). These are very little known and poorly recorded everywhere save in parts of the North Atlantic and the Mediterranean.

The user of this map should realize that most marine fish species are either littoral or shore fishes found on the continental shelves but that these shelves have been adequately fished only in a few areas. Off the continental shelves, the fish fauna of no part of the sea is really well known.

This map clearly indicates that knowledge of the kinds and distribution of fishes is still in its infancy and that a tremendous amount of collecting and identification must be done, even in relatively well-known areas, before our knowledge of the fish resources of the sea is sufficient for really intelligent use.

Local fishery officers (who are usually not ichthyologists) may object to this chart as not properly representing their areas. Our sole defense is that local fishery officers frequently realize neither the richness of the nearby fish fauna nor the percentage of it that is still unrecorded, if not totally unsuspected, including many species possibly of great food value. Actually, the error will almost always be found to be in recording too high a percentage for any area.

This map records merely the finding of species within one local area (10,000-square-mile quadrant). It records nothing of abundance, of knowledge of habits and life history, or of the number of species existing in any area. But it does indicate vast ignorance of the most simple fact we can have about the fishes of an area—the mere occurrence of the species that general knowledge of fish distribution as a whole tells us will eventually be found to occur in that area.

Finally, the number of species increases very greatly toward the warmer regions, and the only areas where knowledge of the composition of the fish fauna is reasonably complete are the temperate or colder regions, where the number of species is relatively small, and where knowledge of the composition of the fauna is therefore relatively easy to obtain. Moreover, it is chiefly these temperate and colder waters that have been scientifically investigated actively and continuously for a long period of time. Knowledge of the sort here mapped will be much more difficult to obtain in the tropics, where the difficulty of the job is far greater and the scientific centers small and few. In general, no information subsequent to 1957 is included.

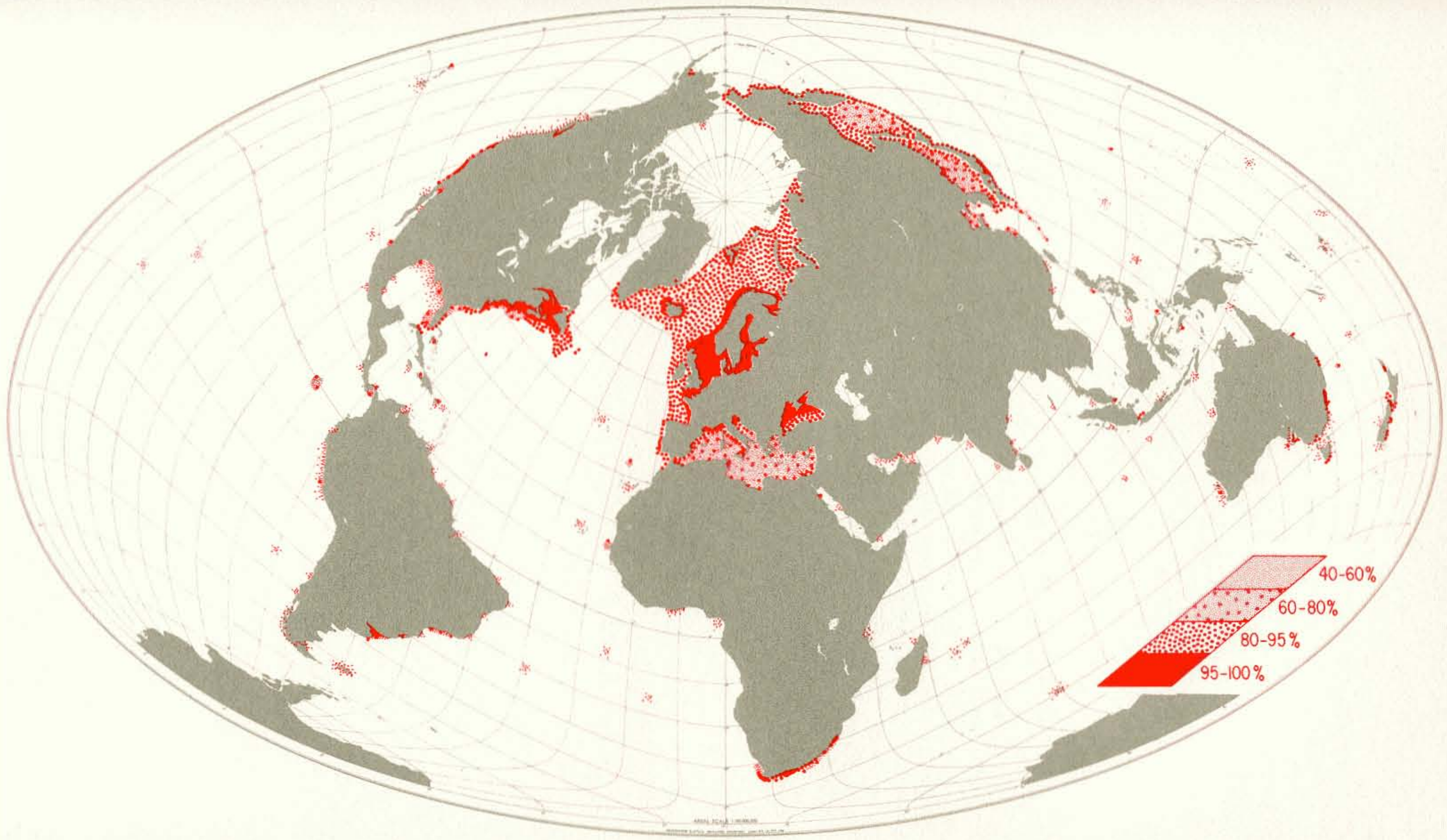

FIG. 17. Knowledge of species of fishes. The intensity of shading indicates the percentage of species (out of the total number occurring or expected to occur) which have been recorded in each 10,000-square-mile quadrant of the sea. Compiled by George S Myers.

Discussion of Figure 18

This map is based upon a reasonably complete knowledge of what has been done in the study of the habits, ecology, and life histories of marine food fishes in different parts of the world. In no area is it believed that sufficient information is available for more than 60 per cent of the food fishes actually present to permit reasonably sound regulation and utilization of the resource. Among areas where the percentage is over 50 are the coast of the North Atlantic States of the United States, the North and Baltic Seas, and the coast of Iceland.

The map implies the almost total lack of knowledge of the habits, ecology, and life histories of most of the world's food fish species.

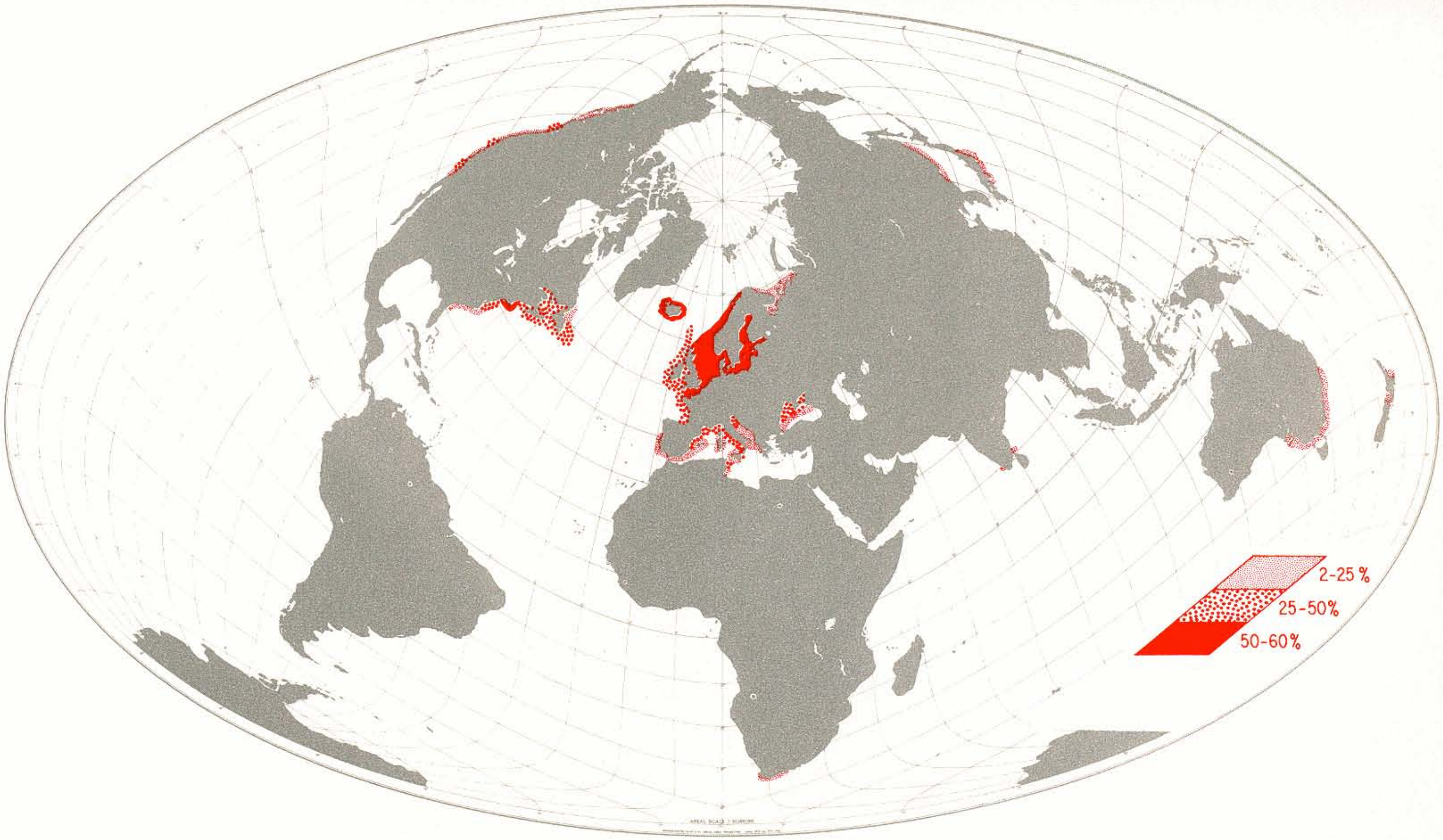

FIG. 18. Knowledge of habits of marine food fishes. The state of knowledge (1951) of habits, ecology, and life histories of marine food fishes of all seas is indicated by increasing intensity of shading. Compiled by George S. Myers.

Discussion of Figure 19

This map is based upon some of the surveys made for Figure 17, in addition to an estimate of the larger or more abundant species available to the fisheries along most of the world's coasts. It omits bottom fishes found at depths of more than 150 fathoms as well as pelagic and bathypelagic species. It is especially useful to indicate the relatively few species upon which the fisheries must be based in cooler regions, and the very numerous species upon which they must be based in the tropics.

Fisheries depending upon relatively few species which are very abundant, as in the cooler plankton-rich seas, are far easier to exploit than fisheries which must depend on large numbers of species, few of them exceptionally abundant, such as occur in most tropical coastal areas. For example, bottom trawling, which is so successful in the North Sea, is seldom or never of great importance in the tropics where much more diversified gear has to be employed, because of the composition of the available food fish fauna and of the rugged or coral-strewn bottom.

In general, areas of equivalent temperature range are equally rich in species, but the picture is not always so simple. The West African tropical marine fauna is not nearly as rich in different species as the Indo-Pacific fauna which occurs on the eastern coast of Africa. The species composition of the food fish fauna of the Pacific coast of the United States is enriched by the excessively large numbers of a single genus (*Sebastodes*) found on it. The Guiana and northern Brazilian coast of South America is poorer in number of species of food fishes than it would be were it not for a solid mud-and-mangrove-swamp coast for 1,500 miles, a type of shoreline that is notably conducive to a species-rich fauna.

The coasts about which we have the least information in regard to number of food fish species (outside the polar areas) are those of Chile and southwestern Africa. The latter is a cooler area of upwelling and perhaps is quite as rich in species as the Peruvian coast, which has between 190 and 200 species now utilized for food (in addition to an estimated 25 species of potential food fishes still unreported).

It must be emphasized that this map is based not only upon the food fish species now utilized; it also includes carefully estimated numbers of other food fishes (i.e., species of reasonably large size and abundance) that are present but unutilized. Larger sharks are included; rays are not.

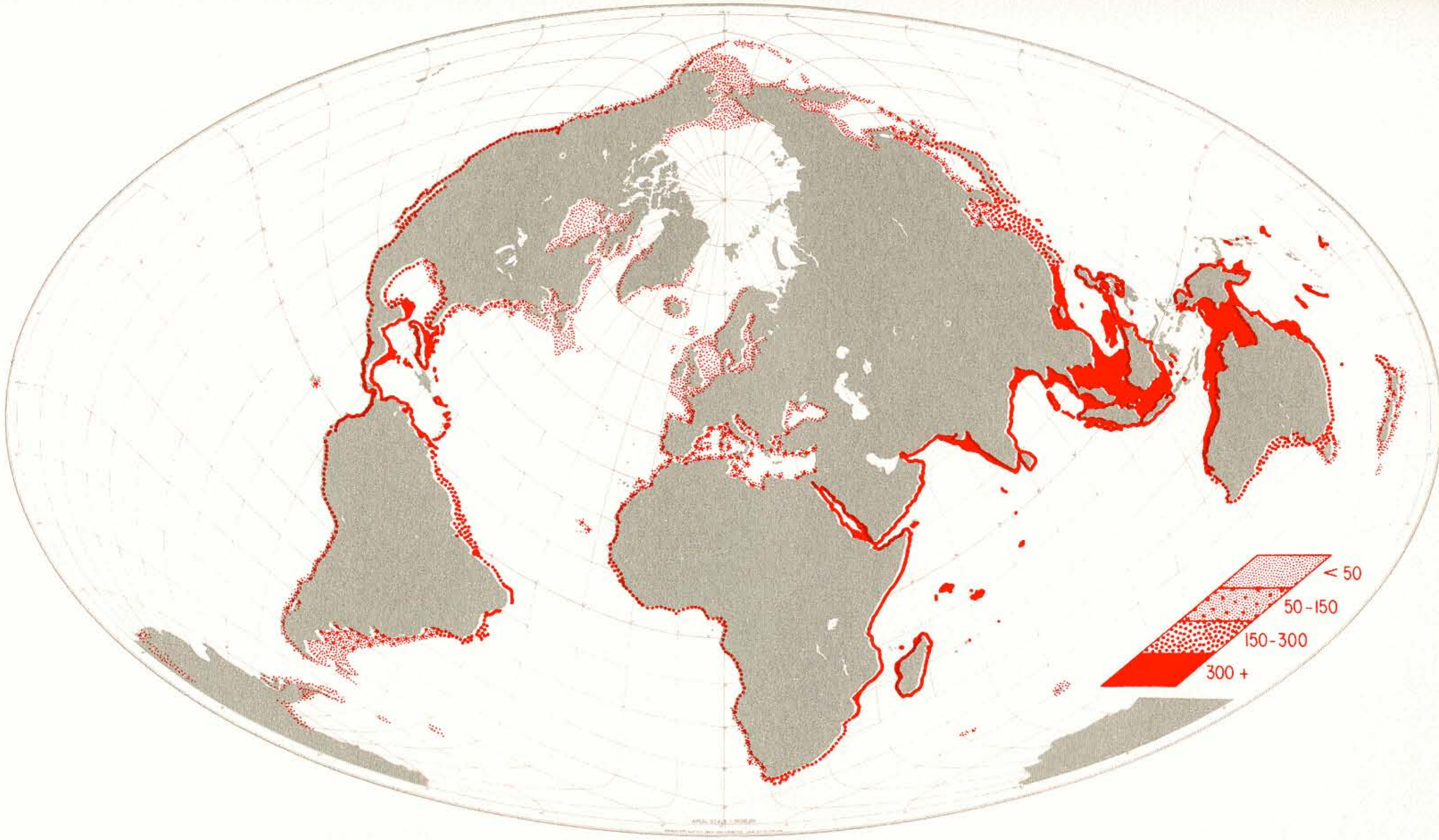

FIG. 19. Species composition of marine food fish faunas. The numbers of species of marine food fishes (1951) available (not necessarily in use) in coastal and shallow waters are indicated by relative intensity of shading. Compiled by George S. Myers.

15

Reptiles

Sea snakes occur throughout the tropical and subtropical parts of the Indian and Pacific Oceans and along the west coast of Africa. There are about 60 species of them, all belonging to one family, the Hydrophiidae. They are closely related to the cobras, and although venomous, they rarely molest people. Most of them are viviparous; a few that are not go ashore to lay eggs. At least one species (*Laticauda colubrina*) can climb. In Singapore, these snakes are said to climb up the poles which support houses built over the water, and to live there, going down into the water only to feed.

Sea snakes swim in aggregations varying from a few individuals to millions. They live near land, tend to be most numerous in estuaries about mangrove roots, and sometimes swim upstream 80 or 100 miles. One species (*Pelamydrus platurus*) swims hundreds of miles out to sea; it is the most widely distributed of all sea snakes. It occurs from the western side of the Indian Ocean off southeast Africa and Madagascar to the eastern side of the Pacific along the tropical American coast, where it is the only species of its family. There are a few records of its occurrence off the west coast of Africa.

Sea snakes prey on fishes, chiefly eels. Most species are about 4 feet long at adult size, but a few grow to be 6 to 9 feet. Fishermen catch sea snakes and market them for food in some parts of the Orient and Polynesia. Although edible, and presumably nutritious, they are not abundant enough anywhere to become the basis of a great fishery. Little is known about sea snakes, and the literature is full of contradictions as well as of lore copied from one work to another.

A few species of turtles have paddles in place of feet and so are adapted for swimming in the sea. These are classified into two families, the Cheloniidae, which contains four genera and species, and the Dermochelyidae, which contains only one.

In sizing up the sea's food resources, people may not be giving enough weight to turtles. In the *Yearbook of Fishery Statistics,* for example, the Food and Agriculture Organization gives the production of an item called "Aquatic Fauna." This lumps together "miscellaneous aquatic reptiles, amphibia and invertebrates"! Even where such statistics are more specifically reported, they are likely to be highly inaccurate about turtles. The reason for this is that ordinarily these animals are not the object of organized fisheries, and most catches are made by subsistence fishermen working out of villages in remote places, and go unreported. Thus turtles may be much more important than is usually recognized.

Marine turtles are chiefly coastal animals of warm waters. There are only five forms which occur around the world. These may belong to world-wide species, or the stocks of the Atlantic may differ enough from those of the Pacific and Indian Oceans to deserve recognition as distinct species or subspecies. This question has not yet been firmly answered because details of anatomy vary considerably, probably being affected by temperature and other environmental conditions. Moreover, they change with age, and not enough specimens have been measured to provide the material necessary for the statistical analysis required to resolve these complexities.

There is considerable variation in habit from one species to another. Some turtles are seagoing; others stay closer to shore, live in tidal waters, in and about estuaries, in lagoons and salt marshes, and a few wander into fresh water from time to time.

No species is quite independent of land, even those that venture far out onto the high seas, for they must all go ashore during the breeding season to lay eggs. They are more vulnerable to careless exploitation during this season than are most fishes and invertebrates, for not only the animals, but their eggs as well, are hunted and easily gathered then. The annual take of the eggs of green turtle in the Irrawaddy Division of Burma, for example, is about 1.6 million a year.

The various species are not equally valuable, nor are those that are valuable sought with equal intensity throughout their respective ranges. In many places they are open game, free for the taking; in others they are given various sorts of protection for conservation purposes. For the most part, such protective devices are based on judgment of what seems right rather than on facts, and there is no basis for quantitatively estimating their effectiveness.

The supply of sea turtles has been severely reduced in many parts of the world where they were once abundant. This is due partly to careless exploitation, but probably more to destruction of the breeding grounds by the spread of human habitation. It does not seem likely that sea turtles could ever become a great food resource. Nevertheless, the yields could probably be improved substantially by the application of appropriate conservation measures. To devise such measures would require extensive studies on the biology of turtle populations to identify the stocks and to learn such essential facts about them as their rates of reproduction, growth, and death, the patterns of their migration, and their general behavior. Information on these facets of their biology is extremely fragmentary, where any exists at all.[1]

16

The Marine Mammals

The marine mammals—whales, dolphins, seals, walruses, sirenians, and sea otter—include a higher proportion of species that are commercially useful than is found among any other group of animals in the sea.

Some of the marine mammals are enormously valuable. However, their exploitation is severely limited by two factors: (1) the populations are relatively small in numbers and (2) the rate of production of young is low. The number of young which a female bears in a lifetime does not allow for much loss, certainly not for such prodigious infant mortality as the oviparous fishes suffer. Thus it happens that while most populations of fishes are remarkably resilient to the effects of fishing, populations of mammals are not. Fishery stocks often continue to yield large catches even though they are being exploited far beyond their level of maximum productivity. It cannot be shown that there are any marine fish populations that have been brought even near to extermination by overfishing. This is not true of the sea mammals. Some populations (of fur seals, for example) have been exterminated. Some entire species, such as the Hawaiian monk seal, have been reduced to the point where their very existence hangs in delicate balance. The history of all the great marine mammal industries is a monotonous repetition of the reduction of one species after another to unprofitable levels. Depleted stocks, such as the Alaska fur seal, have been restored only under governmental or international regulation. In some instances restoration has progressed very slowly. This is true of the sea otter and the northern elephant seal. Fortunately efforts are being made to control whaling. An international convention was established in 1946 to regulate the killing of whales so as to maintain the stocks of these animals at their most productive levels. It is too early in the history of this organization to judge the results of its work.[1]

Relatively little is known about fundamental features of the biology of many of these animals, such as their rates of growth and replacement, the routes of their migrations, their food habits, and the identity of the various stocks. The pelagic marine mammals have much to tell us about parts of the sea which they can reach better than we. Thus their oceanic distribution may indicate areas of fertility that also nourish valuable fishery stocks, and thus serve as a guide to exploration for untapped resources (Figures 20 to 23). They are excellent sampling instruments, their stomachs containing specimens which are not ordinarily available to us otherwise. For example, whales caught in the eastern North Pacific contain larger horse mackerel than Japanese fishermen ever catch, and thus reveal the existence of stocks of that species which should be worth exploring.

The study of pelagic mammals as indicators of fertility and of faunae in remote areas and depths is a research field that has hardly been touched. The following pages will review briefly the uses and status of the various groups.

Whales

BALEEN WHALES. These whales are characterized by a peculiar feeding apparatus in their mouths. They have no teeth. Instead, a series of 300 or more horny plates is arranged along each side of the palate, set at right angles to the long axis of the head. The plates hang down into the cavity of the mouth, about a quarter of an inch apart, varying in length with different species, from 20 to 30 inches in some to 10 or 15 feet in others. The substance of which they are composed, called baleen or whalebone, is tough and more or less flexible. The inner margin of each plate is frayed out in a coarse fringe, with the result that the whole assemblage of plates forms a sieve through which mouthfuls of water can be strained to collect plankton and small, schooling fish.

Clumsy though all this may appear, it is an enormously effective fishing apparatus. The smallest species of baleen whale, the pygmy right whale, grows to be 20 feet long; the blue whale, which is the largest of all animals, grows to be 100 feet; all the other baleen whales reach at least 30 feet when full grown. Not only do they grow large, but they grow fast. The blue whale is particularly spectacular in this respect. At birth it is more than 24 feet long; in two to four years (estimates vary) it is 74 to 77 feet and sexually mature. For a mammal to produce flesh at that rate, and to maintain existence in the sea requires such prodigious concentrations of food as occur only in the most fertile areas. Depending as they do on plankton, the baleen whales feed in surface layers. They are mostly animals of temperate and cold waters (compare Figures 20 and 21). Of the 39,439 baleen whales caught in 1955–56, 80.0 per cent were from the Antarctic.

In the summer these whales tend to concentrate in high latitudes for feeding along coasts or on banks enriched by such processes as upwelling, convection, or divergences of currents. As winter approaches they move toward the equator into warmer water to reproduce and nurture their young.

At least ten species of baleen whales are recognized. These include three right whales, five fin whales (also called rorquals), the humpback, and the California gray whale. They all can yield valuable products, as shown by the fact that the whaling industry has utilized them all at one time or another. Nearly all the baleen whales are subject to conservation regulations under the International Whaling Convention. These regulations, which vary with different species, include catch quotas and minimum size limits. For certain species, total protection is established.

There are probably no underexploited stocks of baleen whales. There are stocks that are going through the slow process of recovering from overexploitation, which some day may be harvested again, and there are those that are now being exploited up to or beyond their level of maximum sustained yield. There are certainly no virgin stocks left. The problem of expanding the production of these animals, should demand warrant it, consists of determining the level of sustained yield in accordance with conservation principles, and then of regulating the industry to that level.

TOOTHED WHALES. The toothed whales have teeth and no baleen. In some species the teeth are fully formed in both jaws; in others they occur only in the lower jaw; in still others they are vestigial and do not show. There are many species in this suborder of whales, including the sperm whales, the bottlenose and beaked whales, all the porpoises and dolphins, and the narwhal. The pygmy sperm whale grows to be about 10 or 12 feet long. It is a poorly known species and although widely distributed, is generally considered rare. It has no commercial value and is not likely to

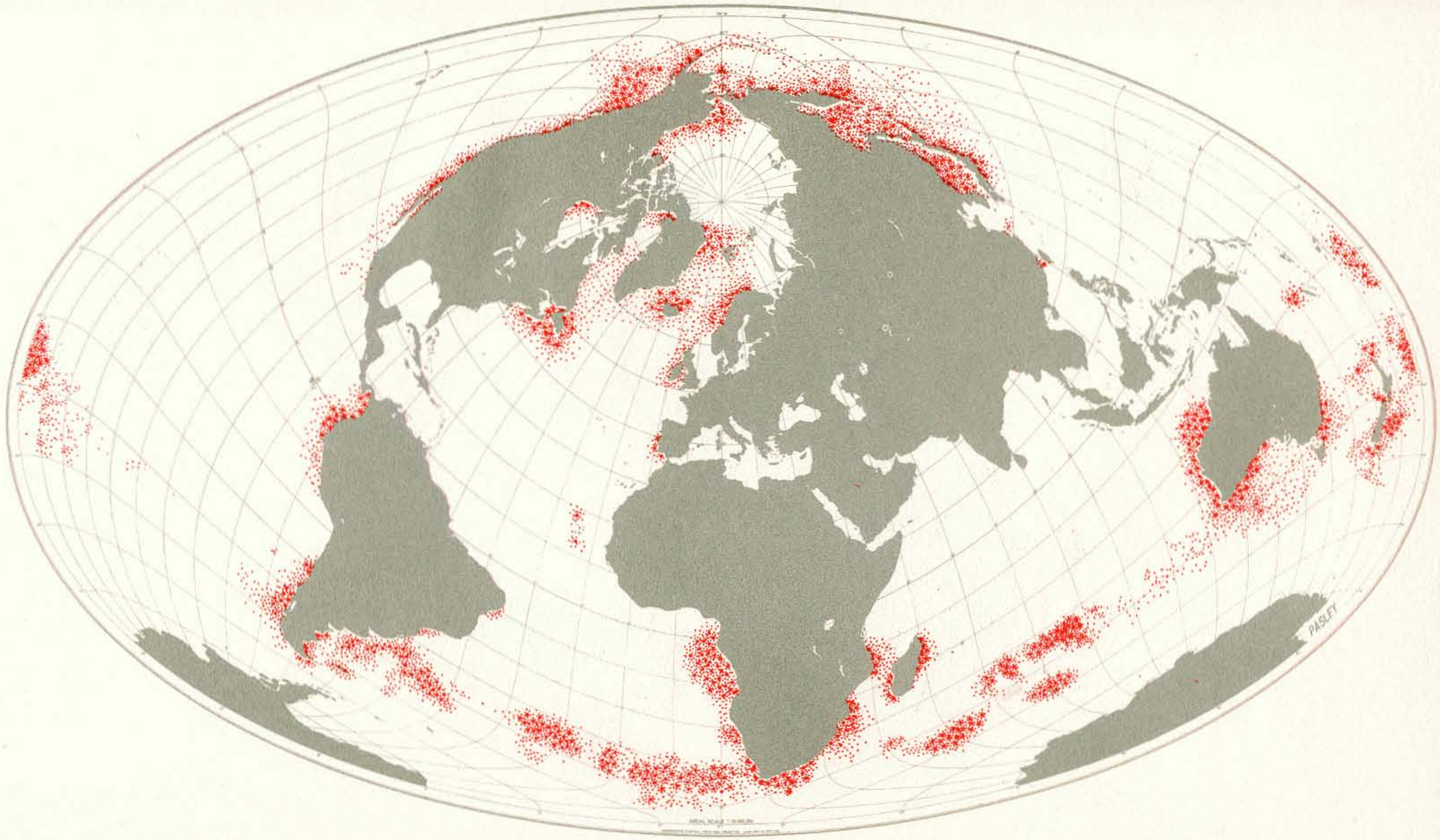

FIG. 20. Baleen whale grounds: summer. Compiled from log records of whaling vessels and from supplementary data supplied by Raymond Gilmore. The larger dots show where several catches were made.

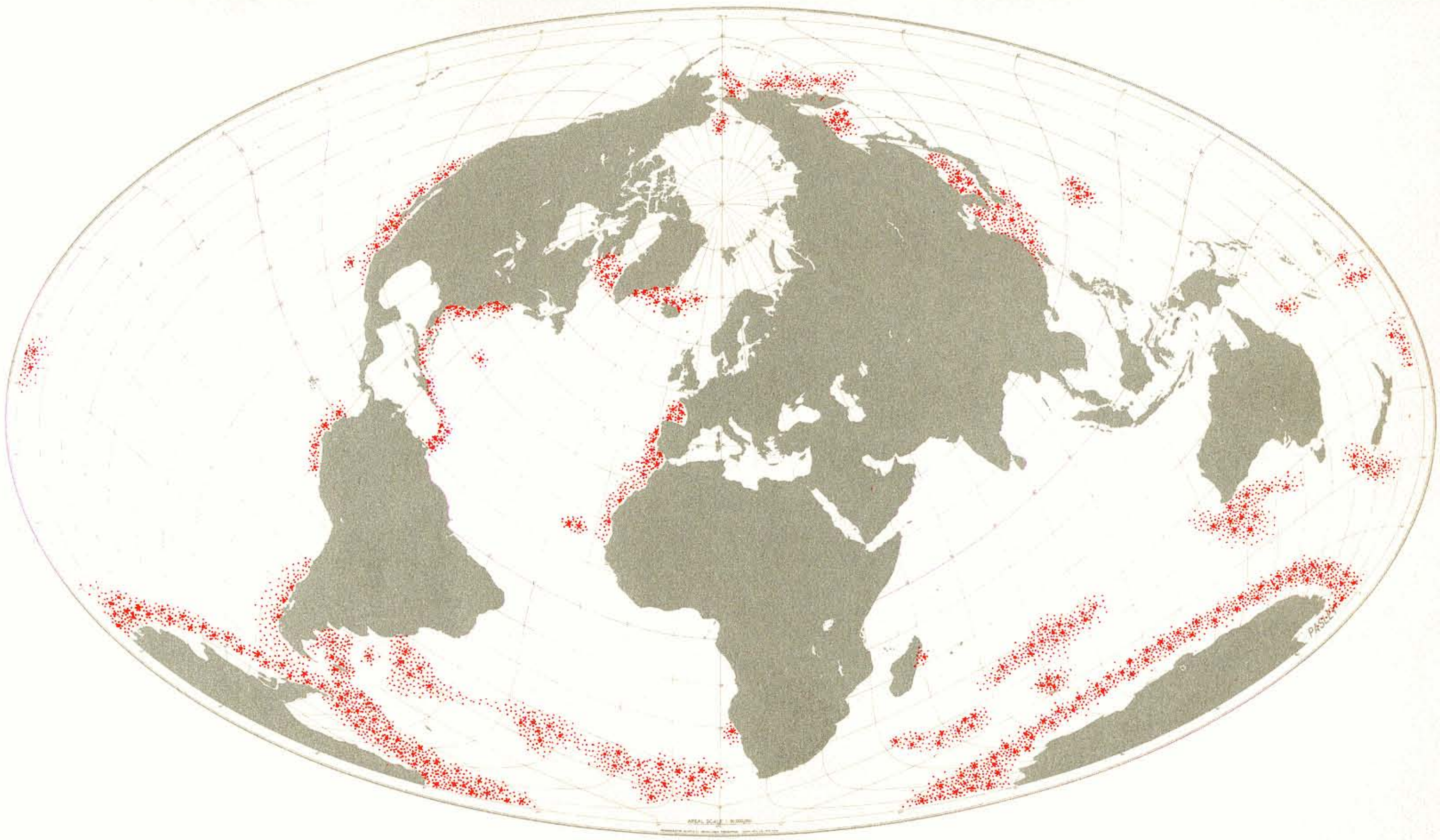

FIG. 21. Baleen whale grounds: winter. Compiled from log records of whaling vessels and from supplementary data supplied by Raymond Gilmore. The larger dots show where several catches were made.

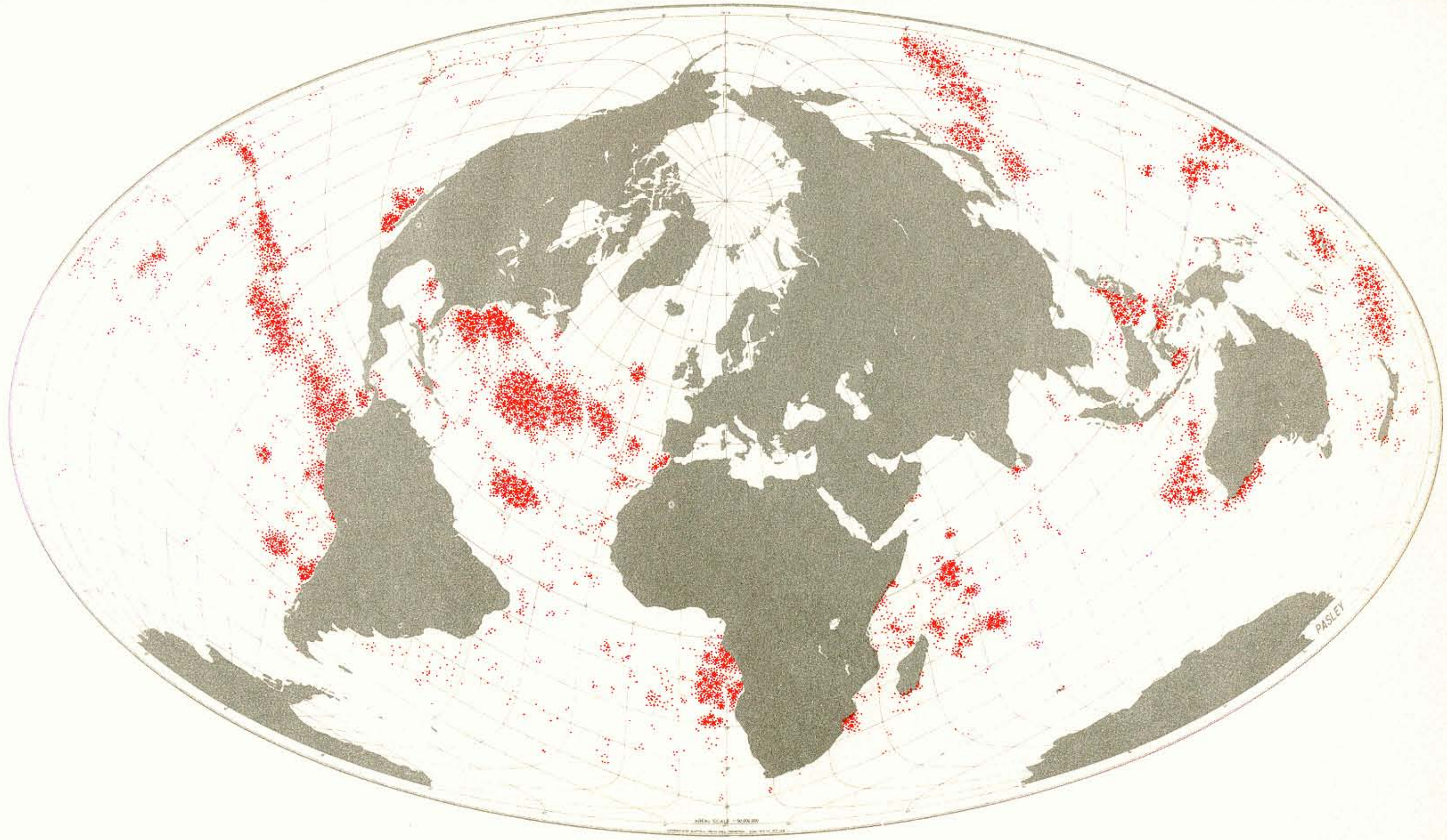

FIG. 22. Sperm whale grounds: April–September. Compiled from log records of whaling vessels and from supplementary data supplied by Raymond Gilmore. The larger dots show where several catches were made.

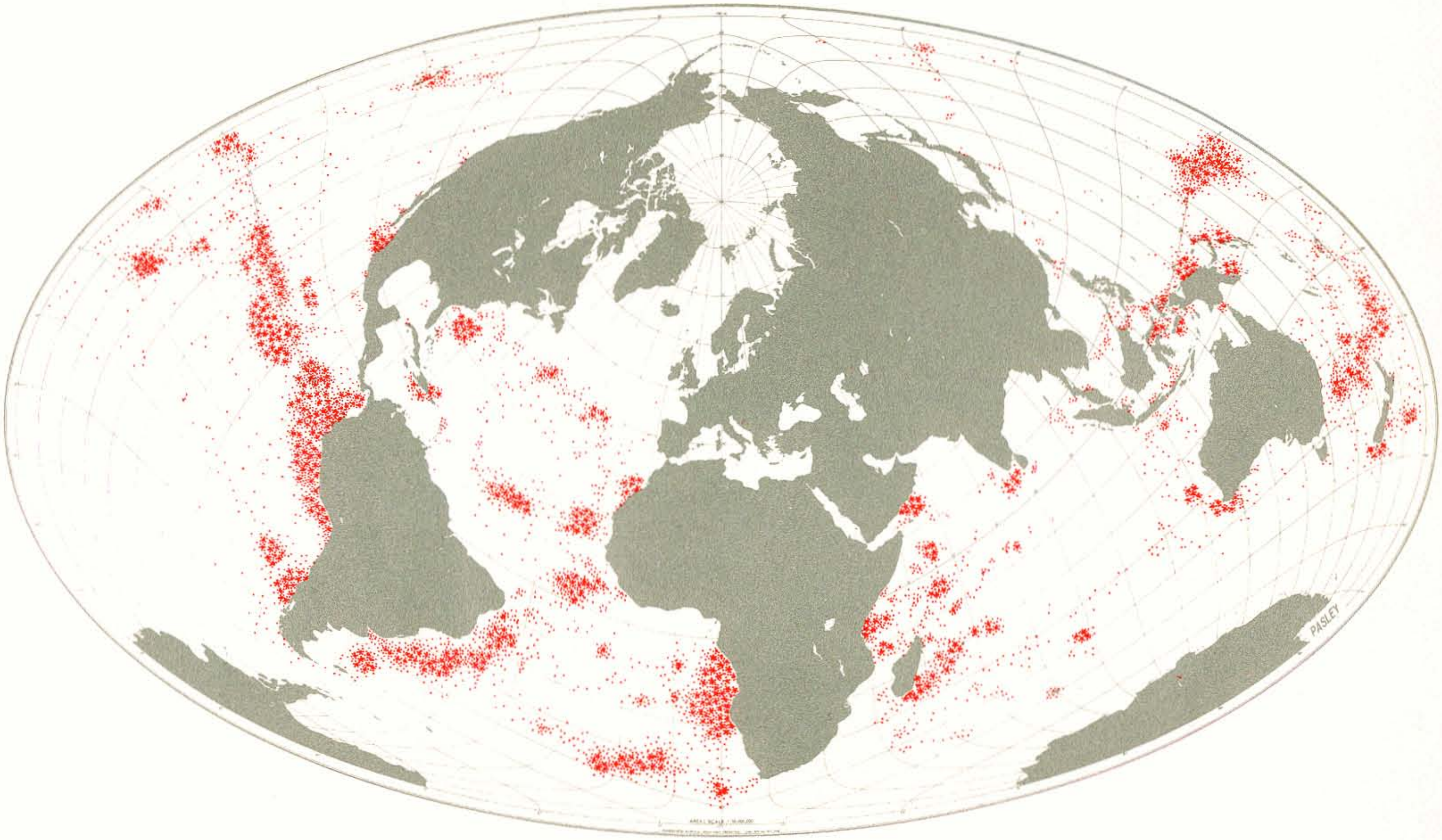

FIG. 23. Sperm whale grounds: October–March. Compiled from log records of whaling vessels and from supplementary data supplied by Raymond Gilmore. The larger dots show where several catches were made.

have any in the future. The sperm whale of commerce, which grows to be 60 feet long or more, occurs all over the world in polar regions as well as in the tropics. Mostly, however, it is a species of warm latitudes, evidently concentrating in areas enriched by hydrographic processes.

The sperm whale is a deep-water animal, able to go down almost half a mile. It evidently feeds at great depths. Its food consists largely of giant squids which inhabit ecological systems that must be very rich to attract and support such large animals. Unfortunately, our knowledge of faunal composition or of the mechanisms maintaining the fertility of these systems is almost a blank.

The oils of the sperm whale are waxy. This is especially true of the spermaceti, which is a clear colorless oil contained in a cavity of the head. Spermaceti solidifies in the air to form a white wax. It is used in cosmetics and for a variety of industrial purposes, including the manufacture of candles and as a dressing for fabrics. Another product of much interest, because of its erstwhile great value, is ambergris, a concretion formed in the intestine of sperm whales. Since ambergris can now by synthesized, the natural product may no longer bring great fortune to its finders.

The sperm whales were the most valuable of whales during most of the eighteenth century and the first half of the nineteenth, when they were intensively pursued all over the world, mostly by Americans. Sperm whaling became reduced almost to the point of extinction in the last half of the nineteenth century, partly as a consequence of depletion of the whales, and partly because of the replacement of whale oil by mineral oil for illumination. Sperm whales are being hunted again, now chiefly by catcher boats working from great factory ships in the Antarctic, on the west coast of South America, off Japan and the Bonin Islands, and in various other areas. Hand whalers take several hundred animals throughout the year in the neighborhood of the Azores. For 1955–56, the Food and Agriculture Organization statistics reported 18,625 sperm whales caught, which was more than 32 per cent of the total catch of all whales. It seems unlikely that the sperm whale is underexploited now; if anything, the contrary is true (Figures 22 and 23).

The bottlenose or beaked whales, of which there are several species, range at full length from 15 to 40 feet. As is true of the sperm whale, they feed in deep water on cuttlefish and squids. The oils derived from them are waxy, and the head contains a spermaceti organ. The whales of this family are not now particularly hunted. The Atlantic bottlenose was taken extensively during the last part of the nineteenth century. A few, probably less than a hundred a year, of Baird's beaked whale are now taken in the North Pacific by Japanese and Russian whalers. Of the other species of beaked whales (*Mesoplodon*), specimens are occasionally captured and used. For the most part, however, they are poorly known, and though widely distributed, are rarely seen. They seem not to concentrate in any particular area, and there is no reason to think they are a potential resource of much value.

The protein content of lean whale meat is about 20 per cent. The 1950 catch, which consisted of 23,623 "blue whale units," contained something like 325,000 metric tons of meat which is the equivalent of the yield from 1,800,000 average weight steers.[2] However, the demand for whale meat is limited. Furthermore whales are hunted for their oil, and although meal is also manufactured on the factory ships and in the shore stations (82,100 metric tons in 1955–56), large quantities of offal are still thrown back into the sea as waste product. In the season of 1955–56, 72,000 metric tons of meat were landed. However, there are many technological problems that must be solved before it can be profitable to whaling companies to prepare meat in an attractive form, carry it to the home port in excellent condition, and market it in competition with beef, mutton, pork, and fish. Whaling companies are quite alert to this problem. Indeed, they have invested large sums in research work to develop new by-products, but so far with no remarkable achievement.

Porpoises

One family of marine mammals (the Delphinidae), contains the numerous species of dolphins and porpoises, as well as the narwhal, white whale, pilot whale, killer whale, and false killer whale. They differ from the baleen whales in lacking baleen, and from the sperm whales, bottlenose, and beaked whales in lacking a spermaceti organ. Most of them have functional teeth in both jaws. The various species vary greatly in form and range in full size from about 5 to 25 feet. They occur all over the world from arctic to antarctic latitudes and in many diverse environments from rivers to the high seas.

Several species are quite unutilized. A few do have commercial value in some areas. These animals are at the head of the food chain, the top dogs of the sea, as anyone who has ever seen a herd of porpoises attacking a school of mackerel can attest. They are not rare animals, yet almost nothing is known about how they figure in the marine economy. How abundant are they? How do they affect the abundance of food fishes? No one knows. Few biologists have the opportunity to study dolphins and porpoises intensely. Consequently, the natural history of these animals is only partially known at best. There is little if any exact information on the seasons, places, and frequency of reproduction, or on the rate of growth and mortality. Hence, there is no basis of judging how much of a harvest the stocks of these animals could sustain. The flesh varies in quality from one species to another. In some it is dark and soft, almost liver-like in texture; in others it is tough. In some it is agreeable to eat; in others it has an unpleasant odor. Evidently the meat must be treated in some way to make it attractive and palatable. To devise such a treatment would require technological research. One obstacle to developing porpoise fishing is that fishermen of all lands look on these beautiful creatures with affection. They have woven all sorts of myths and superstitions about them. Porpoises are their companions and guides. How could anyone harm one?

The common porpoise (*Delphinus delphis*), a cosmopolitan species, is fished commercially around Japan and in the Black Sea, where in some years more than 20,000 are caught. Elsewhere it is not actively pursued, though it is taken occasionally with nets on the coast of Europe. It formerly had some value in an American fishery, but is no longer in demand in the United States. Its blubber oil is of a glyceridic type. The oil from the head and jaw contains isovaleric acid and has some value as a lubricant. The flesh is edible.

The bottlenose dolphin was the object of a United States fishery at Cape Hatteras during the nineteenth century. It was valued for blubber oil, jaw oil, and to some extent for meat. Now it is taken only occasionally by local fishermen in various parts of the world.

The pilot whale, also called blackfish or pothead, is probably the most important species of the dolphin family in the world. As is true of other members of the family, small herds become stranded on beaches from time to time and perish. People use the oil and even meat of the carcasses in some places where these accidents occur. The oil has special value for lubricating watches and other fine instruments. In Greenland and around the Faroe, Orkney, and Shetland Islands, fishermen unite to drive pilot whales ashore whenever they appear. In Japan, small whaling boats take them, along with other species, on the high seas.

The white whale (or beluga) is an arctic species of porpoise which is hunted rather extensively by people of some northern countries, notably Norway (around Spitsbergen and in the North Atlantic), Canada (Gulf of St. Lawrence and Hudson Bay), Russia (White Sea, Kara Sea, and Sea of Okhotsk), and Greenland. A few thousand pilot whales are caught annually in Newfoundland, most of them by being driven ashore. A few are harpooned. The white whale is particularly important in the Eskimo economy, being used as food by men and sledge dogs. The meat is palatable and nutritious. The blubber oil is also useful for food and for illumination. Moreover, the oil of the head and jaws is rich in isovaleric acid and is therefore valuable as a lubricant for fine instruments. The leather makes an excellent product, being waterproof and having remarkable toughness and elasticity. It is used for making boots and bootlaces.

The killer whale is a cosmopolitan member of the dolphin family. It is probably the most voracious of all animals, preying on fishes, walrus, seals, other dolphins and porpoises, and whales of all sizes. A few are taken commercially in Japan and probably also in other parts of the world. Although numerous in total numbers, the killer probably does not congregate anywhere in large enough numbers to induce the development of a special fishery.

The narwhal, a species of the arctic seas, is remarkable for its single long, twisted tusk. In western Greenland and northeast Baffin Island sudden freezes trap them (as well as white whales and other species) in bays, whence they cannot escape. Then Eskimos kill them, save the meat for food, the hide for leather, and the tusk for sale to white traders. The blubber oil is said to be of superior quality.

The Sirenians

These form an order of aquatic mammals which include the manatees and dugongs. They have a face which a nearsighted observer *might* take to be human. The females have a single pair of teats on the breast, hence these animals are thought to be the prototypes of the mermaids of antiquity. Though superficially resembling the whales in many respects, the two groups are anatomically different and unrelated. The sirenians live in shallow seas, bays, estuaries and rivers. They subsist wholly on algae and other submerged aquatic plants. They are sluggish, inoffensive animals, not very intelligent, and apparently at the end of their line of evolution. The naturalist Georg Steller, accompanying the navigator Vitus Bering, found large herds of one sirenian on the Commander Islands in 1741. This was the northern sea cow. These animals were as much as 20 or 30 feet long, weighed up to 8,000 pounds. The meat and fat were said to be superlatively palatable, and northern expeditions used the animals for food. So vulnerable was this species to overexploitation, that it became extinct 27 years after its discovery.

The dugong is another sirenian, which inhabits the Indo-West-Pacific region from East Africa, around the Red Sea to Australia, New Guinea, and the Ryukyu Islands. Once these animals occurred in large herds of several hundred individuals, and were so fearless that they would allow themselves to be touched with the hand. They are no longer either so abundant or so trustful. Their flesh and oil are said to be excellent. They are fished locally in various places though not extensively. The problem with these animals is not how to increase exploitation but how to preserve the species.

Manatees, of which there are at least three species, occur in rivers and on the coasts of both sides of the Atlantic in tropical zones. They were heavily exploited during the nineteenth century for their oil and hides, perhaps also for their flesh, which was described, too, as being of fine quality. Consequently their numbers became seriously reduced. There seems to be no important fishery for them now, nor any prospect of one.

Seals

Whales, porpoises, and sirenians spend all of their time in the water. There is another order of marine mammals, which includes the hair seals and the fur seals, the Pinnepedia, which must go ashore or onto the ice to reproduce. These are the eared seals, the walruses, and true seals. They are carnivores.

EARED SEALS. The eared seals are distinguished from other members of this order by the presence of external ears. In addition, like the walruses, their hind flippers are turned forward under the body in the direction of the head.

There are at least five species of sea lions, two in the Northern Hemisphere and three in the Southern. They feed in the water on fish, mollusks, crustaceans, and sea birds. In summer they resort to favorite rocky places and islets where they gather in colonies of harems and reproduce. Although their pelage is worthless as fur, they have been taken commercially in the past for their oil and hides and "trimmings." The "trimmings," that is, genitalia and gall bladder, were sold to the Chinese people, who valued them for medicinal purposes. Sea lions are quickly vulnerable to undirected exploitation but they can recover with adequate protection. For example, it was estimated that in 1872 there were 27,000 to 33,000 Steller sea lions on the Pribilof Islands. By 1923 there were only a few hundred left.[3] In 1955 there were 5,000. In all of Alaska there were about 40,000 in 1955, in British Columbia 10,000, in Washington 500, in Oregon 1,000, and in California 3,000. There has been much controversy about sea lions. They do eat fish, as well as squids, octopus, crabs, and other things, and they congregate where their prey is plentiful. They also occasionally damage fishing gear. Fishermen therefore frequently urge that their numbers be reduced.

This is not something to do unscientifically, however. How populations of sea lions affect the ecology of their environment should be the subject of special research. This implies a good deal more than examining the contents of a few stomachs to see what they eat. Another question for research is how different annual rates of slaughter affect the abundance of colonies. There is also a need for technological research to determine how to get the greatest value from carcasses of slaughtered sea lions.

There are some five species of fur seals, three in the Southern Hemisphere and two in the Northern. The pelage of these animals, which is soft with a thick under-fur, provides commercial sealskin. In late spring fur seals gather in certain favored places, form colonies of harems, and reproduce. A harem consists of one bull and from 10 to 100 cows. As winter approaches, the northern fur seal deserts its breeding grounds, returns to the sea and journeys far in the direction of the equator. Specimens marked on the Pribilof Islands with flipper tags have been found later swimming 2,000 miles south off the American coast. Other have been found off the northern islands of Japan. The fur seals of the Southern Hemisphere are for the most part nonmigratory.

Wherever exploitation of fur seals has gone unregulated it has resulted in serious depletion of the resource. Thus the Guadalupe fur seal, which occurred on the small islands off the coast of southern California and northern Lower California, was almost exterminated late in the nineteenth century. Indeed, it was thought that they were extinct until a small colony was found on Guadalupe Island in 1928. A few are now living and there is hope that under careful protection this resource might eventually be restored. That this is possible is attested by the history of the northern fur seal, which was almost exterminated by unregulated sealing and subsequently restored to become again a profitable resource. This species breeds on the Pribilof, Commander and Kurile islands in the Bering Sea and on Robben Island in the Sea of Okhotsk. There were over a million animals on the Pribilof Islands when the United States purchased Alaska in 1867. During the next 43 years an intense pelagic fishery, as well as shore sealing on the breeding grounds, threatened to exterminate these herds. Where the harvest had been 165,000 in 1868, it fell to 17,000 by 1900. In 1910 the United States Government took over the Pribilof seal herds. Since then, the annual slaughter has been carried on only by Aleut residents of the islands, working under the supervision of Fish and Wildlife Service agents. The seals are sold at public auction, and the net proceeds go to the national treasury. The flesh of the carcasses is rendered into oil and meal. The meal is used for animal feeds, the oil for various industrial purposes. Under this carefully directed harvesting the herd has grown to number about 1,500,000.

Pelagic sealing was outlawed in 1911 by the Pacific Sealing Convention, to which the United States, Great Britain, Japan, and Russia were parties. To compensate for their refraining from pelagic sealing, the treaty allotted to Great Britain and Japan 15 per cent of the annual harvest of skins taken from the Pribilofs. Russia was a signatory to the treaty only in the interest of the seal herds in the Western Pacific. In 1941 Japan abrogated the treaty, whereupon the United States and Canada made a provisional agreement to protect the fur-seal resource until a new treaty could be negotiated.

The fur seals of South America, South Africa, New Zealand, and Australia also once were abundant and valuable. They were severely depleted by sealing many years ago. Some rookeries never recovered, but others have improved enough under government supervision to be again commercially valuable. Around 20,000 pelts come annually from South Africa and about 1,000 from Uruguay. It would be useful to study these populations to see how they could be restored to profitable levels.

WALRUSES. These occur in arctic regions of both the Atlantic and the Pacific. They gather in herds, usually in the neighborhood of shores or masses of floating ice. Though the males are promiscuous they do not form definite harems as do the sea lions and fur seals. They migrate, for the most part, by riding on ice floes. Thus in the northeastern Pacific they move south to Bristol Bay in the winter, north to Point Barrow in the summer. They feed mainly on thick-shelled bivalve mollusks, but also swallow large quantities of seaweed, whether for nourishment or not no one knows. Walruses have been severely overexploited for oil, hides and ivory. They are now variously protected. In Alaska, for instance, they may be killed only by Eskimos, who kill about 1,300 animals each year, use the flesh and fat as food for themselves and their sled dogs, and carve the tusks into curios.[4] In Siberia the natives are said to have a one day open season, allowing each man to kill enough for his winter's use.

It does not seem likely that even with the most careful regulation, a walrus fishery could come to be of great importance. Probably the most that could be expected is that the resource might be made to hold its own.

TRUE SEALS. The true seals are distinguished by the lack of an external ear and by the characteristics of the hind limbs, which do not point forward as they do in the fur seals and sea lions, but permanently backward. There are perhaps twenty species of true seals in the world. They occur generally along the shores of temperate and cold countries, mostly in the Northern Hemisphere. Only the monk seals live in warm latitudes. There are three populations (perhaps distinct species) of these and all of them are "relicts" close to extinction. Only four or five species live in the Southern Hemisphere, all of them in or near the Antarctic. They vary in habits from one species to another. Some species (such as the bearded seal) are more or less solitary; others (like the crested seal) live in small groups or family parties; still others (the elephant seal, for example) form very large herds. They may migrate seasonally, like the harp seal, which lives in arctic waters in summer and travels long distances southward in winter; or they may spend all their lives about a single locality, as is the habit of the ringed seal of the North Pacific. Their food habits also vary. The harbor seal, for example, eats fish, sometimes valuable species such as salmon. This particular seal often raids fishermen's nets and damages the gear as well as the catches. The ringed seal, on the other hand, pursues and eats principally small, free swimming crustaceans and mollusks and some small fishes.

Several species of true seals are important in the economy of indigenous peoples of the far north, who use their meat for food, their blubber for illumination, their skins for boot soles, boot coverings, dog traces, harpoon lines, and so forth. The products of seals, principally leather and oil, have value elsewhere in the world too, and vessels put out from various countries of Europe, North America, and the Orient to hunt seals. Sealing industries are not nearly so productive as they once were, largely because several of the most valuable species were brought almost to the point of extermination. This is what happened in the last century to the northern elephant seal, the largest of all pinnipeds, which was once the principal quarry of sealers in the North Pacific. Fortunately the species was not quite wiped out and, thanks to protection by the governments of Mexico and of the United States, it is now slowly coming back.

The chief sealing grounds today in the Arctic and North Atlantic Oceans are western Greenland, the Newfoundland district, the Seas around Jan Mayen, Novaya Zemlya, the Kara Sea, and the White Sea.

The principal species sought now is the harp seal of North Atlantic regions. The number of these animals killed annually on the "front" in the North Atlantic (i.e., east of Newfoundland and Labrador), varies between about 150,000 and 355,000. In 1952, the killed of pups and adults, in round numbers, was as follows: [5]

Country	*Number of Animals*
Canada	85,000
Norway	113,000
France	7,000
Total	205,000

Probably only the seal herds of the Antarctic could be regarded as underexploited, and they are too remote to merit sending out special sealing expeditions. The chief problem concerning the seals of the Northern Hemisphere is not how to expand their utilization, but how to set the rate of annual harvest in accord with conservation principles.

SEA OTTERS. This marine mammal is native to coasts of the North Pacific from central Lower California to the western tip of the Aleutians and to Japan on the Asian side. It is rather small as marine animals go, not exceeding 4 or 5 feet including the tail, which is about a quarter the total length. It is remarkable for its beautiful pelage, which consists of dense, fine, deep underfur. These animals spend most of their time at sea, not generally within sight of land. They feed on mollusks, sea urchins, and crustaceans, as well as on various other invertebrates and fishes. They mate during summer in the sea or on shore rocks, give birth to their young in spring and early summer on the floating kelp fronds or on rocks by the sea.

Sea otters were originally numerous enough to support a modest-sized continuing fur trade. Unfortunately that was before the idea of conservation had become established, and the herds of these animals were slaughtered faster than their rate of replacement. During this period, sea otter was the most valuable of all furs. In 1891, the average price was $275 a skin, and it is said that some skins brought as much as $2,500!

The history of the sea otter trade is the same wherever they occurred. Hunters killed 5,000 animals on St. Paul Island in the Pribilofs in 1787, 1,000 animals in 1788. Within six years there were evidently none left. In Cook Inlet, 3,000 skins were taken the first year, 2,000 the second, 800 the third, 600 the fourth, and in 1812, less than 100.[6] This species was saved from extermination by absolute protection as provided under a 1911 treaty between the United States, Great Britain, Japan, and Russia. It is a violation of United States federal law to possess a sea otter pelt without a permit. During the past forty-five years the species has been slowly reestablishing itself so that there are now thousands of them scattered among the islands of the Aleutian chain and of the Alaska Peninsula, and even one colony as far south as central California. If sea otters were again taken commercially, the rate of cropping would have to be very prudently controlled if the resource were to remain productive.

17

Seaweeds

Vegetation of the sea is more primitive in the evolutionary scale than that of the land. Seaweeds vary tremendously in form and elaborateness of organization, ranging from one-celled, microscopic flagellates to giant kelp which grow to be five or six hundred feet long. They have no flowers or seeds, their reproduction and distribution being accomplished by asexual spores which are simpler structures than seeds. They do not have roots but are anchored to the substratum by a structure called a holdfast and absorb their necessary mineral nutrients directly from the sea water through their leaf-like fronds. Like land plants, they possess chlorophyl, by which they utilize the energy of sunlight to synthesize carbohydrates, proteins, and fats from water, carbon dioxide, and, as required, other inorganic chemicals. These products differ chemically from their analogues in land plants. Marine algae have some human nutritional value, but this is not their most interesting use. Some of the chemicals derived from them have peculiar properties which give them special values for industrial or medical purposes. It is these that put algae among the important resources of the sea. However, algae are not universally appreciated; there are great stands of them along some coasts which are almost or quite completely neglected. Even where they are harvested and manufactured into industrial products, they are not used up to their full potential value.

Scientists classify marine algae into four groups according to their principal pigments: green, blue, red, and brown. Only the red and the brown have significant commercial value at present. Red algae range in variety from single-cells of microscopic size through filamentous, branching forms to broad-fronded plants one or two meters long. They are widely distributed, but are most abundant in temperate climates. In general, they occur in deeper water than brown algae, extending from the intertidal zone to depths of 130 meters. Brown algae are more elaborately organized than the red, with great variety of form and size, ranging from small, delicate, filamentous plants to the giant kelps of the Pacific. They, too, are widely distributed but are most abundant in temperate and cool seas.

It is possible by aerial photography to estimate the size of stands of buoyant species of brown algae, thanks to the fact that the plants have fronds which float at the surface and so are always visible. The smaller algae which are exposed only at extremely low tides, if at all, present a more difficult problem. They must be assessed by a combination of processes, including aerial photography, sampling by mechanical grab instruments, and underwater surveying by divers.

The few thorough surveys that have been made show that in any given region, the distribution and density of the marine algae vary according to the geological character of the substrata. Also, the amount of plant material present varies seasonally and from year to year. For example, the standing crop of giant kelp growing in the vicinity of La Jolla, California, varies between 25 and 40 tons (wet weight) per acre. The annual yield, by growth, runs about 4 to 6 tons per acre.[1]

In three widely separated areas surveyed off the coast of Scotland, the total estimated quantity of kelp fluctuated, over the course of several years, between 7.8 and 18.1 tons per acre.[2] In the western part of the Sargasso Sea the quantity of *Sargassum* was found to vary in three years of observation between about 2 and somewhat more than 5 tons, wet weight, per square nautical mile. Assuming these figures to be representative of the whole area, there would be 4 to 10 million tons of pelagic vegetation in the entire Sargasso Sea.[3] Unfortunately this plant is probably not dense enough any place for profitable commercial exploitation. Again, in the Digby Neck area of Nova Scotia, where it was estimated that 80,000 tons of rockweed (*Ascophyllum* and *Fucus*) were growing on 2,500 acres, the density varied from 8 to 57 tons per acre.[4] Thus, variations in the supply is a problem with which anyone exploiting seaweed resources must contend, and the understanding of the causation of these variations must be one of the principal goals of seaweed research.

The principal commercial products of red algae are agar and carrageenin. These consist of 13.2 to 20.8 per cent of moisture, 1.1 to 2.5 per cent of protein, 60.3 to 79.7 per cent of carbohydrates, and 3.5 to 16.6 per cent of ash.[5] In spite of occasional extravagant claims to the contrary, the carbohydrates in these products are not of great value as a source of energy because human enzymes are unable to digest much of them. Researchers have estimated the coefficient of digestibility of carrageenin to run about 33 per cent in dogs, 6 per cent in man, 50 per cent in laboratory rats; that of agar is about 28 per cent in rats. There is some evidence to suggest that agar may act as a nutritional aid when mixed in proper proportions with other feeds.

People in many parts of the world eat red algae in a great variety of forms—fresh in salads, dried, pressed into rolls for chewing like gum, boiled as a vegetable, mixed with meal and made into cakes, boiled with milk for pudding, as the base of a condiment for rice, as a cheap substitute for birds' nests for thickening soups, and as a thickener for puddings. In China the derivative of red algae, agar, is cut into small pieces and treated with soy sauce, vinegar, and red pepper and eaten as a condiment. In Japan, agar jelly is used in making bean cakes. In America agar is added to some breakfast foods to furnish roughage. Moreover, its low nutrient value makes it a useful ingredient of low-calorie bakery products prepared for reducing diets.

Agar is peculiarly useful for making jellies in tropical countries because it sets quickly, has eight to ten times more gelatinating power than gelatin and therefore does not require refrigeration to form a firm jelly, even in the hottest weather. It has other advantages over gelatin for it is acceptable to religious groups that eschew substances originating from the hooves of animals. It does not require sugar to form a jelly as does pectin, and it keeps well because it is not attacked by most putrefying bacteria. This last is a very important property which is probably not nearly utilized fully, for it gives agar value as a temporary preservative. In hot places where refrigeration facilities are lacking, foods like meat and fish, which ordinarily spoil quickly, are sometimes cooked with agar. Thus, by being embedded in a gel which resists bacteria, these foods can remain wholesome for a longer time than foods not so protected.[6]

In Japan a small brown alga called matsumo (*Heterochordaria abietina*) is used for preserving mushrooms. The mushrooms are soaked first in salt water and then packed in barrels in layers alternating with layers of salted matsumo.

The organic composition of brown algae, as of red algae, varies from one species to another. For any one species it varies geographically, and according to depth, and even from one part of a plant to another. It is hardly surprising therefore that published analyses vary. The percentage composition of the dried product as determined in northern Europe, Nova Scotia, Russia, and Japan falls within the following limits:

Carbohydrates	
Mannitol	3 — 27
Alginic acid	11 — 33
Laminarin	0 — 36
Fucoidin	2 — 11
Cellulose	1 — 10
Proteins	3 — 16
Oils, fats, waxes	1.8 — 3.6
Ash	14 — 46

Brown algae are of negligible importance as human food in the Western World. During hard times coastal Europeans have eaten them, and before the days of highly developed transportation of fresh vegetables and fruits they ate them often, but that was more than a hundred years ago. However, in parts of the Orient, chiefly in Japan, China, Indonesia, the Philippines, and in Oceania, brown algae are highly appreciated. In Japan alone, 310,000 tons of brown, red, and green algae were harvested in 1955. The plants are sometimes eaten simply as vegetables, raw or cooked. But mostly they are dried and manufactured into products that are variously used, such as for flavoring sauces on fish and rice, for thickening soups, or for making into savory wafers, cakes, or other confections.[7] At the end of the last war, occupation officials found how important algae are to the Japanese when they tried to get the people to use *Laminaria* (a genus of brown alga) less for food and more for producing potash, which was badly needed then. The Japanese fishery and prefectural officials resisted these efforts. They were quite willing to agree that seaweed might have little nutritional value, but they argued that depriving the people of these sea vegetables to which they had been so long accustomed would have a bad psychological effect. In any case, all food was scarce at that time, so that they needed whatever nourishment the algae afforded, little though it might be.[8]

A few blue-green algae (Cyanophyceae) and green algae (Chlorophyceae), among them sea lettuce (*Ulva*), are eaten in various places, particularly the Orient and Oceania, as vegetables, as garnishes, or for flavoring. The composition of sea lettuce has been assayed as follows: water, 13 to 19 per cent; crude protein, 12 to 19 per cent; and carbohydrates 46 to 53 per cent. Japanese scientists have demonstrated the proteins of these algae to have less nutritive value than those of an edible red alga, *Porphyra*.[9] The nutritive value of the carbohydrates of blue-green and green agae remains to be determined.

It has been suggested, though not demonstrated, that people who eat seaweeds from early childhood, like the Japanese, may acquire a specialized bacterial flora in their intestines which helps to digest these foods. To be sure, there are certain bacteria in the sea which live on algae, thriving on their complex carbohydrates. Perhaps like a number of marine microorganisms that have been artificially cultured in laboratories, they can survive relatively high temperatures. Therefore it is conceivable that they could be hardy enough to flourish in the human alimentary tract once they were introduced to that environment. Thus some Oriental people might derive significantly more food value from seaweeds than people and animals not conditioned to such a diet. This suggests possibilities in artificially cultivating algae-digesting bacteria.

Even if all the carbohydrates and proteins in seaweeds were fully digestible, the harvestable quantities could not add significantly to the present production of those nutrients from other sources. In Japan, for example, where seaweeds are considered such an absolute necessity that there is no question of educating the public to eat them, the total annual production of fresh weed is less than 3 per cent of the rice harvest. When translated into nutrients, the quantity becomes negligible. Thus the value of marine algae to the food supply of a country is less likely to be in their carbohydrates and proteins than in their minerals and vitamins. Algae have an extraordinary capacity to extract mineral salts from sea water. Thus some brown algae of the genus *Laminaria* have been shown to contain 20,000 to 30,000 times more iodine per unit of volume than the surrounding sea water, 300 times more manganese, 200 times more copper, 500 times more phosphorus.

Any use of algae which requires a controlled product must take into account the variations in mineral composition. This is difficult because these variations are more or less erratic and sometimes are very great. The content of iron per kilogram of oven-dried samples of one species of *Pelvetia* taken at Plymouth, England, for example, was 195 milligrams in January 1949, 565 in May 1949, and 2,040 in June 1950.[10] Ranges of variation of other elements in the same samples (Table 17-1) are even greater.

TABLE 17-1. AMOUNT OF CERTAIN ELEMENTS IN OVEN-DRIED SAMPLES OF SEVERAL SPECIES OF ALGAE COLLECTED OFF PLYMOUTH, ENGLAND
(in milligrams per kilogram)

Element	Jan. 1949	May 1949	June 1950
Cobalt	0.35 — 1.46	0.25 — 1.39	0.22 — 2.00
Nickel	1.5 — 8.2	1.6 — 6.0	1.8 — 9.3
Molybdenum	0.15 — 0.69	0.10 — 0.65	0.16 — 1.32
Iron	168 — 717	138 — 638	320 — 3,380
Lead	4 — 26	2 — 12	4 — 16
Tin	0.7 — 1.2	0.5 — 1.8	0.2 — 2.2
Zinc	40 — 136	47 — 76	59 — 116
Vanadium	1.0 — 3.3	0.3 — 2.6	0.5 — 11.9
Titanium	9 — 20	2 — 38	4 — 308
Chromium	0.6 — 2.6	0.4 — 1.8	0.7 — 3.7
Silver	0.2 — 0.7	0.2 — 0.4	0.0 — 0.4
Rubidium	80 — 250	—	—
Lithium	4 — 8	—	—
Strontium	2,200 — 4,000	> 700	420 — 1,150
Barium	50 — 120	13 — 44	16 — 64
Manganese	30 — 800	9 — 155	30 — 121
Copper	4 — 20	< 3 — 14	5 — 31

SOURCE: Tabulated from data given by W. A. P. Black and R. L. Mitchell, "Trace Elements in the Common Brown Algae and in Sea Water," *Journal of the Marine Biological Association of the United Kingdom*, XXX:3 (1952), 575–84.

Biochemists have definitely established that carotene, the precursor to vitamin A, and vitamins B_1, B_2, B_{12}, C, D, and E occur in marine algae. Some Eskimos get about half of their vitamin C from marine algae, which they eat raw, or dipped in broth, hot water, or blubber oil.[11] Like everything about seaweeds, their known vitamin content varies geographically, seasonally, and with depth, as illustrated in Tables 17-2, 17-3, and 17-4. But nowhere has it been measured in a statistically useful way to establish quantitatively the normal seasonal ranges.

TABLE 17-2. VITAMIN C CONTENT IN SAMPLES OF SOME COMMON SEAWEEDS OF THE SAN JUAN ARCHIPELAGO
(milligrams per 100 grams fresh weight)

Brown algae	
From the surface, littoral and upper sublittoral zones. 6 species	4 — 53
Dredged from a depth of 5–10 fathoms. 4 species	1 — 2
Green algae	
From the surface and littoral zone. 2 species	15 — 46
Red algae	
From the surface, littoral and sublittoral zones. 8 species	1 — 60
Dredged from a depth of 5–10 fathoms. 7 species	less than 1

SOURCE: Earl R. Norris, Mary K. Simeon, and Hal B. Williams, "The Vitamin B and Vitamin C Content of Marine Algae," *Journal of Nutrition*, XIII:4 (1937), 425–33.

TABLE 17-3. VITAMIN C CONTENT IN SAMPLES OF SOME COMMON ALGAE OF NORTHERN EUROPE AND JAPAN
(milligrams per 100 grams fresh weight)

Month	9 species of brown algae, northern Europe	3 species of red algae, northern Europe	*Gracilaria confervoides* a red alga, Japan	Sea lettuce a green alga, northern Europe	Sea lettuce and *Enteromorpha* green algae, Japan
January	3 — 31	40 — 50	96 — 159	—	171 — 241
February	4 — 38	27 — 44	—	27	—
March	5 — 61	24 — 63	149	—	204 — 228
April	7 — 75	29 — 61	150	28	171 — 195
May	15 — 59	36 — 83	168	—	131 — 173
June	—	—	16	—	30 — 64
July	—	—	—	—	—
August	—	—	—	—	—
September	11 — 108	46	—	—	—
October	—	49	—	—	—
November	33 — 44	46	—	—	—
December	—	—	74	—	84 — 90

SOURCES: Gulbrand Lunde and John Lie, "Vitamin C in Meeresalgen," *Hoppe-Seyler's Zeitschrift für Physiologische Chemie,* CCLIV:3–6 (1938), 227–40; and Yasuhiko Tsuchiya, "Physiological Studies on the Vitamin C Content of Marine Algae," *Tohoku Journal of Agricultural Research,* I (1950), 97–102.

TABLE 17-4. VITAMIN B (B_1) CONTENT OF SOME MARINE ALGAE FROM THE SAN JUAN ARCHIPELAGO

Material Tested	Where Obtained	Shermen units of vitamin B (B_1) per gram of dried material
Brown algae		
Alaria valida	upper sub-littoral zone	2.5
Laminaria spp.	dredged from 5–10 fathoms	2.0
Red algae		
Porphyra nereocystis	surface	5.5
Porphyra perforata	littoral zone	5.0
Rhodymenia pertusa	dredged from 5–10 fathoms	2.2
Green algae		
Enteromorpha	littoral zone	trace
Ulva lactuca	surface	4.0
Dried brewer's yeast		13.3

SOURCE: Earl R. Norris, Mary K. Simeon, and Hal B. Williams, "The Vitamin B and Vitamin C Content of Marine Algae," *Journal of Nutrition,* XIII:4 (1937), 425–33.

There is considerable difference of opinion about the value of marine algae for stock feeds. Few controlled feeding experiments have been conducted which have taken into account seasonal cycles in nutritive value and variation among the different species of algae. Black has written the following on this subject.

In carrying out digestibility trials with seaweed, one of the main difficulties is the great variation in composition. This, however, is also a marked feature of farm foods, especially grassland products. The changes are typical of all plants and, just as in the case of grasses where the composition is closely related to the ratio of leaf to stem, in seaweeds the composition depends on the ratio of frond (leaf) to stipe (stalk).[12]

Animal feeding studies that have been made in a number of places point to the following general conclusions: Domestic animals can digest much of the carbohydrates of seaweeds. Indeed in Iceland and in the Orkney Islands, sheep live almost exclusively on seaweeds during most of the year. However, the results of such a diet are not good. For instance, on North Ronaldsay (one of the Orkneys) lives a herd of 2,000 or more black sheep which feed mostly on seaweed during a large part of the year. The animals are kept close to the shore by a wall that surrounds the entire island, and they are admitted to pasture only at lambing time or before slaughter. Accounts in literature, evidently copied one from another, glow with enthusiasm over the splendid animals nourished on this diet. On the other hand, people who have actually seen them say they are poor looking beasts and a most unfavorable testimonial to marine algae as animal feed.

It is clear from all experience that although seaweeds are not a satisfactory exclusive food for sheep, cows, horses, pigs, and poultry, they can be used in portions up to about 15 per cent of the normal ration as a supplementary food. In such quantities they are safe. Apart from the digestible carbohydrates, minerals, and vitamins which they provide, they may have a special beneficial effect in enhancing the nutritional value of the basic ration through their mechanical action on the alimentary tract.

They may also be useful in providing minerals, including trace elements, as well as vitamins. Whatever their nutritional value, it can be precisely determined only by systematic biochemical and feeding experiments planned to encompass adequately all the ranges of variation in the qualities of algae—variations from time to time, place to place, and species to species. Moreover, technological research is needed to devise cheap processes of converting the alginates to a more digestible form, of reducing the ash content, of improving the palatability, and of standardizing the product.

Meanwhile there are over a dozen factories which manufacture meal from brown seaweeds. These are located in the United States, Nova Scotia, Eire, Scotland, France, Denmark, the Netherlands, Norway, and South Africa. The product is usually marketed as dried kelp meal, or mixed with fish meal or stick-water concentrates. Perhaps the most elaborate processing is done in a Norwegian factory, which harvests the brown alga *Ascophyllum nodosum,* dries it in the sun, removes the excess salt, and caramelizes the sugar content to eliminate an odor repellent to cattle and horses. The meal made from this process is claimed to have a food value equal to that of oats and to prevent or cure mineral deficiency diseases. It is further claimed that when fed to animals at the rate of 2 to 3 grams per living kilogram of animal, per day, it results in "better milk, eggs, meat, and fur." [13]

In the maritime states of Europe and North America and in Oceania and the Orient, farmers living within convenient traveling distance of the shore gather seaweeds for use as manure. Because the weeds are bulky and watery, it takes 20 to 50 tons an acre to supply enough nitrogen, phosphoric acid, and potash to satisfy the requirements of farm crops. Therefore it is economical to use them only within 8 or 10 miles of shore and only when labor is plentiful and not too dear. The transportation cost can be reduced somewhat by allowing the plants to dry partially on the beach before carting them off, but if they are left too long to the weather, some of their nutrients, especially potash, will be lost.

In general, fresh seaweeds contain at least two-thirds as much nitrogen as average barnyard manure, about one-third to one-half as much phosphoric acid, and about twice as much potash. Its balance as a fertilizer can be improved by adding superphosphate. The trace element constituents must make seaweeds especially valuable for some deficient soils, but here again, for scientific use, seasonal, geographic and species differences in concentration must be taken into account, together with the particular needs of the soil to be treated.

It is not only their nutrients and minerals which give seaweeds manurial value, but their physicochemical action on soil as well.[14] In fact, soil conditioners may ultimately prove to be one of the most important seaweed products for agricultural use. The more soluble salts of alginic acid like sodium alginate seem to enter into firm chemical union with constituents of the particles of soil to which they have been added. Whatever the mechanism, the result is to increase the water-holding power, the stability of soil crumbs, and consequently the availability of oxygen to all organisms living in the soil—microscopic and macroscopic, animal and plant.

Another valuable potential use of seaweeds is as a source of antibiotics. When microscopic fresh water algae like *Chlorella* (of which there are closely related marine forms) are cultivated, the nutrient media in which they are grown must be renewed from time to time. Otherwise, a substance which the plants synthesize limits their own growth. This antibiotic substance also can inhibit growth and metabolic activity of other microscopic algae as well as of some gram positive and gram negative pathogenic bacteria. This discovery was put to very good use during the last war. In several military camps in California and Nevada, open sewage settling pools were heavily inoculated with *Chlorella* and thereby made bacteriologically safe enough so that their effluents could be discharged into local streams without endangering public health. During the summer months, the coliform count was often actually lower in the non-chlorinated pools inoculated with *Chlorella* than in the merely chlorinated pools.

Scientists of the University of California [15] systematically examined Pacific coast marine algae for antibiotic activity. In the course of these researches they obtained from samples of many species of seaweeds extracts which inhibit growth of one or more of three species of bacteria grown in laboratory cultures. The conditions of the experiments rule out the likelihood that this antibiotic effect could be ascribed to iodine or to ocean-borne bacterophage or other contaminants of the algae.

The results of these and later studies show antibiotic activity to be present in the green alga sea lettuce and among several species of browns and reds. It varies in strength from one part of a plant to another, and from one species to another. The assortment of bacteria affected varies among species. It is neither present in all species nor evenly distributed throughout the body of any plant in which it occurs. For example, extracts from fronds are always more active than those from the stipes. It runs a seasonal cycle that parallels in a suggestive way the cycle of trace elements and of vitamins. The antibiotic substances seem to be absent during the winter, at which time the trace elements and vitamins are at their lowest ebb. At around the same time the concentrations of proteins and of alginic acid are highest. The significance of these relations remains a subject for future study.[16]

The antibiotic action of marine algae may explain the preservative value of agar, referred to above. Natives of some Pacific islands apparently use the same principle in wrapping fresh fish in the large fronds of certain seaweeds to delay putrefaction.

The twentieth-century wars have stimulated algal industries to emerge from a rather low level of technological development. Previously these industries had always been directed towards the extraction of only a few products like iodine, potash, soda, and agar, while other constituents of unknown or unappreciated value were wasted. The process of extracting sodium carbonate from the ash of burned kelp originated in France in the seventeenth century. From this beginning an industry grew, spread, and flourished in northern Europe during the eighteenth century and part of the nineteenth and in Japan during the nineteenth and twentieth. With the discovery of other sources of soda, the kelp burning industry suffered a depression from which it was rescued by the development of a process for extracting iodine from seaweed and by an increase in the demand for potash.

For kelp burning, suitable species of algae are cut, dried, burnt, and the ashes treated for the recovery of sodium and potassium salts, iodides and iodine. This is wasteful, because the other minerals and the organic constituents are lost in the process. The kelp-burning industry became obsolescent when cheaper mineral sources of iodine were found, such as the nitrate deposits of Chile and the oil-well brines of California, and when underground deposits of potash were discovered and exploited. Kelp burning now persists only in a few places in France, in Japan, and perhaps in the Soviet Union.

In the United States, commercial harvesting of kelp began on the Pacific coast when World War I cut off the supply of potash, which had formerly been imported from Germany. Several factories went into the potash and iodine production business in California. One of them conducted intensive researches which led to the development of processes to extract a number of chemicals needed for war industries. Chief among these were acetone, acetone oils, potassium chloride, ethyl esters, and organic acids.[17]

But kelp is costly to harvest, and it contains so much water that it is costly to dry. Consequently, these American factories could operate profitably only during wartime. When the war ended, they closed for they could no longer compete with cheaper sources.

Seaweed manufacturers would have gone out of business long ago if iodine and potash were all that could be extracted from marine algae. In recent years they have been extracting from red and brown algae organic components called alginates, which are salts of alginic acid. This interesting chemical has the same function as cellulose in land plants; that is, it gives rigidity to the cell walls. It had been discovered in Scotland in 1883 but had remained unexploited for fifty years. The alginates have unique colloidal properties that make them valuable for a remarkable variety of purposes. Moreover, research going on in private factories, as well as in some European and Japanese governmental laboratories, is leading continually to new uses, new products, and improvements in production processes. Alginate factories are now located in the United States, the United Kingdom, Norway, Spain, France, and Japan.

Chemists define alginic acid as a "hydrophilic colloidal polymer of anhydro-B-D-mannuronic acid units." These units are strung together into a chain of great length. The carboxyl groups of alginic acid react with ions of the alkali metals, as well as of ammonium, magnesium, and ferrous iron, to form the corresponding alginates. These are soluble in water and form viscous solutions at low concentrations. Alginates of other metals, on the other hand, are insoluble in water. The alginates have varying properties depending on the metal to which they are attached.[18] Thus an alginate product can be controlled by appropriate chemical treatment.

Algin is widely used in food industries, for making jellies, and as a stabilizer of ice cream, icings, malted milk, and cheese. It gives body to cake icings and fillings in which a softer gel is required than agar affords. It is used as an emulsifying agent in mayonnaise and other salad dressings. The non-food applications of algin are numerous. To mention only a few: pharaceutical emulsions, pills, tablets, and ointments, hand lotions, toothpaste, shaving cream, sizing material in the textile industry, paper coating, creaming of latex, leather finishing, and wire-drawing lubricant. All these uses are based upon the colloidal properties of algin as such and not upon the properties of algin derivatives.

British scientists in 1944 wrote, "It seems clear that alginic acid fulfills the main requirements of a substance intended for use in the manufacture of fibres. It consists of long chain molecules of high molecular weight possessing reactive side chains." [19] Unfortunately, threads prepared from sodium or calcium alginate are dissolved by soap and soda. In some instances this disadvantage can be turned to an advantage, for soluble yarns may be used in the manufacture of delicate woolen, silk, or rayon textiles or for obtaining special effects. And soluble sodium alginate can be transformed into insoluble alginates of beryllium, cobalt, copper, nickel, silver, bismuth, antimony, zinc, cadmium, aluminum, chromium, barium, and strontium. Of these the beryllium, cadmium, and chromium alginates are the most promising since they are noninflammable, are resistant to decay, and can be spun into fibres.

One or two factories in Great Britain are producing a small but steady quantity of soluble calcium alginate yarn. This is being used in the disappearing thread technique of manufacturing lightweight woolens. Despite a great deal of effort, however, they are finding that in the present state of our knowledge, metallic alginates do not compete successfully with the conventional fibers of wool and cotton, nor with synthetics like rayon and nylon. This is because they are still too costly, they do not take a good color, they do not wear well, they vary too much in quality to permit satisfactory repeatability, and they have a relatively low dry strength and a very low wet strength. On the other hand they do have the advantage of being noninflammable, a property which alone may make it worthwhile to seek ways of exploiting these yarns further. Meanwhile, for general purposes, a great many technological problems will have to be solved before alginates can compete with other substances as raw material for synthetic fibers.

Red seaweeds have been used for 300 years in the manufacture of the gel-forming chemicals agar and carrageenin. Agar is extracted from a certain group of plants collectively called (by some botanists) the agarophytes, which includes various species of *Gelidium*, *Gracilaria*, and other genera. Carrageenin comes from "Irish moss" (*Chondrus crispus*). Both agar and carrageenin are sulfuric acid esters containing D-galactopyranose units joined by 1, 3-glycosidic linkages.[20] There are sufficient differences in structure, however, to give them differing properties and uses. Even agar itself varies in properties depending on its species, its place of origin, and the time of harvesting.

The properties of agar which give it unique value are its very high gel strength and the wide range of temperatures between the points of gelling and melting. A 1 to 2 per cent aqueous solution of agar, for example, solidifies at 35° to 50° C. and melts at 90° to 100° C.

Agar is a staple in bacteriological laboratories for making biological culture media. No satisfactory substitute for it has yet been found. It is also an excellent gentle laxative, and very popular in countries where over-refined foods seem to make such medicinals desirable. It is a principal ingredient in dental impression compounds to make a strong and rather elastic mould. Capsules made of agar are slow in dissolving and can be regulated in composition to carry a therapeutic agent past the stomach to a particular part of the intestine where it is needed.

In food industries, agar is added to cake icings to keep them from getting dry, brittle, or sticky. It is used as a stabilizer in sherbet, pies, meringues, mayonnaise, and salad dressing and as a gelling agent in jelly candies and similar confections. In canning industries it is added to meats, poultry, tongue, and fish to keep the product firm and in shape in the can.

Carrageenin is the gelatinous principle of "Irish moss," which is neither exclusively Irish nor a moss, but the red alga *Chondrus* *crispus*. Although it is very similar to agar, it differs in having a lower gel strength and in certain chemical particulars, such as that it contains small quantities of z-keto-gluconic acid, glucose, and pentose and that its sulfuric acid ester group is attached to C_4 and not to C_6 as in agar. It requires a concentration of 3 per cent or more to form firm gels, and these liquefy at lower temperatures than do agar gels. Carrageenin is used as a stabilizer for chocolate milk, ice cream, sherbet, cheese foods, as a thickener for icings, pie fillings, puddings and similar confections, and as an emulsifying agent in hand lotions, insect sprays, and sizing materials. Its property of coagulating proteins gives it value as a clarifier for beer.

In Japan farmers cultivate red algae as a side line. In recent years this has become the most important of the marine culture industries, in terms of number of persons employed, acreage involved, and total quantity of material produced. The principal crop is laver (Porphyra), which, made into a dried product, is one of the most popular foods in Japan. It is not cheap, however, One sheet of dried laver costs almost as much in the retail market as a hen's egg. One method of culture is to collect the spores on bunches of bamboo sticks or twigs stuck into the mud in an area of high salinity at a level which is just covered at high tide. Some time after the spores settle the bunches are transferred to an area of lower salinity where the fronds grow large and tender.[21] Bamboo racks and coconut palm nets stretched between poles have become more important as spore collectors. Japanese prefectural governments have been attempting to improve laver farms by deepening suitable flats with bulldozers, surfacing the bottom with coarse sand, plowing, and directing channels of stream-fed water of high fertility along strategic courses.

There are waste products resulting from the manufacturing processes of algal industries for which uses have yet to be found. The structure of alginic acid itself is still only partly known, hence is variously described (see p. 284 for one example). R. H. McDowell says ". . . the best evidence indicates a long chain of the pyranose form of d-mannuronic acid, with glycosidic linkages joining the rings."[22] The structure usually assigned to alginic acid relates only to a small part of the whole molecule. As for the organic chemicals other than the alginates, methods for the preparation or extraction of mannitol, laminarin, fucoidin, D-glucose, L-fucose, and fucosterol have been developed in the laboratory. To find uses for these substances would require, first, a great deal of analytical research in chemistry, for the molecular structures are known for only a few of them; and, second, a great deal of technological research to develop economically feasible methods of mass production.

Perhaps the most difficult technological problem impeding the exploitation of algal resources is the high water content of these plants. One lot of fresh brown alga weighing 1,000 tons contained about 836 tons of water. It is often not feasible to remove this water by drying the weeds in the air, particularly in humid climates, and it is expensive to remove it with heat driers. So far, efforts to find other methods such as pressure, electro-osmosis, and plasmolysis, have not been very satisfactory.

Thus, by the time algae have been harvested, transported to a drying center, and dried, they have already become too costly for humble uses except in places where labor is plentiful and cheap. Even there it is not feasible to carry them far inland for agricultural applications. On the other hand, seaweeds contain materials having peculiar properties which make them valuable enough for the sophisticated needs of industrialized people to justify the high production cost. The extraction and refinement of these materials and the quality control of the final products require elaborate industrial establishments staffed with well-trained chemists. In general, these must be located near dependable sources of raw material, and they must also be near industrial centers where machinery, equipment, and skilled and professional workers are readily available. These requirements are strong obstacles to developing the use of seaweed resources in technologically backward areas.

Perhaps the most troublesome problem besetting people who manufacture algal products, as well as those who search for new uses of algae, is the variation in chemical composition of the plants. In many places botanists cannot tell how much geographic variation is attributable to ecological influences and how much to genetic differences in the stocks. On this question George F. Papenfuss of the University of California has written (in a personal letter):

> People come to me repeatedly for advice concerning the identity and the probable variability of the plants which they are investigating. They find that even common species, which presumably are well known, vary immensely in their biochemical properties; and the question arises whether or not they are dealing with one species or a complex of closely related species. In all instances our answer must be that we do not know, for the plants have never been adequately studied.
>
> Since a thorough knowledge of the plants themselves is in all instances a prerequisite to work on their physiology, biochemistry and possible use, I believe that in the long run, the best investment in seaweed research would be in the field of systematics.

Jean Feldmann writes:

> First of all it is necessary to complete our knowledge of the chief aspects and the characteristic formations of the marine vegetation of the areas of the

world which have not as yet been explored from this point of view. Up to now we possess detailed studies only for some favored regions. A more extensive survey of the marine vegetation would make possible detailed comparisons between the vegetation of widely separated regions situated in approximately the same latitudes and where, as a result, ecological conditions should be practically the same.

The vast majority of red algae are grouped in the subclass Florideae. This includes the agar-bearing plants. Concerning these, Kathleen Drew says, "The floridean algae of large areas of the world are still completely unknown." [23]

It appears, then, that the arguments advanced earlier (pp. 53 ff.) on the need for research in systematics are as true of the marine plants as of the animals. This kind of research is not nearly adequately supported by universities or by governments, nor is it likely to be financed by industrial companies.

The biology of seaweeds is another neglected field of research. The same kind of questions apply to them as to the marine animals. What characteristics of environment are critical to their existence and well-being? What are their rates of growth? What are optimum rates of harvesting? These are fundamental questions. Seaweeds have diseases. For instance, the red rot is one of the most serious problems of laver culturists in Japan. What are the vectors of such diseases? Seaweeds are also prominent elements in the ecology of inshore environments. On that ground alone we should no longer continue to neglect the study of these interesting and important plants.

Looking Forward

The present world harvest of marine fishes, invertebrates, and algae is about 26.3 million metric tons a year. Disregarding economic and technical limiting factors, how much could that figure be increased? By a factor of two? Of four? Of ten? That is what people interested in developing marine resources would like most to know, for it bears heavily on the question of how much they should invest in efforts to achieve possible increases. Unfortunately there is simply not nearly enough of the right kind of quantitative information by which to calculate an answer which would have any dependable significance. The best we can do is to make a guess on the basis of (1) what people are now taking out of the sea in areas where fishery industries are relatively advanced, that is, North America, Europe, and Japan, (2) what we know about the geography of fertility and of suitable fishing weather, and (3) the location of harbors for fishing craft. Thus in making this estimate, we limit ourselves by present conceptions of the seas' productivity and by present knowledge of the seas' resources. We also limit ourselves to the present philosophies of exploiting the sea, to existing uses of marine organisms, to the kinds of animals and plants that are now used, to the known methods and equipment for producing them, and to the parts of the sea where it is economically and technically feasible to work with those methods and equipment. In the shadow of these limitations, it looks as though the total world production could increase in the natural course of events only by a factor of something less than two.

We can speculate more boldly about the seas' potential resources if we do not limit ourselves to tradition. As it is now, sea food the world over includes only a few species which are offered in a limited number of products. Suppose we think beyond these familiar things. Suppose we think of other possible products, such as protein flours, soil conditioners, pharmaceuticals, and insecticides. Suppose we imagine there existed some method of collecting sea animals and plants that did not depend on hunting or on catching with nets or hooks. As far as animals are concerned, it might mean herding them into a strategic spot with some such stimulus as sound, light, a chemical, or electricity. It might mean taking them out of the sea at that spot with pumps. Suppose all the brackish inshore waters were cultivated as farms for fish and invertebrates. Suppose that practical methods of improving salt-water environments were developed. This might mean fertilizing or feeding in the cultivated areas; it might mean destroying predatory animals of little value; it might mean installing artificial shelters for young fish. Suppose, too, that knowledge about genetics of marine organisms advanced to the point where it was possible to select for cultivation the stocks having the most desirable qualities in any given environment. Suppose the rates of harvesting all species were scientifically adjusted to provide the optimum yield of all, and suppose marine industries were flexible enough to permit shifting their attention effectively from one species to another. In other words, supposing that these industries were not hag-ridden by backward conventionalism as they are today, then the possibilities of enlarging the use of sea resources might expand very greatly.

Although in general the movement of marine industries is toward improvement, it is a drifting movement, not well aimed, and wasteful. To advance purposefully and aggressively requires fundamental knowledge about the biology and chemistry of organisms within the sea. Throughout the preceding chapters there are frequent references to the need for systematic biochemical assay of marine organisms. This is an essential precursor to developing a science dealing with marine resources after they have been gathered. It is essential to finding uses for species which are now neglected or wasted. It is essential to improving methods of preserving, storing, and transporting those which are now badly used.

One of the most important complexes of problems concerns the development of cheap methods of producing fishery products which are of uniform quality, keep well, and are easily shipped. This is needed in hot countries where marine faunas are composed of relatively small populations of many species and where catches are therefore heterogeneous. It is needed where refrigeration facilities are lacking, where transportation is slow and irregular, and where masses of people who are protein-starved live far inland. Perhaps the product that might best meet all these requirements is a protein flour made of marine organisms.[1]

The technological problems of making fish meal a cheap, acceptable, edible product of standard quality are not solved. There is much need for developmental research there. Perhaps this could best be conducted in a region where such a product is most needed, and by food technologists who are sympathetic with local tastes.

If edible fish meal were perfected and if people became willing to accept it, the demand for raw material would expand enormously. Then interest should turn to many species which are now neglected. Some of these are to be found in the family of the herrings and of the jacks, among certain deep sea fishes like the myctophids (which seem to be enormously abundant, but which we have yet to learn how to catch in large quantities), and among the thousands of species of invertebrate animals whose biochemical properties have never been assessed.

Large quantities of sea foods can be expected to occur in certain areas of the high seas where peculiarly favorable oceanographic mechanisms bring water to the surface from deep levels where great stores of nutrient salts have accumulated. The regions where such areas are known or expected to occur have been shown in Figure 14 (page 37). All of these need to be investigated. One of the regions that has been under extensive exploration by the United States Fish and Wildlife Service is the equatorial current system of the Pacific. These studies have demonstrated the existence of a band of water 400 to 600 miles wide (perhaps extending all the way across the Pacific Ocean) which is rich in nutrients, in plankton, and in oceanic pelagic fishes. Of particular interest in this zone are tunas, which are among the most valuable of all marine species. These are evidently abundant enough to support high seas fisheries, although much developmental work needs to be done to improve the efficiency and reduce the cost of harvesting. Other species that abound in this zone are wahoo, pomfret, dolphin, marlin, and squids. Similar zones occur elsewhere in the world and also remain to be explored and exploited.

The distribution of sperm whales may be a most useful guide to the location of these areas. Townsend,[2] studying log-book records from 1761 to 1920, has plotted the position of whaling ships on days when they took one or more animals. Occasional catches were widely scattered between latitudes 50°S. and 50°N. Within this zone, however, there are certain areas where whalers had the most consistent good luck (Figures 22 and 23, pages 261 and 262).

Sperm whales feed in deep water, mostly on squids and cuttlefish, including species which grow to gigantic size. Virtually nothing is known about the ecology of those great depths. The giant cephalopods must be exceedingly abundant to support the toothed whales. What supports *them?* There may be some association between good whaling grounds and good tuna grounds. At least in the Pacific the most extensive good sperm whale grounds are in a band across the ocean close to the equator but just a little south of the band of water which is rich in tuna. Very likely the two groups of animals are nourished in different parts of the same hydrographic system. If this is true, what about other places which sperm whales frequent, for example, the grounds northeast of New Zealand, the Japan ground, the extensive grounds of the North and South Atlantic, and the small grounds in the western part of the Indian Ocean? Most of these are in parts of the sea which have not been subjected to fishery exploration and they are not associated with existing great fisheries.

The question is, then, whether these grounds are associated with important untapped resources. We do not know. Until we do, our estimates of the potential production of the oceans of the world cannot be very significant. True, there are techniques of measuring the biological productivity in samples of water, but in the present stage of their development these techniques depend on the significance of the samples. They depend on our present conceptions of bionomics in the sea, which may be far from complete. They tell us little about what supports life in the deep levels beyond the range of ordinary photosynthesis, or about the abundance of harvestable useful organisms which, by grazing over wide areas and by aggregating into hordes or schools, concentrate organic material into relatively small space. Thus total biological productivity alone is not yet a satisfying measure of what and how much man can take out of the sea.

What, then, is a measure of it? How much can the yield of the sea be made to increase? The answer is, no one knows.

Does it seem possible that it could be increased enough to add significantly to the food supply in protein deficient areas? Certainly, but the size of the increase will depend on the solution of many problems. Some of these have been discussed in this book.

A great deal of money is now being spent on marine research. Could it be reallocated so as to fill in the existing gaps? No; there is no line of marine research which is being excessively supported. Indeed, with a few rare exceptions, the contrary is true. Impoverishing one kind of research to start another will contribute nothing to marine science.

It is true that scientists are never quite satisfied with what they have. They can generally use more—more assistants, more money, more field and laboratory equipment, more conferences, and so forth. However, in this particular field of science, considering the variations in all elements of the marine environments, the difficulties of observing and measuring them, the size of the oceans, the cost of operating vessels, the massive task of sorting, identifying, and counting biological collections and of analyzing chemical and physical material, of tabulating and working up quantitative data, and of studying all this to see what it means, too little support is given to marine research. True, fairly large amounts are spent in certain areas, but these are mostly for problems of sustaining, improving, or extending the existing great fisheries. Only negligible amounts are used for learning to understand the marine wilderness, or for pursuing new conceptions of full exploitation of its resources.

Suppose it were feasible to finance only one kind of activity. What would make the most significant contribution to expanding the use of ocean resources in a protein deficient region? In other words, it is very fine to be comprehensive, but perhaps that luxury cannot be afforded now. There is not enough time for that. Let us strike immediately at the heart of the problem.

Very well; where is that heart? Whatever kind of research is to be carried out will require scientists. There is a shortage of scientists. Perhaps training men to be scientists is the heart of the problem. We might establish small teaching centers in regions of critical need where resident faculties could give courses consisting of lectures, readings, and assignments. However, these courses should cover matters of particular application to the regions where the centers are situated. Therefore the faculties must have experience about their respective regions. Moreover the faculties must be able to keep alive intellectually. All this necessitates their conducting research in their regions. Therefore, there must be provision for some research as well as for teaching.

If the research is to have any bearing on the purpose of the centers, if it is to help the teachers lead in the advancement of fisheries in their regions, the research must deal with significant problems. Teaching alone, then, is not enough for the centers. There must be research too. If we were to concentrate on only one kind of research, what should that be? A thorough taxonomic and quantitative survey of the biological resources of each region would perhaps be the most useful thing to undertake. However it might be discovered early in such a survey that some of the animals in the area were poisonous (see Chapter 11). That is a very important problem in the tropics. That problem should be attacked before any use could be made of many of the species covered in the survey. Meanwhile the survey would find difficulty in catching some species of possible commercial value, which would necessitate inventing new kinds of fishing gear. Trial and error methods are a frequent approach to gear problems, but they are not efficient and not likely to advance fishing as a science. It would be much sounder to base these inventions on a knowledge of behavior of marine life. However, that would require special research, special scientists, and special equipment (Chapter 7).

It would be discovered in the course of a quantitative survey that the abundance of the marine organisms is not stable, that it oscillates and fluctuates. If investors are to be advised to start new industries, there had better be some sound information about the probable magnitude of these vacillations and about their causes. Consequently, these investors will need advice about the effects which fishing has on the abundance of the stocks, and if their operations are to be scientifically managed, they will need accurate year to year predictions of catches. Obviously such advice must be based on the results of systematic and environmental research (Chapters 5 and 6).

The survey would disclose a number of species which are abundant, sizable, and nutritious, and which therefore have possible commercial value. However, because these species are not used and are unfamiliar, methods of preparing and preserving must be devised and these would require technological studies. Here fundamental biochemical research would probably be more economical and fruitful in the long run than random kitchen-trials.

The centers might avoid these complications by specializing in a nonbiological subject such as vessel improvement. At first this seems like a good solution to the problem. However, the design of vessels for fishing must take into account the kind of fishing; therefore, the kind of fish; therefore, the habits of the fish, and so forth.

Thus, no matter where we attack the problem, we are forced eventually to conclude that the full use of sea resources depends on a web of knowledge. No thread of this web can be singled out as exclusively essential and no one knows enough about the sea to say which threads of the web can be safely ignored for the sake of economy. Nor does this knowledge stop with the sea. One of the most important fields for research is in principles of marine fishery management. Here I use the word "management" in a very broad sense, to include business management, direction of fishery industries, fishery conservation, and laws affecting fisheries. These topics are not independent of each other.

Comprehensiveness in marine biological research is *not* a luxury. It is a necessity which has been much neglected in the programs of most institutions. Our use of the sea as a source of food and other biological raw materials is technologically and philosophically about 200 years behind our use of the land. We have yet to search fully all the corners and depths of the seas, collect and identify all the species of its animals and plants, assay their biochemical composition, explore their possible uses, and develop efficient means of harvesting those worth using. We have yet to learn what controls the rates of their production, the laws governing the patterns of their behavior, or what we can do to manipulate environment to our advantage. And we have to learn how to put all this knowledge to profitable use as it develops. There is no reason to believe that the sea can meet all of the needs of humanity. Indeed, with present antiquated methods and philosophies of using its resources, there is no reason to believe that very much more can be added to present harvests.

But why put up with such antiquity? Why should not technologies and philosophies advance? If we learned how to use the sea resources fully and scientifically, the material rewards should well compensate for all the investment that would be required for the learning. There is no way of evaluating these rewards now. Nor can anyone honestly promise that they will in fact be forthcoming, any more than anyone could once have promised the ultimate use of atomic energy. There is no simple, direct short-cut to a full understanding of the proper uses of the sea. The most economical, efficient way to reach that understanding is not to try to do it penuriously. If we really desire to exploit the sea fully, if it is knowledge that we need to accomplish that purpose—and that is the theme of this book—then we had better make the necessary costly investment and put full effort into the job of acquiring that knowledge.

Notes and References

PART I

Chapter 2

1. Figure 2 was adapted from "Study in Human Starvation. 1. Sources of Selected Foods," Plate 8, *Atlas of Diseases* (New York: American Geographical Society, 1953).
2. Figure 3 was adapted from "Study in Human Starvation. 2. Diets and Deficiency Diseases," Plate 9, *Atlas of Diseases* (New York: American Geographical Society, 1953).
3. Figure 4 was adapted from W. S. Woytinsky, and E. S. Woytinsky, *World Population and Production* (New York: The Twentieth Century Fund, 1953), p. 421.
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5. Figure 5 was compiled by John Lyman from the 1953 Appendix to *Lloyd's Register;* the *World Almanac* (1952); and the *Bulletin of the American Bureau of Shipping* (October 1953). A number of dependent territories were rated on the basis of personal judgment.
6. Figure 6 was adapted from W. S. Woytinsky, and E. S. Woytinsky, *World Commerce and Governments* (New York: The Twentieth Century Fund, 1955), p. 317.
7. Figure 7 is based on data supplied by the U.S. Navy Hydrographic Office.

Chapter 3

1. For the purpose of this model, I assume that it takes five pounds of food to produce one pound of fish flesh, and an additional amount equal to 3 per cent of the body weight, daily, for maintenance. This is a guess, based on data from feeding studies carried on with trout and other species. I have used growth and length-weight data on striped bass as published by Eugene C. Scofield, "A Simple Method of Age Determination of Striped Bass," *California Fish and Game* XVIII (1932), No. 2, 168–70.
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