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Van Camp Sea Food Co.

VAN CAMP SEA FOOD COMPANY

DIVISION RALSTON PURINA COMPANY
840 VAN CAMP STREET, PORT OF LONG BEACH, CALIFORNIA

POTENTIAL RESOURCES OF THE OCEAN

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January, 1965

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FOREWORD

Last year we were asked on several occasions by different entities in and out of the United States Government to participate in thinking and planning respecting what should be the nature, size and scope of the National Oceanographic Program. As one part of this activity we prepared our thoughts in a paper "Fishery Aspects of the National Oceanographic Program." We circulated copies of this to colleagues in the industry, academic ocean researchers, nutritionists, and governmental officials involved in planning and carrying forward such activities. We asked that our ideas be read carefully and critically so that we could all move forward more expeditiously to a greater understanding and use of the ocean.

The response to this request was fruitful beyond our expectations and we wish to use this opportunity to thank each of you who took of your busy time to respond.

Obviously if the government, or the world, is going to invest the large sums in ocean research suggested in that paper, and in our considered judgement required if the world ocean harvest is to be maximized, there requires to be some account taken of whether the potential resources of the ocean are adequate in scope to justify the expense.

The Intergovernmental Oceanographic Commission, a semi-autonomous body in UNESCO, has been dealing actively with the scientific aspects of this question. Pursuant to its requests, its two scientific advisory bodies (the Scientific Committee on Oceanic Research (SCOR) of the International Council of Scientific Unions, and the Advisory Committee on Marine Resources Research (ACMRR) of the Food and Agriculture Organization of the United Nations) have made reports to it upon a General Scientific Framework for World Ocean Study. These two reports are in the process of publication and distribution by IOC to the ocean scientific community of the world for critical comment by individual scientists as well as by their several organizations and representatives.

In our view both of these documents are of extraordinary quality and merit your serious attention and comment. The problems of exploration, understanding and utilization of what 71% of the earth's surface which comprises the World Ocean are so complex, huge and varied that their elucidation will require the concerted efforts of all ocean scientists from every race, country and society. A world organization such as IOC is no better than its constituent scientists make it. The planning work upon which IOC is engaged is of fundamental importance to the progress of ocean science and its ability to contribute to mankind's welfare. It will be no better than you make it through your thoughtful contributions.

The Committee on Oceanography of National Academy of Sciences/ National Research Council has been examining another aspect of this matter, the economic justification of ocean research. It has just published an excellent study of the application of cost-effectiveness technique to support the case for basic ocean research (see Greenberg, Science, December 25, 1964, vol. 146, no. 3652, pp. 1659-1660). The oversimplified conclusion of the report is that an annual non-defense expenditure of $165 million over the next 10 to 15 years could be an "essential component" in saving $3 billion a year, chiefly through conservation practices, and in adding annual production of about another $3 billion. We commend this report to your close examination.

Our Department of Resources has been asked to comment on the probable extent of harvestable resources of the ocean. In a lecture at Universidad Agraria, La Molina, Lima, Peru in November; again at UNESCO's first Latin-American Seminar on the Oceanography of the Eastern Pacific Ocean at the end of November; and in a lecture to the Air War College, Maxwell Air Force Base, Alabama in early December, this subject was dealt with in a preliminary manner. The attached document is the body of the latter lecture. We would appreciate having your critical comments on its concepts so that we can move more surefootedly in our examination of these matters.

Sincerely yours,

Van Camp Sea Food Company

Gilbert C. Van Camp, Jr.
President
January 15, 1965

POTENTIAL RESOURCES OF THE OCEAN

Wilbert McLeod Chapman
Van Camp Sea Food Company

There are major difficulties in giving any clear concept of the potential resources of the world ocean. A first difficulty is that the ocean is so big, various, and variable, that one can harldy form a clear, simple idea about it. The second is that we really do not know very much about the ocean and its resources so that there is difficulty in saying what, and how much, will turn out to be of use to man. Thirdly, for the most part, it does not belong to anybody in particular and it is quite difficult to use the concept potential resource in such a context because almost everything else we think about, except the air, belongs to someone or some country, and even the air space over a country belongs to that country in a real sense.

THE SIZE OF THE OCEAN

Jet airplane travel is destroying gradually a person's ability to judge large geographic distances. Even so it takes the better part of two days to fly Singapore to San Diego, one is not in sight of land very much during this time, and one is only flying over one of the larger parts of the world ocean, the Pacific. Even the Pacific seemed to be larger back about twenty years ago when it took seventeen days and nights of travel on a troop ship just to get from Guadalcanal to San Francisco, and no land was seen in the interim at all.

Perhaps it suffices to say that the ocean is the biggest thing there is around that one can readily think about, and it is too big to comprehend all at one sitting. Like a billion dollars, it is a useful concept and a nice thing to have, but a little difficult to get specifically focused in mind as to details.

All of the communicating seas and oceans of the world, known under the collective name World Ocean, cover about 70.8% of the earth's surface and contain about 1,370 million cubic kilometers of water (Moiseev, 1964). Dissolved in this water is some of almost everything there is on land and air because water is such a wonderful solvent, and the ocean has been here so long, possibly before there was dry land. Because there is so much water there is an enormous amount of material of any sort dissolved in it from gold to hydrogen. Some things are simply more abundant than others. With few exceptions the ocean is also the oldest thing around, because most land, including the highest mountains, have been under its surface at one time or another, and sometimes more than once.

Life started in the ocean and there it still thrives in such enormous profusion and volume as to stagger the imagination. More living matter is currently being created in the ocean than on land for the simple reason that not only does nearly three-quarters of the solar radiation striking the earth fall upon the ocean, but by penetrating into the ocean to a life developing extent by fifty or more meters, it generates new life through microscopic plants that dwell throughout that thickness, rather than just that rising from the surface as on land. Most organic matter on earth is in the ocean; very large quantities of it (and perhaps as much as 90%) is in a dissolved state and not even organized into living matter. The volume of living matter itself that is in the ocean is so vast as to defy comprehension. (Kesteven, 1963).

For eons before there was life on earth, and ever since there has been, a rain of precipitates filtering down out of the ocean has been slowly building up sediments on its bottom. Since life began there has been added to this rain of sediments the debris of living things that did not go back into solution upon death, so that the ocean floor is covered with a great variety of materials useful to man, but seen on land only where upheavals of land masses have brought these sedimentary deposits up to the air, or at least shallowly enough under the earth so man can dig them out. (Revelle, et al, June 1964).

While the narrow, shallow rim of earth under the ocean and around the continents, called the continental shelf, will probably turn out, upon full investigation, to be composed about like the adjacent land masses, it is not necessarily so that the composition of the hard rock under the sediments smoothing over the bottom of the deep-sea bed (or of the submarine hills, valleys and mountain ranges borne by it) will turn out to be the same. In any event the crust of the earth (and all land we see is so called by geologists) is much thinner under the deep-sea bed than it is under the land masses, and its composition there is not yet well known. The mantle below it, on which the crust floats, is perhaps within practical possibility of being drilled into to see from what it is made, and it is the function of the National Science Foundation's "Operation Mohole" to do this. Until this is successfully accomplished, our knowledge of composition of both crust and mantle under the deep-sea bed will remain conjectural. (Oroman, E., 1964; Thompson, G.A. and M. Talwani, 1964).

THE NEWNESS OF OCEAN SCIENCE

At least since there have been men recognizeable as Homo sapiens abroad, and for a long while before that, the sea has been used and studied. The ancients have left their kitchen middens containing the shells and fish bones from their diets behind them as mute witness to their interests in the ocean and its resources. Long before the dawn of the written word certain sea shells were magic symbols of fertility to the dawning neolithic society and were carried far inland by commercial trails long forgotten about, to be found in the lowest village and cave deposits by today's archaeologists.

Aristotle drew together existing knowledge of the ocean and its inhabitants up to his time, and made many natural history studies and conjectures himself upon his observations of the sea and its living inhabitants.

But it was only about 100 years ago that man began a systematic scientific inquiry about the sub-surface ocean with the famous voyage of the "Challenger". It was only 65 years ago that a few northern European scientists got together rather informally to found the International Council for the Exploration of the Sea. Thirty eight years ago a Committee on Oceanography appointed by the National Academy of Sciences took note of the modest state of ocean research in the United States. The interest thus aroused caused private benefaction to come forward. The Scripps Institution of Oceanography and the Wood's Hole Institute of Oceanography thus got their starts. Another NAS Committee on Oceanography reported in much the same vein in 1949, but its report was swamped out of public notice by the Korean War (Anonymous, 1960).

Late in the year 1957 a Third Committee on Oceanography was established by the National Academy of Science. Its report, appearing as recently as seven years ago, was when American Oceanography began to grow. In that year the United States expenditure on oceanography was about $30 million. It has now grown to somewhat more than $125 million per year.

Offshoots from this vigorous committee resulted in the Scientific Committee on Ocean Research being formed in the international field by the International Council of Scientific Unions. From this group, spurred on and supported by NASCO, came the organization of the mammoth International Indian Ocean Expedition, the formation of the Office of Oceanography in UNESCO, and finally the Intergovernmental Oceanographic Commission as a semi-autonomous body in UNESCO. Its first session was held as recent as 1961.

So recently has ocean science and inquiry begun to grow. So large and unknown yet is the ocean.

THE OWNERSHIP OF THE OCEAN AND ITS RESOURCES

The other attribute of the ocean, besides its size and our ignorance about it, that is confusing is that nobody owns it. It is true that there are four classes of oceanic salt water as to ownership. The first is the inland waters which are the absolute property of the coastal country; the second is the territorial sea which, for most practical purposes, belongs to the coastal country except that the international community has some liens upon it such as the right of innocent passage through it; the third is a contiguous zone 12-miles wide in which the coastal country has jurisdiction for narrowly prescribed, and limited special purposes; and the fourth is the rest of the salt water, the most of it, the high seas, which belongs to everybody.

There have been a great many international conferences, arbitrations and adjudications among the community of nations over the past thirty-five years aimed at establishing rules of law under which man's activities in these four classes of salt water can be regulated for the convenience of mankind, and to define the boundaries between them. The most important of these was the Conference on the Law of the Sea convened by the United Nations in Geneva, Switzerland, in the spring of 1958. It resulted in four conventions that codified most aspects of the public Law of the Sea. These were: Convention on the High Seas; Convention on the Territorial Sea; Convention on the Continental Shelf; and Convention on Fishing and the Conservation of the Living Resources of the High Seas.

The first three of these conventions have been ratified by enough countries (22) to put them into force; the fourth requires only five more ratifications to come into force also. At the rate they have been coming it should be in force by the end of 1965. Accordingly, for practical purposes, these four conventions can be assumed to represent international law in this field. The two prime questions not solved by them are the breadth of the territorial sea and the authority of the coastal state over fisheries lying on the high seas off its coast.

This is an extremely complex and lively field of law. There are a number of good recent books on it in most principal languages. An excellent recent review of the whole subject in English is McDougal and Burke "The Public Order of the Oceans", Yale University Press, 1962, 1226, pp. The following summary of the law is vastly oversimplified but will perhaps serve present purposes.

Inland waters and their contained resources, the resources under them, and the air space over them belong to the adjacent country in the same manner as does its land space.

The boundary between inland waters and the territorial sea have been pretty well stabilized in the above conventions. This is no longer a very active field of dispute among nations, although a few small places with odd geography, such as the Persian Gulf, may lead to disputes which will further define this legal situation.

The territorial sea, its contained resources, the land under it and the air above, also belong to the adjacent country as does its land space except that, subject to certain specific conditions, the coastal country cannot interfere with, or hamper, the innocent passage of ships through its territorial sea.

The means of determining the boundary of the territorial seas as between adjacent countries is adequately regulated by these conventions. The boundary between the territorial sea and the high seas is not so determined.

An examination of the history and antecedents of the 1958 and 1960 Conference on the Law of the Sea enables one to say, however, with some degree of assurance, that the boundary between the territorial sea and the high seas is a line each point of which is equidistant from the boundary between the inland waters (or land) of the coastal state and its territorial sea. There is a concensus that the X of this formula is not less than 3 marine miles nor more than 12. Nations have a right to choose any distance desired between these limits, but no clear obligation to recognize the sovereignty of another nation over an X distance of more than 3 marine miles.

In a band of sea every part of which is within 12 marine miles of its coast, called the contiguous zone, the coastal state may exercise the control necessary to prevent infringement of its customs, fiscal, immigration or sanitary regulations within its territorial sea, and to punish infringement of the above regulations.

The rest of the world ocean is open to all nations, coastal or non-coastal, and is called the high seas. On, in, or over this high seas, all nations have, among other things: 1) Freedom of navigation; 2) Freedom of fishing; 3) Freedom to lay submarine cables and pipe lines; and 4) Freedom to over fly.

The "Convention on Fishing" again asserts that all states have a right for their nationals to fish on the high seas subject to their treaty obligations, the interests and rights of coastal states provided in the convention and the duty to provide for the conservation of the living resources of the high seas. Conservation is defined as the aggregate of all measures rendering possible the optimum sustainable yield from those resources so as to secure a maximum supply of food and other marine products. The special interests and rights of the coastal state are defined in such a manner that it can enforce conservation, as so defined, of resources being fished in the high seas off its coast by itself or others, or only by others. Under some conditions it can even enforce conservation measures on the fishermen of other states on the adjacent high seas unilaterally. Provisions are laid down for the peaceful settlement of disputes arising out of these matters running, in the last instance, to compulsory arbitration according to criteria laid down in the convention.

Under the "Convention on the Continental Shelf" the sovereign rights to explore and exploit its natural resources pertain to the coastal state. These resources are defined as the mineral and other non-living resources of the sea bottom and sub-soil together with living organisms belonging to sedentary species, that is to say, organisms which, at the harvestable stage, either are immobile on or under the seabed or are unable to move except in constant physical contact with the seabed or the sub-soil. The continental shelf is defined as the seabed and sub-soil of the submarine areas adjacent to the coast (and islands) but outside the area of the territorial sea to a depth of 200 meters or, beyond that limit, to where the depths of the superjacent waters admits of the exploitation of the natural resources of the said areas. These rights by the coastal state on the continental shelf specifically do not affect the legal status of the superjacent waters as high seas, or that of the air space above those waters.

If one draws on a very large globe a line 3 marine miles from the coast, it can scarcely be told from the line marking the coast; a 12-mile line stands out a little more clearly. But most of the world ocean lies outside a line 12-miles from any land. Subject to the obligation to not overfish the resources lying therein, all states have a right for their nationals thus to utilize these resources. The resources become the property of him who first reduces them to his possession. This is so of the mineral and non-living resources of the deep seabed, which, again, occupies most of the space under the high seas.

It may be noted that not only does no country have any private property rights over this, the larger part of the earth's surface, but that no person can obtain such a private property right at all. Such rights as do exist to harvest and use these resources belong to the several countries and not to private persons. A fisherman, or a miner, on the high seas, can be the object of international law but only sovereign nations are its subjects. A fishermen or a miner does not harvest the resources of the high seas or the deep seabed under any rights flowing to him from international law; he can only exercise the rights that belong to his sovereign permitted to him by the municipal law of his sovereign.

Reflection will bring you to the conclusion that everything you can think of on earth belongs to some person, or to some group of persons organized as a sovereign government, except the high seas, the deep seabed, their resources, and the air above. Departure from this thought to the contemplation of the lack of property rights over the remaining 70% of the earth takes a little doing. Bankers normally show a hesitance in providing loan capital without the security of a piece of property, or something tangible, that can be seized and sold in case of failure of the business. Large industry has shown hesitance in the exploration and exploitation of resources it cannot own. (Mero, 1959). Much talk is heard of fish farming and the improvement of fish breeds as with domesticated animals. But no farmer can afford to raise stock that can be harvested willy-nilly by any other farmer, nor can he undertake the costly process of improving the breed only to turn it loose in the enormous common pasture where it can be harvested by a foreign fisherman a thousand miles away without it even being identified. Except for the general rights noted above international law scarcely goes out upon the high seas. There is nobody of uniform law over this vast area. Citizens upon it respond to the municipal law of the country whose flag their vessel flies.

No nation has yet been strong enough to command all of the world ocean, nor is any such likely to arise in the foreseeable future. All aspects of the ocean (its resources and its role as a highway carrying most of the world's commerce) are too valuable to all nations for them to allow it to come under the governance of anyone.

But as we go more upon the ocean, and occupy it and its bottom more fully, as science and technology is enabling us to do in a vast rush, a body of law for man's governance in this enormous international common must be developed. Neither men nor their sovereigns can live in peace except under law. Basically neither one like to cooperate with others. The great pastures of the ocean require this cooperation imperatively and if there were no other reason for their existence this one alone would bring forth an organization like the United Nations, and its specialized agencies.

With these concepts of enormity, modes and recent knowledge, and common property in mind let us look at how man is doing, and may do, in the use of some of the potentials of the sea.

ENERGY FROM THE SEA

One does not need to go upon the sea to realize the enormous amount of energy contained in it which, if tameable, would be useful to mankind. The enormous waste of energy in waves beating on the shore, the tremendous thrust of tidal bores up particular estuaries and bays, and the titanic power in the flow of the great rivers in the sea such as the Gulf Stream, and Kuroshio, have long excited the imagination of man. In more recent years the great quantities of energy capable of liberation by reason of the juxtaposition of warm surface waters overlying cooler water layers has been apparent, particularly in the tropics and sub-tropics where the eastern boundary current conditions often leave a quite shallow warm surface layer above the cold bulk of the ocean's depth.

Attempts have been made to harness these forms of energy. The Passamaquoddy Bay project is one well known effort in the direction of harvesting tidal currents. The French effort off the Ivory Coast of West Africa is a well know effort to harvest the energy of temperature differences in equatorial seas.

None of these has yet turned out to be successful nor is there any great likelihood that they will be so in the near future. The reason for this is that the science and technology of making easily transportable energy available for mankind's use from other sources is proceeding at such a rapid pace that there seems little likelihood of the similar science and technology with respect to the use of oceanic energy directly catching up from the standpoint of competitive cost in the near future.

It is not generally realized how rapidly man is moving toward the goal of cheap and abundant useful energy. The competitive struggle is between fossil fuels (oil, coal, gas, shale) and nuclear fission, with fusion processes receiving much basic scientific attention and theoretically capable of winning the race in the end.

A few years ago nuclear power was simply a dream in the minds of a few theoretical scientists but the practical applied scientists, technologists and engineers quickly grasped it and have pushed its competitive costs down very rapidly. As they have done so, those with proprietary interests in fossil fuel energy have redoubled their efforts to lower their unit costs of energy production.

In 1962 an eminent authority in the electrical industry stated flatly that nuclear power was not competitive with conventional energy. He estimated that in the period 1973-1978 nuclear power would cost between 6.17 and 6.89 mills per kilowatt hour and that the cost of energy from conventional sources would vary between 3.9 to 5.6 mills per KW. Thus in 15 years he estimated that nuclear power would be still far from competitive with conventional power.

In the meantime nuclear power installations have been constructed or are being constructed. One at Oyster Creek in New Jersey will be completed in 1967-68 and is expected to deliver power at costs as low as 3.66 mills per KW. In the meantime another large plant is being built in the East using low priced coal, designed for completion in 1967, and expected to deliver power at 3.59 mill/KW hours (Abelson, 1964).

Obviously the racers have come much closer in two years time than had been expected to happen in fifteen years only so short a time ago. In doing so they have sharply reduced the cost of energy from either source, and the chances are good that there will be further sharp reductions yet in the cost per unit of producing electrical energy from both sources. California with its population expected to rise from the present 17 million level to 42 million level in 2000 (Brown, 1964) and its relative shortage of fossil fuels, has been rapidly building its power production and the plans for further expansion are astronomical in size. A change in thinking about energy source is taking place. There are some visionaries who say that the last fossil fuel plant to be built in California is now on the drawing boards and that all future expansion will be from nuclear power.

In the face of the rapidly declining cost of energy production from fossil fuels and nuclear fission there would appear to be little likelihood of energy from the ocean becoming competitive in our time.

There is enough uranimum dissolved in the ocean to provide the nuclear fuel for mankind for almost all time to come. The difficulty is separating it from the water. If one ran 2,000,000 acre feet of sea water through a sea water factory (about 660 billion gallons) one could, with perfect efficiency, recover about 5.6 tons of uranium which would convert into about 6.6 tons of uranium oxide, the normal commercial form. At $16,000 per ton this would yield an income of about $105,000. But a plant at the present state of the art to handle this job would cost about $100,000,000 and operating it long enough to handle this much water in a year would cost about $12,000,000. (McIlhenny and Ballard, 1963). Although these figures are so far out of joint presently as to appear to be ridiculous, basic research designed to concentrate uranium from sea water is being pusued steadily (particularly in England) and it is unsafe to say that this will not in time become practical.

Also the quantities of deuterium and tritium in sea water hold out the prospect of practically limitless quantities of fuel for atomic fusion plants (McIlhenny and Ballard, 1963). This will remain of largely academic interest until a practical atomic fusion plant is built. Again, it is unsafe to speculate that a break through in fusion engineering will not bring this about in a few years.

FRESH WATER FROM THE OCEAN

The more than one billion cubic kilometers of water in the ocean is more than any thinkable quantity of humans in any livable concentration on earth could use for all combined agriculture, industry or municipal and domestic purposes for all time. The problem is to separate it from everything that is dissolved in it and transport it to where it is needed, all at a cost that can be afforded. No activity more likely to render great sections of the earth more habitable can be conceived than making fresh water available where none or little is presently at hand.

It must be kept in mind that the ocean provides all the fresh water we presently have. Seventy percent of the solar energy falling upon the earth strikes the ocean and major parts are absorbed in it. More energy strikes the earth in low latitudes than at the poles and the process there goes on more steadily. Thus the low latitude ocean surface is warmed more, more water is evaporated from the ocean surface into the atmosphere and with it goes the enormous energies in the clouds. The imbalance of cold toward the poles, heat toward the equator, the rotation of the earth, the interference of land masses, and other natural forces set up and drive the great ocean currents which transfer the heat energy from the low latitudes to the high. The atmosphere and the ocean compose a vast, closely-coupled heat engine, with the ocean as the great reservoir of energy making up the flywheel that keeps the engine running reasonably steadily and reasonably predictably.

Knowledge and understanding of this great heat engine and its processes are beginning to accumulate as oceanographers and meteorologists ply their professions more energetically and more together; technology and engineering also move apace. It is becoming apparent that there may be ways which man can learn and do to tinker with the workings of this heat engine practically in such a manner as to evaporate fresh water from the ocean and transport it through the atmosphere to where it is wanted and thus, in Kruschev's phrase "make the deserts bloom". The technical problems in the way of doing this are still very large but it is no longer safe to say that scientists and engineers cannot do something with nature that man wants done urgently enough to pay the bills.

In the interval before that happy event occurs research goes on in other fields which gives much hope that the nuclear giant may be harnessed in the near future to get a very large amount of fresh water out onto land where it is badly needed at practical costs.

It must be kept in mind that there are numerous situations where man can now afford to pay rather high water rates for considerable amounts of fresh water. Fresh water distillation plants using diesel fuel have been used for many years already on ocean going vessels, and since the last war they have become practical even on such smaller vessels as tunaclippers, thus much extending their range.

Where fuel is cheap, water is dear, and men are thickly concentrated, distillation plants are already in operation on land to support the domestic needs of considerable cities. Examples are provided by Kuwait, Curacao and Guantanamo Bay. Approximately 20 million gallons per day of such land-based installations are already in operation (Revelle, et al., March 1964).

Much research is going into methods of deriving fresh water from sea water not only by multistage flash distillation, but by long tube vertical distillation, vapor compression distillation, freezing, reverse osmosis, electrodialysis, etc.,. Costs in some of these processes are already in the practical range of what man can pay for water for some purposes in a good many places.

A useful yardstick is provided by the rapidly growing city of Tijuana, Mexico, which now has a population of about a quarter of a million and is still growing rapidly. It lies in a stark desert alongside the Pacific Ocean. It outgrew its municipal water supplies for domestic uses some time ago. Potable water is now sold from tank trucks on a large scale at $1.25 per 1,000 gallons, and under this water cost structure the city still grows rapidly.

Across the border in San Diego the Office of Saline Water Conversion of the Department of the Interior built an experimental multistage flash distillation plant calculated to produce about 1,000,000 gallons per day. By improvements in method made before the plant was recently moved to Guantanamo Bay, capacity was raised to 1.4 million gallons per day which could be produced at a cost of a little less than $1.00 per 1,000 gallons. The power source was ordinary commercial electricity off of the line.

Recent studies by the Oak Ridge National Laboratory, the Office of Saline Water Conversion and the Office of Science and Technology (Revelle, et al, March 1964) indicate the practicality of combining gigantism of plant, modern technology, and modern energy sources into plants that can produce fresh water from the ocean at much less costs than this.

One such scheme to use a technology estimated to be available by 1980 (the reverse osmosis method) and a capital investment of about $450 millions, yields a cost estimate for fresh water of 21 cents per 1,000 gallons in volumes of 1,000 million gallons per day (loc.cit.p.29). Other schemes even larger in capital cost and water yeild are presented as possible of accomplishment in the foreseeable future which might yield large volumes of fresh water at the plant boundary under certain conditions for as low a cost as 11.2 cents per 1,000 gallons (loc.cit., p.18).

From these heady calculations emerges the concept of a gigantic dual purpose plant using nuclear energy which would produce the energy for evaporating fresh water from the ocean, for transporting it to where it was wanted, and for generating surplus electrical power, for industrial uses in such places as needed both fresh water and electrical power, were near to the sea, and could raise the necessary capital. At the most efficient size studied, the capital cost estimated to be required for one such plant would be about $2 billion.

Such a situation arises in California. There a system costing well more than $1 billion is well along in construction designed to transport fresh water from the northern rivers of that state to its desert south, where population and industry is growing so rapidly. At one point the water must be raised a considerable height over the Tehachapi Mountains to enter the southern coastal plain. Much power will be needed for this pumping. All the additional power and fresh water that could be practically produced at the same time at reasonable cost could be used. Accordingly, although the above referred-to report from the Office of Science and Technology is less than eight months old, studies are already well under way in California to incorporate a smaller model of this dual purpose nuclear powered fresh water plus power plant (at a cost of about $100 million) into the California Water Program.

Thus, although much research and engineering is still needed in nuclear power generation in large plants, fresh water conversion in large plants, and the coupling of the two into practical plants to produce fresh water and electricity at competitive costs, this research and engineering is going forward at an increased pace, applications in developing programs of fresh water conversion by these means are under active study, and the production of great volumes of fresh water from the ocean for man's use on land is no longer a visionary prospect.

MINERALS FROM SEA WATER

A very considerable amount of several dissolved things are already recovered from the ocean each year. Common salt has been produced from ocean water by solar evaporation from prehistoric times and this is still the source of great tonnages of salt produced at such diverse localities as San Francisco Bay, San Diego Bay, Black Warrior's Lagoon, Mexico; Cape Verde Islands; Tuticorin, South India; etc.,. Much of the magnesium used in the United States in both metallic and in other compound forms, is recovered from the sea in the Freeport, Texas, plant of the Dow Chemical Company. This is also true of a large part of the bromine used in the United States.

On the other hand, despite the vast array of chemical compounds dissolved in sea water, and available there in volumes far greater than man's need for them, only common salt, sodium and potassium compounds, magnesium and magnesium compounds, and bromine are produced from sea water in commercial quantities. The reason is exclusively economic. The other elements and compounds are not worth the cost of removing the water from them under present technology.

Furthermore this is the outlook for a good long while to come. McIlhenny and Ballard of the Dow Chemical Company (1963) have carried out a most useful study that illustrates the reason why.

They have hypothesized a plant using the most modern available technologies and taking advantages of the economies of what they considered to be about the largest practicalbe size for such a plant. This hypothetical plant would process about 2 million acre feet of sea water per year (660 billion gallons), which is a considerable amount of water, but scarcely a drop in the bucket as far as the ocean is concerned.

This plant would cost about $100 million to construct and about $12,000,000 per year to operate. It would produce about 93 million tons of various elements, metals, compounds, etc., per year from this amount of water and (when converted into the normal products of commerce at 1962 prices) these commodities would bring about $1,353 million per year income to the plant.

This would appear to be an investor's dream, but there are certain flaws in the picture when it is examined a little closer.

The bulk of this product and value ($763 million and 76.3 million tons) would be common table salt. The annual production of this commodity from this one plant would represent about 3 times the amount of table salt used for all purposes in the United States in 1961 and about 3/4 of all that is used in the world per year at present. At this rate of production the $10 per ton used for this calculation would not last long as the market price, the main item of income would shrink sharply, and the plant would soon be buried under a mountain of salt.

The next biggest income hypothecated from the plant's operation would be magnesium oxide with 6 million tons at $53 per ton (1962 price) bringing in about $314 million. This would represent about five times the annual use of this product in the United States and nearly twice its annual use in the world. Thus inventory accumulation and price deflation for it would likely be worse than for salt.

The third largest product would be bromine with 184 thousand tons at $430 per ton (1962 U.S. prices) yielding $79 million. This would be about twice the United States volume of use of this element per year, and the market would quickly collapse.

The plant would additionally provide all the magnesium metal, 41% of the sulphur, 56% of the calcium and 58% of the potassium used per year in the United States. The 1962 prices for these commodities ($705, $23.5, $4.2, and $31.0 per ton, respectively) used to compose the $180 million dollar income these commodities should contribute to the $1,353 million annual income of the plant would be pretty shaky. The eighth largest income producer (strontium with 76 thousand tons at $66 per ton and $5 million gross) would represent nearly eight times the annual use of this commodity in the United States, and there is not much call for it at all outside the United States.

Thus, in total $1,341 million of the plant's $1,352 million annual income would be pretty well shot before the first year of production was completed through simple overproduction, and a fair share of the remaining $12 million would be spent to haul away and dispose of the excess product. The $20,000 realized from 40 pounds of gold, the $28,600 realized from the 6.6 tons of uranium oxide, would not be of much help in paying the year-end bills.

McIlhenny and Ballard point out further that either where a recovery plant for other chemicals than those now recovered from sea water is put as a parasite on a present plant, or upon a fresh water conversion plant, the economic results are about the same under presently available technologies. The best of present saline water conversion plants concentrate the salt water no more than four times. Taking out the remaining water will not be much less costly than taking out all of the original water.

Other methods of concentrating specific compounds or elements from sea water than those contemplated above, are, of course, capable of being developed. As McIlhenny and Ballard say "Much greater problems in science have been solved when the solution looked fartherest away." But under present and immediately forseeable knowledge, understanding and technological art the situation for recovering much more variety of the dissolved minerals in the ocean looks bleak.

MINERALS FROM THE CONTINENTAL SHELF

Great quantities and considerable varieties of minerals are presently taken from the sub-soil of the continental shelf. Petroleum, gas, limestone and sulphur are some commodities presently produced in considerable volume from such situations in the United States. Magnetite (iron) ore is mined commercially in Japan in 90 ft. of water; tin is so mined off Malaysia; diamonds off South Africia; thorium sands off South India; and other examples could be named (Mero, 1963).

There is no reason to think that the mineral composition of the continental shelf will prove to be any more or less rich than that of the adjacent land. Exploration involving seismic, gravity and magnetic surveys are somewhat more simple and less expensive when done at sea than over land. Drilling costs at sea in depths up to 100 fathoms are practical in several instances now, and as experience accumulates they are likely to cheapen.

The big break through in this field which appears to be on the immediate, or close, horizon is the ability of a man with a prospector's pick or other such instrument to live in specially prepared underwater dwelling for prolonged periods and work for hours at a time with "Scuba" gear in depths up to 100 fathoms (Cousteau, 1964). The work of the last year or two in the Mediterranean and Red Sea under Costeau, and the work recently completed under U. S. Navy auspices off Florida, indicate satisfactorily that man is capable physically, physiologically and psychologically of doing this. The present crude technology of these experiments seems likely to be advanced to more sophisticated stages rather rapidly.

Thus it looks as if instead of exploring the sub-soil of the continental shelf indirectly by seismic, gravity or magnetic surveys, or by a dredge pulled at the end of a long wire (as has yet been the practice up to now) man should soon be able to get down and work over the continental shelves by sight and touch, shipping off or digging up samples as required, without as much danger and hardships as those experienced by the desert prospector and his burro for the past hundred years on land.

This should inevitably, open up great new mineral wealth to all coastal countries having a substantial continental shelf. It was in anticipation of these developments that the nations of the world modified international law as they did in the "Convention on the Continental Shelf" so that the resources of these adjuncts of the continents could be brought to harvest under law.

There is another sort of mineral on the continental shelf that is oceanic in origin and gives promise of much future production. These are the phosphorite nodule deposits that are found so plentifully on the continental shelf at all (or most) places where there is substantial upwelling of water from the deep sea. Known major deposits of phosphorite nodules have been found off Peru, Chile, Mexico, the west and east coasts of the United States, Argentina, Spain, South Africa, Japan and on the submerged parts of several islands around the Indian Ocean.

A number of such deposits are known off the coast of California, some of which are expected to yield as much as 100 million tons of phosphorite (Mero, 1963). Since California uses an equivalent of over 400,000 tons of phosphate rock per year and has no commercial grades of phosphorite in deposits ashore, the discovery of these large off shore deposits has excited interest. A subsidiary of the Union Oil Company did advance as far as to least 30,000 acres of such deposits off San Diego from the Department of the Interior.

MINERALS FROM THE DEEP SEA BED

The deep sea bed has not, heretofore, been mined. There is reason to think that within the next generation deposits of truly oceanic origin on the deep sea bed will become major sources of such metals as nickel, cobalt, copper, manganese, molybdenum, vanadium and some others now used as essential ingredients in industry and not overly abundant on land in commercial deposits.

Manganese Nodules

The most exciting of these deposits are the so called manganese nodules. They are called this because they always contain a substantial amount of manganese, and may be up to 50% manganese. However, they contain a number of other elements as well, in greater or lesser concentrations. The composition of the nodules vary considerably from ocean to ocean and as to locality within an ocean. In the Atlantic the composition of the nodules is relatively uniform and high in iron content. In the Pacific the composition of the nodules varies widely from place to place and apparently with some pattern (Mero, 1963).

One of the exciting aspects of these deposits is their enormous extent. They cover broad areas of all oceans. Their estimated present volume is substantially more than 1 trillion tons. Crude preliminary measurements in 25 locations in the Pacific indicated an average in the eastern part of that ocean of 30,000 tons of nodules per square mile. Similar measurements in the middle Pacific yielded an average of 55,000 tons per square mile, and in the western Pacific of 25,000 tons per square mile (Mero, 1963).

Assuming that only ten percent of these nodule deposits prove economic to mine there are sufficient supplies of many metals in these nodules to last industry for thousands of years at present rates of production. There also is evidence that these nodules are accreting out of the ocean now as they have been doing for past millenia and that manganese is thus being accumulated three times as rapidly in them as it presently is being used by man, cobalt twice as fast, nickel as fast, etc., (Mero, 1963)

The nodules are loose on the ocean bottom. They are easily photographed and picked up in small lots by the oceanographer's dredge. They range in size from small peas to largish balls. There is no reason why they cannot be picked up readily by an oversized vacuum cleaner type of hydraulic dredge, pumped to the surface, and into waiting ore boats. Two companies are said presently to be in the design stage of equipment of this nature for this purpose.

The metallurgy presents problems that have not yet all been worked out but which are under active investigation by the Bureau of Mines and others.

The capital costs for engaging in such an enterprise would be substantial, but not overwhelmingly large for a number of United States companies. Mero (1963) estimated that a deep sea hydraulic dredge of the type he had in mind would run about $6 million per unit, including design and development costs, and that a plant to process the nodules recovered would cost $60 to $70 million. He estimated that the gross value of the products recovered and processed per year by such equipment would be about $250 million and, at metal prices prevailing in April 1963, might yield a return on invested capital of between 30 and 100% per year. A single such operation, he reckoned, could produce about 50% of the United States consumption of nickel, over 100% of that of manganese, about 5% of that of copper, about 35% of that of cobalt, about 7% of that of molybdenum, as well as appreciable amounts of vanadium, titanium, ziroconium, etc.,

If this all appears to be somewhat visionary, it may be observed that one company thought well enough of the prospects to hire Mero away from the University of California to aid it in the design and development of equipment for these purposes.

<u>Other Mineral Deposits of Ocean Origin</u>

Although manganese nodule deposits hold presently the most immediate interest for large scale mining of the deep sea floor there are other major resources of similar ogigin on other parts of the ocean bottom that hold just as large interest for the longer term as techniques of ocean mining are developed and as high grade ore deposits on land are exhausted. Substantially speaking these deposits on the deep sea floor are inexhaustible.

Red clay covers about 40 million square miles of ocean floor. At least ten quadrillion tons of it are available. It is a mixture of compounds as are the manganese nodules. Elements of particular interest in it are copper, cobalt, aluminum, and nickel. These deposits have an average composition of 20% alumina and 0.02% copper. They contain at least 10 trillion tons of alumina and 10 billion tons of copper. Red clay is by present standards a lean ore, but the future may consider it to be richer (Mero, 1963).

Calcareous oozes cover almost 50% of the ocean floor, or some 50 million square miles. Some assay as high as 95% calcium carbonate, and are very similar in composition to the compounds which account for 95% of the cement rock market. Deposits of nodules assaying about 75% barium sulphate are found in several locations off California and Ceylon. About 11 million square miles of the ocean floor is covered by Diatomaceous oozes which in some cases are almost pure silica. They could be used for any purpose for which diatomaceous earth is now used.

Although up to now these enormous deposits of minerals of oceanic origin have been sheltered from man by the thick overburden of water and the lack of practical technologies with which to deal with them, this will not necessarily remain the case for long. Actually there are some attractions to deep sea mining as compared to land mining.

Because of their common property nature the political and property costs and risks associated with land deposits are absent. Aside from water there is no overburden to remove, no drilling costs, no need for explosives and ore breakage. There are no drifts to make or shafts to sink and no townsites to buy and develop. With available camera equipment the whole deposit can be explored and every ton of ore to be expected accounted for before mining starts. Ocean mining lends itself to full automation with minimum labor requirements. Cheap sea transportation can be used from mine to market without the need for other intervening forms of transportation (Mero, 1963).

FOOD FROM THE SEA

As is well known all life on earth is nourished by the basic products of interaction between solar radiation, carbon dioxide, chlorophyll, trace elements and water. The basic output of this transmutation is carbohydrates, proteins, vitamins, oils and the other things composing living matter. Only the plants (in significant amount) contain the chlorophyll through the agency of which the solar energy can be bound with chemicals to create living matter. Upon these plants the great range of planetary animal life, including ourselves, fully depends.

Sea water has dissolved in it all of the chemical ingredients required to support plant production. It receives over 70% of the solar radiation that strikes the earth. Scarcely a drop of salt water within 100 feet of the sea surface is devoid of plant life, and plant life is found deeper in the ocean than that in considerable amounts. Accordingly, as with so many other things about the ocean, it supports more photosynthesis and plant food production that can be readily imagined or than a much vaster human population than that presently living could eat.

The ocean varies as much by area in its production of life as does the land. There are ocean "deserts" as well as extremely fertile ocean areas, as with the land. Mostly this is due to certain required chemicals being exhausted in the superficial layers of the ocean where insolation is heaviest and plant life most abundant.

By contrast, below the level to which solar radiation can reach and plant life subsists (say 150 to 200 ft. in most ocean areas) these chemicals are superabundant. Where there is vertical circulation of these nutrient rich deeper waters to the surface, plant life again flourishes in abundance comparable with the most productive farm lands. Such places are Peru, Chile, California, South West Africa, West India, South East Arabia, the Japanese home islands, the Grand Banks, etc., etc.

With the ocean operating just as it is now a conservative estimate of the weight of carbon fixed into living matter annually by ocean plants (phytoplankton) is 19 billion tons (Schaefer, 1964). Although we are all acquainted with the kelps and algae of the sea shore and shallow inshore waters, most of ocean plant life (as contrasted with most of that with which we are acquainted on land) is composed of one-celled organisms of microscopic size.

Although they are produced in these vast amounts in the ocean, and sometimes in such profusion that miles of ocean are rendered cloudy, or soupy, or even colored by their presence, it is unlikely that they will ever be of much importance to man directly as food. The reasons for this are several. The most important is that even a maximum abundance there is still so little dry weight of plant life per cubic meter of water that the cost of separating the water from the plant life is beyond all possible range of direct value of the living matter as food. This highly abundant phytoplankton must be much concentrated by other organisms before it can be further concentrated by man and used by him directly.

This concentration is done by animals of all sizes which graze upon the plants of the ocean much as cattle graze upon the grass of the prairie. Thus animal protein arises in vast bulk in the ocean, in greater bulk than man needs or could use. Upon the smaller of these multitudinous one-celled animals and plants feed multicelled animals of larger size that may be visible to the human eye, or even rather large (as with jelly fish, krill, etc.,), which drift freely with the ocean currents and are called plankton. Where plant plankton is being produced actively, and animal plankton is grazing on it profusely, it is possible with a small meshed net to catch pounds or gallons of such plankton quite easily.

From this fact publicists have put forward the idea that plankton soup will be the salvation of mankind. This is sheer buncombe. In the first place plankton soup is not something for which children would cry for a second bowl because of its fine taste. In the second place its separation from the water and processing into stable and transportable shape is impractically costly. Thirdly, it not only contains a great variety of plants and animals that could not be separated from each other practically, but in any one place in the ocean the compositions of the plankton catch changes grossly from day to day in a manner making a reasonably standard product quite impossible. Lastly, the total productivity of ocean areas change rapidly from day to day and from season to season in manners as yet unpredictable, and the frequent location of maximum plankton concentrations of the nature to which we are referring would not be easy or cheap.

Although very large quantities of organic material is converted into protein directly utilizable by man by oysters, clams, mussels, barnacles, shrimp, etc., and phytoplankton is put into directly utilizable form on a large scale by such fish as anchovies, another level of concentration by living things is ordinarily required before all of this vast production of tiny oceanic food units can be captured by man in a form that he can use and at cost that he can afford. This is done by the bony fish, the sharks, the squid, whales, porpoise, and the myriad other larger animals of the ocean. When these proliferate and congregate in such manner that man can cheaply catch them, process them into acceptable food, and transport them to consumption centers in still acceptable form at acceptable price, only then does ocean production become food for man.

THE WEB OF LIFE

The web of life in the ocean is incredibly complex as we know it now, and we are still pretty ignorant about it. Well over half (perhaps as much as 90%) of the organic matter in the ocean is not in living form at all, but is in forms resulting from excretion, death, bacterial action, and enzymatic dissociation that has left it outside the living form. (Kesteven, 1962).

In any event, in a rich sea area like that off Peru, the first life of practical size for man to use in large volume is a fish like the anchovy that lives normally almost entirely on microscopic phytoplankton. Associated with the anchovy are sardines, some mackerels, and some other fishes that appear to be able to subsist indiscriminately on plant or animal plankton. These are the sorts of fish that are most abundant and exist in great schools that can be caught easily and cheaply. Although properly prepared these fish are excellent as direct human food, most people do not accept them readily and the market for them is thin. They go into fishmeal which is fed to poultry, swine and cattle, by which route they enter the human diet, and into fish oil which is mostly used for margarine.

Upon these vast swarms of herbivores and half carnivores live the bonito, the tuna, and such fishes that are readily acceptable directly by humans in their diet. Upon the others, and these latter, subsist the squid and great sharks; upon the great squid live the giant sperm whales.

A wholly different chain of life of similar complexity arises from the shallow ocean floor involving the bottom-living diatoms and detritus, sedentary molluscs (such as clams, oysters and mussels), the crustacea (such as shrimp, crab and lobster), and bottom fishes (such as flounders, cods, etc.,) etc.

At intermediate depths are other chains of life of similar complexity. They contain fish like the hake which are near the bottom at one time and even up to the surface at others, the ocean perch which regularly inhabit the middle layers well up from the bottom, the lantern fishes which may move up and down from the dark deep to the surface diurnally, etc.

All of these chains of life interlock in various feeding and life history manners, in incredible complexity.

The reason for noting this complex natural scene even so hastily is to point out that the carbon originally fixed by the plants into organic matter transfers from stage to stage of life in the ocean as one of these organisms is eaten by another up the scale, and then by another and yet another. These stages are called trophic levels.

As the carbon moves from trophic level to trophic level, it is diminished in volume at the new trophic level. The reason for this is that much of it is lost through metabolic action and waste products that are excreted (carbon dioxide in breathing, urea products, and faeces, as well as cast off shells in crustaceae, etc.,). For a long time it has been customary among scientists dealing with this subject to use the rule of thumb that as the biological carbon moves from one trophic level to another it diminishes by a factor of ten. For instance, ten pounds of anchovy eaten by one bonito will yield one pound of live bonito.

It is now becoming well known that this conversion factor is entirely too conservative. Lindner (personal communication) finds that shrimp convert their food into body weight with an efficiency of about 25%. Lasker (personal communication) working with the krill (Euphausia pacifica) finds that when it is feeding either wholly on zooplankton, it converts its food to body weight at efficiencies ranging from 11% to 40%, and averaging (as with shrimp) about 25%.

Schaefer (1964) has calculated what would happen with 19 billion tons of carbon fixed into phytoplankton if it were converted into second stage carnivores (just about the average trophic level at which he estimated the world fisheries to be presently working) at ecological efficiencies of 10%, 15%, and 20%. He arrives at a total weight of second stage carnivores (fish, shellfish, squid, etc.,) of 190 million tons at the 10% level, 640 million tons at the 15% level, and 1.52 billion tons at the 20% ecological efficiency annual production would be 7.6 billion tons.

Adequate studies have not yet been made which would convert ecological efficiency as Schaefer uses the term, or the more generally used concept of food conversion to body weight, into a general idea of overall ocean efficiency in conversion of food from one trophic level to another. Since a 25% average conversion of food to body weight does not appear to be out of expectation for marine animals (chickens produce one pound of weight from less than three pounds of feed) and the 19 billion tons of biologically fixed carbon per year in phytoplankton is a notably conservative estimate, perhaps a rough number of 2 billion tons per year of second stage carnivore generation could be taken as reasonably conservative estimate of the actual production of fish and squid by the ocean per year in forms large enough to be harvested and used by man.

THE HUMAN NEED FOR ANIMAL PROTEIN

There are about 3 billion people on earth presently. Each of them requires about 70 grams of protein per day to remain in a healthy nutritional condition (Schaefer, 1963). This works out to a human need of about 76 million tons of protein per year for the present human population. Schmitt (manuscript) gives reasons indicating the possibility that the human population will level out at about

30 billion. Such a population would require about 760 million tons of protein per year to fill its nutritional requirements.

Of course most protein now entering the human diet is not animal protein and perhaps it never will be. At present the protein at the point of consumption is approximately 67% of plant origin, 24% of meat and milk origin, 4% of poultry and egg origin and 5% of fish origin (Schaefer, 1963).

Theoretically it would perhaps be possible for man to subsist healthily simply on plant proteins, for all of the essential amino-acids are present in the plant protein (King, 1965).

As a practical matter this is not the case because the main source of man's food energy is the cereal grains, and other seeds (wheat, corn, rice, barley, millet, beans, peanuts, soybeans, etc.,) and these are short of lysine and the sulphur containing amino-acids that man needs in his diet to stay in energetic health. Thus, as a practical matter, the human diet requires a considerable amount of animal protein to protect health and energy. Certainly the percentage thus required will change as civilization, society, and habits change. Perhaps an animal protein component of the protein requirement of a diet for 30 billion people of 40% would not be ridiculous. This would require about 300 million tons of animal protein per year.

FISH AND THE HUMAN ANIMAL PROTEIN NEEDS

Fish range in protein content from about 15% of 24% (Olcott and Schaefer, 1963) and perhaps an average of 20% for rough calculation is not too far out of the way. Fish protein contains all of the amino-acids required by the human body in proportions well balanced to maintain health and energy. As we have seen above the ocean is producing about 2 billion tons of fish and squid in the second carnivore stage at the present time in total weight. This means a production of animal protein at this trophic level of about 400 million tons per year.

When one considers the conservative nature of all of these estimates, and the fact that the average fish catch in the world is shifting rapidly toward the first carnivore trophic level, one can say with some assurance that a world ocean is producing more fish and animal protein than a human population of 3 billion people can possibly use, and appears to be capable of producing somewhat more animal protein than a population of 30 billion people would need. The fact that most of it now dies a natural death and returns its components to the sea is beside the present point.

THE PRESENT DIETARY SITUATION OF THE WORLD

Let us turn, then, from these theoretical considerations, which are so rosy, to a look at the world as it is working under a population pressure of about 3 billion people, and under the social and economic conditions that actually exist. There is nothing rosy about it at all.

It is generally considered that 30 grams per day of animal protein in the human diet is sufficient for maintaining the human body in vigorous health; 15 to 30 grams per day is considered to be on the border line of a healthy situation; and less than 15 grams per day is considered to be in the danger zone. (Olcott and Schaefer, 1963).

The actual situation in the world today is that 19.5% of the human population has an average of more than 30 grams of animal protein in its daily diet; 19.8% have between 15 and 30 grams per day; and a whopping 60.7% majority has less than the danger limit of 15 grams per day (Meseck, 1962). The per capita daily consumption of animal protein in some selected countries are: U.S.A. 66 grams; Japan 15 grams; Egypt 13 grams; Pakistan 8 grams; and India 6 grams (Meseck, 1962).

These are some of the figures behind the statements by the nutritionists of WHO, FAO and UNICEF (Sen, 1963) that 1.5 billion people are presently living under conditions of protein malnutrition damaging to health and energy and that 0.5 billion people are suffering from protein malnutrition at the level characterized as sickness. The protein malnutrition diseases of kwashiorkor and marasmus are well known as the largest single killers of pre-school age children on a world wide basis.

It is noted that these serious conditions of protein malnutrition are concentrated in the developing world, the tropics and the sub-tropics, for the most part. This is the area where social unrest is most rampant on a world-wide basis as any daily newspaper will indicate. This is the area characterized by northerners as inhabited by lethargic, indolent people who seem unable to care for themselves adequately as their populations increase, and who do not know enough to stop increasing. On the other hand, these people say they have been preyed upon by the northerners so long, and so robbed of their sustenance, that they have difficulty in recovering and progressing now that the northerners have gone, or been sent, home.

Perhaps a good share of this acrimonious dialogue arises from the typical protein deficiencies of the human diet in the developing world. There are large populations of humans where the normal lot of an infant is to suffer for a time from protein deficiency disease. Clinical work adequately shows that this not only results in physical and mental retardation (NAS/NRC, 1961). Thus perhaps a good deal of the root cause of social unrest, slowness in economic development, difficulties in governance, and other socially undesirable traits of the developing world arises from protein malnutrition, and is capable of cure in one generation. A corollary to such an hypothesis would be that correction of the protein malnutrition cause would be a necessary precondition to correction of the social and economic problems of the developing world.

In any event the World Health Organization, the Food for Peace Program, UNICEF, FAO and the other United Nations agencies and bilaterial aid programs concerned with these problems are now giving the most serious attention to improving the protein nutrition of the developing world as rapidly as is possible.

There are many reasons why this problem developed and why it is difficult to resolve. Broad areas of middle Africa have endemic livestock diseases which prevent much animal protein being raised on the land. Great areas of heavily populated South East Asia require the arable land needed for livestock raising for the production of cereal crops. Religious scruples prevent many people from eating any meat, others prevent large populations from eating any pork, and some primitive people even eschew chickens on religious grounds, at least at certain periods.

This present world problem was a long time arising from complex sources, but it cannot be so long in being resolved because the temper of the times and the pressure of added population exciting further serious unrest will not permit it.

THE PRESENT FISHERIES

We have noted above that the ocean produces more animal protein in sizes that can be practically used by man in greater volume than man can use, and that large sectors of the human population are suffering from protein malnutrition on a socially unacceptable scale. Let us see what the fisheries are doing in reaction to this.

In 1850 the world catch of fish and shellfish (excluding whales) was about 1.5 to 2.0 million tons. By 1900 it had increased to about 4 million tons; in 1930 to 10 million tons; in 1950 to 20.2 million tons; in 1960 38.2 million tons (Moiseev, 1964); and in 1964 production is estimated to be about 50 million tons. In addition to this the whale production in 1961, at least, was about 2.5 million tons (Moiseev, 1964). Most of this expansion in the world fisheries has come from the ocean. During the first five years of the decade ending with 1962 the growth rate of the marine fisheries was 4.5% per year. During the last half of that decade it was 8% per year (Olcott and Schaefer, 1963). It seems presently to be accelerating.

The total world catch of fish, whales, shellfish, other aquatic animals and acquatic plants was 47.2 million tons in 1962. Of this less than 10% (4.67 million tons) came from fresh waters (Moiseev, 1964). Even this last figure is suspected of being somewhat too high because a large component of it is from official statistics provided by Communist China when it was apostrophizing the "Great Leap Forward", which fell flat on its face. Despite the considerable and valuable product of fresh water pond culture, especially in connection with rice paddy cultivation in Asia, there is evidence that fresh water fish production on a world-wide basis is not doing much better than holding its own, nor is it expected to do much better than this in the future. The reason is that man as a whole is destroying the productive capacity of the fresh waters through overfishing, construction of dams and diversions, use of pesticides and otherwise tampering with the environment, just about as fast as he is building ponds with which to raise more fish. The expansion in production of aquatic food must be expected only from the ocean on a substantial scale.

It is instructive to look at the composition of the world catch of aquatic food. In 1962 85.9% of this was fish (40.4 million tons); 7.6% (3.5 million tons) was shellfish; 5.1% (2.4 million tons) was whale; 1.4% (0.7 million tons) was other aquatic animals. In the period 1938 to 1962 the fish component of this production had increased from 18.3 to 40.4 million tons (by 221%); the crustacean component had increased from 1.6 to 3.5 million tons (219%); the whale component had shrunk from 2.9 to 2.4 million tons; the aquatic plant component had increased from 0.5 to 0.7 million tons; and the other aquatic animal component had increased from 0.1 to 0.2 million tons (Moiseev, 1964). Obviously the important aquatic crop is fish and shellfish (93.4 of the total) and it is upon these that dependence must be placed for food from the waters.

Since most food from the waters is fish (85.9% in 1962) and most of this is from the ocean (88.4% in 1962) it is instructive to look at the composition of the world catch of marine fish. In 1962 the herring and anchovy (clupeoid) component of the catch was 41.1% (14.6 million tons); the cod, haddock and hake (gadoid) component was 15.5% (5.51 million tons); the horse mackerel, sea perch, etc., (Percomorph) component was 12.0% (4.27 million tons); the tunas and mackerels (scombroid) component was 6.7% (2.38 million tons); the flat fish component was 3.4% (1.2 million tons); the salmonoid (salmon and smelt) component was 1.5% of the catch (0.55 million tons); the sharks and ray (elasmo branch) component of the catch was 1.0% (0.37 million tons); and all the other kinds of fish was 18.5% of the catch or 6.77 tons.

It is reasonable to expect that the 18.8% of the catch that was unallocatable by species groups in the above tabulation was actually distributed among these groups in about the same proportion as the other 81.2% of the catch. If that were so then in 1962 51% of the world ocean fish catch was clupeoid fish; 24% was composed of gadoid and perciform fishes; and only 15% was composed of scombroids, pleuronectids, salmonoids and elasmobranchs.

This reinforces the calculations of the food production capabilities of the ocean as set out above by indicating that the average world fish catch is composed of fishes not much above the first stage carnivore level.

It is obvious from this tabulation that the important volume producers of animal protein food from the sea are not the fancy fish such as salmon, tuna, sole, bonito, corvina, and halibut, (or even the staple codfish) but instead are the lowly herrings, sardines and anchovies. As a matter of fact the increase in production of herring-like fishes between 1938 and 1962 (from 5.37 million tons in 1938 to 14.66 million combined total catch (9.65 million tons) of all cod-like, tuna-like, salmon-like, and flat fishes in 1962 (Moiseev, 1964). Furthermore the anchovy catch of Peru and Chile alone has increased by something between 2 and 3 million tons from 1962 to 1964.

A great deal is heard publicly of salmon, trouts, etc., and particularly of the rosy future ahead for the selective breeding of this sort of fish in order to expand food production from them. As a matter of fact the total world catch of all salmonoid fishes declined from 5.3% of the world fish catch in 1938 to 1.5% in 1962 and in actual volume from 0.85 million tons in 1938 to 0.55 million tons in 1962. It never provided a substantial part of ocean food production, and never will. Total salmon and trout resources of the world are too small to be of much significance from this viewpoint.

Most of the publicity respecting ocean fisheries arises from the North Atlantic, where commercial fisheries as we know them today had their origin and where the nations surrounding it have long been reputed as principal fishing nations of the world (Norway, Portugal, Iceland, England, Spain, etc.,). As a matter of fact the entrie fish catch of all countries in the whole of the North Atlantic was only 7.1 million tons in 1938 and increased to only 12.06 million tons in 1962 (Moiseev, 1964) and a major contributor to this increase was a country considered as a land-locked state in 1938 - Russia.

In 1938 most scientists and fishery experts, whose knowledge derived principally from these northern seas, considered tropical seas to be essentially barren. A good many still do. In the intervening years the catch of a single species of fish, the anchovy (Engraulis ringens) in the tropical waters of only two countries (Chile and Peru) has increased from about 50,000 tons in 1954 (substantially nothing in 1938) to about 10 million tons in 1964, which will compare favorably with the total catch all countries will make of all kinds of fish in the entire North Atlantic in 1964 and be considerably more than all the European countries will take from the whole Atlantic this year.

From these statistics emerges a view of world fisheries other than is normally considered, composed of the following parts:

1) The most important products from the aquatic realm by value and volume are the living resources (about 50 million tons per year at the present).

2) The dominant part of this production is fish (86%).

3) The dominant part of the fish catch is from the ocean (88.4%).

4) The major component of the fish catch from the ocean, and the most rapidly growing, is that provided by the herring-like fish (at least 41.1% of the total in 1962, and perhaps somewhat more than 50% in 1964, having more than doubled since 1955).

5) The rapidly growing fisheries are not in the northern seas, nor in southern seas, but in tropical seas (the tropical fisheries of Peru and Chile having come from less than one half per-cent of world marine fish production in 1954 to nearly 20% in 1962 and probably somewhat over 20% in 1964).

6) The production of animal protein from the ocean is increasing at a much more rapid rate than is the human population of the world (a growth rate of about 8% in the marine fisheries from 1957 to 1962 versus a growth rate in the human population in the neighborhood of 2 1/2%) (NAS/NRC, 1963).

Thus we note:

(a) One of the prime social and economic needs of the human population of the world to be animal protein in the diet;

(b) the ocean itself is producing more animal protein than 10 times the present human population could use, although most of it now dies a natural death and returns to the web of life in the ocean unused by man; and

(c) the ocean fisheries of the world are responding to this need of humanity by a much more rapid rate of growth than the human population is undergoing.

THE DISTRIBUTION OF ANIMAL PROTEIN FROM THE SEA

One might say upon hearing these things that the prime dietary crisis of mankind (shortage of animal protein) will shortly correct itself and all will soon be right with the world so far as food is concerned. While this could be true nothing on the present world scene indicates that it will happen quickly.

A very large amount of fish that is caught is discarded and not landed. This is true of all trawl fisheries whether for molluscs, crustacea or fish, where the "trash" fish are ordinarily discarded at sea.

The actual fact is that most of the increased production of food from the sea that is landed is being consumed by the industrialized countries (where there is already adequate volume and great variety of animal protein available in most places at most times) and not by the developing countries (where the need for animal protein is great and urgent). There are a great many complicated reasons for this which are difficult to disentangle, and seemingly impossible to correct quickly, but the biggest one is purchasing power.

The people of the industrialized countries have adequate disposal income with which to buy any and all foods they want from anywhere. In the United States, for example, the total part of the consumer's budget spent on all foods is presently a little less than 20%, the first time in history that this has happened to a numerous people. As the disposable income of the inhabitants of the industrialized countries increases they tend to eat more protein and less carbohydrates. The average daily intake of 66 grams of animal protein per capita in the United States as contrasted with 6 in India is a case in point. The situation is much the same, however, in industrialized Europe and is trending in the same direction in Japan.

Furthermore, the strong trend in the use of fish in the industrialized countries is not directly in the form of fish as it comes from the sea but as fishmeal used in the more efficient production of animal protein from poultry, swine and cattle. The greater portion of the rapidly increasing fish production in Peru, for instance, is consumed not as fish in Peru but as chicken in North America, Europe and Japan, (and increasingly in the rest of the world too as scientific chicken raising proliferates geographically into the developing world), and increasingly as pork and beef as well.

Very little needed human food value is lost in this process. The thing that is really short in supply in the world is not calorie food or protein food, but the lysine and sulphur containing amino-acids found in good proportions in fish and the flesh of other animals but poorly in seed crops of plants. (Sunflower seed is high in sulphur containing amino-acids but is not used as a protein supplement on a large scale). Chickens are able to convert these amino-acids from 5% level of fishmeal in diet almost at a one to one ratio into chicken flesh. The small percentage of fish meal in the chicken diet produces a sufficient increase in the chicken's rate of growth and its efficiency in converting grains to animal protein to more than pay for the extra cost. The result is an even greater supply of cheap, readily acceptable animal protein food for humans. It is chickens, rather than humans directly, that are stimulating the important part of the increase in the world fish production.

While this is the actual situation in the world today, it is not quite so black as it is painted here, probably it is inevitable, and quite possibly it is all working out for the best about as quickly as anyone could otherwise devise.

While most of the fish catch of Peru (for instance) goes to the industrialized countries as fish meal to be fed to chickens, and there is great dietary need for animal protein in Peru, the per capital fish consumption in that country is increasing rapidly and perhaps more swiftly than could be arranged in any other way. The rapid growth of the fisheries has stimulated the coastal economy in Peru enormously. This has raised the purchasing power of the local inhabitant sharply so that he can afford more protein in his diet. Also it has drawn large numbers of ill-nourished people in the Andes down to the coast where income and fish are available. The great volume fisheries in turn have made the fish price in coastal Peru cheaper than could have ever been done through small fisheries developed solely for local consumption. At the present time the fishing industry of Peru and the Peruvian Government are launching a massive joint internal campaign to stimulate the use of fish in Peru among those sectors of the population most in need of added animal protein in their diets. Such a campaign would not be possible if there were not a large fishing industry supported by exports.

Again, in West Africa, a similar thing seems to be going on, in a less organized, but still substantial manner. This is the type locality of the protein deficiency disease, kwashiorkor, and perhaps its intensity in the heavily populated jungle in from the West African coast is greater than elsewhere in the world. The very rich fish resources are presently being developed most intensively by foreign fishermen (Russian, Japanese, Spanish, French, Italian, etc.,) for foreign markets. But the foreigners want selected fish (tunas, bream, snappers, shrimp, etc.,) that are sufficiently high priced in the world market to warrant the cost of freezing and shipping them overseas. The catch of fish less desired in the industrialized countries (sardine, herring, mackerel, shark, etc.,) is disposed of locally. By this means the amount of fish available for local consumption in West Africa is increasing sharply (Chapman, 1964). At the same time local fishermen are learning and adapting more modern fishing methods for the supplying of fish locally. This process is going on particularly rapidly in Ghana, Senegal and the Ivory Coast.

This same thing is also beginning to occur on a smaller scale in Northeast Africa where the beginning Russian fishery in the Gulf of Aden is already supplying badly needed fish to Egypt and the Sudan. It is quite probable that this same process will be repeated elsewhere as the great unused fish resources of tropical seas are developed one by one.

Another major benefit for the developing countries is arising from the sharp developments that have been taking place in the improved efficiency of chicken production in the industrialized countries. These scientifically sophisticated methods of providing live animal protein cheaply near the point of consumption from dry foods which can be obtained, transported and stored cheaply are being transferred lock, stock and barrel to tropical countries, and where this has been done a revolution in the human diet is proceeding.

Also as this is done these countries are increasingly importing fishmeal from Peru, Chile or South Africa and considering ways and means of building up their own local herring-like fisheries so that they can have their own local sources of fish meal for chicken production and thus conserve foreign exchange. Examples are provided by Colombia, Venezuela, India, Pakistan, etc.,.

Fish Protein Concentrate

Lastly, a considerable amount of research is now going on respecting the use of fish meal as fish protein concentrate directly in the human diet. The great promises that this holds include the following:

1). Fish proteins contain all the amino-acids required by the human body in proportions well adjusted to keeping the body in vigorous health. Vitamins, calcium, traceminerals, poly-unsaturated animal oils, etc., contained in the fish are plus dietary factors as well.

2). The proteins of all fish are substantially the same. Thus a fully dehydrated and defatted product, made of a considerable variety of "ocean run" fish mixed together, is as valuable nutritionally as that made from selected high priced fish.

3). Fish proteins can be dehydrated cheaply and the proteins not damaged in the process if reasonable care is used.

4). Dehydrated fish proteins can be packaged economically so that they can be shipped and stored for long periods of time cheaply and in a stable form.

Considerable technical problems are still to be solved before much fish protein concentrate can begin providing a considerable contribution to the world human diet directly. Among these are:

1). Present fishmeal plants, practically speaking, cannot be adapted to producing fish protein concentrate under conditions of acceptable hygiene for direct human food. New processes and plants require to be developed and built. Experimental work among these lines is proceeding.

2). The polyunsaturated nature of fish oils, which make them unique and particularly valuable in certain usages, are costly to remove in their entirety from the sorts of fish most usable for fish protein concentrate production and, if left in the fishmeal, can become rancid. Methods have to be developed further for removing the oil cheaply, safely, and satisfactorily, or for stabilizing it so that it does not oxidize to an objectionable extent. Work along both lines is being conducted.

3). Chickens like fishmeal and accept it readily. Fishmeal which is roughly refined and of a taste not readily acceptable by many humans is providing a very large and rapidly growing world market as supplementary food for chickens, pigs and cattle whereas the market (as contrasted to the need) for highly refined fish protein concentrate manufactured to hygienic standards suitable for human food is, as yet, nominal. In turn humans, as a whole, will accept chickens in their diet more readily than they will accept fish protein concentrate. Accordingly industry manufactures the product having best acceptance, lowest cost of production, and highest profit margin. That is fishmeal for chickens.

Much scientific and technological research, as well as engineering and market promotion study, is presently going into the resolution of the problems concerning fish protein concentrate for direct human consumption and none of them at this juncture appear to be incapable of solution.

Conservation and Fishery Disputes

The decade of the 1950's was particularly rife with disputes among nations over fishery jurisdiction growing, assertedly, out of possible conservation problems in the high seas but actually, for the most part, out of economic and political considerations. This led to the two United Nations Conferences on the Law of the Sea in Geneva in 1958 and 1960.

With the rapidly continuing proliferation of high seas fisheries in the 1960's more actual conservation problems can be expected to arise now and in the near future. These arise in selected places for selected species. The worst and oldest have been associated with the whale fisheries of the Anarctic particularly, the salmon and halibut fisheries of the North Pacific, the plaice fishery of the North Sea, and now in the last few years with the yellowfin tuna fisheries of the Eastern Pacific and the long line tuna fisheries of the world (but particularly that for yellowfin in the Atlantic).

As noted above, the entire production of all whales, salmon and salmon-like fish, flat fish, and tunas in 1962 amounted only to 6.54 million tons or less than 14% of aquatic production in that year. Probably less than a tenth of the total available stocks of all such fishes, as a whole, are affected by any such overfishing problems, or perhaps the stocks of fish presently producing less than 1% of aquatic food on a world-wide basis and unlikely to be producing half that percentage ten years from now even if perfectly managed by the best conservation standards.

The case of the Pacific salmons, from whence arise most acrimonious disputes among nations over fishing rights (and have done for twenty-five years), is particularly curious.

The total production of Pacific salmons would be not much more than a quarter of a million tons per year if they were perfectly managed by the disputing countries, which is not the case with any and has not been for many years. This is about one half of 1% of the present world production of aquatic food, and not likely to be more than a quarter of a percent of world fish production ten years from now no matter how these disputes are settled. A high proportion of the governmental funds which Canada and the United States devote to fishery purposes is spent attending to Pacific salmon (hatcheries, fish ladders, stream improvements, patrol and enforcement costs, research, political and diplomatic activities, etc.), and the situation is not much different in Russia and Japan.

Considering the great stakes all four of these disputing countries (Russia, Japan, Canada and the United States) have in access to the abundant resources of the open high seas, and the jeopardy in which their salmon disputes is putting this access, an outsider might properly wonder if the four countries could be as well off in the long run to simply write off these disputatious fisheries and concentrate on developing the more productive fisheries off their coasts and elsewhere in the world ocean. The world diet of man, or the diet of these particular countries, would scarcely be affected.

Yet man, in whatever race or country, is not entirely rational or temperate. The tiny bird in the hand is often more entrancing than the great flock in the barnyard. The forest sometimes cannot be seen because the tree is in the way. Accordingly, such disputes go on, and they will continue to increase unless governments decide to abide by the undertakings they pledged in the 1958 "Convention on Fishing and the Conservation of the Living Resources of the High Seas".

Whether they do or do not, it is likely that the production of animal protein from the sea will continue to grow until man's need for it is sated, for there is plenty in the ocean for all for the foreseeable future.

If one corner of the ocean pasture is closed off, it will more than likely only divert fishing pressure to another less-used corner.

For several years the Japanese have been abstaining from the taking of salmon east of 175 degrees west longitude, pursuant to the provisions of the International Convention establishing the International Commission for the North Pacific Fisheries. In the meantime, the Japanese and Russians have developed fisheries for ocean perch, flat fish, Atka mackerel, etc., off the coast of Alaska ten times more productive than the whole American and Canadian salmon fisheries put together.

In doing so they have uncovered other large ocean fish resources in the area which they are pushing on to harvest.

OCEAN RESEARCH

Most of the information set forth above was not available twenty years ago and much of it was unknown ten years ago. You may have noted that in its preparation no publication older than 1959 and few older than 1963 have been cited, whereas most citations have been from papers published in 1964, or still in press, or in manuscript stage.

This was neither contrived nor accidental. It just happens that more knowledge and understanding of the ocean has been accumulated in the last few years than in the previous history of mankind.

But it was as recently as 1957-1958 that the big boost in ocean research and ocean fishery development began. Then with the International Geophysical Year man, for the first time, attempted to look at his plant in one glance with all his scientific tools and powers. This IGY was organized by a group of scientists, not governments, through their international professional organization, the International Council of Scientific Unions.

At the same time four other events of consequence to ocean production were taking place. U.S.S.R. was putting afoot the first concentrated application by any nation of modern science and technology to the purpose of harvesting the world ocean. It still is the only country that is doing so on a large scale and its fish catch this year will go beyond 5 million tons (that of the United States will remain comfortably in the neighborhood of 3 millions where it has been for 25 years.

Secondly, the National Academy of Sciences of the United States appointed another of its committees on Oceanography (NASCO). This one, however, did its work so dynamically that:

(a) in the course of a few years the Government had appointed an Interagency Committee on Oceanography (ICO) to attempt to correlate the activities of the 22 agencies and bureaus that deal with ocean research in the United States Government,

(b) a thing actually known as a National Oceanographic Program had emerged, and

(c) the budget for the National Oceanographic Program had about quadrupled to a level of $124 million by 1963.

There have been great stirrings in ocean research in the United States during these brief years with the construction of new research ships and laboratories being authorized and funded, the training of scientists being subsidized, and exploratory cruises and research initiated in all seas. This was not done to the level in fishery oceanography and development that was being done in Russia, but still it was on a pretty good scale considering past United States ocean research history.

Thirdly, ICSU appointed its Special Committee on Oceanic Research (SCOR) and it was no accident that the guiding spirits of it were the same as those of NASCO. This remarkable body rather quickly did two things:

(a) organized, initiated and got funded the 22 nation International Indian Ocean Expedition which (with something between $40 and $60 million) was the largest, most diverse and extensive, and well funded investigation that had ever been, and

(b) succeeded in getting established the Office of Oceanography and the International Oceanographic Commission in UNESCO.

The latter organization (first meeting in 1961) took over the coordination of the International Indian Ocean Expedition, sponsored the eleven nation International Cooperative Investigation of the Tropical Atlantic (the field stages of which have been completed), and is presently sponsoring the "Cooperative Survey of the Kuroshio" as well as several other notable activities in international research.

Fourthly, in 1958 the Special Fund of the United Nations came into being. Its function was to aid nations in planning and executing predevelopment surveys for industrialization through multi-year projects requiring a minimum of $250,000 of outside money (provided by the Special Fund). It initiated the Peru Fishery Project, then the Ecuador Project, the Chile Fishery Project, the India Fishery Project, the Nigeria Project, the Philippine Project, the Korea Project and the Aden Project. In the immediate future are the Ghana, Central-America, Argentine, East Pakistan, and Lake Victoria Fishery Projects. By this means millions in new money are being pumped into ocean research and fishery development each year. The results are already becoming ponderable.

These last two developments also helped awaken interest in ocean research and fishery development in national fisheries agencies and in FAO of such consequence that it looks presently as if the FAO Fishery Unit is to be reinvigorated and restimulated to do adequately the task for which it was originally designed.

All of these activities have produced much new knowledge and understanding of the ocean and its resources. All are still increasing in size and competence except that in the United States. Here the budget for the National Oceanographic Program has stabilized at about $124 million for the past three years, and for this reason the program is beginning to stagnate and get into trouble. Research vessels already authorized and funded are coming off the ways and there is insufficient money with which to operate them efficiently. Splendid new laboratories previously funded are coming into commission but there is insufficient money with which to operate them effectively. Scientists are coming out of Universities, but there is a federal freeze on hiring new men. Accordingly, the skilled manpower with which to analyze the data being acquired rapidly are not being hired. In consequence the National Oceanographic Program is beginning to jam up pretty badly in the United States.

In view of the fact that we are spending $5 billion per year on space research and exploration for which no one can express a clear utilitarian reason other than keeping up with the Russians, one might think that the Congress might begin some embarrassing inquiries into executive thought on the subject of ocean research. However, the 22 agencies and bureaus of the United States Government that engage in Ocean Research report to 35 Committees of Congress, none of which has an ocean scientist on its staff (Wakelin, 1964). Thus it becomes a little hard to find where responsibility rests for the National Oceanographic Program in either the legislative or the Executive Branch of the United States Government.

Presumably as long as the Russians and others keep up their ocean research and continue to publish it, we can to this extent find out whatever they are learning about the ocean which they do not consider to be sufficiently important to classify.

Accordingly a report of this nature written ten years from now will certainly be based upon much more information about the ocean and its resources than this one has been able to draw upon. If new understanding and knowledge flows in during the next decade as rapidly as it has during the past one, we should have a much better grasp of the kinds and volumes of resources in the ocean and how they may be extracted for man's use.

CONCLUSIONS

Thus we have had a look at the resources of the ocean and the potentials they hold for man. It has been a too brief look. Many rather important aspects have not been noted at all. A report of this nature written ten years from now will certainly be much different than this one is. The present report can be summed up as follows:

1). Energy is enormously abundant in the ocean. Competition from other cheaper sources of energy (nuclear fission and fossil fuels) makes it unlikely that ocean energy will be harnessed practically for man's direct use in the foreseeable future, or at least until the derivation of electrical energy from atomic fusion becomes practicable.

2). There is more fresh water in the ocean than man can use if he can learn to separate it from the salts and living matter it contains and transport it to where he wants it at a price he can afford to pay. Multiple stage flash distillation processes already are providing 20 million gallons per day of fresh water in certain areas and that method plus other methods of salt water conversion are sufficiently advanced in science and technology so that the cost of fresh water from such sources is becoming economic under a good many other situations in the world. It is likely that the next few years will see nuclear power and salt water conversion plants coupled together in certain localities in units capable of producing one to two billion gallons per day per unit.

There is reason to think that relatively modest expenditures in ocean research and meteorology might, in time, develop practical methods of weather control suitable for the transport of water from the ocean through the atmosphere to where it is needed, utilizing available planetary energy.

3). Substantially speaking, all of the metallic elements, and many others, are available dissolved in the ocean in greater volumes than man needs. There does not seem to be much chance that any substantial increase will be made in the variety of dissolved substances recovered from the ocean in the near future because the same elements can be had from other sources cheaper than they can be separated from the water of the ocean.

4). The production of minerals from the sub-soil of the continental shelf is increasing sharply both as to variety and volume. There is every reason to expect that this will continue to be the case as new technologies for extraction in this environment become familiar and particularly as the techniques for man to live and work in water depths up to 100 fathoms become perfected and customary. All of this is proceeding apace now. Aside from minerals of continental origin, phosphate (and some other) deposits of oceanic origin will be added to this store of utilizable continental resources.

5). Vast deposits of metal ores of oceanic origin most useful to man are available lying on the deep sea bed in profusion greater than man can ever use. They include manganese, nickel, cobalt, zinc, vanadium, copper, molybdenum, iron, aluminum and several other elements.

In some instances these deposits are probably growing more rapidly than man is presently using the metal. There appears to be a good likelihood that one of these most abundant deposits, manganese nodules, will begin to be worked on a substantial scale in the next few years and that, as a result, manganese, nickel, cobalt and perhaps even copper will become cheaper to produce from the deep sea bed than from land deposits.

6). The ocean is, for practical present purposes, a limitless source of animal protein highly suitable for the human diet when viewed on a total rather than specific basis. It is presently producing about 2 billion tons of fish and shellfish per year of sizes practical for man to use. This is well more than the amount of animal protein required to keep a human population 10 times the present size in vigorous health, but most of it is dying unused by men and returning to the web of life in the ocean.

Man is presently utilizing about 50 million tons of fish from the ocean per year. The production of the sea fisheries has been growing by about 8% per year for the past few years or more than three times as fast as the human population. Production is increasing particularly rapidly in tropical and sub-tropical seas where large presently unused, or little used, resources are known to exist. The southern (ocean) hemisphere is little fished yet, and very large resources are known to exist in several parts of it. Even in areas of the northern ocean that have been long and intensively fished great latent resources are known to exist. Examples are provided by the pilchard and mackerel of the North Sea, the capelin of the Arctic, the anchovy, hake and mackerel of California, etc., etc.

Much research is going on respecting ocean food production, processing and distribution. The process of eradicating protein malnutrition from the world could be much speeded up if a small part of the funds now devoted to space exploration by the United States and Russia were diverted to these mundane objectives. Nevertheless, much progress is being made, and much more can be expected in the near future.

7). The major aspects of the Law of the Sea have been codified and developed in four conventions arising from the 1958 Law of the Sea Conference. Three of these are in force, and the fourth is likely to come into force next year. If man were a fully reasonable, moderately unselfish, politically mature, and moderately myopic animal, these four conventions would provide an adequate framework of international behaviour under which he could peacefully and profitably harvest these enormous resources of the sea. Under existing circumstances one can reasonably anticipate increasing disputes among nations over these matters, and the field of the Law of the Sea would appear to hold a splendid future for bright young men aspiring to a professional career.

8). The United States at last has a National Oceanographic Program. This is presently beginning to stagnate while we explore outer space, but it will come to life again in the future. In the meantime, we are learning much about the ocean from the research activities of other nations, particularly Russia.

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