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The Dream of Harvesting Plankton

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

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

of organisms is many times that of fishes. This implies fishing for plankton.

Plankton is distributed unevenly and often diffusely and it varies enormously in quality. Therefore, the chief problems of utilizing it would be first to find ways of concentrating and collecting it, then of controlling and standardizing the products. Long ago, people solved these problems simply and directly, perhaps in the only way feasible, by exploiting the work of whales and such plankton-eating fishes as herring, pilchard, and menhaden. These animals are very efficient in concentrating plankton and transforming it into their own flesh which, for any one species, is a product of comparatively uniform quality. However, it does take at least ten pounds of plankton to make a pound of whale or of herring. Could we do better? Is it likely that we could invent a mechanical apparatus, a sort of artificial whale that could be used to harvest plankton more cheaply than whales or herrings do it, and thus open up vast new sources of protein? This is not a new idea. Many times in the past people have considered the feasibility of capturing plankton and preparing it for human or animal consumption. One of the first articles on this subject described eight yachtsmen who made breakfast by cooking marine copepods in Norway in 1891.¹ Shortly before World War II the German State Biological Institute at Heligoland investigated the possibility of harvesting plankton as a new food source for the German market. In 1941 Sir John Graham Kerr wrote a letter proposing that a special committee of biologists investigate the possibility of obtaining food directly from marine plankton. A month later A. C. Hardy² published an article suggesting that plankton could serve as a source of food in England during the wartime food shortage.

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

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

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

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

	Protein %	Fat %	Carbo- hydrate %	Ash %	P ₂ O ₅ %	Nitrogen %
Copepods . . .	70.9-77.0	4.6-19.2	0-4.4	4.2-6.4	0.9-2.6	11.1-12.0
Sagittae	69.6	1.9	13.9	16.3	3.6	10.9
Diatoms	24.0-48.1	2.0-10.4	0-30.7	30.4-59.0	0.9-3.7	3.8-7.5
Dinoflagellates	40.9-66.2	2.4-6.0	5.9-36.1	12.2-26.5	0.7-2.9	6.4-10.3

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

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

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

R. S. Wimpenny, of the Fishery Laboratory at Lowestoft, and Dr. K. Kalle, of the German Hydrographic Office, suggest⁷ that large quantities of oil might be obtainable from the patches of the diatom *Coscinodiscus concinnus* that occur sporadically on the surface of the North Sea in summer after a fortnight's fine weather in late May when there is a thermocline. There the oil might simply be pumped off the surface of the sea and the water separated off. No doubt there are similar situations in other parts of the world. Experimental pumping at the appropriate season in an area where these patches occur and chemical analysis of the material collected would be necessary in order to assess the quantity and values of oils that could be obtained from this source.

Although carotenoids are generally distributed among plankters,

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

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

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

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

* International unit

† Microgram

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

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

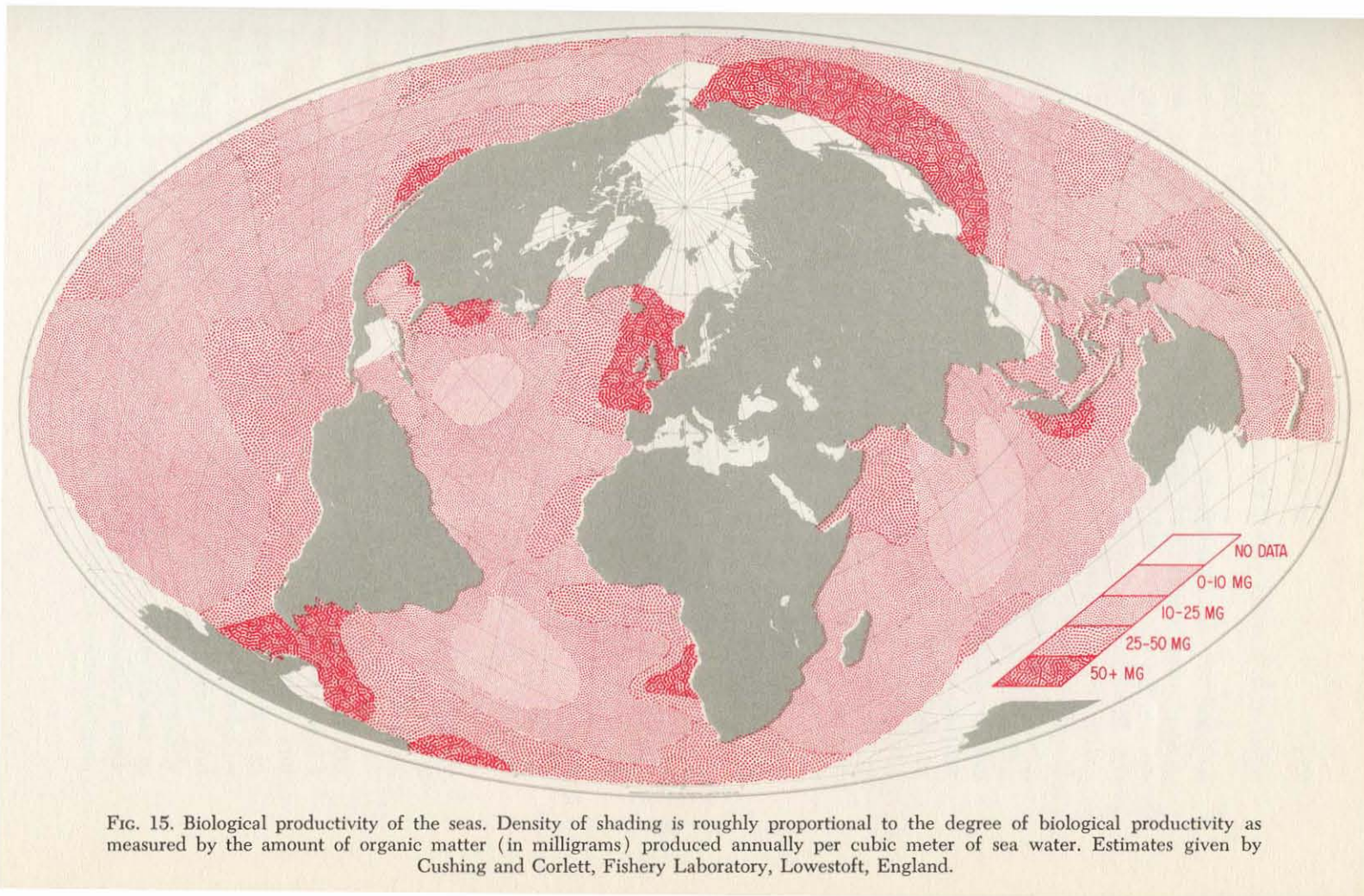


FIG. 15. Biological productivity of the seas. Density of shading is roughly proportional to the degree of biological productivity as measured by the amount of organic matter (in milligrams) produced annually per cubic meter of sea water. Estimates given by Cushing and Corlett, Fishery Laboratory, Lowestoft,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

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

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

George Clarke¹⁴ of Harvard University, in discussing plankton as a food source for man, based some pertinent calculations on such a net. He assumed that a rich area of the sea should yield an average of 0.1 grams (dry weight) of plankton per cubic meter of water. He assumed further that the stramin net is 20 per cent efficient. Then a normal, conical net with a round opening 2 meters in diameter would require about $3\frac{1}{4}$ hours to collect a little over $1\frac{1}{2}$ pounds (750 grams, dry weight). In 24 hours of continuous operation, which is feasible if two nets are fished alternately, a 2 meter net would collect about 12 pounds (5.5 kilograms, dry weight) of plankton. The largest conical tow-net which has been fished successfully is the $4\frac{1}{2}$ meter net used on the research vessel, *Discovery*.¹⁵ This net was of coarser mesh than stramin. Even so, using Clarke's assumptions, it would collect 61 pounds (27.5 kilograms, dry weight) of plankton in 24 hours of fishing.

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

Philip Jackson¹⁶ estimated the probable costs of plankton fishing in this way: He assumed (a) an average population density of 0.1 grams (dry weight) per cubic meter for mobile harvesters, and 0.01 grams (dry weight) per cubic meter for "fixed" harvesters in tidal estuaries, (b) 2,000 hours harvesting per year, (c) 200 hours traveling to and from harvesting areas (where applicable), and (d) a 20 per cent straining efficiency for large tow nets (probably on the low side) and 90 per cent for small nets or filter fabric in non-towing methods where a finer mesh can be successfully used. Allowing a cost of £3,600 for operation of a 60-foot motor fishing

vessel, the cost of producing a dry ton of plankton by the various methods which have been suggested would be from £1,800 to £3,000 (\$5,040–\$8,400).

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

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

* References:

- A. C. Hardy, Private letter to David Cushing and John Corlett.
 A. C. Hardy, "Plankton as a Source of Food," *Nature*, CXLVII (1941), 695–96.
 James W. S. Marr, "On the Operation of Large Plankton Nets," *Discovery Reports*, XVIII (1938), 108–20.
 R. F. Shropshire, "Plankton Harvesting," *Journal of Marine Research*, V (1944), 185–88.
 George L. Clarke, "Plankton as a Food Source for Man," *Science*, LXXXIX (1939), 602–3.
 Chancey Juday, "The Utilization of Aquatic Food Resources," *Science*, LXLVII (1943), 456–58.

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

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

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

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

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

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

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

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

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

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

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

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

The consensus of opinion was that probably no mechanical device of man will ever equal the efficiency of whales and fishes. Nevertheless, a few scientists thought the question of the feasibility of plankton harvesting has not been settled. Dr. Hart suggested the use of a "mechanical whale," that is, an apparatus that would engulf water and press out the plankton, simulating the manner of

a whale taking in mouthfuls; Mr. Rae suggested a factory ship with open collecting channels in its hull; several others, a combination of pumps and filters. Most frequently mentioned was pelagic nets, fished near the surface at night. Dr. Havinga suggested that nets used less energy than other apparatus, because water did not have to be displaced, but Mr. Rae thought them much too slow.

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

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

Professor Hardy and Mr. Wimpenny thought that the question of profitable plankton harvesting is not yet settled. Wimpenny, Friedrich, and Rae thought it would be desirable to spend money on a pilot experiment if only for the useful scientific information about plankton that would be obtained. On the other hand, Jackson¹⁸ concluded that "plankton harvesting could not be economically feasible unless and until areas of greatly increased population density can be either located or produced by artificial means or a radically novel and cheaper method of harvesting becomes available."

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

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

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

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

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

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

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

In short, a science of plankton fishing would have to be developed, based on knowledge about the organisms. Until we have that knowledge, it will not be worthwhile to spend a great deal of money

on fishing apparatus for trial-and-error experiments. Meanwhile, general knowledge about plankton, including its abundance and behavior, should be one of the many useful products of research on environment (Chapter 5) and on behavior.