Marine Biology

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CONTINENTAL SHELF

Introduction

Research in marine biology carried out from the Naval Arctic Research Laboratory or through it and interlocking agencies provides a substantial base for more refined studies requiring arctic or subarctic marine organisms or conditions. Before 1948 (see MacGinitie 1955, pp. 1-3) observations were so few as to be almost useless. In the course of work in 1948 and 1949, MacGinitie and co-workers studied mainly the benthic invertebrate fauna of the continental shelf area and Elson Lagoon close by the laboratory (about 71°20′ N., 156°41′ W.). To one familiar with the environment and the equipment they had, the MacGinitie team's results approach the awesome; they could be accomplished only by a combination of unusual knowledge of the ways of invertebrates with practical seamanship and almost unbelievable persistence. Use of the superlatives these scientists deserve would probably alienate anyone not acquainted with the difficulties under which they worked. The extent of their contributions may be indicated by the fact that earlier workers had reported the presence of a few amphipods and a few polychaetes; the MacGinitie team studies (MacGinitie 1955; Pettibone 1954; Shoemaker 1955) cover about 100 species of amphipods and 88 polychaetes with considerable information on behaviour (particularly of breeding) and ecology. Because of the smallness of the team, the brevity (less than two years) of the field work, and the paucity of equipment, the scope was also very limited.

Inventory

Most of the work from Barrow in marine biology to date has been devoted to inventory taking. Because the chance for a role of distinction for NARL in marine biology depends precisely on the attraction of superior experimental biologists and these will come to the laboratory only if dependable supplies of experimentally intriguing organisms are provided, a good inventory with easily retrievable data is indispensable.

The MacGinitie studies provide the core block of knowledge mainly of bottom invertebrates within a few miles of Barrow. Subsequent work near Barrow increased the knowledge of the fishes and cetaceans (Maher and Wilimovsky 1963; Hurley and Mohr 1957) and some parasites of marine vertebrates (Rausch 1962; Schiller 1967). Another study (Mohr *et al.* 1957) revealed a bed of marine algae (the Skull Cliff "kelp bed") about 50 miles west of Barrow, and confirmed an

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existing impression that the biota is rather poorer east of Point Barrow and a little richer westward toward Wainwright.

Besides being limited mainly to the inner portion of the arctic shelf, which averages about thirty miles wide, the knowledge is mainly about animals that, with the exception of the foraminiferans, are large and conspicuous. Anything which might slip through a millimetre mesh was ordinarily not taken or was lost in the washing of bottom deposit material.

Observations are also limited mainly to periods of open water; MacGinitie did under-ice dredging (devices other than dredges have very small yields) accomplishing by dint of great effort *two* hauls in February and *one* in March during his 1949-1950 work. I find no report of other winter dredging. Thus there is little good winter information, and as there has been so little shelf work done since 1950 there are no data on how the stock changes through seasons and years. (Compare this with the information amassed on the lemming.) Neither is there information on how many individuals of any species occur off Barrow, except for the very general knowledge that more of some things than of others were taken.

For a brief period in one year Wilimovsky (1954) and his associates used a beam trawl with aperture eight feet wide from the LCM *William E. Ripley* and some years later another researcher had just a few hauls with a six-foot aperture Isaacs-Kidd midwater trawl. Neither was used often or widely but their rake indicated clearly that the swifter and shyer species and the adult stages of some species were not represented in proportion to their actual occurrence in nature in the earlier collections.

Another deficiency of the existing inventory is the uncertain location of the stations. The best locations are only fair; those farther to sea, vague.

Plankton of the inshore area, in which some interaction with shore and bottom should occur, has barely been examined. Johnson's (1953) studies, which have the only grid of plankton stations, barely touch the inshore area. Bursa (1963) had very limited collections of the phytoplankton. Virtually all the sampling has been done in summer. There has been no sampling in the leads in April and May when the bowhead whales are hunted while apparently feeding; I have guessed that the zooplankton is heavy then and that its growth has followed an earlier and significant increase in phytoplankton. F. E. Durham (personal communication) has some bowhead gut material indicating that they do feed (most whales apparently disgorge when they are harpooned), but almost nothing is known of the plankton which is their food.

Systematics

Taxonomy of Barrow organisms has taken little account of variability or population phenomena (except for Holmquist's (1965) studies), karyotypes, chemical characteristics, or other aspects of current major taxonomic concern. Some macroscopic groups (for example sea squirts) are still to be given first comprehensive study. Specialist studies, such as that of Steele and Brunel (1968) on the amphipod, *Anonyx,* will describe more clearly a larger macrozoan fauna than we now know.

Greatest changes will come in our knowledge of small forms. Even "alpha" taxonomy has yet to be done with unicellular algae, the bacteria, the protozoans other than foraminiferans, and the spirochaetes and more obscure microbes of the sea. On grounds of biological logic, that is, in the sense that in microbes most energy transformations take place, they must be of vast importance. Presumably cryophylic, they should at least rival in interest counterparts on the land.

In addition to the protophytans and protozoans, essentially untouched groups of small forms include hydroids, turbellarians, nematodes, rotifers, Kinorhynchs, and the "micros" among the mollusks, segmented worms and arthropods; in sum probably considerably more organisms than we know at present.

A principal service needed *from* the taxonomists is the preparation of a series of aids that will permit a properly attentive worker, for example a systematist with no knowledge of a particular group, or a physiologist with no experience whatever with naming organisms, to know any organisms occurring often enough and in numbers enough to be suitable for experimental studies.

Aids should include carefully constructed keys, with good diagrams, photographs, measurements, and a modicum of ecological detail. As MacGinitie originally provided with the amphipods, the systematists should supply the laboratory with a working colour-print atlas of living examples of several important groups. Especially appropriate for inclusion would be the amphipods in which living examples at dissecting scope magnification characteristically have distinctive colours, although in preservative for even a short time they tend to fade to disheartening homogeneity — as a nonspecialist sees them. These animals are potentially of real importance for experimental purposes, but the potential is not obvious as one examines, for example, the accounts of 100 species of amphipods covered in Shoemaker's (1955) paper, illustrated mainly with dozens of pedal and antennal details of leached-out remnants. In life many have distinct colouration and they have behavioural, physiological, and other problems more than enough to keep a laboratory full of good biologists busy with worthy problems.

Microscopy

Few investigators have sought small free-living organisms or have examined any of the marine organisms microscopically. To observe the effects of the parasite, Thalassomyces, I studied sections of one infected individual of the pelagic amphipod, Parathemisto. It proved to have gregarine protozoans in the midgut and ciliates, probably suctorians, on swimmerets; the Thalassomyces had pushed aside the central nerve cord. In about a year of study of calanoid copepods of the basin and the northeastern or eastern Greenland waters, Julio Vidal (personal communication) isolated calanoids of at least five genera (Augaptilus, Chiridiella, Microcalanus, Scaphocalanus, and Spinocalanus) with suctorians attached, well over a hundred individuals. From these and other observations one may remark that energetic investigation with the naked eye, but especially with dissecting and compound microscopes, will discover very many parasitic (broad sense) relationships; furthermore that an almost infinite spread of significant problems of structure and function is to be found at the microscopic level in organisms from the dinoflagellates to kelps and ciliates to cetaceans; and that even a modest beginning has yet to be made.

Biogeography

The Barrow area has yet to be placed in a marine biogeographical context by anyone familiar with its organisms. It appears in various accounts usually with Barrow matters somewhat out of focus. The significant adjacent areas also are very poorly known so that a biogeographical synthesis cannot now be adequate. Generalizations which lump the Barrow area with the Grand Bank off Newfoundland as "subarctic" are misleading.

Ecology and Animal Behaviour

The materials for consequential ecological studies of the Barrow marine biota are not yet at hand. The MacGinitie work was illumined by a master ecologist's understanding and the summary study (MacGinitie 1955) is a masterful guide and a beginning to an ecological study of the region. The fact remains that an inventory and an ecological analysis of the results cannot be made anywhere by a handful of people with minimal equipment in eighteen months — and Barrow presents more difficulties of operation than most other places.

There is no comprehensive web of geological stations although a few observations at sea have been made in the course of beach or permafrost studies. As most inshore areas, Barrow lacks proper oceanographic studies. Determinations of turbidity, temperature, salinity and dissolved oxygen have been made mostly by people without special competence for the work. Also lacking are measurements of such important factors as light over and under water and ice, and of major and minor nutrients. The measurements that have been made have little spread in space or time. There are too few covering too short a time.

MacGinitie (1955) and others (Mohr and Tibbs 1963; English 1961) have tended to emphasize the importance of limitations on light: angle of entry into water, turbidity, ice and snow reflections, and others; Dunbar (1968) appears to de-emphasize such limitations emphasizing rather the extraordinary efficiency of polar marine unicellular algae, high in chlorophyll *C*, in using light of low intensity. Whatever is the emphasis, there is yet to be amassed a proper body of measurements of the energy received by the biological web at Barrow; of the light penetrating the sea and some calculation of how much of it may be used by what organisms (neither planktonic nor benthic plants are properly known); of the energy available from tundra sloughing or from materials carried from the land by rivers, or into the polar enclosure by ocean currents.

The MacGinitie summary paper either starts or indicates community studies that need to be made, but so far there is at most inadequate information even of what (particularly how many of what) occurs where. There is need for sampling devices that do not dislodge organisms from their positions on or in a bottom sample. Devices such as anchor dredges or the modified Campbell grab with camera may be partial answers to sampling difficulties. There is little knowledge of the interaction of organisms with physical environment, with others of the same species, or with other kinds of organisms. There is no knowledge of population changes or interactions.

Ecological studies such as plot or transect analyses, which may be carried out by wading or diving with only moderate difficulty in other areas, are grossly hampered at Barrow by the ice cover and by sediments made into slurry by grinding ice and currents. There is virtually no possibility of useful intertidal studies. Subsurface studies going beyond a single season would need to be in deep enough water not to be demolished by pressure ridges in the ice cover. Such work would impose great difficulties of relocating and sampling. Several programs that offer considerable prospects of significant results are suggested.

The first of these is to set out extensive artificial reefs deep enough (approaching 50 feet, for example) not to be dislodged every winter by pressure ridges. These would involve depositing discarded metallic objects as a linear reef normal to the shore-line, possibly with satellite cluster reefs. With metal lines and buoys attached at the start, they might be provided with removable panels for study of interactions of organisms, fouling, succession, and the like, with panel information supplemented by trap results. The ferric mass of many drums and fractured vehicles should be readily relocated and divers might reattach lines and buoys. Wherever artificial reefs have been constructed so far, they have been taken over promptly by the organisms of the area and have ranked with the sections of high population in the surrounding areas.

A second approach is that of the marine pond. For this our models are Mogil or "Grave" Lake of Kildin Island on the Murman coast, and Nuwuk Lake at the tip of the Point Barrow spit. In both cases there is a lake deep enough to have an unfrozen pool large enough to counteract evaporative water loss (in Grave Lake, according to report, percolation from the nearby sea maintains a normal arctic seawater salinity), and with a drainage basin broad enough so that the closest tundra sloughing does not make the lake dystrophic. Such a lake is a limited marine microcosm which can be modified systematically in a series of experiments. Because Nuwuk Lake is now on an island (it was readily accessible between 1952 and 1960 when previous observations were made), it would probably be necessary to install a wannigen station for observers or to excavate and build up one or more similar basins closer to the laboratory.

There are many potentially fruitful experiments with such a marine pond that suggest themselves to any ecologist. After measurement of dissolved elements one might augment one or more of the trace elements that are at particularly low levels and effect other types of fertilization indicated by levels of nitrogen compounds. After a check of conditions and populations in one year, one might stir the bottom sediment (that of Nuwuk Lake is a deep deposit of sulfide mud) a little or much with pumped air or with oxygen, after which all should be studied again. One might introduce various primary producers — an inoculum of a unicell such as an arctic diatom or one of the smaller species of brown or red algae from the Skull Cliff kelp bed. One might introduce living barnacles or some other fecund consumer and one might, with particular profit, set up an artificial reef. "Management" of environmental factors and accuracy of measurement are obviously possible beyond anything practicable in the open sea, whereas such a system escapes many of the disadvantages of a laboratory tank. Experience with the unmanaged events in Nuwuk Lake gives confidence that good experimental designs could give worthwhile scientific yield.

Tank or flask studies in the laboratory may produce other useful results as they do at other latitudes. They are very likely to be particularly valuable with unicellular algae and protozoans for which responses to light (in the many ways it is known to affect organisms), temperature, agitation, nutrients, associated organisms, accumulated metabolites, and so on, are probably significant. One might test d'Ancona-Volterra (=Gausean) competitions, Margalefean succession, and other ecological models.

In summary, ecological marine research has barely begun at Barrow; it is very likely to be attended by exasperating difficulties, but there are possibilities of results of the same high interest as those developed in arctic terrestrial ecology.

One utilitarian ecological task that is seriously overdue is a study of pollution of the northern sea. In an earlier day Eskimo villages did not grow beyond the capacity of the nearby land and sea to yield enough fish, game, and whales to provide protein. Eskimos in such villages produced little that did not disintegrate inoffensively in a few seasons. Barrow today has both much greater amounts of waste and many new persistent objects and substances. On shore in summer it is visually and olfactorily degraded; at sea there have been *no* observations. With bacterial decomposition slowed by cold, one must guess that bottom organisms are affected adversely, but it is necessary to examine the area to find the extent of any sludge and the degree to which a health hazard may exist. The area of contamination also restricts the possibility of any exploitations of shellfish.

The exploitation of northern oil, so far as it touches on the sea, presents quite another set of problems, for the equipment used and the intensity of the operation make for very rapid changes. From Californian experience, it is feared that the operator will show little foresight in pollution matters and little concern for the environment. The lack of concerned observers augurs ill for ecology. In their studies of 1949 and 1950 George and Nettie MacGinitie (as would be anticipated from their many contributions to knowledge of behaviour of Californian invertebrates) made many observations on behaviour of Barrow organisms (relations of commensals to various hosts, colonial behaviour of certain amphipods, and so on), but these were mostly aborted at the level of asking a significant question, because time was inadequate, and decisively, because temperature controls failed continually and animals died.

Many significant problems in marine animal behaviour may be studied at NARL with rather modest modifications of or additions to existing equipment (circulating seawater, light and temperature controls). Obviously appropriate programs are those involving responses to conditions of high as compared to lower latitudes, and particularly those related to extremes of available light and food. Possibly most fruitful would be studies of individuals of the same species (as certain crustaceans, annelids or mollusks) from Barrow and from Friday Harbor, or Churchill. Undertaking joint studies with laboratories with established germane programs is desirable.

Generalizations about the effects of latitude on the size of marine plants and animals are among those that should be tested. For example, with barnacles one might determine normal sizes with age, rates of shell growth, maximal ages and survivorship, attainable sizes, and the like. The notion that polar animals are larger, certainly not true for larger taxa, may be true for a species extending through many degrees of latitude.

The use of Nuwuk Lake or of artificial marine ponds would increase the range of experimental possibilities for animal behavioural studies.

Embryology and Life Cycles

Investigation of the development of marine organisms might not seem an especially appropriate activity for what is, indeed, an outpost-laboratory. There are, however, very good reasons for regarding embryology as having a potential role of especial importance for NARL. MacGinitie (1955, esp. pp. 36-53) has provided data on "reproduction phenomena" on nearly 150 species of eleven phyla of invertebrates. Although few of these have been maintained in the laboratory, Mohr *et al.* (1961) found in Nuwuk Lake apparently flourishing foraminiferans and several other sorts of protozoans, flatworms, roundworms, a nemertean, a priapuloid, a bivalve and a gastropod mollusk, a small earthworm, several polychaete worms, and crustaceans (one species each of ostracod and mysid, two amphipods, and more than a dozen copepods). Because Nuwuk Lake is, or was, a rather poorly nourished lake with an ice and salt regime and a vulnerable food web, those of us who have worked there believe that a number of the inhabitants may be sufficiently hardy to be good laboratory animals. The development of the whole curious group, priapuloids (a species of which at least occurred in Nuwuk Lake) is very incompletely known. Some other Nuwuk animals and quite a few of the species (coelenterates, mollusks, polychaetes and tunicates) that MacGinitie found breeding are fairly closely related to species used in classical and experimental embryological studies. The echinoderms, although not observed in breeding, are worth investigation.

How much one might do with studies of living marine algae must be determined. The kelp bed off Skull Cliff would very likely yield the same algae that were taken when it was discovered: three browns and seven reds. Provided that they were not dislodged from the rocks they were growing on and that they were given nutrients and trace metals, these should thrive in the real or a synthetic Nuwuk Lake and some should be suitable for laboratory propagation. Alternation of generations, fertilization, morphogenesis, growth rates and the like could be studied.

I believe that no cycle of a marine organism has been worked out at Barrow although the cycles of a few species that occur there have been studied at laboratories at lower latitudes. In the cases where a cycle is known for a species in an area with quite a different environment, it is possibly desirable to determine how development has responded to the special conditions of a far northern habitat. Knowledge of the life cycles of principal marine organisms: when and where they breed, how many eggs of what kind are carried or placed where, what stages develop how rapidly, when and where they mature, and so on, is indispensable for work on population ecology. It is a prerequisite also for many kinds of experimental studies, particularly physiological studies.

J. F. Tibbs (in discussion and in letters) has pointed out that polar seas, both north and south, at latitudes above those with subarctic or subantarctic abundance should be particularly favourable for working out life cycles. Because there are no more than a few species in most families, organisms are likely to have developmental stages that need not be confused with those of closely related organisms. Where there are two or several species with developmental forms similar enough to be confused, breeding of the different species, characteristically not prolonged in cold waters, may not occur at the same time.

Tibbs hopes to follow the development of radiolarians, an important marine group on which earlier work on developmental cycles is known to be mistaken. Because radiolarians have not responded well to culture, complete cycles have not been determined in any laboratory. It appears that it should be a relatively uncomplicated task working from Barrow or a drifting station to fit developmental stages into a correct sequence provided that frequent plankton samples were taken with fine nets sufficiently gently so as not to shatter the fragile radiolarians.

Probably even more important would be to determine the reproductive events of a number of radiolarians where existing accounts are either known to be mistaken or are at least suspect.

Physiology and Biochemistry of Marine Forms

Other papers presented at the NARL Symposium have stressed studies of temperature relationships; much remains to be done with marine organisms.

One might find in at least ten chapters of Nicols' (1967) book on marine animals problems in which studies of Barrow animals would significantly expand knowledge. Species that are apparently common, and whose size and other characteristics are suitable, could be suggested for many studies. Recently a chemical neurophysiologist, seeing specimens of the large isopod, Mesidotea (Idotaega), remarked that it should be ideal for both electrical and chemical studies of vision.

The range of organisms for marine plant physiology, while smaller, is enough to support significant research. Northern phytoplankton has been subjected to few experimental studies. NARL should be an excellent base for getting cold water forms into culture and for studying a variety of environmental and nutritional effects (as well as providing food for experimental animals). The few macroscopic marine algae that one may be confident of collecting are enough for many studies of environmental effects. I believe there have been no studies of photosynthesis, energy transfer, respiration or other physiological processes in far northern marine plants. *Ulva* (fragments of which have been taken), and three brown and seven red algae provide a range of pigments and most likely a range of physiological modes. Measurements of their physiological parameters should have the same high levels of interest and importance that the pioneering studies of Irving (1951), Scholander *et al.* (1950), and Wohlschlag (1953) have had.

The biochemical study of Barrow marine organisms is to my knowledge confined to the single study of Lewis (1962) on chain length and unsaturation of lipids of a fish and a crustacean. His approach (gas chromatographic analysis of methylated lipids) should be extended to an analysis of annual cycles of kinds and amounts of lipids in the same and in other prominent species, and should be combined with studies on the morphological disposition of the lipid pool and of its physiological role.

Of all the physiological-biochemical studies, I should name the isolation, chemical identification and functional characterization of principal enzyme systems as having the greatest interest for polar biologists. In these cryergic enzymes, rather than in any visible structure or process, is the difference between Barrow organisms and those of lower latitudes. Their elucidation should be a task of high priority.

Other biochemical objectives of many sorts are well worth pursuing: carotenoid pigments of crustaceans, especially euphausiaceans; photosynthetic and associated pigments of unicellular and of macroscopic algae; visual pigments of many animals; dermal or epidermal pigments of crustaceans, cephalopods and fishes; serological systems of fishes and mammals; differences in biochemistry of bowhead whales, and belugas (which do not leave northern waters) and gray whales (which migrate to tropical Mexico each winter), and so on.

At this stage in the life of NARL, the most appropriate biochemical problems for study are those that can be started with sampling at Barrow and carried to a stage at which further changes can be restrained until materials are taken to a complete biochemical laboratory. In the future the biochemical capabilities of the laboratory may well be increased.

To a very important extent the history of genetics has been the finding and exploiting of a series of organisms in which it has been possible to associate an underlying hereditary mechanism and a clearly defined expression of that mechanism (a structure, a behavioural pattern, a chemical compound) in which generations are short, and which are easily bred. So far few marine organisms have been proposed for genetic studies (Ray 1958), but this is probably so because few marine organisms have been "domesticated". There is no reason to suppose that few marine organisms suitable for genetic studies exist or that they are absent from polar seas. Properties such as those related to life in the cold obviously have potential interest for geneticists. Unicells (bacteria, algae, protozoans) seem particularly likely candidates for roles in genetic research. However, geneticists, with notable exceptions, esteem comfort and convenience; they would probably require services and support not now contemplated.

Marine Fishes and Mammals

Barrow area fishes were studied for some years in the early fifties by Wilimovsky and his several co-workers. Like the MacGinitie work, theirs was largely inventory with similar uncertainties about places and numbers, and some information on breeding states was obtained. The range of collecting was somewhat wider: Barter Island to Kuk Inlet; and some more adequate equipment (*e.g.*, a large beam trawl) was used in the Point Barrow-Kuk Inlet sector. Much of what has been said above about systematics, ecology, behaviour, and so on, of invertebrates can be applied to the fishes with no or with little modification.

Pinnipeds (harbor seal, bearded seal, walrus) have not been the objects of biological studies (other than as hosts of parasitic worms at Barrow). They are important to the Eskimos and, with the unnatural concentration of people at Barrow in the past two decades, may be under excessive hunting pressure. Some study of the populations is needed.

Cetaceans have been represented by at least five species at Barrow. Ray (1885) talked with Eskimos who had seen narwhals, but they were considered long extinct in Barrow waters in 1883. A Dall's porpoise was taken in an Eskimo gill net in 1952 but it is not clear how often they occur in the area. I observed a beluga foetus among the piles of walrus segments in the village in 1953. The men appeared to be entirely familiar with the beluga, but regarded it as occurring more to the west (and south) and considerably further east; it is not as common as the pinnipeds. These three are the toothed whales.

Two whalebone whales occur commonly at Barrow, the bowhead (Alaskan population of the Greenland right whale) and the gray whale. The most recent comprehensive account of the bowhead dates from the 1860's (Eschricht and Reinhardt 1861). Various aspects of the biology of bowhead and gray are under study by Durham (unpublished manuscript). His study text provides new observations based on more than 30 butcherings, adds new observations on osteology (especially the skull and limb girdles), myology, other soft parts, on various aspects of physiology including the disposition of mass, on embryology and on distribution and population trends. Durham has visited bowhead whaling villages other than Barrow studying bony remains and discussing whale occurrences and practices with the whalers. He has also studied gray whales at Barrow and at Point Richmond, California.

These whales as they occur at Barrow have been characterized by MacIntosh (in conversation) as constituting the greatest single existing opportunity for whale research. In all other situations biologists await the pleasure of those butchering the whales commercially. At commercial shore stations whales are already long dead when they are drawn to the flensing deck; tissues are beyond use for precise biochemical or cytological study. In any case, investigators must be quick, sometimes working almost between slashes of the flenser.

At Barrow, if a serious effort were to be made, it would be possible to organize a shore team and mobile laboratory. In agreement with whalers it is possible to take and draw onto the ice an April or May bowhead, have a scientific team take anatomical, histological, cytological, serological, parasitological samples, and a variety of other materials of quality almost never attained; make all appropriate measurements, and turn over to the village nearly as much of the whale as is taken ordinarily and in not much more than the ordinary amount of working time. A similar beaching of a gray whale during summer would provide a like range of measurements and materials for investigation.

It is not to be supposed that such an effort would all go smoothly, but it is probably reasonable to hope for three generally effective bowhead operations in five whaling seasons. Three such operations when the materials were worked up would increase our detailed knowledge by at least an order of magnitude.

THE DEEP BASIN

Introduction

Study of the basin beyond the shelf has had few options for the scientists. Most operations have been from platforms fixed in slowly and erraticly moving pack ice. Areas of sampling have been restricted. On the other hand there is somewhat more homogeneity of the environment (fewer niches to seek out) than inshore. Much more of the work too can be done by a solitary technician; and very many more man hours with better spread through the seasons were devoted to drifting station work from 1952 to 1955 and from 1959 to the present than to work on the continental shelf. Three sets of plankton samples from an automatic plankton sampler on naval submarines have helped to fill in the picture. Thus the work is in some respects much further along than parallel work on the shelf.

Plankton and Ice-Interface

Horvath (see Mohr 1959) took the first plankton samples from a hydro-igloo on thin (less than 10 ft. or 3 m.) ice at the rim of Fletcher's Ice Island, T-3, at 86°45′ N. in November 1952. He took a number more during 14 months divided among three tours of duty in 1952 to 1955, at the end of which T-3 was over the shelf of Ellesmere Island. English (1961) took part in IGY-drift station Alpha in 1957 and 1958 providing observations on ice-interface communities, photosynthesis and other aspects of plankton, measurements of primary productivity (by chlorophyll *a* and C^{14} techniques), measurements of light energy in open water and under flow-ice and giving useful estimates of amounts of open water in leads. Grice (1962) reported 18 copepod species and their distributions taken by an automatic sampler attached to the submarine *Seadragon* during a polar run. Mohr and Geiger (1962) made comparisons of the general performance of the *Seadragon's* device with that of nets suspended from the drifting stations. Since 1959, teams from University of Southern California, University of Washington, and McGill University have worked on the NARL drift stations; respectively their principal objectives have been: inventory and water-mass indicator organisms, productivity and population analysis, and scattering layer analysis.

Collections to date may be presumed to have taken the macroscopic plankters except those that are quite uncommon or are elusive. English's excellent "umbrella nets", collapsible, with mouths several metres square that can be passed through the narrow hydroholes are showing, by catching series of such supposed rarities as bathypelagic proboscis worms (*Dinonemertes*) and liparid fishes, that there is still need for catching gear working in ways different from those we have used.

Most important macroscopic organisms are the copepods. Arctic copepod taxonomy is still inadequately known at least by American workers. Brodskii (1950; Brodskii and Nikitin 1955) has provided the principal taxonomic study of the Calanoidea. Johnson (1956, 1963a, b) has made the most impressive contribution analysing icebreaker collections from the southern border of the Canada Basin, and station Alpha, to about 85° N. Geiger (1966) has noted size variation in one important species. Dunbar and Harding (1968) have related collections made from T-3 in the summer of 1964 in the Beaufort Sea between 80°34′ and 85°53′ N. with principal water masses. Hughes (1968) analysed the distribution of the 8 most common (of 25 species recognized) copepods in the summer of 1966 (apparently about 75-76° N.) and the following winter (*c.* 79° N.) in an area just south of Dunbar and Harding's (1968) stations. His samples were taken with a plankton pump. The copepods being at once the most important and potentially useful for considerations of many sorts — and taxonomically the most difficult — it is very desirable that an updated counterpart of Brodskii's (1950) monograph, with improved figures and keys, be produced.

Of other prominent groups with a number of macroscopic plankters the jellyfishes (medusae, siphonophores and ctenophores) have been studied by Shirley (1966). Dawson (1968) has studied the chaetognaths and an illustrated key to these is being prepared. Knox (1959) studied the T-3 1952-55 pelagic polychaetes; unless new devices such as the English umbrella net show them to be numerous, there is probably no need of a key to them. The rather few taken by University of Southern California drifting station representatives since 1959 have not been worked up. Barnard (1959) reported on the Horvath T-3 amphipods, Tencati and Geiger (1968) have reported on those from the ARLIS II-East Greenland collections; Tencati is preparing an illustrated key to basin species.

With a great part of the foregoing studies, one or more factors reduce the value of the work. Sometimes hydrological determinations parallel to the sampling were not made. Sometimes line capacity did not permit proper depth sampling. Winches were mostly not of a kind or in a condition that permitted controlled operation of nets. Some of the studies, *e.g.* that of Hughes (1968), treat samples from different areas as essentially identical on the hypothesis that populations of a single watermass (in sense of Coachman) are practically homogeneous.

Microplankters as discrete organisms have had little attention from NARL workers. Green (1959) reported on *Globigerina* (which he thought might be benthic) in his study of skeletons in sediments taken north of Ellesmere Island, from 86°45′ N. to the shelf by Horvath (see Mohr 1959) from T-3. Kennett (in press) has demonstrated in an analysis using scan-grams that arctic drift station *Globigerina pachyderma* are distinct from antarctic *G. pachyderma.* Hülsemann (1963) reported on the Horvath T-3 radiolarians and Tibbs (1967) on radiolarians, three tintinnids, *Globigerina,* and unicellular algae (one silicoflagellate and four peridinians) taken from ARLIS I as it moved westward into the influence of Bering Strait (Pacific) water. He noted that the colour of luminescence of the globular peridinian, *Noctiluca,* was different from that of medusae. Keller (1967) has noted changes in the form in *Ceratium arcticum* from different parts of the ARLIS I track.

Of the various University of Southern California field men, only Tibbs (1967) made specific efforts to take protistans. I find no indication of such efforts by other teams. Accordingly, record of protozoans is very inadequate and of unicellular algae, almost entirely lacking. No work was done on bacteria.

Plankton studies of several sorts are needed:

1) A highly standardized series related to previous collections but provided with comprehensive parallel physical data, the samples to be taken with standardized nets at controlled depths, with metered flow at depth, or raised at controlled rates, the positions of the stations being determined precisely.

2) Measurements giving a comprehensive knowledge of light energy available to organisms in leading areas and under principal types of ice cover (with influence of snow cover and without) through the photic zone and through the months of the year with light.

3) Experimentation with a wide range of gear (for example use of various sorts of traps, variations of the collapsible nets) to complete inventory.

4) The taking of microorganisms for inventory, for photosynthesis studies, for physiological and biochemical studies.

5) These studies should be combined in an effort to test Dunbar's (1968) hypothesis that heterotrophic use of dissolved or particulate organic material results in major recycling of materials, and that the high efficiency of chlorophyll-*c* containing algae in low-light-level photosynthesis (scotosynthesis?) makes it doubtful (Dunbar 1968, p. 39) that even in the Arctic Ocean light is a limiting factor to plant growth. As part of such a study, we are looking into the modification of Yentsch's new submersible plankton pump with packaged power as a means of sampling particles and both very small and ordinary plankters.

6) A range of studies of photosynthesis in leads, under ice, at ice interface, and in mixed and pure cultures of phytoplankton should be undertaken. In these considerable effort should be made to insure that, whether oxygen production, C^{14}, pigment analysis, or ATP, as by Holm-Hansen and Booth (1966) are used, the determinations are comparable to studies made in other latitudes and in the southern hemisphere.

7) The community of the under surface of the floe as an ecological unit has yet to be studied.

8) Although on the drifting ice stations far fewer organisms than at Barrow offer advantages for physiological, biochemical, or biophysical study, and working conditions there are especially unsatisfactory, study of some particularly significant problems should probably be at least begun on the drifting stations where suitable organisms are directly accessible and where some of them may be started toward "domestication"; for instance scotosynthetic algae could be used for controlled light studies, and big-eyed amphipods for behavioural or neurophysiological studies.

9) Drifting station studies should be augmented whenever possible with samplings from icebreakers and particularly from submarines.

Bottom Organisms

The story of bottom work is largely one of inadequacies; for instance winch performance has been inadequate for most stations. The studies of Hunkins *et al.* (1960) and of Menzies (1963) indicate persuasively that the arctic bottom is not rich; Menzies suggests that the Arctic Ocean at 300 m. is about as poor as the Antarctic is at 4,000 m. and contrasts the best Arctic Basin growths with the invertebrate thickets shown in Bullivant's (1959) photographs in the Ross Sea. Green's (1959) account of fall-off of kinds and individuals of foraminiferans taken north of Ellesmere Island remains the most significant south-north transect; and Mohr's (1959) account of marine biological work at T-3, 1952-1955, despite mistakes and incompleteness, and Mohr and Geiger (1968) give a reasonably accurate general impression of the bottom biota as it is now known.

Analysis of the many successful long cores made in 1968 from T-3 should have considerable biological interest. It should provide much evidence on the history of the basin, a subject debated on the basis of very limited materials.

Many more bottom photographs are needed. Ideally at least some of these should be made in conjunction with sampling (as with the Emery-Smith-Campbell grab) of biota and water.

The work on the bottom is so limited that time for dredging (the Menzies small biological trawl has given the best yields of the devices we have used) should be found when the drifting station is moving well, and particularly when rises are encountered. Information is scanty for the slopes of the continental shelf and of the Lomonosov Ridge.

Work on microorganisms, which is a major desideratum even for inventory, will require microbiologists. A specialist or specialists are also needed to work over samples for protozoans and small multicellular animals, as many of these require special attention for study. Observation of both microorganisms and macroscopical groups in life should be attainable and is essential if anything of their roles is to be known.

CONCLUSIONS

Limits

I have indicated that at no sector and level of arctic marine biology are all the obvious tasks finished, nor in many cases has even a beginning been made. Because polar projects are more expensive than ordinary ones, special efforts should be made to screen proposed research designs very carefully for appropriateness and quality, to determine that the investigators are capable and that they are willing to carry the proposed work to fruition.

To find really superior scientists for many of the researches that would bring most credit to NARL and do most to confirm the wisdom of expanding facilities there, it will be necessary to give the scientists some of the amenities they can count on at the laboratories at which they now work (as at Plymouth, Woods Hole or Friday Harbor). These range from prompt, frank, and full responses to correspondence and professional attitudes of support staff, to careful maintenance of equipment. For biology it would certainly be well to have a resident biologist.

Minimally it should be kept in mind that scientists good enough to be appropriate for the new NARL are already busy. It is worthwhile to point out to a number of them the particular advantages of northern work, and to provide those who are convinced with support and courtesy akin to that available at other laboratories so that NARL is not a mainly July and August base for only some superior work.

Benefits

A specific charge of the convener of the Symposium was to state the benefits of marine biological work. The worth of polar studies to science, as far as the work has been or will be good, is great, and appropriate to the cost, because of the exceedingly interesting influences of cold, of light and of the other special conditions of the environment. With better planning, support and integrated build-up of results, it can be more valuable, with more return on investment.

Benefit to supporting agencies I shall not mention now, not because I regard this as unimportant but for quite opposite reasons: partly because support has been borne by too few agencies, partly because the matter requires fuller treatment than is possible here.

To our hosts and neighbours of the Arctic Slope, I think potentialities of benefit are significantly large and I think we may say much of what may be taken from the environment on a sustained yield basis. Observations have been made on changes in Eskimo whaling that could make for retrieval of a significantly larger proportion of whales killed. Whaling, like certain forms of hunting, probably has important value of manly accomplishment beyond calories obtained and may need very much to be continued and protected for social and psychological reasons, but the proteins, fats, and associated vitamins are not negligible. Development of Eskimo ethics of conservation while introducing more effective whaling methods may be a significant benefit that biologists of the laboratory can bring. Some extension of our knowledge of the stocks of shrimps, snails, bivalves, fish, seals, walruses and cetaceans is necessary before we can say how much more protein can (in some cases it may be how much less should) come from the arctic Alaskan sea.

From the marine biologists too should probably come, in cooperation with sanitary engineers, some word on the limits of disposal of community refuse to the sea.

The University of Alaska has certainly gained some glory from having provided a mantle of operation for much good work. However, I must conclude that mutual benefits that could very simply accrue from more frequent interactions between the biologists of College and of NARL have been lacking.

It may be said most sincerely that an early appraisal of living resources, of conditions before modern exploiters use the savagery of sophisticated tools to alter the environment, is one of the most valuable objectives. If, beyond this, the scientists of NARL give an example of sober and economical use of living resources in doing clean and significant scientific work, that will indeed be of benefit to the nation.

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