Oceanography and Biology of Arctic Seas

Symposium on Marine Sciences of the Arctic and Subarctic Regions

Introduction

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The Arctic Ocean and the Subarctic Greenland, Norwegian, and Bering Seas form a mediterranean sea which is separated from the Atlantic and Pacific Oceans by islands and high submarine ridges. For more than a hundred years oceanographers have addressed the problems related to surface currents and fronts as well as to the exchange of water masses between the various parts of the system. They have also tried to understand the formation of well-ventilated deep water and the transport of heat and ice between the Arctic seas and the World Ocean. The interaction of ocean, ice, and atmosphere has recently become the theme of major cooperative projects. Biologists, together with physicists and chemists, have become interested in the properties of sea ice and its fauna and flora. The abundance of fish and warm-blooded predators in Subarctic waters has attracted the attention of not only fishermen, whalers, and sealers, but also marine biologists who are interested in the phyto- and zooplankton which are particularly rich in the Polar Front zone.

There are also intensive studies in the marine geology and geophysics of the region which are leading to new insights into the history of sea-floor spreading and glaciation. The study of Arctic and Subarctic seas has gained considerable momentum over the past decade. Polar studies are of global significance for the understanding of climate and oceanic circulation. There is a growing interest in the possible environmental impact of the exploitation of oil and gas and the importance of the polar waters as fishing grounds and for sea transportation, which have given rise to major national research programmes in Norway, Alaska, Canada, and the USSR. New concepts and programmes of a global nature as well as new technologies, including ice-breaking research vessels and remote-sensing facilities, are at hand or will become available in the very near future and call for closer international cooperation. ICES therefore decided in 1985 to organize a Symposium on Marine Sciences of the Arctic and Subarctic Regions in order to discuss the present state of knowledge and to consider future research needs, particularly for international and interdisciplinary projects.

Apart from being a forum for scientific discussion, ICES has the longest tradition of fostering international cooperation in northern waters. Most important was the Polar Front Survey of the International Geophysical Year in the late winter and late summer of 1958. Twenty-five vessels from eleven countries participated in the systematic mapping of the entire frontal system between the line Newfoundland – Azores – Gibraltar and the pack ice of the Labrador and Greenland Seas. It was the first effort to describe the seasonal variations of a large-scale oceanic feature. The results are fully documented in the IGY Atlas (1970) edited by G. Dietrich.

Two years later the experiment “Overflow 1960” addressed the outflow of Subarctic Intermediate Water from the Norwegian Sea across the Iceland–Faroe Ridge into the North Atlantic. In two surveys one week apart, nine vessels worked a very narrow station grid. In “Overflow II”, in 1973, thirteen vessels covered the Greenland–Iceland–Scotland Ridge twice for four weeks, each vessel collecting standard data and carrying out individual projects. Joint programmes in later years involved fewer vessels and were less strict in the coordination of efforts. Moored current meters were employed for continuous recordings. Project MONA was the first year-round observation of the outflow of Subarctic Intermediate Water. Since 1985 those observa-
tions have been extended to monitor the northward flow of Atlantic Surface Water. In the framework of Project NANSEN, current meters were moored along the Arctic Front between Iceland and the Faroe Islands.

The interest in features and processes within the Subarctic – Arctic system dates back to the early studies by Fridtjof Nansen and Håkon Mosby. During the past three decades systematic surveys have been carried out by Norway, Iceland, and the USSR in order to delineate the year-to-year variations in the frontal system. From February to July 1982 ICES organized the Deep Water Project in the Greenland Sea.

United States and Canadian groups also became engaged in the Greenland Sea in the early 1980s. New methods were employed in addition to the conventional ones. Tracer studies proved particularly powerful in polar waters where the $t/s$ ratio provides only a weak signal of the vertical processes. Remote sensing by satellites and aircraft and the satellite-tracked drifter buoys show the dynamics of the ice flow and of the Polar Front sensu strictu. The first joint project of this kind employing both vessels and aircraft of various nations was the Marginal Ice Zone Experiment (MIZEX), which started in 1983 under US auspices.

Plans for an oceanographic Fram Strait project, as developed by the Comité Arctique, did not materialize because of the lack of private funding after the drop in oil prices. In joining the Arctic Ocean Sciences Board (AOSB), national institutes picked up essential parts of the plans and developed the Greenland Sea Project (GSP). Its main objective is the study of formation of the Deep Water by vertical convection and the intrusion of Arctic water masses. GSP is, to a large extent, carried out by European research vessels with a strong American input in the field of ocean tomography and remote sensing. The RV “Polarstern” provided a powerful and broad platform for work in the pack ice.

Studies in the Arctic Basin had also been initiated by Nansen before the turn of the century. Manned drifting ice islands supported by US, Canadian, and USSR agencies provided a wealth of data over more than two decades after World War II. Further observations were carried out by submarines. The most recent ones were reported from British upward-looking sea-ice studies in 1987. US aircraft moored current-meter arrays on the slopes of the Eurasian and Canadian Basins and along the Lomonosov-Alpha Ridge. The ice-breaker cruises by the RV “Ymer” (Sweden) in 1981 and the “Polarstern” (FRG) are new types of nationally sponsored, but internationally manned, expeditions to the High Arctic. In her 1987 expedition the “Polarstern” reached the North Polar Basin at 86°N after crossing the Barents Basin and the mid-ocean Nansen–Gakkel Ridge.

This review of the development of marine research in Arctic and Subarctic waters is biased with regard to topics, national efforts, and regional coverage. Little mention is made of marine geosciences as they are generally not covered by ICES. Soviet studies have not been touched upon nor has the vast amount of work carried out in the Pacific Arctic and Subarctic, which are outside the normal sphere of ICES. When planning the Symposium we had hoped to attract contributions to fill those gaps of communication.

The Symposium was held from 28 to 30 September 1987 at the Escuela de Ingenieros at Santander. It was attended by more than 120 scientists from most of the ICES member states, including major delegations from North America, the Scandinavian countries, Poland, and the Federal Republic of Germany. Soviet participation was smaller than one might have expected on the basis of the titles submitted and the great effort devoted to Arctic research by the USSR.

Mr Cendrero and the Spanish team were good hosts to the Symposium. The participants had the opportunity to visit the FRG ice-breaking research vessel, the “Polarstern”, during its port call in Santander.

All together, 116 titles were submitted to the steering group, which divided them for oral or poster presentation. At the poster sessions each author had the opportunity to address the audience, highlighting the results and some of the ideas behind the particular work. In the following, some of the results of the Symposium will be briefly reviewed. A number of interesting contributions came from areas outside the home waters of ICES on the Atlantic side of the Arctic.

For the Arctic Basin, Aagaard reported on the advances in understanding the subsurface circulation as derived from a few current meters moored at strategic points as mentioned above. The thickness and structure of pack ice in the High Arctic were described by Wadhams.

Longhurst summarized the biological work in the Canadian archipelago and in Hudson Bay, relating phytoplankton studies to detailed analysis of limiting factors such as nutrients and ice cover as well as to studies in the reproductive physiology of calanoids.

For the Pacific Subarctic regions, reference was made to the complex ecological approach by Alaskan teams (Alexander, Grebmeier, Niebauer). Grebmeier compared the poor benthos on the Alaskan Shelf with the rich one on the Bering/Anadyr Shelf, which is closely linked to phytoplankton production. The development of phytoplankton blooms depending on stratification in fronts of the Marginal Ice Zone of the Bering Sea was studied by Alexander. She stressed the importance of storms and frontal shear processes as well as upwelling in frontal eddies to nutrient supply and, hence, new production. Similar findings were reported by Kattner for the Marginal Ice Zone of the East Greenland Sea.

The Barents Sea is at present the target area of the Norwegian Pro Mare Project, which is based on ecosystem concepts similar to the Bering Sea model. Contributions by the Pro Mare team on various aspects of oceanography and plankton ecology of the region formed a major part of the Symposium and gave rise to comparisons with the Bering Sea. Soviet studies in fish
ecology and long time series of hydrographic features and variations in ice cover were also reported.

Observations over many years on oceanographic features, phytoplankton, zooplankton, and fish in the waters north of Iceland were reviewed by Icelandic scientists. They demonstrated the impact of the periodic expansion of polar water masses on the biology and, hence, fisheries of the region.

The Greenland Sea and the Fram Strait were the subjects of a great number of papers. The area is very attractive as all typical features of polar seas are to be found close together. The northward-flowing West Spitsbergen Current and the southward-flowing East Greenland Current are separated by a rather narrow intermediate zone of returning Atlantic water. The Marginal Ice Zone is closely linked with the Polar Front with its well-developed eddies. Within the pack-ice zone a large polynya is formed every summer off East Greenland. It seems to have a positive effect even on the benthos of the shallow shelf banks (Piepenburg).

Over several years a group of Polish scientists studied the bathymetry, hydrography, sedimentation, flora, and fauna of Hornsund in Spitsbergen in detail. Another fjord project still under way is being carried out by Norwegian scientists in Balsfjord. They focus on, inter alia, the secondary production by copepods and other zooplankton in relation to pelagic fish such as capelin and herring.

In terms of research strategy, the Symposium reflected the recent trend towards complex, multidisciplinary projects, e.g., MIZEX, Pro Mare, Bering Sea, Hornsund, Balsfjord. Most of those efforts are being carried out by scientists of one nation only. The interaction of modelling and field studies is increasing, coupling physical and biological phenomena, as reported, for example, by Niebauer for the Bering Sea. Current meter recordings and tracer oceanography as well as new theories on the role of double diffusion and current shear contributed to the great progress in understanding the processes related to the "life history" of the Deep Water of the Greenland Sea and the Norwegian Sea.

Estimates of total ice transport and, hence, horizontal energy advection, were made possible by remotely sensed passive microwave measurements which were validated by in situ measurements of ice flows and by submarine observations on ice thickness. Those studies are of crucial importance for global energy budgets and for the development of prognostic scenarios of climatic changes. Of similar importance are long time series, such as the sets of oceanographic data from the Kola section since the year 1900, and the shorter time series for waters north of Iceland and off Spitsbergen.

Biological oceanographers still focus on spring blooms of phytoplankton and their relation to nutrients. The recent studies suggest that nutrient depletion is not as dramatic and limiting as was supposed by earlier authors. In fact, frontal eddies and the large Subarctic gyres contribute many nutrients to the euphotic zone, resulting in high new production which is not grazed down in the upper layers. Much phytoplankton and detritus sink down and are transported to the South. One might conclude that the overall production in Arctic water— at least off East Greenland — is not much lower than in the Weddell Sea at similar geographical latitudes and under similar ice cover. There are, though, very substantial differences in the benthic invertebrates and in fish. Direct comparisons, however, between the Arctic and the Antarctic had been excluded in advance from the Symposium programme.

Copepod grazing does not affect the early spring bloom in the near ice zone but becomes more important later in the season. Egg production as a measure of "growth" in adult copepods and studies of reproduction and overwintering in calanoid copepods are at present key issues in polar zooplankton work. They provide the parameters for general production models.

The papers on marine mammals— although limited in number — reflected the great progress made by Canadian and Norwegian workers in understanding the ecological importance of Arctic seals. For the first time, a detailed breakdown was provided on their impact on the natural mortality of fish.

Ichthyological surveys demonstrate the contrast between the high abundance of various kinds of demersal and pelagic fish in the Subarctic seas and the very poor fish populations of the High Arctic waters. An invited review by Luka and Mukhin (not contained in this volume) dealt with the great difference in exploitation level between the eastern and the western sides of the Subarctic Atlantic. The position of the Inuit in relation to marine science and to the harvesting of seals was addressed by a Canadian contribution. The impact of pollution on marine mammals in the northeastern Baltic and in Canadian waters was given as another example of the interaction of man with Arctic marine communities.

What was missing or under-represented at the Symposium?

Apart from the geographical bias mentioned above, serious gaps in recent polar research programmes were noted in the discussions. Benthos and fish in Arctic waters have been neglected in recent years. Comparative community studies along the lines presented by Grebmeier for the Bering Sea and by Piepenburg for Belgica Bank off East Greenland should be supplemented by data on consumption and growth rates. More data on distribution and food intake of seabirds and seals are required for realistic ecosystem models. The microbiology of ice, water columns, and sediments in the High Arctic region has been neglected.

The study of sea ice in the Arctic is still in a rather immature state. Little is known about the development of the interstitial flora and fauna during the development of ice floes. On the other hand, is there a wash-out of organisms while the multi-year ice steadily melts from underneath? We assume that the ice algae of the multi-year ice of the Arctic are of less importance as
feeding grounds for herbivorous crustaceans than the much thinner ice of the Antarctic, which provides winter food for krill and other organisms. Nevertheless, more observations in autumn, winter, and early spring are needed to see what happens to surface plankton during the formation of sea ice and before the start of the spring bloom. There is a general demand for more information on life in the pack ice and in the Arctic winter.

The gaps in our knowledge regarding the physical oceanography of the Atlantic outlets of the Arctic Ocean have been dealt with in detail by the planning groups of the Greenland Sea Project and the Fram Strait Project. They refer mainly to the formation of Deep Water in the Greenland Sea as outlined by Meincke and to the coupling of ocean and atmosphere in the Marginal Ice Zone as described by Kellner.

**Future international cooperation** was the theme of a separate session where participants looked into the needs and potential of cooperative ecological studies in Arctic waters. They considered the present situation and particularly the future prospects to be quite promising for major joint projects. Powerful ice-breaking research vessels are available or planned, which will permit systematic studies to be made of plankton, sea-ice biota, and benthos linked with nutrient chemistry in the ice-covered areas. These large vessels also provide good facilities for experiments with live organisms. The large-scale Greenland Sea Project organized by the Arctic Ocean Sciences Board is under way to understand the formation, circulation, and exchange of water masses in the Greenland Sea and the Fram Strait. Remote sensing by aircraft and satellites provides broad-scale and yet detailed pictures of the surfaces of water and ice on a continuous basis.

Such experimental and observational approaches should be linked with biological field work and with complex ecosystem models making use of powerful modern computer facilities. The models should include the total water column as well as the ice cover and the sea bed and should deal with the entire food web.

More information is needed on small-scale physical processes such as turbulence and shear under the ice and on the biochemistry of ice, water, and organisms under Arctic conditions. The role of aggregates ("marine snow") and of metabolites should be studied in ice water. Participants stressed the importance of a better understanding of the processes and rates of interactions between the various compartments of the system, such as trophic levels/vertical layers and horizontal patches in various Arctic biotopes: open water, fronts and eddies, marginal ice zones, permanent pack ice, and temporal polynyas. The latter are the least studied cosmos of all Arctic features.

The East Greenland Polynya was selected as a most promising site for an international ecological project. Comparative studies of other polynyas should be encouraged as well as studies of fronts. Such projects should also involve scientists from countries which have no polar research facilities of their own.

Meanwhile, the first planning meeting for the international polynya study took place in Bremerhaven in the spring of 1988, and both the scientific concepts and the time frame of a cooperative study, which will start by 1992, were discussed.

No plans have been tabled so far for a major international project in the Arctic Ocean proper. This would be a great challenge. More current-meter moorings, scientific work by submarines, tracer oceanography, modelling, and remote sensing are required for an adequate understanding of the vertical and horizontal transport and mixing processes and their relevance to atmosphere and biosphere. Since the early biological studies on ice islands very little has been reported about the biology of the Arctic Basin, e.g., on the ecological importance of the leads and small polynyas in the otherwise permanent heavy ice cover.

The present volume contains only a limited number of the contributions to the Symposium. The Editorial Board had to be very selective in order to adhere to the prescribed number of printed pages. A few papers dropped out during the process of reviewing and rewriting or failed to meet the final deadline. Almost all contributions are at least listed by title and abstract; wherever possible it is noted where such papers will be published.

The Editor was assisted by Sigrid Marschall. The Technical Editor of the volume was Judith Rosenmeier. Their skillful attention is much appreciated.