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Marine Mammals as Oceanographic Sampling Platforms

by Thomas G. Smith

THIRTY YEARS AGO, at a meeting devoted to finding new directions for Arctic biological oceanography, it was suggested that marine mammals might someday be used as "educated" oceanographic sampling platforms. They are "educated" because, through millions of years of evolution, they have developed the ability to find and consume such prey as the arctic cod, *Boreogadus saida*, a keystone (Paine, 1966) Arctic species that to this day has largely eluded the efforts of scientists who have tried to study it (Welch et al., 1993).

The ice-covered and ice-filled waters of the polar regions have thwarted the attempts of oceanographers to study the Arctic marine ecosystem. Ship-based oceanographic work has been largely confined to the short open-water season, with only a few sporadic and fragmented attempts in winter to study the drift ice, ecosystems (Herdmann, 1948; McRoy and Goering, 1974; Lønne and Gulliksen, 1989), or areas containing polynyas (Kane, 1853; Smith, 1931; Kupetskii, 1962; Sadler, 1974; Dunbar, 1981). Valuable data on seasonal and interannual variation in primary and secondary productivity, obtained largely from long-term, shore-based studies, have shed some light on the controlling variables, such as temperature, ice cover, timing of the stratification of the water column, and nutrient recirculation (Grainger, 1977, 1979; Alexander, 1980). All of these efforts have suffered from either inadequate time series or sampling that was restricted to a limited geographical area. They have provided only limited regional descriptions, and these cannot yet be used to construct an integrated picture of Arctic marine ecosystem dynamics.

Arctic seals, whales, and polar bears have been studied much more intensively than organisms lower down in the marine trophic pyramid. Studies of bears and seals have shown that large interannual changes in productivity occur in certain regions of the Arctic (Stirling et al., 1977; Smith, 1987; Kingsley and Byers, 1998). Studies of higher vertebrates have resulted in some interesting recent attempts to apply the "top-down" modeling approach. Such modeling uses the energy requirements of bears, seals, and whales to estimate the energy flow through the ecosystem (Welch et al., 1992) or to calculate the standing crops of upper trophic-level components (Stirling and Øritsland, 1995; Kingsley and Byers, 1998) of regional Arctic marine ecosystems. To date, this appears to be the most practical and workable means available, but the assumptions and quantitative uncertainties at various stages in the model make it a blunt tool. Such models still cannot be used to identify, much less to quantify, the mechanisms causing changes at levels lower down in the trophic pyramid.

The advent of satellite-linked VHF and other satellite-based remote sensing has opened the doors to research on a large geographical scale and an intensive schedule of sampling, both essential to furthering our understanding of Arctic marine ecosystems. Polar bears, *Ursus maritimus*, and Arctic cetaceans are especially useful as "educated" oceanographic platforms, since they can carry sizeable instrument packages and they range widely through the vast expanses of the oceanic environment. The behaviour of polar bears is correlated directly with the distribution of their chief prey species, the pagophilic ringed seal, *Phoca hispida*. The migrations and diving behaviour of belugas and narwhals reflect the distribution and density of fish, such as arctic cod and Greenland halibut, *Reinhardtius hippoglossoides*, and possibly of nektonic invertebrates, such as squid or octopus. One of the most interesting results from studies to date is that belugas consistently go to certain deepwater areas to feed, in some cases traveling great distances from the center of their summer distribution to do so. Further research on these "hot spots" of whale feeding may help us understand the mechanisms that promote the concentration or productivity of Arctic fish or invertebrates. In the future, more sophisticated mammal-carried instrument packages will allow us to measure key physical oceanographic parameters and also identify and enumerate the prey species consumed by the whales and seals.

The first stage in satellite-telemetry studies of some Arctic marine mammal species is being completed. The seasonal movements and annual migrations of polar bears and belugas are becoming well known for many of the North American stocks (Garner et al., 1990; Smith and Martin, 1994; Bethke et al., 1996; Richard et al., 1998, 2001; Dietz et al., 2001). We are studying diving behaviour and identifying feeding locations (Martin and Smith, 1992, 2000; Heide-Jørgensen et al., 1998, 2001; Martin et al., 2001). For Arctic cetaceans, a large gap in our knowledge concerns the location and use of winter habitat. So far, the loss of the instruments through failure of the tag attachments has kept us from learning about the whales' winter habits. The narwhal, which offers the tusk as a hard-tissue attachment site, might provide the best opportunity to keep tags on throughout the winter season. Tagging later in the season, or capturing and holding belugas and narwhals in sea pens for late-season release, might also help us to obtain data on their winter distribution and behaviour.

Little is yet known about the similarities or differences between belugas and narwhals. Although they appear to share similar winter habitats, their summer distribution is quite different. Both are capable divers (Martin et al., 1994), and they appear to feed on the same fish species. Comparisons of their physiological capabilities and behaviour using telemetry will increase our understanding of how they partition their resources in the Arctic marine ecosystem.

The next step in telemetry studies of Arctic cetaceans will be to build on existing information to gain greater precision in enumerating the stocks, delimiting their ranges, and evaluating the impact of harvests from areas where stocks mix during seasonal movements. Bears, belugas, and narwhals all cross domestic and international jurisdictional boundaries, making this new information especially pertinent to the proper management of these harvested populations. Since rapidly increasing human populations in the Arctic still depend on subsistence hunting for their nourishment, there is no doubt that a more detailed scientific knowledge is required to manage renewable resources effectively.

The next major leap forward in the study of Arctic marine mammals will be to use them to their full potential as "educated" oceanographic sampling platforms. Few studies have attempted to relate the distribution or behaviour of Arctic marine mammals to physical oceanographic parameters. Most ship-based and land-based oceanographic studies suffer from sampling inadequacy, especially as related to geographical scale. For example, in the past, biological oceanographers studying phytoplankton or secondary consumers would obtain vertical or oblique samples from the water column at relatively few sites in a large body of water. For temperate oceanic areas, such an approach was felt to produce reasonable estimates of quantity of phytoplankton and standing stocks of zooplankters (Johnstone, 1908). It soon became apparent, however, that variation—both temporal (Hart, 1942) and spatial (El-Sayed and Mandelli, 1965)—was the norm. Also, estimating primary productivity and standing crops was particularly difficult in the ice-covered polar regions because of sampling problems. The Arctic marine environment consists of large areas of landfast ice, extensive and recurring open-water expanses of leads and polynyas, and vast fields of shifting, consolidated first-year or multi-year pack ice. In this diverse environment, localized and poorly understood phenomena, such as ice-edge upwelling (Zakharov, 1967; Alexander and Neibauer, 1981; Rey and Loeng, 1985), glacier front and iceberg-generated circulation (Doake, 1976; Neshyba, 1977), and epontic algal growth (Horner and Alexander, 1972), create patchy areas of high primary and secondary productivity. This patchiness, in turn, concentrates fish and nektonic invertebrates, which attract resident and migratory higher vertebrates. Arctic cod and other fast-moving organisms such as cephalopods are not only closely associated with the under-ice surface, but can also be found, at different times, at any depth in the water column. Arctic scientists remain puzzled by the extremely clumped and unpredictable distribution of cod (Quast, 1974; Welch et al., 1993), which makes estimating their standing stock virtually impossible.

One trophic level higher, the ubiquitous ringed seal can be either absent, thinly distributed, or irregularly clumped in its distribution over wide ocean areas, especially in the open-water season (Harwood and Stirling, 1992). Its winter distribution in the fast-ice breeding habitat is also extremely patchy (Smith and Stirling, 1978; Hammill and Smith, 1989).

Little can be said with accuracy about energy flow through the Arctic marine ecosystem when it is viewed as a whole and on a broad regional scale. Knowledge of planktonic and benthic components is missing, and there are no measures of the standing crops or production of Arctic fish species (Welch et al., 1992).

It is apparent that the oceanographic conditions promoting primary and secondary production in the Arctic are localized, and they can vary greatly in magnitude from year to year. Longer time-scale variation related to periodic phenomena (Vibe, 1967; Imbrie and Imbrie, 1979) and the possible additive effect of anthropogenic influences (Abelson, 1989; Etkin, 1990; Skinner et al., 1998) can also play a role in controlling Arctic marine ecosystem productivity. In the future, oceanographers will attempt to monitor real-time changes in water masses over large distances, using innovative techniques such as long-distance, low-frequency sound transmission (ATOC, Acoustic Thermometry of the Ocean Climate; Worcester et al., 1999). Recent initiatives to study ocean-atmosphere boundary phenomena, such as the SHEBA project (Surface Heat Budget of the Arctic Ocean; Welch, 1998), all aim at developing some degree of ecosystem-level predictive capability. This predictive capability is widely held to be one of the primary goals of scientific inquiry (Platt, 1964) and is considered the basis for risk assessment and management (Levin, 1988). Such integrated science projects, combined with input from the monitoring of "educated" sampling platforms such as bears, seals, and whales, which can precisely locate and describe hidden, patchy, and changing areas of dense plankton and fish aggregations, will greatly advance our understanding of the structure of Arctic marine ecosystems and the factors that control them.

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