# Using Narwhals as Ocean-Observing Platforms in the High Arctic

BY KRISTIN L. LAIDRE AND MADS PETER HEIDE-JØRGENSEN

Figure 1. Narwhals make daily perpendicular dives to the bottom (>1,800 m) of Baffin Bay between November and April while feeding in > 98% ice cover. *Photo by Mads Peter Heide-Jørgensen*

OFFSHORE ARCTIC waters are the most remote and unexplored areas of the Northern Hemisphere. Generally covered by sea ice for most of the year, these waters are characterized by darkness for up to six months and inhospitable temperatures reaching -40°C in mid-winter. With few exceptions, offshore Arctic ecosystems are logistically difficult, or sometimes impossible, to observe with traditional platforms like vessels or airplanes, which can be impacted by severe environmental conditions. Oceanographers are increasingly relying on data collection from nontraditional platforms adapted to the Arctic to investigate major scientific questions about ecosystem changes in the Arctic Ocean.

Baffin Bay is a large basin adjacent to the North American continent; its maximum depth is approximately 2,500 m. The bay extends southward into Davis Strait and is bordered to the west by Baffin Island and to the east by Greenland. This region is characterized by a warm northward-flowing subsurface current of North Atlantic origin on the West Greenland shelf and a cold southward flowing surface current of polar origin along the east Baffin Island coast toward the Labrador Sea. The advection of warm water from the West Greenland Current can be traced as a distinct temperature maximum along the entire 1000-m isobath to Cape York at 7°N and beyond. The advection of colder, low-saline polar water from the Lancaster, Jones, and Smith sound regions (or Canadian Arctic Archipelago) dominates near-surface waters in Baffin Bay (Tang et al., 2004). The strength of the surface current in western Baffin Bay is important as it supplies cold and fresh polar water to the Labrador shelf and slope where it influences the deep water ventilation area in the Labrador Sea.

Evidence of significant warming at greater than 700 m depth in Baffin Bay and Davis Strait has been reported for the period 1920–2003 (Zweng and Müenchow, 2006). Deep basin temperatures exhibited a statistically significant warming at depths between 400 and 2,400 m, with maximum warming as large as 0.2°C per decade observed between 600 and 800 m. This warming may be due to enhanced advection of warm North Atlantic water across the West Greenland shelf areas and into the deep basin of Baffin Bay.

Despite the critical importance of Baffin Bay and Davis Strait to North Atlantic circulation, few oceanographic data are available from this area during winter months. Heavy sea-ice cover restricts research vessel access, and thus few measurements are available for assessing interannual variability and long-term change. Because investigations of Arctic/subarctic freshwater exchange rely on an accurate understanding of intra- and inter-seasonal hydrographic measurements, wintertime sampling is required. Given the limitations of surface vessels and aircraft, wintertime data collection must rely on sampling by nontraditional platforms.

## MARINE MAMMALS AS AUTONOMOUS OCEANOGRAPHIC SAMPLERS?

Marine predators use areas of the ocean that are poorly known, and some species offer unique opportunities to collect data at relatively low cost from regions where traditional oceanographic measurements are financially and technically prohibitive (Lydersen et al., 2002; Fraser and Hofmann, 2003). Diving mammals and sea birds can be fitted with instruments that record the animals location, diving depth, and concurrent oceanographic parameters, thereby creating real-time autonomous sampling platforms (Fedak et al., 2002). The application of this integrated biological and oceanographic approach permits data collection from remote, ice-covered waters where use of conventional ship-based CTD casts is difficult.

Among the Arctic top predators that inhabit the Baffin Bay pack ice, the narwhal (*Monodon monoceros*) is perhaps the most conspicuous (Figure 1). The largest numbers of narwhals worldwide are found in the eastern Canadian high Arctic and West Greenland seas. They make extensive annual migrations (> 2,000 km per year) from high Arctic summering grounds to offshore wintering grounds in Baffin Bay and Davis

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Figure 2. Narwhals are captured in nets on their summering grounds and secured between two inflatable boats while they are instrumented. *Photo by Kristin Laidre*

Figure 3. Photo of satellite-linked, depth-temperature tag that can be attached to narwhals. Note the external temperature stalk on top is protected from the sea ice by a metal shield. *Photo by Mads Peter Heide-Jørgensen*

Strait, where more than 50,000 whales occupy dense pack ice between November and April (Koski and Davis, 1994; Innes et al., 2002; Heide-Jørgensen et al., 2002). Satellite tracking studies show that narwhals have high site fidelity so whale locations within discrete wintering grounds can be predicted (Heide-Jørgensen et al., 2002). Narwhals make minimal horizontal movements on these ice-covered wintering grounds and feed intensively on the bottom (below 1,500 m) on Greenland halibut (*Reinhardtius hippoglossoides*) (Laidre et al., 2003, 2004a, 2004b).

Narwhals are among the deepest diving cetaceans—in winter, they regularly descend to more than 1,800 m as many as 10 to 25 times per day (Laidre et al., 2003). These dives last over 25 minutes and are performed perpendicular to the bottom to maximize transport time, given aerobic constraints, to reach demersal prey. This behavioral feature makes the narwhal an excellent "ocean sampler," as deep perpendicular dives are ideal for repetitive depth and temperature casts. Narwhals also have strong affinity for the Arctic offshore pack ice, an area where few oceanographic studies have been accomplished due to inaccessibility. An advantage of using narwhals is that their movement patterns are predictable and their wintering areas in central Baffin Bay have been identified. Therefore, it is possible to conduct controlled oceanographic sampling targeting specific regions of Baffin Bay by tagging whales that use specific wintering sites.

## OCEAN EXPLORATION PILOT PROJECT

In a one-year project funded by the National Oceanic and Atmospheric Administration's (NOAA's) Office of Ocean Exploration, we instrumented three narwhals with temperature and depth recorders in order to examine the feasibility of using the species as oceanographic water-column samplers in central Baffin Bay. In the first portion of the study during August 2006, narwhals were captured on their summering grounds in Melville Bay, Northwest Greenland, using a land- or boat-anchored net (Figure 2) (Heide-Jørgensen and Dietz, 1995; Heide-Jørgensen et al., 2002, 2003). The whales were instrumented with satellite-linked depth-temperature tags (Figure 3) mounted on their dorsal ridges using 6-mm nylon pins. The handling procedure lasted approximately 30 min and was conducted while the whales were held in a net between two inflatable boats (Figure 4). The instruments provided data on the narwhals' movements, diving behavior, and water-column temperatures for eight consecutive months.

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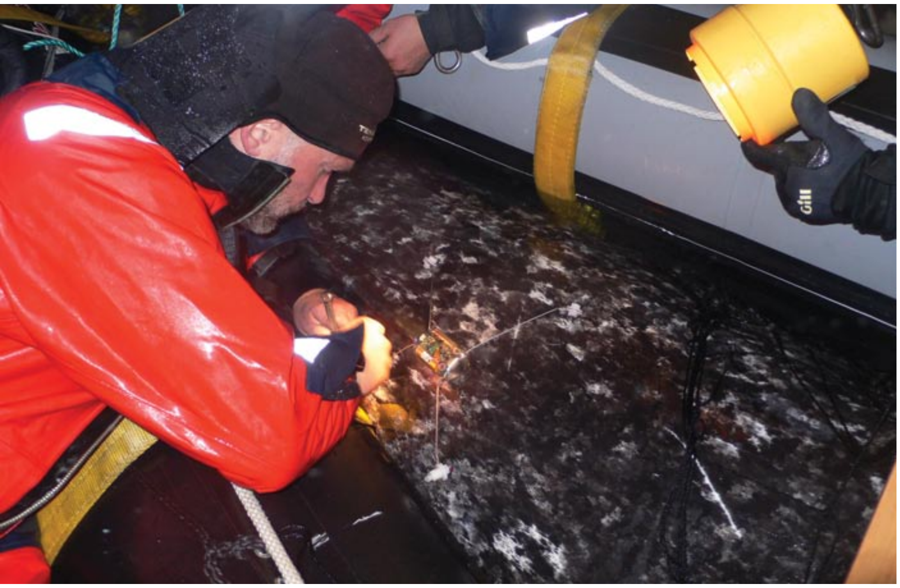

Figure 4. Satellite-linked temperature tag being secured to the dorsal ridge of a narwhal in Melville Bay, West Greenland. *Photo by Kristin Laidre*

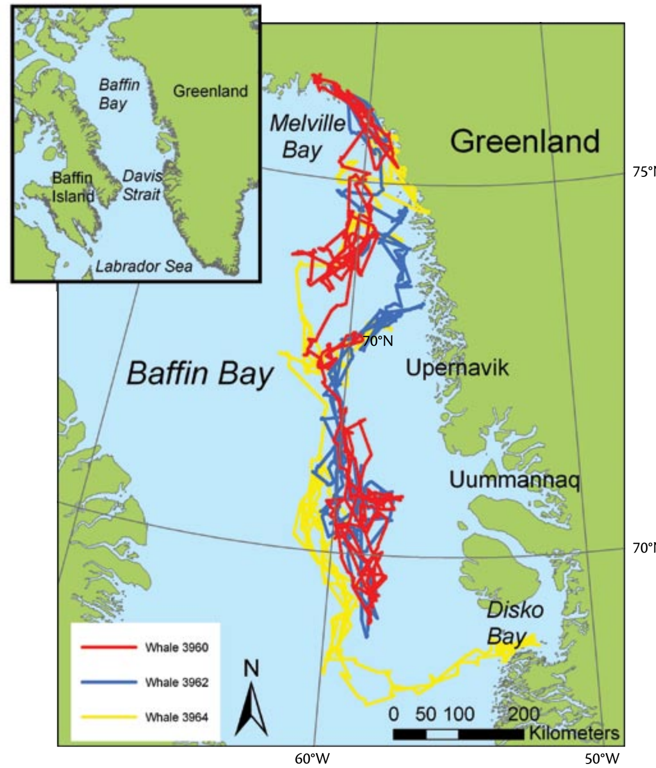


Figure 5. Satellite-tracking data collected from three narwhals tagged in Melville Bay, West Greenland, in 2006. Narwhals make an extensive southbound migration to their wintering grounds, traveling over 1000 km in two months.

Tags naturally fall off the whales' dorsal ridge and sink to the bottom.

The satellite tags, designed and produced by Wildlife Computers (Redmond, Washington), sampled temperature-depth pairs on each daily foraging dive, together with geographic position, time, and date, using an external temperature stalk for instantaneous recording of ambient temperature. Temperature at depth was measured every 10 sec at a resolution of 0.05 m and 0.1°C; data from each dive were resampled in one of ten depth bands between the surface and deepest dive during a six-hour period. Data were then packed for efficient transmission through the 32-byte data window provided by Service Argos, NOAA's polar-orbiting satellites.

On average, each satellite-tagged narwhal provides more than 10 geographic locations per day, at least two of which have a maximum precision of less than 1 km (Figure 5). Over each 24-hour period, a single representative narwhal transmits approximately 410 temperature readings (SD 90) ranging in depth from 1–1500 m. Narwhals on the wintering grounds have limited options for long-distance movements to search for prey because they are confined to small open-water regions (Figure 6). Locations of high-density benthic prey on the wintering ground enforce restricted horizontal movement and require that dives originate and terminate in the same lead system (Laidre et al., 2004c). This means that although there is some degree of intermonthly spatial variability in temperature sampling, as narwhals move among shifting leads and sea-ice cracks during winter, temperature casts are repetitively collected in the same area over short periods (less than a few days). This eliminates spatial variability, which often confounds climatology studies, and allows for a relatively small and well-defined area of Baffin Bay and Davis Strait to be continuously monitored throughout the winter.

Narwhals have an estimated aerobic dive limit of approximately 25–30 minutes (Laidre et al. 2002), which is approximately the time it takes for a round-trip dive from the surface to 1,500 m. Diving in the pack ice is performed specifically for intense feeding on Greenland halibut prey (Laidre et al., 2004a), and whales target the demersal fauna close to the bottom (Figure 7). Thus, dives to these depths are performed perpendicular to the bottom to maximize time at the bottom. This alleviates problems with temperature sampling in three-dimensional space, which might be encountered with an animal moving in a more varied pattern through the water column. Detailed studies of narwhal diving have documented that mean ascent rates are not significantly different from mean

Figure 6. The pack ice of Baffin Bay where narwhals overwinter for six months of the year between November and April. *Photo by Kristin Laidre*

Figure 7. Pod of narwhals in the wintertime pack-ice habitat. *Photo by Mads Peter Heide-Jørgensen*

descent rates (about 3 m $s^{-1}$) (Laidre et al., 2002; Laidre et al., 2003); thus, the temperature casts are taken at relatively constant speeds.

The second portion of the expedition was conducted in the Baffin Bay pack ice in March 2007. It focused on collecting oceanographic data to calibrate the narwhal depth-temperature tag data by sampling a transect of stations across the narwhal wintering grounds for salinity and temperature. Fifteen CTD (conductivity, temperature, and depth) casts were made to 500-m depths with a SeaBird 19 CTD through holes bored in the sea ice (Figure 8). Two stations near the coast were located in an area where the sea ice was too thin for landing a helicopter, so samples were collected from a ship. An additional 13 offshore stations were collected by landing a helicopter on large and stable ice floes. Oceanographic data demonstrated that the warm West Greenland current moves north along the coast, with temperatures above 4°C between 200 and 400 m and a similar increase in salinity. A characteristic cold layer < 1°C was seen across the surface down to about 100 m at all stations. Concurrent acoustic data from marine mammals were collected at each oceanographic station. Species recorded included narwhals, belugas (*Delphinapterus leucas*), bowhead whales (*Balaena mysticetus*), ringed seals (*Phoca hispida*), and bearded seals (*Erignathus barbatus*) on approximately 16 hours of digital audiotape (DAT) recordings and 56 hours of sonobuoy recordings.

## SUMMARY

The inclusion of autonomous biological platforms significantly expands Arctic water temperature sampling opportunities. Deployment of satellite-linked oceanographic data recorders on ice-adapted marine mammals may be an effective method for obtaining large amounts of data from areas where oceanographic sampling is logistically difficult or needs to be supplemented during inaccessible periods (Figure 9). Narwhals as autonomous biological sampling platforms offer persistent, high-resolution, basin-wide sampling in ice-covered regions as well as operation near the critical ice-water interface. Narwhals have the special advantage that they repeatedly survey specific ice-covered regions throughout the winter months, eliminating the confounding effects of spatial variability and low temporal coverage.

An understanding of Arctic outflows, their role in the Arctic's freshwater cycle, and their impact on climate variability rests on accurate quantification of fluxes and water-mass characteristics. The interdisciplinary and experimental approach creates a synergy between Arctic oceanographers assessing the regional effects of ocean circulation and marine ecologists focused on the biology and ecology of high Arctic top predators. The successful implementation of this project opens the door for long-term, inexpensive monitor-

Figure 8. Narwhal temperature-tag data were calibrated by creating a hole in new Baffin Bay pack ice and lowering a Seabird CTD to 500 m with a battery-operated winch. *Photo by Kristin Laidre*

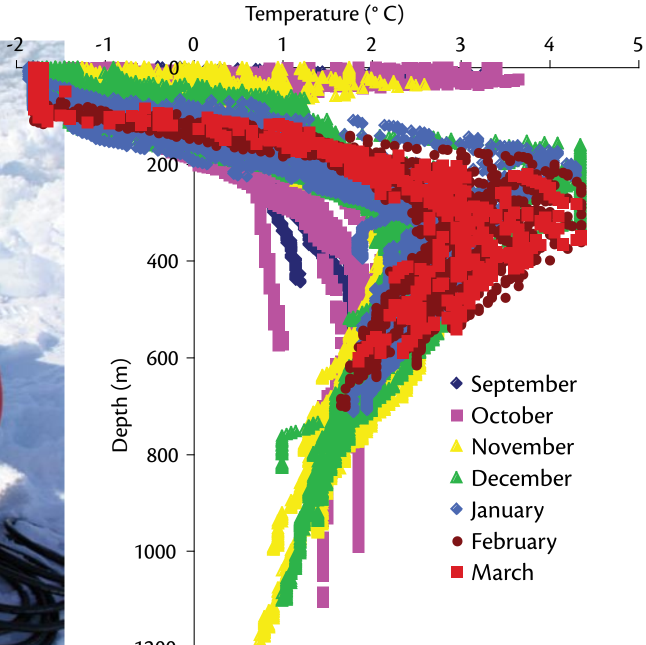


Figure 9. Depth-temperature profiles collected from a single narwhal diving in Baffin Bay during 2006–2007. Each color represents a different month.

ing of Baffin Bay and Davis Strait using narwhals as winter ocean-observing platforms. Furthermore, the success will likely influence the use of marine mammals as sampling platforms for other remote marine ecosystems, with wide-ranging prospects for ocean observing and intensive sampling of less-accessible waters.


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