ARCTIC
VOL. 71, NO. 1 (MARCH 2018)

InfoNorth

Four Hundred and Fifty-Year-Old Skeletal Remains of Atlantic Cod (*Gadus morhua*) Found on Multiyear Ice in High Arctic Canada

by Richard E. Crawford, Elizabeth Striano, Peter Amarualik Sr., Nancy Amarualik, Steven L. Cumbaa, Noel Alfonso and Aaron T. Fisk

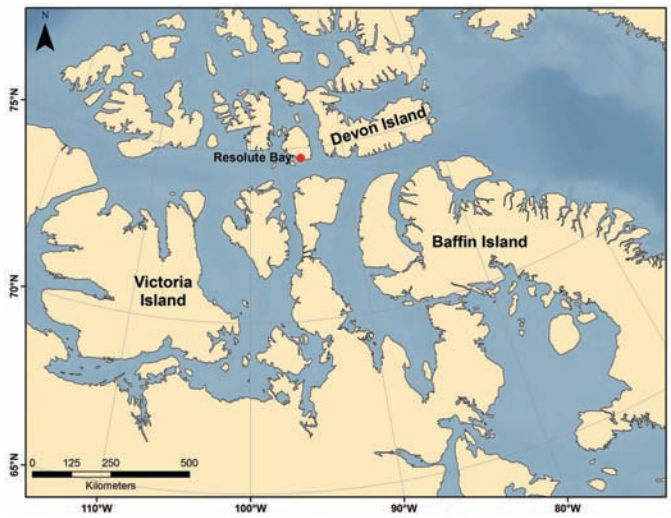

FIG. 1. Location of fish bones found by Peter and Nancy Amarualik on a multiyear ice floe in Resolute Bay, Nunavut.

In spring **2008, Peter Amarualik Sr. and his wife**, Nancy, found an unusually large assembly of multiyear ice pans that had grounded at the entrance to Resolute Bay, Nunavut, Canada, off the coast of Cornwallis Island (Fig. 1). The Amarualiks, Inuit residents of the Hamlet of Resolute and naturalists, knew that the ice's deep blue colour indicated it was quite old, perhaps thousands of years old. They also understood that the ice likely came from "up north" and was the remnants of pieces that had broken off from one of Greenland's or Ellesmere Island's ice shelves. After drifting, the ice eventually entered Lancaster Sound, where westward-flowing currents that travel along the sound's northern shore carried the ice to Resolute Passage. The ice then drifted into Resolute Bay itself, where it foundered in the shallows along the east side of the Bay's entrance.

At the time, the appearance of multiyear ice was not remarkable. But the warming spring sun had been melting snow cover for the last few weeks, exposing several large boulders on one of the pans. The ice pan was once multiyear landfast sea ice, and the boulders were distinctive glacial erratics—rocks 2–3 m tall that must have tumbled onto the ice from a nearby shore. By definition, a glacial erratic's makeup is geologically dissimilar from the native composition of its surroundings. Even from a distance, the Amarualiks could see that these rocks were unique. They drove onto the ice to get a better look.

Near one of the boulders, they found a fish skeleton unlike any they had seen before. It came from a fish approximately 75 cm long, which would have made it larger than any local fish inhabiting Bay waters. Its tooth-filled jaw suggested that it was an aggressive predator. The Amarualiks thought that it might be a deep-water species from the Arctic Ocean. They packed up the bones and brought them back to their house, with the plan to one day show them to someone curious enough to have them identified. Then they could add the information to the collection of artifacts they had assembled over the years.

IDENTIFICATION

In 2013, Peter showed the bones to Dr. Richard Crawford, a retired scientist who had spent much of his career studying the fish of Resolute Bay. Rick and Peter had worked together during the 1980s at South Camp, a field research station operated by Fisheries and Oceans Canada. Rick was at Resolute in 2013 as a member of the Ocean Tracking Network (OTN) team from the Great Lakes Institute for Environmental Research (GLIER) at the University of Windsor in Ontario, Canada. The OTN team was studying the movement and ecology of fish and marine mammals in the region, working with Inuit hunters and fishermen, including Peter. Rick agreed with Peter that the bones were from a fish larger than any that typically inhabited the area. Although he could not identify the species, he suspected the fish was related to the abundant, but much smaller, Arctic cod (*Boreogadus saida*) found in the region. Rick took high-resolution photographs of the bones with a Zeiss Macro-Planar T lens to pursue identification (Fig. 2).

Rick sent the image to Noel Alfonso at the Canadian Museum of Nature in Ottawa, asking for help in identifying the fish species. Although Noel was an expert

in Arctic fish fauna, he did not recognize the bones, so he passed the image on to his colleague, Steve Cumbaa, a paleoichthyologist at the museum. Steve responded with the following message on 29 June 2016:

> The bones, as far as I can tell from the photo, are all from the head and anterior vertebral column of a single individual of the Atlantic cod, *Gadus morhua*. My comparison with the reference skeletons in the museum's collection showed that the bones of the Greenland cod, *Gadus ogac*, are similar, but not as good a fit. The bones are quite distinct from those of the Arctic cod, *Boreogadus saida*. Peter Amarualik was quite right when he suggested the bones were from a species exotic to Lancaster Sound. According to the information I have, the Atlantic cod is known from the North Atlantic around Iceland and north along the Greenland shore, but in the western North Atlantic only from Cape Dyer, Baffin Island, southward. This would be roughly 1500 km SE of Lancaster Sound as the crow flies (much farther as the cod swims!).
>
> Compliments too to the photographer on including the scale in the nicely focused photo. It made identification easy, and I was able to determine by comparative measurements that the bones represent a cod which was approximately 700 mm in total length, which is a pretty good size. The colour and condition of the bones appear similar to bones that have been buried, as perhaps in an archaeological context, but that would not seem to make sense given what was said about their discovery. Suffice it to say they appear to be old: decades to hundreds of years or more. Hope this helps.

Given the bones were from a species, Atlantic cod (*Gadus morhua*), that is more than 2000 km from its current northernmost range (Froese and Pauly, 2017), Peter and Nancy were likely correct that multiyear ice brought the bones from a far distance. Ice drift in Baffin Bay follows a counterclockwise circulation pattern, traveling north along the western Greenland coast and then south along the eastern coasts of Ellesmere and Baffin Islands (Kwok, 2007). Although Lancaster Sound tends to contribute sea ice to this circulation rather than receive it, geostrophic dynamics, coupled with geometrical constraints and the direction of surface drift through the archipelago, can explain the existence of multiyear ice on the north shore of Lancaster Sound (LeBlond, 1980). This pattern of ice movements would suggest that the cod bones originated from the Greenland side of Baffin Bay. Although Atlantic cod are found in Hudson Bay, it is unlikely the bones originated there because of the path of multiyear ice in the Canadian archipelago. Atlantic cod are not found in the Arctic Ocean, so sources from the west are also unlikely.

The range of Atlantic cod may have shifted south since the last mini-ice age (roughly 1300 to 1850 CE), and the bones found could alternatively have been placed on the ice farther north, potentially on the east coast of Ellesmere

FIG. 2. Fish bones collected by Peter and Nancy Amarualik on a multiyear ice floe in Resolute Bay, Nunavut. Picture by Richard Crawford.

Island. Indeed, some of the last remaining ice shelves in the Canadian Arctic are on the northern coast of Ellesmere Island (Mueller and Vincent, 2006). Reports from the late 1800s indicate extensive ice shelves along most of the northern Ellesmere Island coast (Jeffries, 2002). By 1982, these ice shelves had been reduced by more than 90%, and by 2004, only a few major locations were left (Koenig et al., 1952; Mueller and Vincent, 2006). There is no evidence of recent ice shelf regrowth, and the breakup of Greenland's ice shelves is ongoing. Regardless of its source, the multiyear ice on which Nancy and Peter found the bones was indeed old.

DETERMINING THE AGE OF THE BONES

Once the bones were identified as having come from a species exotic to the region, the next step was to then work out their age. Both Peter and Steve thought that the colour and condition of the bones was consistent with bones from old archaeological sites. The bones also closely matched Atlantic cod bones salvaged from the *Mary Rose*, a warship from the English navy of King Henry VIII that foundered off the south coast of England in 1545 during a battle with a French invasion fleet (Hutchinson et al., 2015).

On the basis of this information, Rick and Aaron Fisk, leader of the OTN team in Resolute and professor at GLIER, arranged to have Peter send a sample of the bones to the A.E. Lalonde AMS Laboratory at the University of Ottawa. There, the age of the bones was radiometrically determined using carbon-14 analysis, the standard method for determining the age of biological material. Radiocarbon calibration was performed using OxCal v4.2.4 (Bronk Ramsey, 2009) with an IntCal13 calibration curve (Reimer

et al., 2013); material codes are described in Crann et al. (2017). Carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotopes were also determined for the bone samples at the G.G. Hatch Stable Isotope Laboratory at the University of Ottawa. The isotope analyses can provide insights into the geographic origin of the bones, as well as ecological information. Similar analyses were conducted on the Atlantic cod bones found stored in the wreck of the *Mary Rose* (Hutchinson et al., 2015).

The radiocarbon aging analysis indicated that the bones were likely more than 400 years old, deposited on the ice during the period 1479 to 1654 CE, with a median date of 1563 CE. This date is very close to the date of the wreck of the warship *Mary Rose* in 1545 CE, on which Atlantic cod bones were found (Hutchinson et al., 2015). Atlantic cod fisheries expanded significantly in European waters during the years when the bones were deposited on the ice, even back to the 13th century (Orton et al., 2011). Hutchinson et al. (2015) used $\delta^{13}C$ and $\delta^{15}N$ to identify the fishing grounds of Iceland and Newfoundland as the source of the *Mary Rose* Atlantic cod bones. Thus, the bones that Peter and Nancy found may have been put on the ice by early fishermen working in the North Atlantic region, potentially along the western coast of Greenland.

The range and median date of the bones found by Peter and Nancy indicate they were deposited on the ice (1479–1654 CE) during the middle part of the Little Ice Age (~1300 to 1850 CE). This timing, along with the period of European fishing of Atlantic cod, supports our contention that the bones likely came from the west coast of Greenland and not from locations north of Lancaster Sound. Drinkwater (2005) reported that Atlantic cod are known to have extended their range northward relatively rapidly in the past, particularly in response to warming water. If these bones were deposited during the Little Ice Age, it is unlikely that the Atlantic cod range extended to the far north.

Unfortunately, the $\delta^{13}C$ (−14.0‰) and $\delta^{15}N$ (22.6‰) values determined for the Atlantic cod bones provided little clarity for the source location of the bones. Although the $\delta^{13}C$ value is similar to that of Atlantic cod bones collected in Newfoundland (Hutchinson et al., 2015), the $\delta^{15}N$ was well above any Atlantic cod values reported to date, including those from archaeological sites for cod and other species (Barrett et al., 2011; Ascough et al., 2014; Hutchinson et al., 2015). This $\delta^{15}N$ value is also higher than that reported for marine fish from the Arctic, including top predators such as the Greenland shark (*Somniosus microcephalus*) (McMeans et al., 2013).

This finding demonstrates that multiyear ice can hold archaeological artifacts and provide insight on the history of fish ecology in the Arctic. It also shows that traditional knowledge and local customs are invaluable in identifying these unique occurrences. The Amarualiks' curiosity and expertise, combined with their local insights, provided the knowledge needed to help further the ecological history of the area.

ACKNOWLEDGEMENTS

Funding for the field research was provided by Ocean Tracking Network through the Canada Foundation for Innovation and the Natural Sciences and Engineering Research Council of Canada and Polar Continental Shelf Research Project.

REFERENCES

Ascough, P.L., Church, M.J., Cook, G.T., Einarsson, Á., McGovern, T.H., Dugmore, A.J., and Edwards, K.J. 2014. Stable isotopic ($\delta^{13}C$ and $\delta^{15}N$) characterization of key faunal resources from Norse period settlements in North Iceland. Journal of the North Atlantic 7(sp7):25–42. https://doi.org/10.3721/037.002.sp703

Barrett, J.H., Orton, D., Johnstone, C., Harland, J., Van Neer, W., Ervynck, A., Roberts, C., et al. 2011. Interpreting the expansion of sea fishing in medieval Europe using stable isotope analysis of archaeological cod bones. Journal of Archaeological Science 38(7):1516–1524. https://doi.org/10.1016/j.jas.2011.02.017

Bronk Ramsey, C. 2009. Bayesian analysis of radiocarbon dates. Radiocarbon 51(1):337–360.

Crann, C.A., Murseli, S., St-Jean, G., Zhao, X., Clark, I.D., and Kieser, W.E. 2017. First status report on radiocarbon sample preparation techniques at the A.E. Lalonde AMS Laboratory (Ottawa, Canada). Radiocarbon 59(3):695–704. https://doi.org/10.1017/RDC.2016.55

Drinkwater, K.F. 2005. The response of Atlantic cod (*Gadus morhua*) to future climate change. ICES Journal of Marine Science 62(7):1327–1337. https://doi.org/10.1016/j.icesjms.2005.05.015

Froese, R., and Pauly, D., eds. 2017. FishBase: *Gadus morhua* Linnaeus, 1758. http://fishbase.org/summary/69

Hutchinson, W.F., Culling, M., Orton, D.C., Hänfling, B., Handley, L.L., Hamilton-Dyer, S., O'Connell, T.C., Richards, M.P., and Barrett, J.H. 2015. The globalization of naval provisioning: Ancient DNA and stable isotope analyses of stored cod from the wreck of the Mary Rose, AD 1545. Royal Society Open Science 2(9), 150199. https://doi.org/10.1098/rsos.150199

Jeffries, M.O. 2002. Ellesmere Island ice shelves and ice islands. In: Williams, R.S., Jr., and Ferrigno, J.G., eds. Satellite image atlas of glaciers of the world: Glaciers of North America. U.S. Geological Survey Professional Paper 1386-J. Washington, D.C.: United States Geological Survey. J147–J164. https://pubs.usgs.gov/pp/p1386j/

Koenig, L.S., Greenaway, K.R., Dunbar, M., and Hattersley-Smith, G. 1952. Arctic ice islands. Arctic 5(2):67–103. https://doi.org/10.14430/arctic3901

Kwok, R. 2007. Baffin Bay ice drift and export: 2002–2007. Geophysical Research Letters 34, L19501. https://doi.org/10.1029/2007GL031204

LeBlond, P.H. 1980. On the surface circulation in some channels of the Canadian Arctic Archipelago. Arctic 33(1):189–197. https://doi.org/10.14430/arctic2554

McMeans, B.C., Rooney, N., Arts, M.T., and Fisk, A.T. 2013. Food web structure of a coastal Arctic marine ecosystem and implications for stability. Marine Ecology Progress Series 482:17–28. https://doi.org/10.3354/meps10278

Mueller, D.R., and Vincent, W.F. 2006. Microbial habitat dynamics and ablation control on the Ward Hunt Ice Shelf. Hydrological Processes 20(4):857–876. https://doi.org/10.1002/hyp.6113

Orton, D.C., Makowiecki, D., de Roo, T., Johnstone, C., Harland, J., Jonsson, L., Heinrich, D., et al. 2011. Stable isotope evidence for late medieval (14th–15th C) origins of the eastern Baltic cod (*Gadus morhua*) fishery. PLoS ONE 6(11): e27568. https://doi.org/10.1371/journal.pone.0027568

Reimer, P.J., Bard, E., Bayliss, A., Beck, J.W., Blackwell, P.G., Bronk Ramsey, C., Buck, C.E., et al. 2013. IntCal13 and Marine13 radiocarbon age calibration curves 0–50,000 years cal BP. Radiocarbon 55(4):1869–1887.

Richard E. Crawford was a biologist at the Freshwater Institute, Fisheries and Oceans Canada in Winnipeg, Manitoba from 1980 to 2004, with a focus on Arctic cod in Resolute Bay. Richard worked as part of the OTN team in Resolute Bay, bringing his extensive and invaluable knowledge of Arctic cod and Arctic ecosystems and his connections to the local community to the project. Richard passed away in October of 2017. Aaron T. Fisk is Canada Research Chair and professor at the Great Lakes Institute for Environmental Research, University of Windsor, Windsor, Ontario, and Pew Fellow in Marine Conservation. Peter and Nancy Amarualik are residents of Resolute Bay, Nunavut, and Peter is with the Resolute Bay Hunters and Trappers Organization. Steve Cumbaa and Noel Alfonso are with the Canadian Museum of Nature in Ottawa, Ontario. Elizabeth Striano is a science writer and principal at A Green Footprint LLC. Corresponding author: afisk@uwindsor.ca