Limnol. Oceanogr., 46(4), 2001, 999–1000

Carbon isotope ratio variations in Bering Sea biota: The role of anthropogenic carbon dioxide

Cullen et al. contend that isotopically ''light'' anthropogenic carbon dioxide (fossil fuel burning and deforestation effect) is making the major contribution to the observed decline in phytoplankton $\delta^{13}C$ measured by proxy in whale baleen. The progressive decline occurs via direct depression of $\delta^{13}C$ and enhanced fractionation from the increase of $[CO_2]_{aq}$. This position hinges on the assumption that the increase in mixed-layer $[CO_2]_{aq}$, which several investigators have noted in lower latitudes, is of similar magnitude in the Bering Sea. They project that the accompanying depression in dissolved inorganic carbon (DIC) $\delta^{13}C$ and increased fractionation by phytoplankton over the 30-yr period in question may be the source of at least half of the observed decline in biotic isotope ratios. Their calculations all depend on these assumptions, and they are basically straightforward.

Cullen et al.'s Fig. 1 omits the isotope data prior to the mid-1960s shown in Schell (2000) (shown updated in Fig. 1). If the invasion effect is a major contributor to the decline in biotic isotope ratios since 1967, then the same effect should have been evident in the prior 20 yr, during which the $\delta^{13}C$ of atmospheric CO_2 declined by ~0.3‰. The whale baleen $\delta^{13}C$ remained relatively constant, however, and then *increased* to a maximum in 1966, ~1.3‰ higher than the 1947 value. If the invasion of carbon dioxide was depressing the isotope ratios in $[CO_2]_{aq}$, then the implication is that phytoplankton demand was increasing toward a maximum in 1966 that was dwarfing the invasion signal. Actually, the baleen $\delta^{13}C$ data between 1948 and 1976 show no significant decline until the North Pacific ''regime shift,'' a major climatic change that occurred in about 1976 (Francis and Hare 1993).

The effects of increasing oceanic $[CO_2]$ are unquestionably affecting all latitudes in the world oceans and depressing $\delta^{13}C$ values, including those in the Bering Sea. The devil, as usual, is in the details. In the upwelling regions and high latitude zones of deep winter mixing, the observed effects are much smaller because of the lack of time for equilibration and/or greater dilution arising from deep winter mixing. Nevertheless, Cullen et al. contend that, all else being equal, the invasion effect can account for >50% of the observed decline in $\delta^{13}C$ in whale baleen. I can find no evidence that the effect is of this magnitude in the North Pacific (>50°) or Bering Sea. There can be no large anthropogenic increase in $[CO_2]$ in seawater without the accompanying decline in $\delta^{13}C$ and increase in $\Delta^{14}C$. Their assumed decrease in the $\delta^{13}C$ of the DIC pool uses an annual decline of ~0.013‰, which is in line with the estimated global average of ~0.017‰ yr^{-1}. Gruber et al. (1999) show a value in this range for 50° on a global meridional basis, but this is heavily weighted by North Atlantic values that do show a pronounced invasion effect. For the high latitudes in the North Pacific, this is not supported by the observed data (data in Ortiz et al. 2000 are near 40°N). Quay et al. (1992; www.ncdc.noaa.gov/ogp/papers/quay.html) show no significant change in DIC $\delta^{13}C$ north of 50° over the indicated time period—in fact, their average $\delta^{13}C$ values for 1993 were slightly above those from 1970. In agreement, the $\delta^{13}C$ values of particulate organic matter collected at Sta. Papa (50°N, 135°W) by Wu et al. (1999) showed no significant trend, up or down, over 8 yr of sampling, although intraseasonal variability was pronounced.

For the Bering Sea, we have also observed that $\Delta^{14}C$ values in fauna and DIC (Schell and Saupe 1989) show reservoir depressions that closely match the values observed by Östlund and Stuiver (1980). Surface ^{14}C in DIC ranged from −10‰ to +98‰ in 1984 and 1985, well below the values in the midlatitudes (~150‰). These data indicate significant upwelling and deep mixing that has not equilibrated with the atmosphere (e.g., contrast the ^{14}C profiles of GEOSECS Sta. 218 and 219 at >50° with those of Sta. 213 and 214 at <40°). Actual whale baleen ^{14}C data are very limited. Values immediately prior to the massive nuclear weapons testing in the early 1960s were approximately −85‰ and rose to +60‰ by 1966 (Schell and Saupe 1993), indicating that a significant influx of radiocarbon (and carbon dioxide) occurred but well short of equilibration.

The depth of mixing is evident in the data on chlorofluorocarbons (CFCs) in the Bering Sea and North Pacific. The very deepest penetration is in the western region, near Hokkaido Island, of >2000 m (Warner et al. 1996), and the Bering Sea has widespread areas of CFC presence >1500 m, almost double the depth at 40°N (Warner and Roden 1995). Thus anthropogenic influxes are being diluted to a much greater extent than those in lower latitudes.

Timing is also important. Cold water and high productivity enhance invasion, but the season is short. The whales feeding in the western Bering Sea are in a region characterized by annual deep mixing in winter and resupply of nutrients with subsequent on-shelf advection. This is followed by spring-summer production occurring during northward transport across the shelf. With velocities in the Anadyr current and Bering Strait ~15–30 cm s^{-1}, residence times on shelf are in the 2–3 *month* range before transport into the northern Chukchi Sea. Equilibration while in restricted mixing environments is thus temporally limited. In sum, strong mixing and short residence times likely combine to minimize the anthropogenic effects, and I can find no evidence in the existing oceanographic data to support the hypothesis of Cullen et al. in these northern waters to the extent that they propose.

I noted that the long-term decline in whale $\delta^{13}C$ values in the Bering/Chukchi Sea might not be due solely to lower phytoplankton growth rates, and, as anthropogenic CO_2 concentrations continue to increase, invasion effects may be-

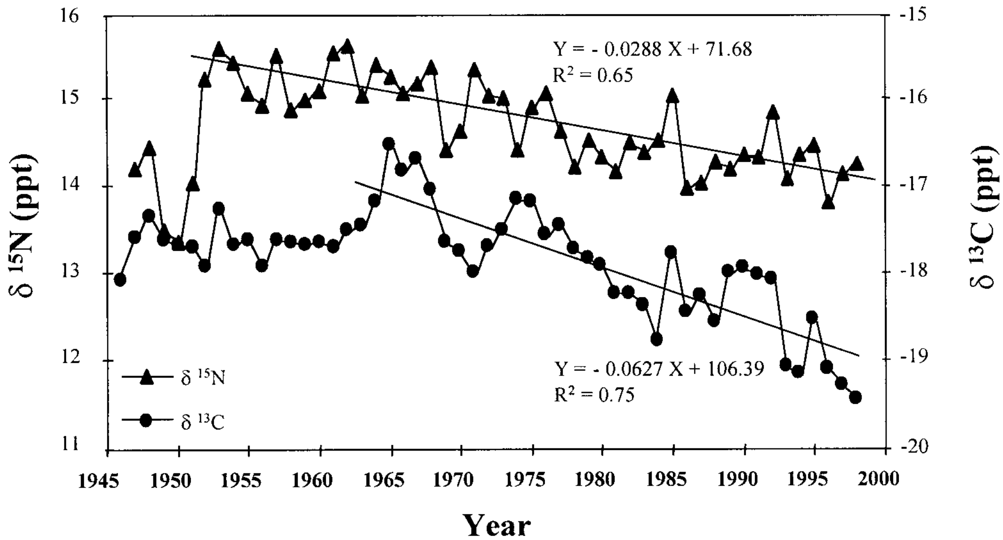

Fig. 1. Average δ^{15}N and δ^{13}C values in bowhead whale baleen grown in the Bering and Chukchi Seas, 1947–1998 (updated from Schell 2000). Data for 1947–1952 are from only two whales, and the sharp changes evident are unexplained. SDs around each point are approximately $\pm$0.5 for carbon and $\pm$0.6 for nitrogen. Least-squares regression lines are from 1965 to 1998 for carbon and from 1952 to 1998 for nitrogen. The "regime shift" in the North Pacific occurred in 1976.

come more prominent. New information that supports the hypothesis that the decline in baleen δ^{13}C may be linked to lowered productivity is present in the nitrogen isotope data. The same baleen plates have been subsequently analyzed in detail for nitrogen isotope ratios (Lee 2000), and the data show that the average δ^{15}N values have declined by 1.3‰ since 1952 (Fig. 1). This pattern is certainly not a direct anthropogenic effect but must arise from either a gradual shift in the nitrogen dynamics of the system or dietary change by the bowhead whales (unlikely). If the seasonal euphotic zone is receiving less advected nitrate, one possible explanation may be an increased importance of nitrogen fixation that is diluting the N pool with material of low δ^{15}N (~0‰).

Careful isotope ratio analysis on shell carbonate from long-lived bivalves in the region may provide a means for sorting out the relative importance of possible effects. I am in complete agreement as to the need for more work in the area. Major changes are occurring in the Bering Sea ecosystem, and, in general, they have been detrimental to top consumers, including humans.

Donald M. Schell

Institute of Marine Science
University of Alaska Fairbanks
Fairbanks, Alaska 99775

References

FRANCIS, R. C., AND S. R. HARE. 1993. Decadal-scale regime shifts in the large marine ecosystems of the North-east Pacific: A case for historical science. Fish. Oceanogr. **3:** 279–291.

GRUBER, N., AND OTHERS. 1999. Spatiotemporal patterns of carbon-13 in the global surface oceans and the oceanic Seuss effect. Global Biogeochem. **13:** 307–335.

LEE, S. H. 2000. Use of the Beaufort Sea as feeding habitat by bowhead whales (*Balaena mysticetus*) as indicated by stable isotope ratios. M.S. thesis, Graduate Program in Marine Science and Limnology, University of Alaska Fairbanks.

ORTIZ, J. D., A. C. MIX, P. A. WHEELER, AND R. M. KEY. 2000. Anthropogenic CO_2 invasion into the northeast Pacific based on concurrent $\delta^{13}C_{DIC}$ and nutrient profiles from the California Current. Global Biogeochem. Cycles **14:** 917–929.

ÖSTLUND, H. G., AND M. STUIVER. 1980. GEOSECS Pacific radiocarbon. Radiocarbon **22:** 25–53.

QUAY, P. D., B. TILBROOK, AND C. S. WONG. 1992. Oceanic uptake of fossil fuel CO_2: Carbon-13 evidence. Science **256:** 74–79.

SCHELL, D. M. 2000. Declining carrying capacity in the Bering Sea: Isotopic evidence from whale baleen. Limnol. Oceanogr. **45:** 459–462.

———, AND S. M. SAUPE. 1993. Feeding and growth as indicated by stable isotopes, p. 491–509. *In* J. J. Burns, J. J. Montague, and C. C. Cowles [eds.], The bowhead whale. Special Publication No. 2, Society for Marine Mammalogy.

———, AND ———. 1989. Primary production, carbon energetics and nutrient cycling, pp. 101–140. *In* J. Truett [ed.], Environmental characterization and biological utilization of the North Aleutian nearshore zone. Final Reports of Principal Investigators. NOAA Outer Continental Shelf Environmental Assessment Program. Vol. 60, U.S. Dept. of Commerce.

WARNER, M. J., J. L. BULLISTER, D. P. WISEGARVER, R. H. GAMMON, AND R. F. WEISS. 1996. Basin-wide distributions of chlorofluorocarbons CFC-11 and CFC-12 in the north Pacific: 1985–1989. J. Geophys. Res. **101:** 20,525–20,542.

———, AND G. I. RODEN. 1995. Chlorofluorocarbon evidence for recent ventilation of the deep Bering Sea. Nature **373:** 409–412.

WU, J., S. E. CALVERT, C. S. WONG, AND F. A. WHITNEY. 1999. Carbon and nitrogen isotopic composition of sedimenting particulate material at Station Papa in the subarctic northeast Pacific. Deep-Sea Res. II **46:** 2793–2832.

Received: 27 November 2000
Accepted: 30 January 2001
Amended: 31 January 2001