Response to Comment on “Otolith δ¹⁸O Record of Mid-Holocene Sea Surface Temperatures in Peru”

We find the arguments of Béarez et al. unconvincing. We did not contend that Galeichthys peruvianus is a tropical species. Rather, G. peruvianus was selected for its wide temperature tolerance and was captured during both El Niño and La Niña events at Huanchaco, Peru (1, 2). The northern range boundary Béarez et al. cite (6°S) is incorrect. In a prior publication (3) Béarez stated that this species is native to Ecuador, an observation corroborated by other authors (4), which undermines the cool climate suggestion. Our sea surface temperature (SST) conclusions rely on δ¹⁸O data, not the presence or absence of species [although presence-absence data show predominantly tropical fauna at Ostra and Siches (5, 6)].

Béarez et al. confuse individual migration with species range and provide no data supporting migration. Between 91 and 94% of Peruvian G. peruvianus are caught in coastal water less than 15 m deep (and all in water <35 m deep)—thus, their habitat is ideally suited to reflect regional SST (7). All age-size classes were captured throughout the El Niño/Southern Oscillation (ENSO) SST cycle in north-central Peru (2), suggesting no ontogenetic or seasonal migration. Strong correlation between modern δ¹⁸Ootolith profiles and SST at Puerto Chicama demonstrates that these fish remained in nearby waters throughout their lives (1, 2).

Béarez et al. fail to explain how their hypothetical migration scenarios could cause the δ¹⁸Ootolith profiles. The seasonal δ¹⁸O range of the Ostra otoliths is similar to that caused by the 1997–1998 El Niño in modern otoliths, with negative summer δ¹⁸O values similar to modern otoliths during El Niño (1, 2). Therefore, neither southerly nor vertical migration, both of which would result in more positive δ¹⁸O values, can account for the data. For migration to cause seasonally negative δ¹⁸O values, the fish would have had to transit between tropical Ecuador and central Peru twice annually. This scenario is highly unlikely for many reasons, including the tendency for fish to narrow, not expand, their ambient temperature range. δ¹⁸O values at the Ostra otoliths’ margin, indicating the season of death, show both winter and summer capture, further undermining the migration hypothesis.

The suggestion that local estuaries caused the δ¹⁸Ootolith profiles is misleading to those unfamiliar with the Peruvian coast. Compared to other regions, the Peruvian shore face is steep, the tidal range is narrow, and the volume of water in the braided rivers is low. The Peruvian “estuaries” are only small river mouths. The δ¹⁸Owater in the mouth of the Santa range from −12.8‰ to −14.1‰ (8). No otoliths record any value similar to this.

Regarding the proper identification of otoliths, archaeological remains were originally identified to family level for sea catfish (Ariidae) at Ostra and Siches (5, 9). The otoliths were later identified as G. peruvianus because they are morphologically most similar to otoliths from that species, which is the only common arid in the area today. All archaeological G. peruvianus are identified this way, including those of Béarez (10). As Béarez et al. note, the only alternative species to G. peruvianus are tropical, contradicting their assertion of temperate SST. The otoliths in (1, 8) were bisected at perpendicular angles; thus curvature variation is an artifact of sample preparation and meaningless for identification.

Although Béarez et al. are correct that Siches is 4°30’S, their argument regarding its significance is unfounded. The difference in mean SST between the Paita and Talara datasets is less than 0.4°C, not 2°C to 4°C (11, 12). This small variation is within the ±3° to ±4°C range we stated in (1) and does not change our conclusions. Furthermore, the Siches samples contain the smallest δ¹⁸O range of all the otoliths. This suggests that these fish did not pass through a large temperature gradient, supporting our arguments for the nonmigratory nature of the fish and the significance of our paleotemperature estimates.

The comments by Béarez et al. focusing on diversity, equitability, and trophic level are based on a misinterpretation of our text. We do not attribute causality to presence/absence of anchovies alone, but to changes in the overall food web in response to upwelling variation (1). Thus, the comments related to anchovy range have no bearing on our conclusions about multispecies ecosystem changes.

In their discussion of Ostra, Béarez et al. suggest that the former embayment near this site could have provided habitat for some fish species. Geochemical records from embayment mollusks suggest this environment was evaporative (13, 14). As stated in (1), fish entering the embayment would record more positive, not more negative, δ¹⁸Ootolith values. Thus, the embayment cannot account for the δ¹⁸Ootolith profiles.

Béarez et al. suggest that a sessile proxy may be better suited for SST reconstructions. To that end, we present δ¹⁸O data from the cockle Trachycardium procerum (Figs. 1 and 2) that corroborate our enhanced seasonality interpretation of otolith data from Ostra. Modern T. procerum were collected near Casma in 1984 after the strong 1982–1983 El Niño (15). The δ¹⁸Oshell range measured during El Niño is 1.5‰ (Fig. 1). Including published data from contemporaneous T. procerum, the mean El Niño range is ~1.3‰ (13, 15). The δ¹⁸O range from an Ostra shell (5830 ± 90 14C yrs B.P.) is 1.6‰ (Fig. 2). The mean δ¹⁸O range in four T. procerum from fossil deposits near Ostra is ~1.5‰ (13). All but one ancient shell have δ¹⁸O ranges greater than that measured in carbonate precipitated before the 1982–1983 El Niño depicted in Fig. 1 (15). It is unlikely that each of these five shells, dating to four different periods (5500 ± 150 to 6000 ± 150 14C yrs B.P.), grew during an El Niño event of equal or greater magnitude than the 1982–1983 event. A more likely explanation is enhanced seasonality similar to that measured by the Ostra otoliths.

Fig. 1. δ¹⁸O profile through ontogeny (left to right) of T. procerum excavated from the Ostra site (5830 ± 90 14C yrs B.P.). Note that because of lower sampling resolution than that depicted in Fig. 1, the range in seasonal δ¹⁸O is potentially underestimated relative to the modern valve.

Fig. 2. δ¹⁸O profile through ontogeny (left to right) of T. procerum excavated from the Ostra site (5830 ± 90 14C yrs B.P.).
in the contemporaneous otoliths (1). This conclusion is supported by the Ostra specimen (Fig. 2) that contains two consecutive δ18O oscillations indicative of seasonal, not inter-annual, variation. Unfortunately no absolute paleotemperatures can be calculated because the Santa embayment was evaporative, thus the molluscan δ18O values are elevated relative to nearby marine values (13, 14).

Béarez et al. argue that warm-tropical, transitional (wide temperature-tolerant species), and warm-temperate mollusks coexisted in the Santa embayment. We addressed this previously (16), demonstrating DeVries and Wells’ data (17, 18) do not support contemporaneity of these faunas. We have now analyzed the data (13) cited by Béarez et al. and find the radiocarbon dates on mollusks in the Santa and adjacent Salinas de Chao embayments unequivocally support our contention of warmer SSTs before 5800 cal B.P. and cooler SSTs thereafter (Fig. 3) (1, 6, 19).

Close examination of the comments and citations of Béarez et al. strengthen our original interpretations. Our data represent the most direct measurement of mid-Holocene paleotemperature on the coast of Peru, and are part of a larger body of research supporting the hypothesis of significant changes in mid-Holocene Pacific SST and ENSO history (6, 20–25).

References and Notes
15. U. Brand, personal communication. Sr/Na analyses performed through ontogeny on T. procerum from the Ostra site were indicative of significantly elevated salinity, potentially as high as 40%, due to evaporation.
CORRECTIONS AND CLARIFICATIONS

ERRATUM
post date 14 February 2003

TECHNICAL COMMENTS: Response to Comment on “Otolith $\delta^{18}$O record of mid-Holocene sea surface temperatures in Peru” by C. F. T. Andrus et al. (10 Jan. 2003, www.sciencemag.org/cgi/content/full/299/5604/203b). Reference (1) should have been cited in the first sentence, which should read “We find the arguments of Bearez et al. (1) unconvincing.” All subsequent references should be renumbered as number + 1. The numbers in the reference list are correct.
Response to Comment on "Otolith δ¹⁸O Record of Mid-Holocene Sea Surface Temperatures in Peru"

C. Fred T. Andrus, Douglas E. Crowe, Daniel H. Sandweiss, Elizabeth J. Reitz, Christopher S. Romanek and Kirk A. Maasch

Science 299 (5604), 203.
DOI: 10.1126/science.1077525