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Is global climate change influencing the overwintering distribution of weakfish *Cynoscion regalis*?

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The pattern of stable isotope signatures in a sub-sample of 67 juvenile weakfish *Cynoscion regalis,* captured at the mouth of the Christina River, 113 km upstream of the mouth of Delaware Bay (U.S.A) in the autumn of 2000, suggested that they resided at the location since recruitment. The possibility that young *C. regalis* departed from the generally characteristic life-history pattern of marine migrants at this latitude, *i.e*. emigrating offshore with the adults in autumn was bolstered by the collection of 69 individuals during the winters of 2000–2006 from the travelling screens of a power plant located at river kilometre 88 including an 118 mm total length juvenile captured in mid-February 2006.

Key words: juvenile fish; migration patterns; mid-Atlantic.

Members of the family Sciaenidae are fishes with global importance as commercial and recreational species. The life history of many members of this group invokes the image of a coastal conveyor belt with adults spawning offshore and near estuaries, and young spending their first year of life in various estuarine habitats. At higher latitudes, young-of-year (YOY) complete the cycle by accompanying the adults offshore during their autumn migration to overwintering grounds. One of these species, the weakfish *Cynoscion regalis* Bloch & Schneider is abundant along the mid-Atlantic shore of the U.S.A., and it has been reported that the mid-Atlantic Bight and inner continental shelf of central New Jersey are important spawning regions (Able & Fahay, 1998).

Within estuaries, young *C. regalis* display variable patterns of habitat utilization but a general synthesis of reported distributions and movements in the mid-Atlantic Bight suggests that the conveyor-belt concept extends to these ages (Wilk, 1979). The YOY *C. regalis* are not believed to overwinter in estuaries north of Pamlico-Albemarle Sound, NC, USA (35°18′ N; 76°10′ W) (Mercer, 1983). The presence of a large number of juveniles captured in mid-autumn 2001, *c*. 113 km upstream of the mouth of Delaware Bay, however, is highly atypical of the patterns that have been previously reported for the seasonal movements of this species. The stable isotope

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signatures in a sub-sample of 67 specimens indicated further that these fish resided at this location since recruitment. There is mounting evidence that climate change is affecting the latitudinal distribution of marine species towards the poles in both hemispheres (Perry *et al.,* 2005). This context is used to examine the possibility that increasing ocean temperatures may be shifting the latitudinal limits of overwinter survival for age 0 year *C. regalis* to the north. The data reported here are bolstered by additional independent data provided to the investigators.

Juvenile *C. regalis* were obtained from two sources. First, 67 YOY were captured by a 9·6 m otter trawl just inside and near the mouth of the Christina River, an upstream tributary of the Delaware River located at river kilometre (≈km) 113 (≈km 0 is located at the Delaware River and Bay entrance), on 10–11 October 2001 (Fig. 1). After removal of gut contents, tissue samples from a random sub-sample of eight fish were analysed for their δ^{13}C, δ^{34}S and δ^{15}N stable isotope content. Secondly, data for 69 YOY ranging in size from 54 to 152 mm total length (L_T), which were removed from the travelling screens of a power plant during the winter months of December to March 2006 were obtained from operators of the facility located at ≈ 88 km.

Details of field and laboratory processing of whole fish (gut contents removed) prior to and including stable isotope analysis were detailed in prior studies, and are only briefly summarized here (Wainright *et al*., 2000; Weinstein *et al.,* 2000; Litvin & Weinstein, 2003, 2004). Whole specimens were freeze-dried to a constant mass, ground to a fine powder, then analysed by continuous flow elemental analysis and mass spectrometer stable isotope system. Isotopic composition is expressed in δ notation as:

$$\delta X = [(R_{\text{sample}}\ R^{-1}_{\text{standard}}) - 1]\ 10^3,$$

where $X = {}^{13}$C, ^{34}S or ^{15}N and $R = {}^{13}\text{C}\ {}^{12}\text{C}^{-1}$, $^{34}\text{S}\ {}^{32}\text{S}^{-1}$ or $^{15}\text{N}\ {}^{14}\text{N}^{-1}$ of the samples and the standards. The standards used were Peedee Belemnite for carbon, air for nitrogen and Canyon Diablo triolites for sulphur. Instrument precision was ±0·2‰ for δ^{13}C, ± 0·3‰ for δ^{15} N and ± 0·5‰ for δ^{34}S.

Canonical discriminant analysis (SPSS, 2004) was used to extract patterns in the isotopic signatures of trawl captured *C. regalis* based on their capture location in comparison to earlier study results for the Delaware Bay (Weinstein *et al*., 2000, 2005; Litvin & Weinstein, 2004). For the present study, the previous analysis of post-settlement individuals from six regional habitats, open waters and marshes of the upper, mid and lower Delaware Bay (Fig. 1), was extended to include isotopic data from the eight randomly selected individuals captured in the Christina River. The ability of the discriminant functions to discern capture location was tested by reclassification and jackknife validation (Litvin & Weinstein, 2004).

Long-term observations of juvenile *C. regalis* use of Delaware Bay are consistent with the idealized behaviour of young marine migrants (Chao & Musick, 1977; Szedlmayer *et al.,* 1990; Lankford & Targett, 1994; Grecay & Targett, 1996; Able & Fahay, 1998; Paperno *et al.,* 2000; Litvin & Weinstein, 2004; Weinstein *et al.,* 2005). Small juveniles recruit throughout the estuary early in summer, and by spending sufficient time in a given open-water region or marsh creek acquire the distinct

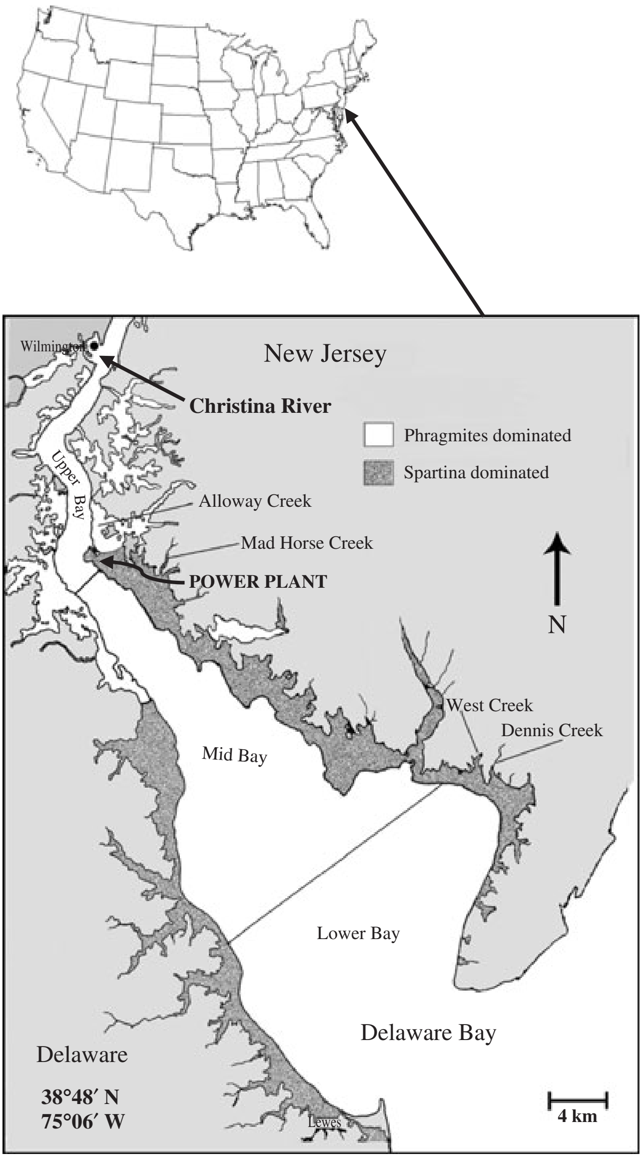

FIG. 1. Location of the Christina River, a tributary of the Delaware River, Delaware Bay, U.S.A. The extent of brackish tidal salt marshes dominated by *Phragmites australis* is noted in the unshaded portion of the shoreline.

isotopic signature of that region, *i.e.* they exhibit substantial site fidelity (Deegan & Garritt, 1997; Litvin & Weinstein, 2004). While growing rapidly, young *C. regalis* begin to move out of the marsh creeks and upper Delaware Bay, either moving directly or sometimes in saltatory fashion to lower Delaware Bay habitats and the bay mouth (Litvin & Weinstein, 2004).

The 67 YOY *C. regalis* reported here ranged in size from 85 to 136 mm standard length (L_S) and differed markedly in their stable isotope signatures from those

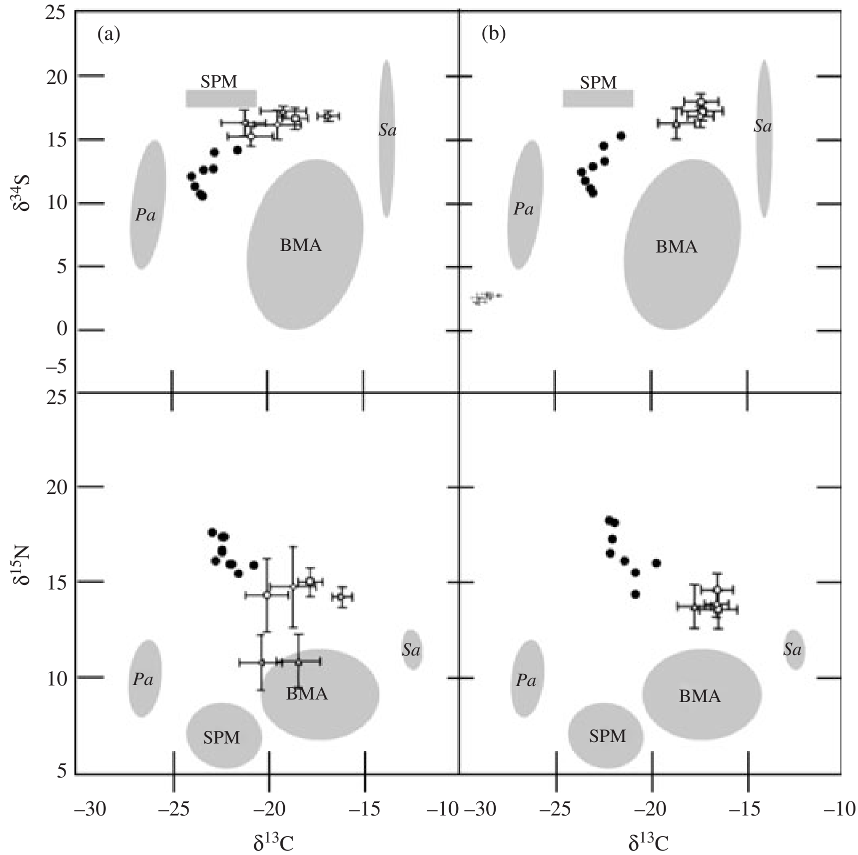

FIG. 2. Dual-isotope plots of $\delta^{15}N$ and $\delta^{13}C$ and $\delta^{34}S$ and $\delta^{13}C$ comparing *Cynoscion regalis*, and primary producers (vegetation) collected in Delaware Bay open waters, tidal salt-marsh creeks and seaward of Delaware Bay mouth: (a) lower bay creeks (□), lower bay open waters (▷), Mad Horse Creek (◇), mid-bay open waters (△), Alloway Creek (○), upper bay open waters (◁) and Christina River (●); (b) bay mouth: 1998 (○), 1999 (□), 2001 (△), 2002 (◇). Primary producers are shown in both (a) and (b) [phytoplankton measured as suspended particulate matter (SPM), benthic microalgae (BMA), *Phragmites australis* (*Pa*), and *Spartina alterniflora* (*Sa*)]. Ellipses for vegetation are mean *v*. ± S.D.

described previously (Litvin & Weinstein, 2003, 2004; Weinstein *et al*., 2005), *i.e*. were characterized by isotope signatures that were strongly depleted on both the carbon and sulphur axes, but enriched on the nitrogen axis [Fig. 2(a),(b)]. The latter is consistent with patterns in other species that might be influenced by anthropogenic sources of N in the upper reaches of Delaware Bay and River (Wainright *et al*., 1996; Litvin & Weinstein, 2003). The significant difference in the isotopic signatures of fish from the Christina River relative to other habitats within Delaware Bay was supported by the canonical discriminant analysis of stable isotope signatures. The vast majority of individuals collected in the river were classified to their site of origin with $>80\%$ accuracy (Litvin & Weinstein, 2004).

Thus, it appears that these fish had been in the upper estuary near the saltwater boundary for some time, perhaps since early recruitment. This conclusion is corroborated by the collection of 69 YOY *C. regalis*, ranging in size from 54 to 152 mm L_T, from submerged portions of a power plant's travelling screens at *c.* 12·2 m depths during the winter months of December 2000 to March 2006. For the first time in the plant's 25+ year operating history, juvenile *C. regalis* were impinged in wintertime, with one 118 mm L_T individual captured on 10 February 2006, a heretofore unrecorded phenomenon in Delaware Bay.

In earlier studies, YOY *C. regalis* ($n = 417$) were collected at the Delaware Bay mouth and a short distance offshore in late October and early November in 4 years (1998–1999 and 2001–2002) prior to their emigrating offshore [Fig. 2(b)] (Litvin & Weinstein, 2004). The size of these individuals ranged from 71 to 190 mm L_S. Larger *C. regalis* (>100 mm L_S) with an isotope signature dominated by *Phragmites australis* (indicative of residence in brackish waters; Fig. 1) were rarely observed in these samples (*c.* 5%, the average value over the 4 years). Certainly, none was encountered in the autumn with the degree of stable-isotope carbon and sulphur depletion (and nitrogen enrichment) observed in the Christina River fish [Fig. 2(a), (b)]. The Christina River *C. regalis* therefore may have stayed in upper Delaware Bay to overwinter. This is a new observation given that an extensive review of the published literature and available monitoring reports suggests that juveniles do not overwinter north of Pamlico–Albemarle Sound in North Carolina (35°30′ N; 75°44′ W) (Mercer, 1983). At a minimum, future sampling efforts should be extended into the winter months in the mid-Atlantic Bight region to determine if similar patterns are emerging for other species, possibly in response to climate change and a warming world (Kerr, 2006).

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