J. Mar. Biol. Ass. U.K. (2002), **82**, 177–180
Printed in the United Kingdom

Immigration of southern fish species to south-west England linked to warming of the North Atlantic (1960–2001)

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Evidence is provided that warming of the North Atlantic is responsible for the northward extensions of the ranges of warm water fish species, causing increasing numbers of southern immigrant species to appear off the Cornish coast of the UK. The increasing number of immigrant species is significantly correlated with temperature increases in the North Atlantic over the last 40 years.

INTRODUCTION

In recent years the progressive northward spread of fish species has been recorded (Quero, 1998; Swaby & Potts, 1999); and it has been proposed that records of southern marine species reaching the British Isles are linked to global warming (Swaby et al., 1992, 1996; Swaby & Potts, 1999). Global warming is expected to shift the distributions of all terrestrial species poleward at a rate of 50–80 km per decade (UKCIP, 1998). Littoral species may be expected to behave similarly and the northward latitudinal extensions of 193 km (120 miles) of some species over the last 70 y have been attributed to rising sea temperatures (Southward et al., 1995). Evidence for the effect of climate change on marine life in the south-west has been reviewed by Southward & Boalch (1994). They note a marked switch in demersal fish species caught off Plymouth from warm water to cold water species from the 1920s to the 1950s, that was reversed in the 1970s, which they relate to sea temperature changes. However, to date, statistical correlations linking such trends with temperature change have not been made.

The effects of warming at any one location are likely to be losses of northern species at the southern extremity of their ranges, while there will be gains of southern species at the northern extremity of their ranges. Since it is difficult to demonstrate the absence of a species conclusively, it is preferable in the first instance to use the immigration of southern species as an indicator of the biological effects of warming.

Here we consider the immigration of southern fish species to Cornwall, using pre-existing records over the period 1960–2001 for all new species in Cornish waters (up to 12 miles from the coastline) from the Environmental Records in Cornwall and the Isles of Scilly Automated (ERICA) database. No unbroken water temperature records, representative of Cornish coastal waters, exist for this period, so the fish data have been related to temperatures for the North Atlantic from Levitus et al. (2000).

METHODS AND RESULTS

Fish records

Changes in fish distribution were chosen to indicate the biological effect of temperature change because they are thermal conformers, unable to regulate their temperature independently of the surrounding water (Brill et al., 1994), so they thermoregulate by actively swimmimg to remain in waters that meet their physiological optima (Magnuson & Destacio, 1996). Fish are well-monitored by fishermen, sea anglers and scientists, so their changing distributions are likely to be reported. Consequently unusual specimens are regularly brought to the Marine Biological Association, Plymouth Marine Laboratory and the National Marine Aquarium for identification.

Records from the ERICA database are given for warm water fish, new to Cornwall from 1960 to 2001, together with their dates and locations of first recording are given in Table 1. The cumulative numbers of warm water immigrants species to Cornwall from 1960 to 2001 are given in Figure 1A. The data show that over the first 15 y there were no new southern species; thereafter the numbers have increased at an accelerating rate. Some of the recorded new fish species (Table 1) now visit south west waters regularly and in increasing numbers (D. Herdson, personal communication).

A limitation of such data is that while new fish species are recorded, the retreat of those species in intervening cooler periods cannot be reflected in the data. Thus the choice of new species records precludes the detection of cyclical variation in distributions of species as described by Southward et al. (1988a,b).

Temperature data

Various temperature data sets for water off south-west England have been assembled for the purpose of determining the role of changing temperatures as the principal determinant of biological events, cycles and trends (Maddock & Swann, 1977), however, none extend from

https://doi.org/10.1017/S0025315402005325 Published online by Cambridge University Press

Table 1. *First records of southern, warm water fish to Cornwall (1960–2001) (extending to the 12 miles fishing limit). The fish records are drawn from the ERICA (Environmental Records in Cornwall and Isles of Scilly Automated) set up by the Cornwall Biological Records Unit (Institute of Cornish Studies, University of Exeter) in the 1970s, which since 1997 has operated under the aegis of the Environmental Centre for Cornwall and the Isles of Scilly at Cornwall Wildlife Trust.*

Year of record	Fish species
~1980	Flying gurnard *Dactylopterus volitans*. Found at 90 m 50°00′30″N 06°10′30″W (north-west of the Longships) (Quero & Guéguen, 1981). First British record.
1982	Blue marlin *Makaira nigricans*. 'The remains of a specimen 3.66 m long were washed up at St Agnes, Isles of Scilly' (Wheeler, 1992).
1984	Sharp-nosed or seven-gilled shark *Heptranchias perlo*. South of Bishop-Lizard (Capetta, 1985). First British record.
1985	Big-eye tunny *Thunnus obesus*. 'A single specimen of this normally tropical and subtropical pelagic species was caught off Newlyn Harbour, Cornwall' (identified by R. Swinfen and A. Wheeler for the British Record Fish Committee).
1987	Smooth pufferfish *Sphoeroides pachygaster*. Stranded on Whitsand Beach, east Cornwall (Reay, 1988). First British record.
1989	Flathead grey mullet *Mugil cephalus*. A single specimen from the Camel Estuary (Reay, 1992).
1990	Short-beaked garfish *Belone svetovidovi*. Mount's Bay (Swaby et al., 1991). First British record.
1993	Blue runner *Caranx crysos*. Off St Ives (Swaby et al., 1996). First British record.
1994	Greater amberjack *Seriola dumerili*. St Ives Bay (S. Swaby & P. Gainey, personal communication). Second British record; the first was in 1951 in the Salcombe Estuary (Wheeler, 1969).
1995	Red scorpion-fish *Scorpaena scrofa*. Off Land's End (P.A. Gainey & D Herdson, personal communication).
1995	Saupe *Sarpa salpa* gurnard's head near Zennor (P.A. Gainey, M. Deeble & D Herdson, personal communication). Wheeler (1969) mentions only one record (in 1932) from northern Europe.
1995	Sailfin dory, *Zenopsis conchifera*. South of Looe (Swaby & Potts, 1999). First British record.
1998	Black or small-scaled scorpion-fish *Scorpaena porcus*. Eddystone Reef (Herdson, 1999). Earlier records in 1926 were not considered reliable (Wheeler, 1969), but another for North Wales in 1994 is recorded by Henderson (1994).
1998	Short-snouted seahorse *Hippocampus hippocampus*. Cornish side of the Tamar (Herdson, 1999).
1999	Almaco jack *Seriola rivoliana*. Eddystone Reef (Herdson, 1999) second British record. The first British record was off Torquay in 1985 (Herdson, 1999).
2000	Saddled seabream *Oblada melanura*. Black Head, St Austell Bay, 30 July 2000, specimen in The Natural History Museum, London (D. Herdson, 2001). First British record.
2001	Big-eye thresher shark *Alopias superciliosus*, found dead on shore at Gunwalloe Fishing Cove (A. Wheeler, personal communication)*.
2001	Barracuda *Sphyraena sphyraena*, caught off the Lizard. Identity not formally confirmed at time of going to press (D. Herdson, personal communication)*.

*, records not used in the statistical analysis.

1960 to the present without a break. The most important loss has been monitoring programmes carried out by the Marine Biological Association, many of which were terminated in the late 1980s (Southward et al., 1995). Data gathered by Levitus et al. (2000) are the most comprehensive and continuous temperature records available for the North Atlantic, showing a 0.37°C rise in the annual temperature anomaly from 1948 to 1998. We have opted to use these data to relate to the fish records.

Statistical correlation of the temperature and fish data

There are significant correlations between the annual numbers of immigrant fish species and mean annual

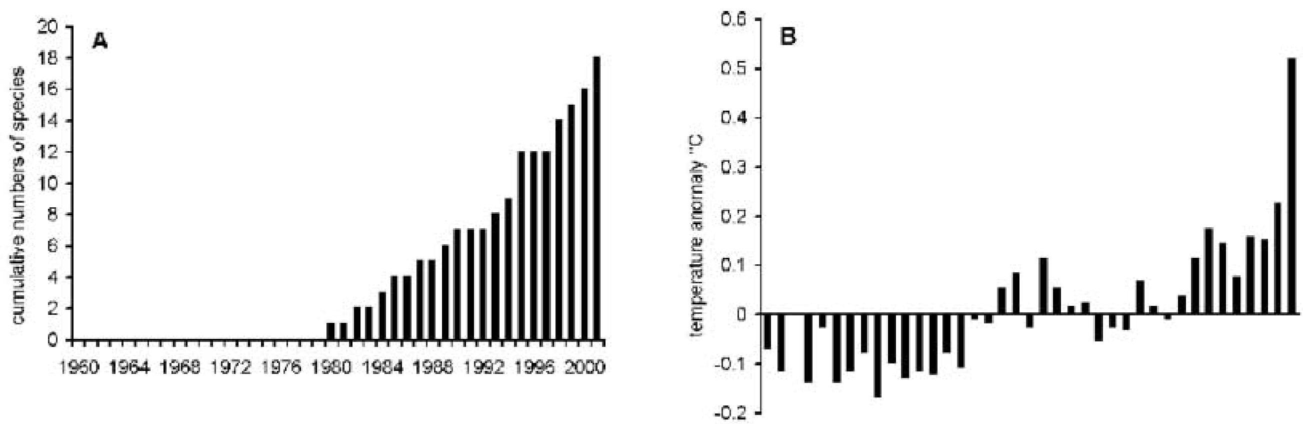

Figure 1. (A) Records of new species to Cornwall from the ERICA database from 1960 to 2000 (see Table 1). The data are given as mean cumulative annual numbers, calculated as 5-y running means; (B) records of 5-y running mean seawater temperatures for the North Atlantic from 1960 to 2000 (Levitus et al., 2000; data from www.sciencemag.org/feature/data). There is significant correlation between the annual numbers of fish species and the mean annual temperature anomaly from 1960 to 2000 for various lags (see text).

https://doi.org/10.1017/S0025315402005325 Published online by Cambridge University Press

temperature anomaly for the North Atlantic from 1960 to 2001 (Figure 1A). The five-yearly temperature and fish species data were correlated using a Spearman rank correlation, adjusted for ties according to the b-form of the coefficient (Kendall, 1970). A permutation test, allowing for ties, established the null distribution of expected Spearman ρ-values for various lags between the temperature and fish data, against which the observed correlations could be tested.

While correlations are significant for various lags (0–5 y) between annual temperature and fish species numbers, they are highest for a lag of two years (Spearman ρ-value=0.68; $P<0.0001$). For the five-yearly data the highest correlation (ρ=0.91; P=0.002) occurs when there is a 2-y lag between temperature and fish data. That the analyses of annual and 5-y grouped data were performed with similar results indicates that the correlations are robust and independent of grouping the data.

DISCUSSION AND CONCLUSION

It is notable that the fish records correlate significantly with temperature data for the North Atlantic. A possible mechanism to explain this correlation is the increasing heat content of North Atlantic waters brought to European shores by the Gulf Stream and North Atlantic Drift. The world's oceans now contain an order of magnitude more heat from greenhouse warming than remains in the atmosphere (Levitus et al., 2000), and temperatures are likely to increase further. If the rate of temperature increase over time were linear, a constant rate of immigration of southern species would be expected. However, the rate of temperature increase over the last 20 years appears to be exponential (Figure 1B), so an accelerating rate of immigration of southern species is to be expected (Table 1; Figure 1A).

There have been numerous anecdotal observations on northerly extensions of fish ranges in response to global warming and its effects on sea temperatures. More detailed studies have been conducted by Quero (1998) and Swaby et al. (1999). Quero considered northerly shifts in the distribution of tropical fish species which before 1950 had not been recorded north of Portugal (~41°50′N). These he believed to be linked to the winter warming of the northward flowing shelf edge current, or the European slope current (Pingree et al., 1999), which has increased in temperature by 2°C from 1972 to 1992 (Le Cann & Pingree, 1995). Five species which live on the upper slope between 200 and 600 m, at the depth of the shelf edge current may have been carried north by it, with ranges of these tropical species apparently extended northward by the marked warming of the shelf edge current itself. The five species are sailfin dory (*Zenopsis conchifer*), rosy dory (*Cyttopsis roseus*), sea toads (*Chaunax pictus* and *C. suttkusi*), smooth pufferfish (*Sphoeroides pachygaster*) and thorny tinselfish (*Grammicolepis brachiusculus*).

The northerly spread of *Z. conchifer* is also catalogued by Swaby & Potts (1999). The rate of northerly spread of *Z. conchifer* is approximately 60 km per decade over the period 1960–1995. Quero (1998) provides plots of the changing distribution of each of these shelf edge species with latitude over the period 1965–1995. Both authors attribute the northerly extensions of their ranges to ocean warming, but in neither case do they relate their biological observations to sea temperature data.

It is unclear exactly why there is a 2-y lag between the best correlation of the fish records (Figure 1A) and the North Atlantic temperature data (Figure 1B). Such a 2-y lag has been noted before in biological data related to temperature data. Southward and collaborators (1995) noted that their barnacle index had a correlation with sea temperature, when a 2-y lag is introduced. This they attributed to the average interval between the onset of reproduction in successive generations. For our data (Figure 1) such a lag may be due to delays in the mean temperature for the North Atlantic reaching British waters, or perhaps to delays in observing and reporting new fish species.

The effect of warming of the North Atlantic (Figure 1B) on fisheries is likely to be important, as the southern limits of the ranges of northerly species move further north (Russell & Stebbing, 2000). Cod (*Gadus morhua*) is the most important commercial northern species vulnerable to warming, at the southern extremity of its range off south-west England. However, it is difficult to separate the effects of climate change from other environmental factors, let alone the effects of fishing (Brander, 1996). Planque & Fredou (1999) have shown that recruitment is statistically related to temperature for a number of populations of cod, specifically to sea temperatures at the latitudinal limits of the species' distribution in the North Atlantic. These results support our finding that changes in sea temperatures can be responsible for shifts in the distribution of fish populations. Cod in the North Sea are close to the southern limit of their distribution, which is likely to shift northward with rising temperatures.

We conclude that there are significant correlations between warming of the North Atlantic and the immigration of southern fish species to Cornwall. As fish appear to respond to warming by the northerly advance of the distributions of southern species in a systematic way, they may provide a useful index of the effects of warming in the North Atlantic.

The authors acknowledge help provided by Mr M. Atkins, Dr K. Brander, Mr D. Herdson and Mr A. Taylor. A.R.D.S. acknowledges receipt of an Earthwatch Millennium Fellowship.

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Submitted 20 September 2001. Accepted 18 February 2002.