Journal of Sea Research xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Journal of Sea Research

journal homepage: www.elsevier.com/locate/seares

Long-term temporal and spatial changes in the richness and relative abundance of the inshore fish community of the British North Sea Coast

Peter A. Henderson

Pisces Conservation Ltd., IRC House, The Square, Pennington, Lymington, Hants. England SO41 8GN, United Kingdom

ARTICLE INFO

Keywords:
North Sea
Inshore fish
Temporal variation
Latitudinal variation
Temperature
Estuarine fish assemblage
Species abundance distribution
Resilience
Stability

ABSTRACT

Changes in temporal and spatial composition of the British inshore North Sea fish community are reviewed. Sampling from the cooling water filter screens of power stations bordering the North Sea commenced in the early 1960s. To date, a total of 112 marine fish species have been recorded, a high proportion of the total inshore fish species complement of shallow North Sea British waters. The unrecorded top predators, such as large sharks, swordfish and tuna are not regularly observed in waters < 20 m deep. The greatest species number (92) is reported from fully marine waters in East Anglia. A group of 18 ubiquitous, high abundance, taxa form a core inshore community throughout the region in both estuarine and marine waters. They show a high level of concordance in relative abundance along the British east coast from the 1970s to the present. A second group of 20 species are abundant, but more restricted in habitat. Where they do occur, this group are usually always present and form together with the ubiquitous taxa the local core community. The third group of 67 species, are never abundant and are restricted in occurrence both spatially and temporally. Total species richness declines between 50 and 56°N, probably because high summer temperatures allow the southern North Sea to support summer migrants entering via the English Channel. Since the 1960s there has been a notable recovery in fish diversity and abundance in large industrialised estuaries such as the Thames and the Firth of Forth. Linked to spawning and nursery habitat gain, smelt, *Osmerus eperlangus,* and bass, *Dicentrarchus labrax*, have greatly increased in abundance. There is no evidence for a decline in species richness since the 1970s. However, elasmobranch species number has declined while two species *Raja clavata* and *Scyliorhinus canicula* have remained abundant and one, *Mustelus asterias,* has increased in abundance. It is argued that overexploitation and habitat destruction remain, as they have been for the last 300 years, the most serious threats to the health of North Sea inshore fish communities. There are no clear signs that climate change is causing species loss, although it may be influencing relative species abundance as species at the southern edge of their range such as the viviparous blenny, *Zoarces viviparous*, have declined in the southern British North Sea. Power station water temperature records do not show a warming trend, in some estuarine locations temperature has declined with reduced thermal pollution; the temperature record cannot explain the observed major changes in fish relative abundance observed since the 1970s.

1. Introduction

This paper uses data derived from power station cooling water intakes collected since the 1960s together with earlier historical accounts to examine spatial and temporal variation in species diversity, equitability and relative abundance within the inshore fish community along the North Sea coast of Britain from the English Channel to Scotland. These massive data sets, collected from cooling water intakes, offer a unique resource for the study of the shallow inshore fish community of the North Sea. Large cooling water intakes at base load power stations have the unique feature that they sample continuously from a fixed locality, at a standardised rate of flow under all weather conditions. The period from the 1960s to the present covers a period of great change in the North Sea including the collapse of major fisheries for example herring, recovery of once fishless polluted estuaries such as the tidal Thames and notable climate change from the extreme winters of the 1960s to mild conditions in the 1990s. Long-term power station data gives insight into the stability and powers of recovery and resilience of inshore fish communities. This study identifies the speed and nature of the changes in the inshore British North Sea fish community and examines the possible roles of (1) fishing, (2) habitat damage and recovery and (3) climate change and increased water temperature in particular.

E-mail address: peter@pisces-conservation.com.

http://dx.doi.org/10.1016/j.seares.2017.06.011
Received 24 March 2016; Received in revised form 21 June 2017; Accepted 23 June 2017

Please cite this article as: Henderson, P.A., Journal of Sea Research (2017), http://dx.doi.org/10.1016/j.seares.2017.06.011

2. Materials and methods

Commencing in the 1950s, there was a rapid construction of thermal power stations with once-through cooling water systems at estuarine and coastal sites along the North Sea coast of Britain. These entrained large numbers of fish and other marine species in the condenser cooling water flow which is in the range of 20 to 30 $m^3 s^{-1}$ for a 600 MW unit. Total flows can be considerable, for example, the large 2400 MW coal fired Longannet Power Station in the Firth of Forth required about 91 $m^3 s^{-1}$ of cooling water at full output. Once organisms have entered the intake they either pass through the cooling water circuit and return to the sea or, if large enough, they are retained by the 5–9.5 mm mesh fine screens. The screens are in continual motion so the impinged fish are lifted clear of the water and washed off into troughs which lead to trash baskets where they are collected for disposal or returned to the sea.

From the early 1960s biologists began to use power station filter screens as sampling devices. Of primary interest during the early studies was the recovery of estuarine waters from pollution. In the Thames Estuary, reports of fish being caught at West Thurrock in 1964 lead by 1967 to the collection of samples at 5 Thames Estuary stations, Fulham, Brunswick Wharf, Blackwall Point, Barking, and West Thurrock (Wheeler, 1969). In Scotland, the earliest studies were November 1961 to November 1962 at Kincardine Power Station (unpublished report by D.P. Sharman, some results subsequently published by Greenwood and Maitland, 2009). From the 1970s onwards biologists used power station sampling to study fish communities (Hardisty and Huggins, 1975; van den Broek, 1980; Davis and Dunn, 1982; Wharfe et al., 1984; Attrill and Power, 2004; Henderson, 2007; Greenwood, 2008). This resulted in 1989 in the first synoptic account of the inshore fish fauna of England and Wales based on power station sampling which concluded that 118 of the 122 fish species known to live inshore were recorded from the screens of only 12 coastal power stations (Henderson, 1989). Power station sampling offers a highly cost-effective and efficient way to sample the fish fauna and gave the clear advantage over traditional fishing methods that it could be undertaken throughout the year regardless of weather. Power station sampling has the weaknesses inherent in all sampling techniques, species vary in their vulnerability to capture. Power station samples show size selectivity at both the lower end, fish $<$ 25 mm long are often not retained, and at the upper size range, as very large species such as sharks may escape capture (they are still occasionally caught as demonstrated by the recent capture of a 2.5 m long blue shark, *Prionace glauca*, at Pembroke power station). Further, species that are immobile during the period of sampling will not be caught, which probably explains the observation by Henderson (1989) that the only group of inshore fish never recorded in power station samples were clingfishes (*Gobiesocidae*).

We can visualize the action of power station intakes as a marine analogue of a terrestrial pitfall trap. Although organisms are pulled into the orifice with the flow, fish and other swimming organisms typically have the power to escape even when close to the orifice. Their capture appears to be linked to their lack of perception of the danger prior to entering the system, upon entry they are in a dark disorientating space which offers them no clear signal as to the direction of escape. Any hesitation or movement in the direction of flow rapidly draws them away from entrance and their only hope of escape.

The fish sampling data from the cooling water filter screens at 10 coastal and estuarine power stations situated along the British North Sea east coast and one French locality were collated. The sampled power stations, dates of sampling and methodology are given in Table 1; summary information on the volumes of water pumped, intake configuration and environmental conditions are given in Table 2; their geographical positions together with other locations mentioned in the text are shown in Fig. 1.

The intakes are positioned in water of sufficient depth to give about 1 m of water above the intakes at extreme low water spring tide. Thus, the intakes are taking fish from waters typically $<$ 20 m deep.

The sampling method varied with the design of the power station, but the general principle was to collect the debris washed off the moving screens, sort it, identify to species and weigh (almost always wet weight) and measure the captured fish. The filter screens have a solid square mesh of 5 to 9.5 mm and experimental observation has shown that they will retain all flatfish of standard length (SL) $>$ 25 mm and round fish with a standard length greater than approximately 60 mm (Turnpenny, 1981). Smaller fish are retained with reduced efficiency and their rate of capture might not reflect their abundance in the environment. Gobies $<$ 30 mm SL are frequently retained as they catch on weed and other debris. Similarly, pipefish which can easily penetrate the mesh are typically caught in large numbers. Because fish presence and abundance is highly seasonal it was normal to sample regularly over the year. Details of the particular sampling regimes are described in the references listed in Table 1.

At some stations collections were only undertaken to create a species list or give estimates of relative abundance, these are listed in Table 1 as qualitative studies.

Power stations maintain detailed temperature records of cooling water temperature logged automatically from thermistors situated in the intakes prior to water passage through the condensers. Monthly mean power station cooling water intake temperature can be obtained from https://www.cefas.co.uk/cefas-data-hub/.

Sample rarefaction to estimate species richness from standardised sample sizes was undertaken using the Vegan R package (Oksanen et al., 2015). Multi-dimensional scaling (MDS) was used to ordinate the change in species assemblages through time using the CAP package (Pisces Conservation Ltd). The Bray-Curtis semi-quantitative similarity measure was used. Trend analysis of time series used the Trend R package (Pohlert, 2016). Concordance of ranked abundance was obtained using the kendall.global function in the R package Vegan.

3. Results

3.1. Changes in water temperature

One of the key variables determining the presence of fish in inshore North Sea waters is the temperature. Fig. 2 shows the change in the average monthly summer maximum and winter minimum temperature with latitude; while the winter minimum varies little with latitude, there is a marked decline in the summer maxima from around 18 to 20 °C in the Thames and East Anglian region to approximately 14 °C north of Spurn Head.

Long-term continuous average monthly temperature records for 5 power station cooling water intake systems along British North Sea Coast are presented in Fig. 3. The most southerly intake time series at Dungeness shows no long-term monotonic trend between 1968 and 2013 (Mann-Kendall test, tau = 0.043, p = 0.139). Kingsnorth in the Medway Estuary has a significant positive temperature trend (Mann-Kendall test, tau = 0.135, $p < 0.001$). A seasonal Mann-Kendall test showed that this temperature increase was predominately concentrated on the months of March to June. Within the main Thames Estuary, power station data show evidence for cooling since the 1960s. At West Thurrock, there is a non-significant decline in temperature between 1964 and 1993 (Mann-Kendall test, tau = -0.065, p = 0.071) and Pettitt's test for change-point-detection indicated a single significant change around November 1976 which is marked in Fig. 3. This is probably linked to the reduction in thermal discharges from the late 1970s onwards as power stations closed (see https://en.wikipedia.org/wiki/List_of_power_stations_in_England for closure dates). At Sizewell, between 1967 and 1994 there is no significant temperature trend (Mann-Kendall test, tau = 0.059, p = 0.11). The commissioning of Sizewell B with grid synchronisation in February 1995 is linked to a notable increase in winter minimum intake water temperature until the closure of Sizewell A on 31 December 2006 (see Fig. 3); subsequently,