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Long-term changes in fish-assemblage composition from cooling-water intake screens in the Forth Estuary, Scotland, UK

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*Changes in the composition of fish assemblages collected on two closely located power stations' intake screens over nearly four decades in the middle Forth Estuary, Scotland were examined. There were no significant differences in fish assemblages from Kincardine in 1979 and 1961–1962 or between Longannet in 1979 and 1994. Otherwise, the 1979 assemblages from both locations were significantly different from the 1999 and 2000 Longannet assemblages and from each other. The long-term differences may have reflected local environmental changes, notably a considerable increase in smelt (*Osmerus eperlanus*) abundance due to improved water quality, and declines in some species (eelpout (*Zoarces viviparous*) and cod (*Gadus morhua*)) because of regional environmental influences such as increases in water temperature and overfishing.*

Keywords: fish assemblage, long-term change, Forth Estuary, power station, intake screens

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Estuaries typically support high densities of resident and transient fish (Haedrich, 1983). Estuarine fish populations are often monitored to assess environmental quality (Elliott *et al.*, 1988) and to examine trends in abundance of indicator species (e.g. Greenwood *et al.*, 2002). Long-term, continuous monitoring is preferred, but sampling programmes are costly and ensuring consistency over time is challenging. Useful information on major changes in estuarine fish assemblages can be obtained by comparing contemporary and historic data, even if individual collection periods are short (Pombo *et al.*, 2002; O'Connell *et al.*, 2004). We used unpublished data collected at the cooling-water intake screens of two nearby power stations to examine changes in fish-assemblage composition over nearly four decades in the Forth Estuary, Scotland. This means of sampling small-bodied estuarine fish is efficient; collects benthic, demersal, and pelagic species (Henderson, 1989; Maes *et al.*, 2001); and has been used to provide samples for autecological studies (e.g. Turnpenny *et al.*, 1981; Maitland *et al.*, 1984; Claridge *et al.*, 1985; Maes & Ollevier, 2002).

The earliest data included in this study were recorded from November 1961 to November 1962 at the intake screens of Kincardine Power Station (56°4′11″N 3°43′38″W) and reported by D.P. Sharman (Department of Agriculture and Fisheries for Scotland, Marine Laboratory, Aberdeen, unpublished report). Sub-samples of weekly 24-h screen catches were identified and estimates of total monthly catches were made for thirteen named taxa (Table 1) and all taxa together. We calculated the abundance of unnamed ('other') taxa by subtracting the sum of the named taxa from the total abundance; this occasionally gave negative values and we assumed that catches of other taxa were negligible in these months (which we have also observed from our own data). Further collections at Kincardine were made twice per month from January to December 1979 by one of us (P.S.M.). On each occasion, collections of 20-min duration were made. This procedure was also followed at Longannet Power Station (56°2′45″N 3°41′0″W; about 4 km downstream of Kincardine) in 1979 and again in 1994 (both by P.S.M.). Data were collected at Longannet from January 1999 to December 2000 (by M.F.D.G.) and generally consisted of eight 30-min samples per month. Although sampling in 1999–2000 was both diurnal and nocturnal, there was little difference in assemblages between day and night, so all data were included. Kincardine began operating at part-load in 1958 (120 MW), operated at 360 MW during the Sharman study and at 760 MW from the end of 1963 until the cessation of operations in 1986. Longannet was commissioned in 1972, fully operational by 1973, and is scheduled to operate beyond 2020. Salinity at both Kincardine and Longannet tends to be polyhaline (Elliott *et al.*, 1990; Greenwood, 2002). One other power station, Cockenzie, operates in the general area but is actually outside the estuary in the fully marine conditions of the Firth of Forth so that comparisons were not deemed worthy of inclusion in this study.

To maintain consistency with Sharman's early data, we grouped our data into the same taxa (Table 1) and summed all collections by month. It was not possible to use abundance data directly because water volumes filtered during each sampling session were not always recorded. Instead, we calculated each taxon's percentage contribution to total monthly abundance. Each month was assigned to quarters (January–March, April–June, etc.) and Bray–Curtis similarity

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Table 1. Mean monthly percentage contribution of fish to total assemblages collected at the cooling-water intake screens of Kincardine and Longannet power stations.

	Sprat, *Sprattus sprattus* (L.)	Herring, *Clupea harengus* (L.)	Whiting, *Merlangius merlangus* (L.)	Cod, *Gadus morhua* (L.)	Flounder, *Platichthys flesus* (L.)	Plaice, *Pleuronectes platessa* (L.)	Gobies (principally *Pomatoschistus* spp.)	Pipefish (principally *Syngnathus* spp.)	Lamprey (principally *Lampetra fluviatilis* (L.))	Saithe, *Pollachius virens* (L.)	Sandeel (principally *Ammodytes* spp.)	Eel, *Anguilla anguilla* (L.)	Eelpout, *Zoarces viviparus* (L.)	Others
Kincardine 1962/1961*	28.32	32.24	5.79	17.23	1.39	3.35	4.95	0.58	0.70	0.04	3.26	1.01	0.48	0.66
Kincardine 1979**	36.15	29.66	11.63	1.38	1.91	0.32	4.50	5.46	1.57	0.12	1.16	0.79	2.96	2.40
Longannet 1979**	25.85	26.03	32.50	1.52	4.39	0.33	3.55	0.34	1.05	0.44	0.15	0.33	0.73	2.79
Longannet 1994**	40.72	37.37	11.48	0.33	2.14	1.52	1.16	0.38	0.73	0.00	0.00	0.04	0.00	4.13
Longannet 1999**	39.59	26.90	10.38	1.02	4.16	4.05	5.96	3.01	0.38	0.24	0.02	0.17	0.08	4.04
Longannet 2000**	41.10	36.84	4.27	0.49	1.53	4.08	4.13	1.92	0.18	0.15	0.09	0.08	0.04	5.11

*, November 1961–November 1962; **, January–December.

between all pairs of samples (N = 73 total monthly samples) was calculated on square-root-transformed data (Bray & Curtis, 1957). We tested the null hypothesis of no significant difference in assemblage composition between the six station-periods (Kincardine 1961–1962, Kincardine 1979, Longannet 1979, Longannet 1994, Longannet 1999, and Longannet 2000), allowing for differences between seasons, using a two-way analysis of similarities (ANOSIM; Clarke, 1993) with station-period and season as factors. The pairwise differences in ANOSIM R were plotted using non-metric multidimensional scaling (nMDS; Clarke, 1993). Taxa responsible for differences between locations and periods were determined with a two-way similarity percentages analysis (SIMPER; Clarke & Gorley, 2006), again with station-period and season as factors.

Our results indicated significant differences in intake-screen fish-assemblage composition (ANOSIM global R = 0.461, P = 0.001) between station-periods (Figure 1). Multiple comparison tests revealed that significant differences ($P < 0.0033$, the Bonferroni-corrected significance value) were between Longannet 1979 and all other station-periods (except Longannet 1994) and between Kincardine 1979 and all other station-periods (except Kincardine 1961/1962). There were no significant differences in screen-catch composition between any of the other years and the difference between Longannet 1999 and Longannet 2000 was particularly small (R = 0.127, P = 0.211). The SIMPER analyses revealed that the screen-catch composition in Longannet 1979 was generally different from the other station-periods because of the relatively high contribution by whiting and relatively low contributions by sprat, gobies, plaice, and pipefish (Table 1). The screen-catch composition from Kincardine 1979 mostly differed from the other station-periods because of the relatively high contributions by pipefish, eelpout, lamprey, and sandeels; and because of the relatively low contributions by others, flounder, and plaice.

The patterns that we observed may reflect long-term local and broad-scale influences on the Forth Estuary fish assemblage. Smelt (*Osmerus eperlanus* (L.)), were present in the Forth Estuary in the early 1960s (as reflected in Sharman's species list and records of fishery landings; Howard *et al.*, 1987) but were extirpated by overfishing, siltation, and low dissolved oxygen (none were collected in 1979; P.S.M., unpublished data). Improvements in water quality attributable to commissioning of secondary sewage treatment facilities (Balls *et al.*, 1996) led to the species first being detected in upper Forth Estuary trawling in 1989 (Costello *et al.*, 2002). A similar resurgence in the species was noted in the Medway Estuary following enhancement of water quality (Wharfe *et al.*, 1984). The species was the sixth-ranked in abundance at Longannet in 1999–2000 and the principal contributor to the 'others' category in this study, reflecting a major difference in assemblages between 1979 and the 1990s. In contrast, chronic warming of the Forth Estuary due to climate change has apparently led to the decline of eelpout, a species close to the southern edge of its geographic range, which was again reflected in power-station intake catches. Greenwood *et al.* (2002) calculated that the species could be extinct in the Forth Estuary by about 2020. Climate change has induced northward shifts in a range of a number of North Sea fish (Perry *et al.*, 2005) and has led to notable changes in fish-assemblage composition in the Severn Estuary, as shown from intake-screen data at Hinkley Point B

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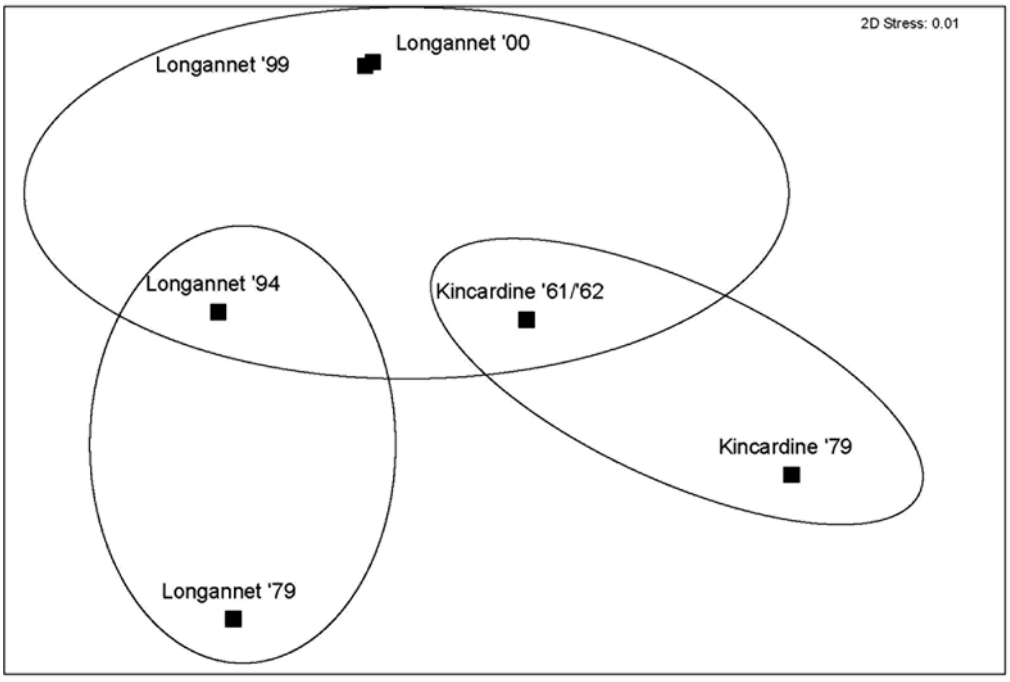


Fig. 1. Differences in fish-assemblage composition from the cooling-water-intake screens of Kincardine and Longannet power stations, with sampling years indicated. Distances on the plot represent the magnitudes of differences in fish assemblages from analysis of similarities and ellipses enclose station-periods that were not significantly different.

Power Station (Henderson, 2007). The early 1960s marked the onset of the 'gadoid outburst', a period lasting until the mid-1980s during which gadoids, in particular cod, were abundant (Beaugrand *et al.*, 2003). The effects of overfishing and increasing water temperature on larval cod's planktonic prey has led to reduced survival (Beaugrand *et al.*, 2003). Data from this study indicated a marked decrease in the contribution of cod to intake screen catches at Kincardine from 1961 to 1979 (Table 1). There was a significant decline in whiting abundance in the Forth Estuary from 1982 to 2001 (Greenwood *et al.*, 2002) and this was reflected in the decrease in percentage contribution at Longannet from 1979 to 1994 and 1999/2000 (Table 1). In conclusion, the multi-decadal snapshots of fish assemblage structure of the Forth Estuary provide an interesting view of biological responses to changing environmental conditions. The assemblages from the late 1970s were most different from contemporary assemblages.

REFERENCES

Balls P.W., Brockie N., Dobson J. and Johnston W. (1996) Dissolved oxygen and nitrification in the Upper Forth Estuary during summer (1982–92): patterns and trends. *Estuarine, Coastal and Shelf Science* 42, 117–134.

Beaugrand G., Brander K.M., Lindley J.A., Souissi S. and Reid P.C. (2003) Plankton effect on cod recruitment in the North Sea. *Nature* 426, 661–664.

Bray J.R. and Curtis J.T. (1957) An ordination of upland forest communities of Southern Wisconsin. *Ecological Monographs* 27, 325–349.

Claridge P.N., Hardisty M.W., Potter I.C. and Williams C.V. (1985) Abundance, life history and ligulosis in the gobies (Teleostei) of the inner Severn Estuary. *Journal of the Marine Biological Association of the United Kingdom* 65, 951–968.

Clarke K.R. (1993) Non-parametric multivariate analyses of changes in community structure. *Australian Journal of Ecology* 18, 117–143.

Clarke K.R. and Gorley R.N. (2006) *PRIMER v6: user manual/tutorial*. Plymouth, UK: PRIMER-E.

Costello M., Elliott M. and Thiel R. (2002) Endangered and rare species. In Elliott M. and Hemingway K.L. (eds) *Fishes in estuaries*. Malden, USA: Blackwell Publishers, pp. 217–265.

Elliott M., Griffiths A.H. and Taylor C.J.L. (1988) The role of fish studies in estuarine pollution assessment. *Journal of Fish Biology* 33A, 51–61.

Elliott M., O'Reilly M.G. and Taylor C.J.L. (1990) The Forth estuary: a nursery and overwintering area for North Sea fishes. *Hydrobiologia* 195, 89–103.

Greenwood M.F.D. (2002) *The fish populations of the lower Forth Estuary, including the environmental impact of cooling water extraction*. PhD thesis, University of Stirling, Stirling, UK.

Greenwood M.F.D., Hill A.S. and McLusky D.S. (2002) Trends in abundance of benthic and demersal fish populations of the lower Forth Estuary, East Scotland, from 1982–2001. *Journal of Fish Biology* 61 Suppl. A, 90–104.

Haedrich R.L. (1983) Estuarine fishes. In Ketchum B. (ed.) *Ecosystems of the world 26. Estuaries and enclosed seas*. Amsterdam: Elsevier, pp. 183–207.

Henderson P.A. (1989) On the structure of the inshore fish community of England and Wales. *Journal of the Marine Biological Association of the United Kingdom* 69, 145–163.

Henderson P.A. (2007) Discrete and continuous change in the fish community of the Bristol Channel in response to climate change. *Journal of the Marine Biological Association of the United Kingdom* 87, 1–10.

Howard F.G., McKay D.W. and Newton A.W. (1987) Fisheries of the Forth, Scotland. *Proceedings of the Royal Society of Edinburgh* B 93, 479–494.

https://doi.org/10.1017/S1755267208000080 Published online by Cambridge University Press

Maes J. and Ollevier F. (2002) Size structure and feeding dynamics in estuarine clupeoid fish schools: field evidence for the school trap hypothesis. *Aquatic Living Resources* 15, 211–216.

Maes J., Ollevier F., Pas J., Taillieu A. and Van Damme P.A. (2001) Sampling of fish and crustaceans at the cooling water intake of an estuarine power plant: a comparison with stow net fishery. *Archive of Fishery and Marine Research/Archiv fur Fischerei und Meeresforschung* 49, 27–36.

Maitland P.S., Morris K.H., East K., Van der Wal B. and Potter I.C. (1984) The estuarine biology of the river lamprey, *Lampetra fluviatilis*, in the Firth of Forth, with particular reference to size composition and feeding. *Journal of Zoology* 203, 211–225.

O'Connell M.T., Cashner R.C. and Schieble C.S. (2004) Fish assemblage stability over fifty years in the Lake Pontchartrain Estuary; comparisons among habitats using canonical correspondence analysis. *Estuaries* 27, 807–817.

Perry A.L., Low P.J., Ellis J.R. and Reynolds J.D. (2005) Climate change and distribution shifts in marine fishes. *Science* 308, 1912–1915.

Pombo L., Elliott M. and Rebelo J.E. (2002) Changes in the fish fauna of the Ria de Aveiro estuarine lagoon (Portugal) during the twentieth century. *Journal of Fish Biology* 61, 167–181.

Turnpenny A.W.H., Bamber R.N. and Henderson P.A. (1981) Biology of the sand-smelt (*Atherina presbyter* Valenciennes) around Fawley power station. *Journal of Fish Biology* 18, 417–427.

and

Wharfe J.R., Wilson S.R. and Dines R.A. (1984) Observations on the fish populations of an east coast estuary. *Marine Pollution Bulletin* 15, 133–136.

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