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# Trawls and cooling-water intakes as estuarine fish sampling tools: Comparisons of catch composition, trends in relative abundance, and length selectivity

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**Abstract**

Fish populations in estuaries are often monitored with traditional sampling gears such as trawls. Trawling is relatively expensive and may be hindered by environmental conditions such as tides and substrates. Power station cooling-water intake screens have been effectively used as estuarine fish sampling devices for many years, but very few quantitative comparisons of intake fish-catch characteristics with samples from other collection methods have been made. Fish collected at the cooling-water intake of a large power station in the lower Forth estuary, UK, were more similar in assemblage composition to fish caught by nearby pelagic trawling than to fish caught by Agassiz (demersal) trawling, mostly because the intake and pelagic-trawl catches were largely composed of clupeids (*Sprattus sprattus* and *Clupea harengus*). The intake catch was typified by pelagic, demersal, and benthic species, however, and was less variable than the catches made by the two trawls. Monthly trends in relative abundance correlated reasonably well between the intake and trawl samples. Fish collected at the intake tended to be significantly smaller than those collected by trawling, which was probably attributable to the intake's smaller mesh size. The study highlighted the utility of a cooling-water intake as an efficient, low-cost fish sampling device, which should be considered as an alternative to trawling as the cost of the latter increases into the future.
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## 1. Introduction

Fish populations in estuaries may be sampled for a number of reasons, including (a) to assess distribution, (b) to examine changes over time, (c) to assess community and population structure, (d) to estimate population/community production, (e) to estimate optimum yields from a harvested population, and (f) to assess the relationship between fish abundance and environmental factors (natural or anthropogenic) (Potts and Reay, 1987; Hemingway and Elliott, 2002). 'Traditional' fish-sampling gears often include active capture methods, particularly trawls (e.g., Elliott et al., 1990; Pomfret et al., 1991; Fraser, 1997). Trawling is relatively expensive, however, and may be hindered by adverse environmental conditions including poor weather, unsuitable substrates, and strong currents (Henderson and Seaby, 1994).

Alternative means of sampling include passive gears such as stow nets, gill nets, and the collection of fish impinged on the cooling-water-intake screens of thermal power stations (Maes et al., 2001). The ease of sampling fish and other organisms at cooling-water intakes has allowed extensive long-term databases to be assembled, which have been used to assess trends in relative abundance of exploited species (e.g., Barnthouse, 2000; Liao et al., 2004), to examine effects of climate change (e.g., Attrill and Power, 2002; Genner et al., 2004), and

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to address ecological theories (e.g., Philippart et al., 1998; Magurran and Henderson, 2003), for example. Nearly all of the known inshore fish species of England and Wales have been collected by cooling-water intakes (Henderson, 1989), demonstrating the efficiency of the method.

There have been surprisingly few published attempts to quantitatively assess fish sampling by cooling-water intakes in comparison with other sampling methods. (Turnpenny and Taylor (2000) cite some of the grey literature on the subject.) Different sampling techniques tend to be selective in some way and so catches may not be representative of the population(s) in the area being investigated (Gee, 1983). Aside from species identity and relative abundance of individuals, length data are perhaps the most commonly collected information from fish samples (Potts and Reay, 1987), for they are useful in determining characteristics such as age and growth rates. Many studies have qualitatively noted that fish collected by cooling-water intakes differ in size from those collected by other methods; intake-caught fish are often smaller due to lower capture velocity and finer mesh (e.g., Langford et al., 1977; van den Broek, 1979; Thomas, 1998). Henderson and Holmes (1991) described the cooling-water intake catch of fish at Hinkley Point power station (UK) as being 'the same species in the same relative proportions' as fixed-net fishermen in adjacent estuarine waters, without formal assessment of the similarity. Love et al. (1998) observed declines in the rate of impingement of three southern California rockfishes to be similar to the decline in numbers observed by divers.

Of the few quantitative comparisons between cooling-water intakes and other sampling methods, Margraf et al. (1985) described significantly smaller sizes of fish and shrimp collected by a 3-m otter trawl (5-mm cod-end liner) compared with impinged fish and shrimp from the intake screens (9.5-mm square mesh) at the P.H. Robinson generating station, Galveston Bay (Texas). Brooks et al. (2002) found that the decline in relative abundance of 17 fish species at various cooling-water intakes in Southern California was significantly correlated with declines in numbers of the same species observed during visual surveys. Turnpenny (1983) observed a weak but statistically significant positive correlation between catch of fish at the cooling-water intake of Fawley Power Station (England) and gill-net catches in the intake canal (data from both methods were collected on one day per week for a year). Perhaps the most comprehensive published account comparing cooling-water intakes with traditional gears is that of Maes et al. (2001). They found that the cooling-water intake screens of the Doel nuclear power plant captured 33 fish species compared with 32 species from adjacent stow nets; 26 species were common to both methods. Abundance of fish per unit volume of cooling water sampled was generally significantly higher than from the stow nets (Maes et al., 2001). Finally, fishes collected on the screens of the cooling-water intake (4-mm square mesh) tended to be significantly smaller than those collected by stow net (12-mm cod-end mesh): of 22 species tested, lengths of 10 were smaller from impingement samples and only one was smaller from stow-net collections (Maes et al., 2001).

The present study provides quantitative comparisons of fish sampling at a cooling-water intake (Longannet Power Station, Forth estuary, UK) with 'traditional' gears (Agassiz and pelagic trawls). This was important because it was desirable to investigate alternative sampling methods given the scaling back of the long-term trawling programme in the Forth estuary (see Elliott et al., 1990; Greenwood et al., 2002). The study's first objective was to compare the structure of the fish assemblages collected by each gear; the null hypothesis of no significant difference in the composition of fish samples between the three gears was tested. The second objective was to determine whether the cooling-water intake gave similar changes in relative abundance over time as trawling; the null hypothesis of no significant temporal correlation in relative abundance between the gears was tested. The final objective was to compare lengths of fish collected with the intake to trawl-collected fish lengths; the null hypothesis of no significant difference in length-frequency distribution or median length between the gears was tested.

## 2. Materials and methods

### 2.1. Study area

The Forth Estuary stretches eastwards from the upstream limit of tidal intrusion in Stirling downstream along some 48 km to the seaward limit just east of the Forth Road Bridge (Wallis and Brockie, 1997). Freshwater inputs to the estuary are largely from the rivers Forth and Teith and the Allan Water, with the flow rate varying with season from a mean of 24 $m^3\ s^{-1}$ from June to August, increasing to 93 $m^3\ s^{-1}$ between December and February (Wallis and Brockie, 1997). The tidal cycle is semi-diurnal, with a mean spring tidal range of 5.0 m and a mean neap range of 2.5 m, and the tidal excursion varies between 8 and 16 km (Webb and Metcalfe, 1987). For the purposes of the European Water Framework directive, the lower Forth Estuary is classified as a Type 2 Transitional Water (TW2), i.e., partly mixed/stratified; mesohaline or polyhaline; strongly mesotidal; sheltered; intertidal/shallow subtidal; sand and mud substratum. At the Longannet trawl fixed station (between 56° 02.35′N 03°40.41′W and 56° 02.35′N 03°39.42′W), which is the area of primary interest to this study, water depth is 5.5–6.5 m, salinity varies from 0 to 34, and the substratum is medium sand and mud (Pomfret et al., 1991; unpublished data).

### 2.2. Sampling methods

Data for the present study were selected from power station and trawl sampling programmes undertaken in the Forth estuary in 1999–2000 (Table 1). Longannet Power Station is a coal-fired thermal electricity generating station of the direct-cooled or 'once-through' type with capacity of 2400 MW (4 × 600 MW units). There are four pumps each capable of withdrawing approximately 22.75 $m^3\ s^{-1}$ of cooling water through an intake structure 163 m from the shoreline. The intake consists of twelve vertical apertures, each

Table 1
Dates and tidal state (LW, low water; HW, high water) of sampling events. Trawl events consisted of one Agassiz and one pelagic trawl (each 20 min, 0.8 km), and cooling-water-intake events typically consisted of a 30-min sample

| | Trawls | Cooling-water intake |
|---|---|---|
| January 1999 | 25 Jan. (LW)[a,b,c], 26 Jan. (HW)[a,b,c] | 19 Jan. (LW, HW)[a,b] |
| April/May 1999 | 7 Apr. (LW)[a,b], 14 May (LW)[a] | 8 Apr. (LW)[a,b], 14 May (LW)[a] |
| July 1999 | 13 Jul. (LW)[a,b], 23 Jul. (HW)[a] | 13 Jul. (LW)[a,b], 21 Jul. (HW)[a] |
| September 1999 | 8 Sep. (HW)[a], 13 Sep. (LW)[a,b] | 20 Sep. (LW, HW)[b], 27 Sep. (LW, HW)[a] |
| December 1999 | 14 Dec. (HW)[a,b], 16 Dec. (LW)[a,b] | 16 Dec. (HW)[a,b], 17 Dec. (LW)[a,b] |
| January 2000 | 12 Jan. (LW)[a], 17 Jan. (HW)[a,b] | 7 Jan. (HW)[a], 10 Jan. (LW)[a,b] |
| April 2000 | 7 Apr. (LW)[a,b], 12 Apr. (HW)[a] | 6 Apr. (LW[a,b], HW[a]) |
| June/July 2000 | 27 Jun. (HW)[a], 5 Jul. (LW)[a,d] | 5 Jun. (LW, HW)[a] |
| September 2000 | 11 Sep. (HW)[a], 15 Sep. (LW)[a,b] | 21 Sep. (LW[a,b], HW[a]) |
| December 2000 | 8 Dec. (HW)[a], 18 Dec. (LW)[a,b] | 5 Dec. (HW)[a], 14 Dec. (LW)[a,b] |

[a] Sample used for assemblage and temporal correlation analyses.
[b] Sample used for fish-length comparison.
[c] Pelagic-trawl sample excluded because of poor gear deployment.
[d] Pelagic-trawl sample excluded because net was inundated with jellyfish and torn (Agassiz and intake data were excluded from assemblage comparisons in this month).

$5.18 \times 3.05$ m, with coarse bars 7.6 cm wide set at 38.1-cm intervals to prevent large debris such as logs from entering the CW system. The total intake surface area is approximately 157.75 m$^2$. The water from each culvert enters two screen wells horizontally, and is sucked vertically downwards through four rotating drum screens of diameter $16.46$ m $\times$ 3.35 m width and 8-mm square mesh size. Debris is collected on screen ledges, and is removed at the top of the screens' rotation by wash-water jets. The removed material travels down channels and into two trash-collection baskets, one each for screens 1 and 2 (the 'west' screens) and screens 3 and 4 ('east' screens). Each sampling session consisted of collecting fish that had been washed off the fine mesh drum screens following impingement, by using a 5-mm-mesh handnet placed over the point of discharge into the trash basket. The time sampled was noted (usually 30 min), and it was possible to standardise quantity of fish obtained per unit volume given knowledge of pump capacity, number of pumps operational at the time of sampling, and duration of sampling. In general, eight sampling sessions per month were completed from January 1999 to December 2000; these included all factorial combinations of tidal phase (spring/neap), tide height (high/low water), and diurnal period (daylight/darkness). Only data collected during daylight hours were used in this study in order to match sampling conditions during trawling.

Trawl data were collected at the Longannet site of the Scottish Environment Protection Agency's lower Forth estuary sampling programme (Elliott et al., 1990; Greenwood et al., 2002), approximately 0.5–1 km SE of the cooling-water intake. These data were collected in five months of the year (January, April/May, June/July, September and December), each month including one pelagic and one Agassiz (bottom) trawl taken at LW and HW (Table 1). Trawling was generally undertaken during spring tides (tidal range >3.5 m; Lindsay et al., 1996). Exceptions to the sampling regime for the pelagic gear included January 1999 (HW and LW) due to gear failure, and July 2000, when the net tore due to jellyfish inundation. Trawls taken in April/May 1999 were all at LW. Each trawl consisted of an approx. 0.8-km haul at 1–1.5 m s$^{-1}$. The pelagic trawl was a modified commercial sprat net of opening 7.1 m wide by 2.5 m high, and internal stretched cod-end mesh size of 12 mm, while the Agassiz trawl was of 2-m width and 15-mm stretched-mesh cod-end. Fish sampled by trawling and at the cooling-water intake were identified to species, counted, and measured for total length to the nearest mm.

### 2.3. Data analysis

To test the null hypothesis of no difference in sample composition between sampling methods, Analysis of similarities (ANOSIM; Clarke, 1993) was conducted on 51 pelagic-trawl, Agassiz-trawl, and cooling-water-intake samples (i.e., 17 samples per gear, matched by month and tidal condition; Table 1). Species abundance data for each sample were standardised to percentages of the total catch of all species in that sample, in order to allow comparisons between the inherently different volumes and areas sampled by each gear, and Bray–Curtis similarity % was calculated for all pairs of samples (Bray and Curtis, 1957). ANOSIM $R$ values range from 0 (completely similar) to 1 (completely different). Non-metric multidimensional scaling (MDS; Clarke, 1993) plots allowed the differences in catch composition to be visualized in two dimensions. Similarity percentages (SIMPER; Clarke, 1993) analysis determined the species that typified each gear's catch composition and which species discriminated the catches from the different gears, based on >90% cumulative contribution to total similarity or dissimilarity.

To test the null hypothesis of no significant correlation in trends in relative abundance between sampling methods over the study period, correlation analyses were conducted for several common species. Comparisons of pelagic-trawl catches with cooling-water-intake catches were made for sprat (*Sprattus sprattus*) and herring (*Clupea harengus*), and comparisons of Agassiz-trawl catches with cooling-water-intake catches were made for whiting (*Merlangius merlangus*), cod (*Gadus morhua*), flounder (*Pleuronectes flesus*), plaice (*Pleuronectes* *platessa*), and pogge (*Agonus cataphractus*). Data for each month were sums of all samples collected in that month and for intake data were standardized to number of fish per $10^4$ $m^3$ of cooling water sampled. If data were normally distributed (after natural-logarithm-transformation, if necessary), then Pearson correlation analysis was used, otherwise Spearman's rank correlation analysis was used.

To test the null hypothesis of no significant difference in fish total length between sampling methods, it was necessary to use non-parametric statistics to overcome the non-normality of the data. Mann–Whitney *U*-tests were used to test for differences in median fish length between sampling methods, and Kolmogorov–Smirnov two-sample tests were used to test for differences in length–frequency distribution between sampling methods. The analyses were limited to common species for which at least ten individuals had been collected by each sampling method, within 1 week of each other (to lessen biases caused by growth, for example). Comparisons of pelagic-trawl catches with cooling-water-intake catches were made for sprat, herring, and smelt (*Osmerus eperlanus*), and comparisons of Agassiz-trawl catches with cooling-water-intake catches were made for flounder and pogge. Data from each month were tested separately.

## 3. Results

### 3.1. Fish catch composition

The fish catch composition was significantly different between the three sampling methods (ANOSIM $R = 0.616$, $P = 0.001$), so the null hypothesis of no difference between sampling methods was rejected. Pairwise comparisons revealed that the greatest differences in catch composition were between the Agassiz trawl and the other methods (Agassiz-pelagic comparison: ANOSIM $R = 0.920$, $P = 0.001$; Agassiz-intake comparison: ANOSIM $R = 0.879$, $P = 0.001$). The catch compositions of the pelagic trawl and cooling-water intake were quite similar (ANOSIM $R = 0.229$, $P = 0.001$). These results were apparent from the MDS plot (Fig. 1), which also revealed that, although catch composition was very similar between pelagic trawl and cooling-water intake, the cooling-water-intake samples were intermediate in composition to the pelagic-trawl and Agassiz-trawl samples. The greater within-gear variability in catch composition of the trawl samples compared to the cooling-water-intake samples was also apparent from the MDS plot.

Species typifying the Agassiz trawl catches were pogge, flounder, plaice and whiting; species typifying the pelagic trawl catches were sprat, herring, and whiting; and species typifying the cooling-water intake catches were sprat, herring, whiting, plaice, gobies (*Pomatoschistus* spp.), flounder, and smelt (Fig. 2). Species discriminating the Agassiz trawl from the pelagic trawl included the above-named typifying species, as well as sea snail (*Liparis* spp.) and fatherlasher (*Myoxocephalus scorpius*), both of which made up a greater proportion of the catch in the Agassiz trawl, and gobies, which made up a greater proportion of the catch in the pelagic trawl (Fig. 2). The typifying species of the Agassiz trawl and cooling-water intake also discriminated the catch composition of these two sampling methods, as did the relatively high abundance of sea snail and cod in Agassiz trawl catches and the relatively high abundance of pipefishes (*Syngnathus* spp.) in the cooling-water-intake catches. In addition to the species typifying the pelagic trawl and cooling-water-intake catches, the catch composition differed between the two methods because the cooling-water intake had a greater proportion of pipefishes and cod, and the pelagic trawl had a slightly higher proportion of river lamprey (*Lampetra fluviatilis*) (Fig. 2).

To investigate how much influence the very abundant clupeids (sprat and herring) had on the results, the ANOSIM analyses were repeated with clupeids excluded. The difference in catch composition between the Agassiz trawl and the other gears decreased (Agassiz-pelagic comparison: ANOSIM $R = 0.628$, $P = 0.001$; Agassiz-intake comparison: ANOSIM $R = 0.715$, $P = 0.001$) and the difference between the pelagic trawl and cooling-water intake increased (ANOSIM $R = 0.308$, $P = 0.001$).

### 3.2. Trends in relative abundance

The null hypothesis of no correlation in relative abundance over the study period between fish caught in trawls and fish collected at the cooling-water intake was accepted for four of seven species that were analysed (herring, cod, flounder, and pogge) and rejected for the remaining three species (sprat, whiting, and plaice) (Fig. 3). Some correlations that were not statistically significant appeared to nonetheless correlate reasonably well when examining the plots in relative abundance, e.g., herring (Fig. 3b) and flounder (Fig. 3e); in the case of herring, the relatively low power of the non-parametric test may have explained the lack of statistical significance.

### 3.3. Fish total lengths

Nearly two-thirds of tests (19 of 30) gave rejection of the null hypothesis that there was no difference in median length

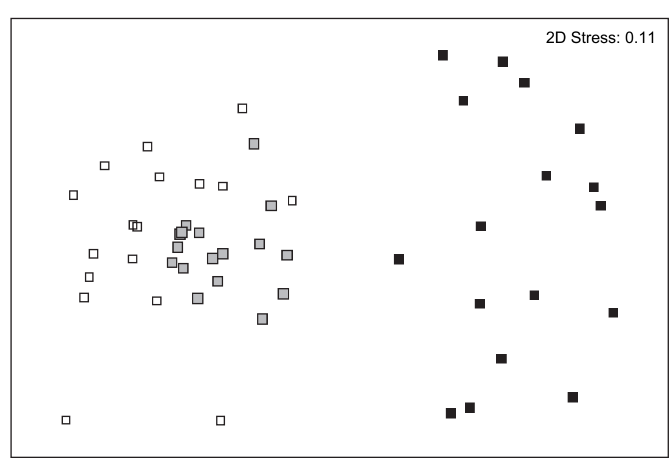


Fig. 1. Non-metric multidimensional scaling ordination plot of Bray–Curtis similarity in fish catch composition from Agassiz trawl (■), pelagic trawl (□), and cooling-water-intake (▨) samples.

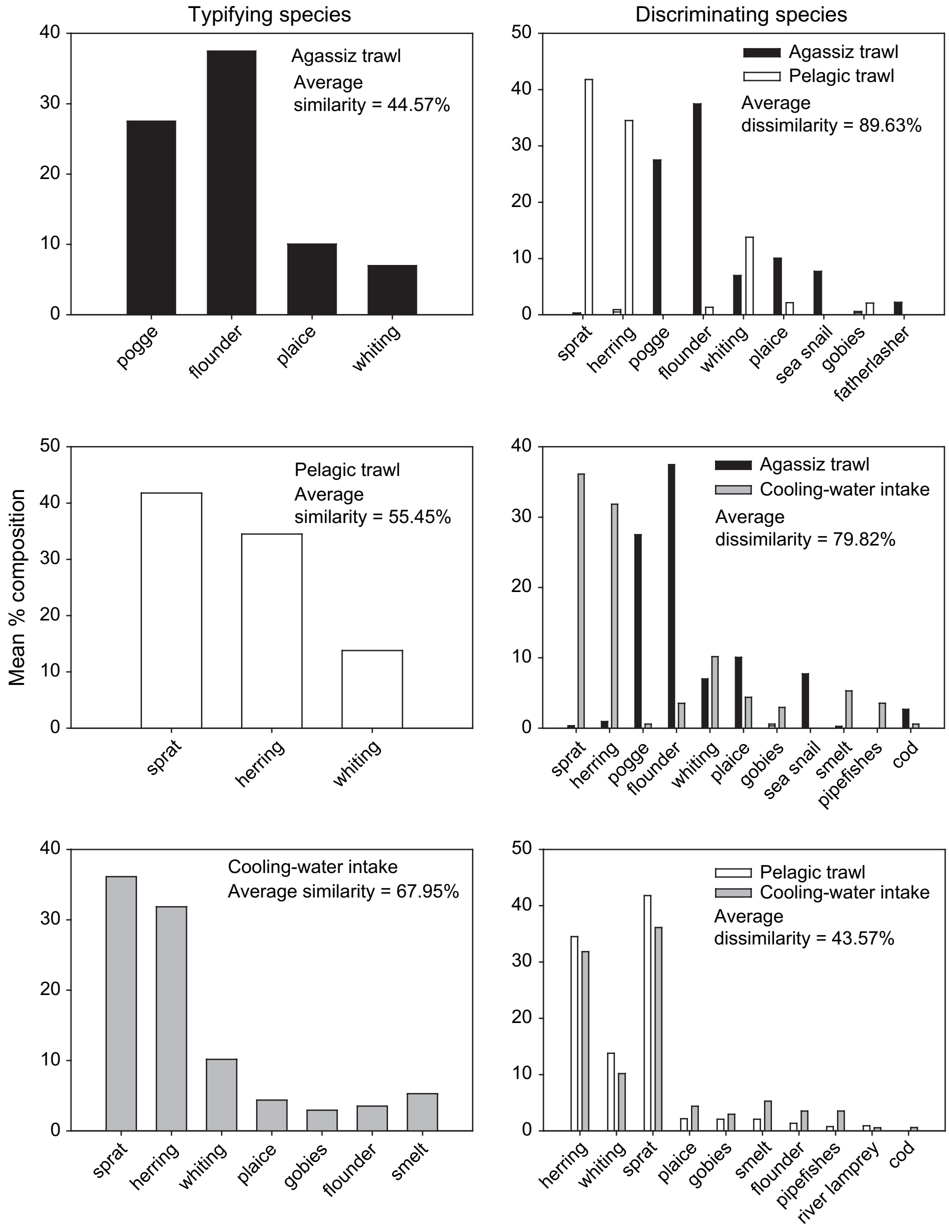


Fig. 2. Species typifying and discriminating between the different sampling methods, as determined by similarity percentages analysis. Species are ranked from left to right in order of decreasing contribution to average total similarity or dissimilarity, with only the species contributing to a cumulative total similarity or dissimilarity of >90%. Average similarity refers to average Bray–Curtis similarity between samples from the same gear, and average dissimilarity refers to average Bray–Curtis dissimilarity between samples from two different gears.

or length-frequency distribution between fish caught in the trawls and fish collected at the cooling-water intake (Figs. 4–6). Sprat captured with the pelagic trawl were significantly smaller than those collected at the cooling-water intake (in four of six comparisons; Fig. 4). In contrast, herring (five of ten comparisons), flounder, and pogge captured with Agassiz or pelagic trawls were significantly larger than those collected at the cooling-water intake (Figs. 5, 6).

## 4. Discussion

The present study confirmed the utility of cooling-water intakes as estuarine fish sampling tools. It is possibly only the second published quantitative comparison of cooling-water-intake samples with trawl samples, after Margraf et al. (1985). The fish assemblage collected at the cooling-water intake was much closer in composition to pelagic-trawl samples than to Agassiz-trawl samples. This was largely because of the dominance of sprat, herring, and, to a lesser extent, whiting, in the intake and pelagic-trawl samples. It was notable, however, that the catch composition of all three gears was significantly different and that the catch from the intake was intermediate in structure to the two trawls, albeit skewed toward greater similarity to pelagic trawls. The number of species typifying the catch composition of the cooling-water intake was about double those of the two trawls, and included

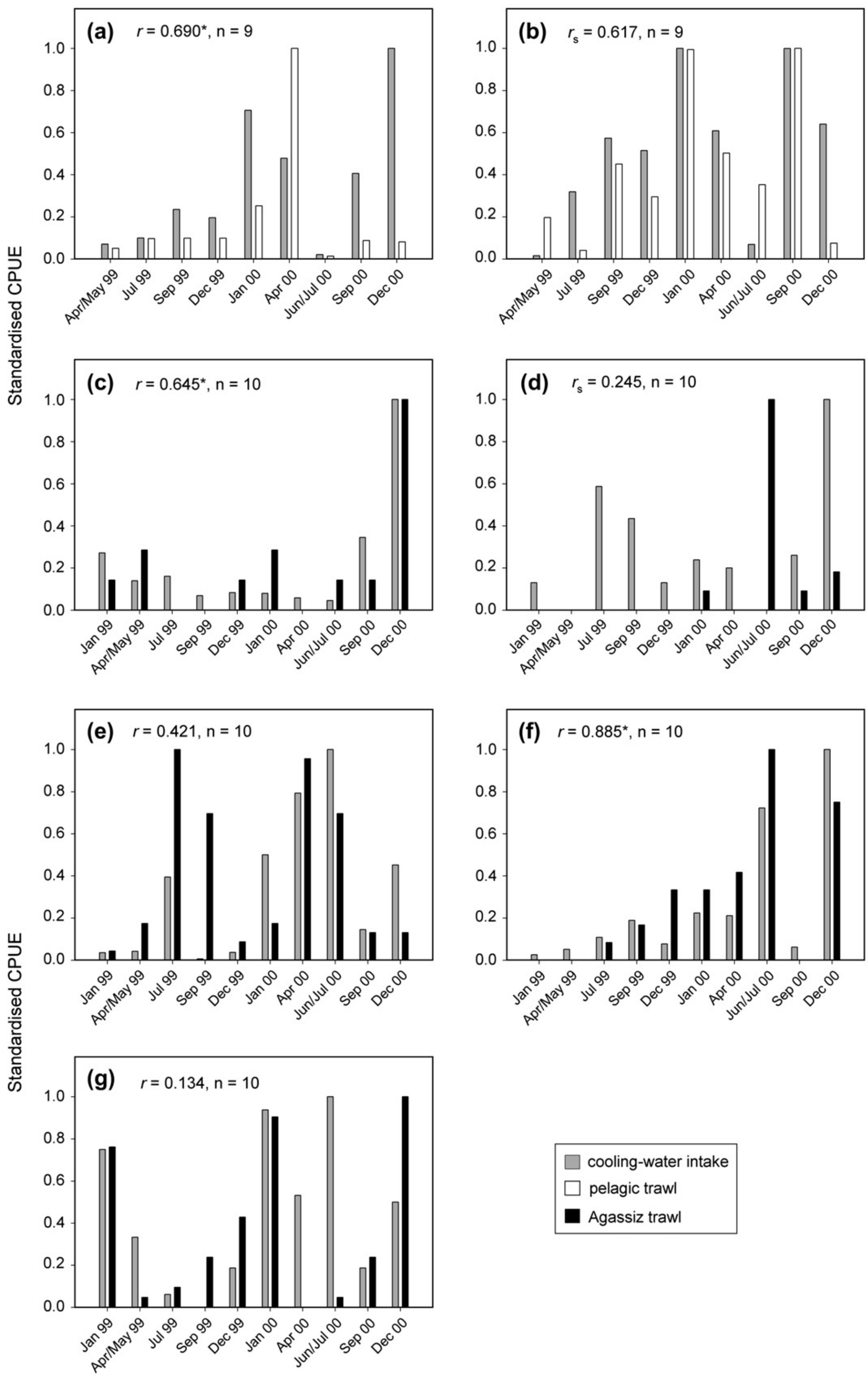


Fig. 3. Monthly trends in abundance of common fishes from cooling-water intake samples and trawling. (a) sprat, (b) herring, (c) whiting, (d) cod, (e) flounder, (f) plaice, (g) pogge. Catch per unit effort, CPUE (sum of monthly samples) is standardised to proportion of maximum monthly CPUE for each gear. Pearson correlations ($r$) and Spearman rank correlations ($r_S$) are shown ($*P < 0.05$).

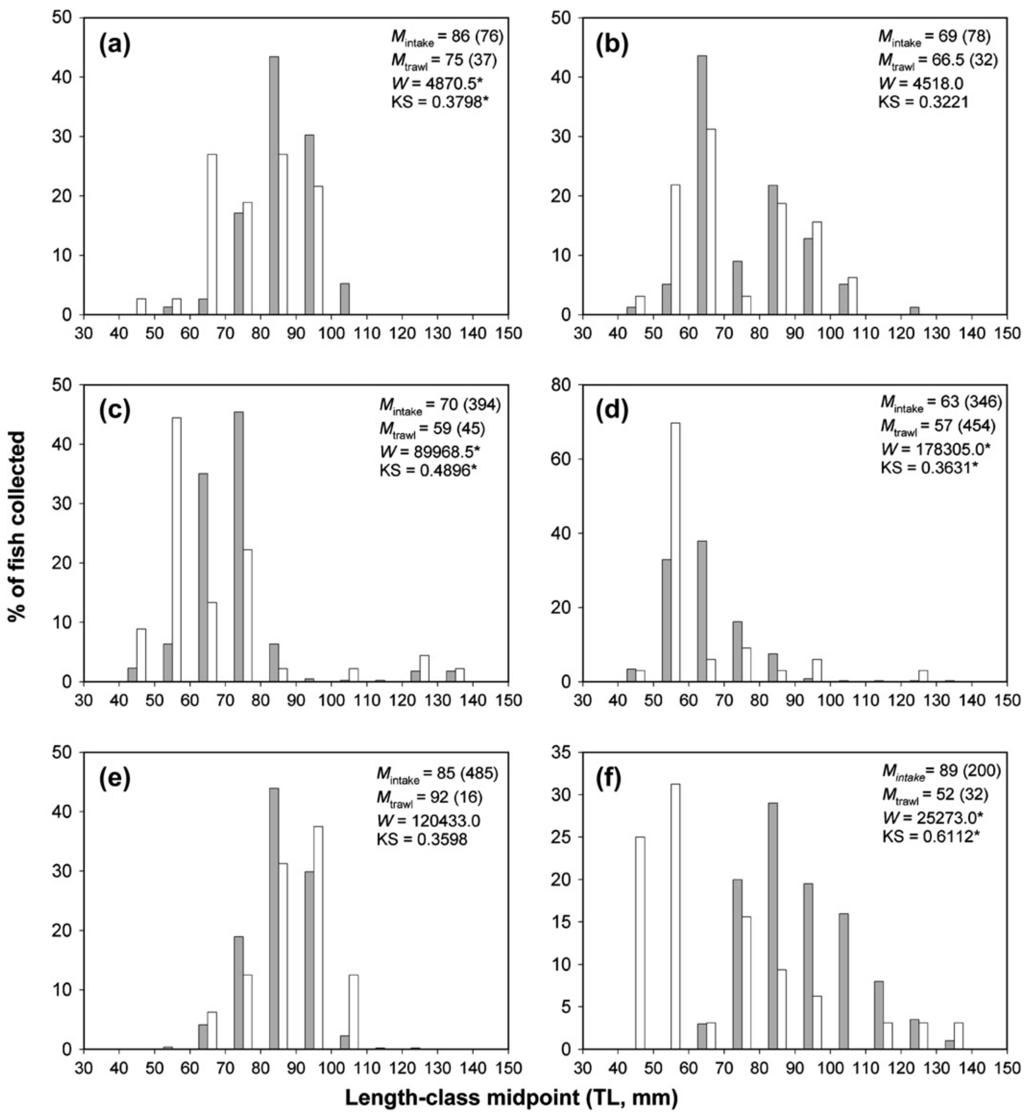


Fig. 4. Length frequencies of sprat collected from the cooling-water intake of Longannet Power Station (▒) and by pelagic trawling (□) in (a) July 1999, (b) September 1999, (c) December 1999, (d) April 2000, (e) September 2000, and (f) December 2000. Box contains median lengths (M), Mann–Whitney W statistic, and Kolmogorov–Smirnov (KS) statistics; *statistically significant difference ($P < 0.05$). Numbers of fish measured are indicated in parentheses.

pelagic (sprat, herring, and smelt), demersal (whiting), and benthic (flounder, plaice, and gobies) species. For this reason, cooling-water intakes have been aptly described as ‘acting as a pitfall trap for animals walking over the substrate and as a suction trap for swimmers’ (Henderson et al., 1992). Some species (e.g., clingfishes, Gobiesocidae) are rarely taken in power station samples, however, and this may be due to their relatively sedentary habits and means to attach to structure. As with all sampling gears, it is important to acknowledge that not all members of the fish assemblage will be collected and those that are will be caught with differing efficiencies.

Differences in median size and length-frequency distribution were apparent in the majority of intake-trawl comparisons. On the basis of mesh size, it would be reasonable to expect that the cooling-water intake (8-mm mesh) would catch smaller fish than the trawls (15-mm mesh) (Margraf et al., 1985; Maes et al., 2001). This was indeed the case for the majority of significant differences. The exception was sprat, which was significantly greater in size from cooling-water-intake samples than from the pelagic trawls. This could indicate age-specific differences in habitat preference, with larger individuals occupying the margins of the estuary closer to the intake and smaller individuals tending to occupy the region closer to the middle of the estuary where trawling occurred. If so, this is different from the ontogenetic movement to deeper areas with increasing size that is apparent in some estuarine fish (e.g., Nelson, 1998). In any case, the intake-trawl fish-length differences observed in this study are of practical consequence when assessing the environmental impact of the cooling-water intake: estimates of fish population size that are based on trawl data (e.g., Elliott et al., 1990) must take into account the size distribution of the trawl-caught fish in relation to the intake-collected fish. It is therefore advisable to conduct estimates of population size with traditional gears of similar

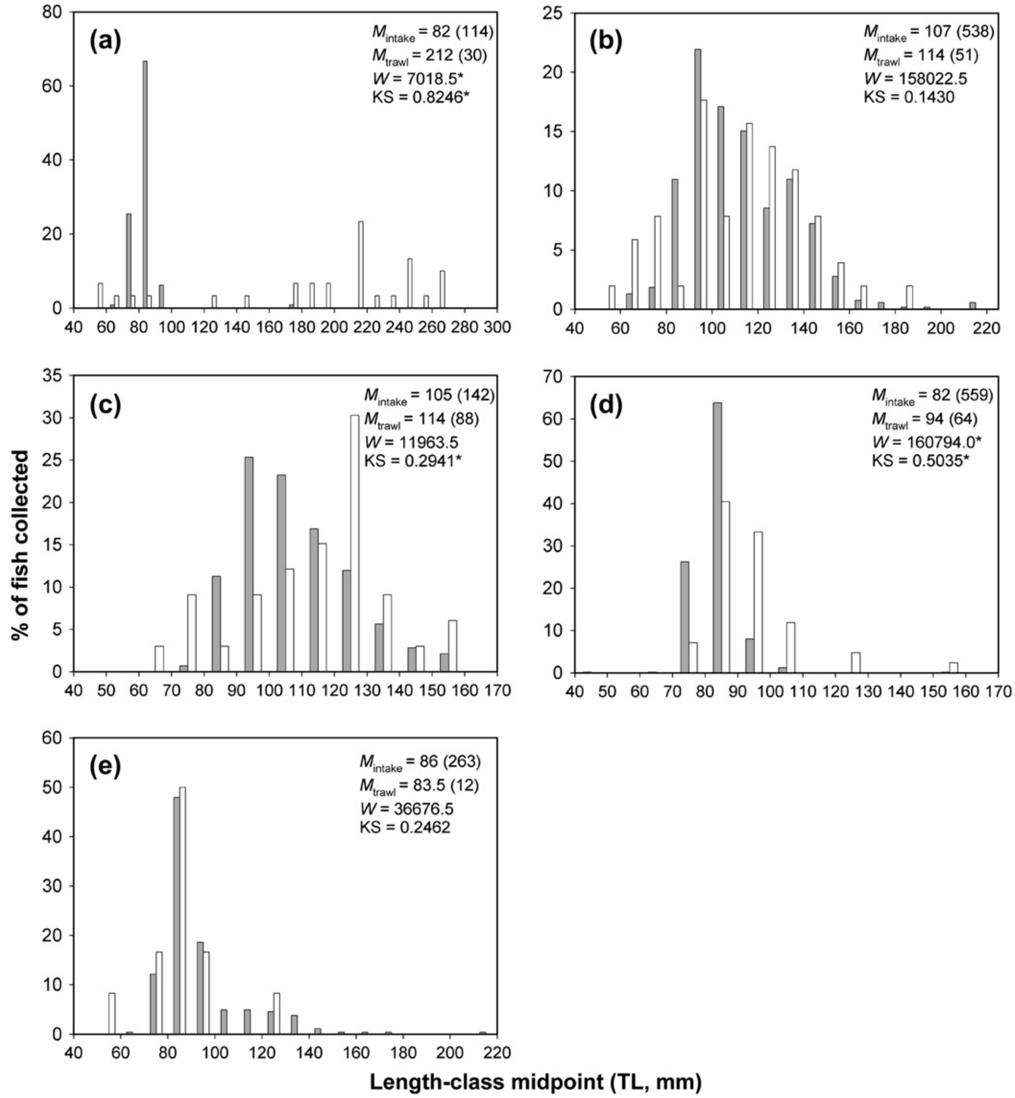


Fig. 5. Length frequencies of herring collected from the cooling-water intake of Longannet Power Station (■) and by pelagic trawling (□) in (a) September 1999, (b) December 1999, (c) April 2000, (d) September 2000, and (e) December 2000. Box contains median lengths (M), Mann–Whitney W statistic, and Kolmogorov–Smirnov (KS) statistics; *statistically significant difference ($P < 0.05$). Numbers of fish measured are indicated in parentheses.

mesh size to the intake screens (Hadderingh and Jager, 2002), and if this is not possible, to apply size-specific correction factors.

Trends in relative abundance between the cooling-water intake and the trawls correlated quite well given that the indices were based on a maximum of two trawl or intake samples per month. As noted above, the methods did not necessarily sample the same sizes or ages of fish, so disagreement was not entirely unexpected. Nevertheless, the results of this study give confidence in the ability of the cooling-water intake to identify trends in relative abundance. Brooks et al. (2002) demonstrated that declines in Southern California rockfishes from visual surveys correlated significantly with declines in rate of impingement at several cooling-water intakes. Turnpenny (1983) suggested that the weak, albeit statistically significant correlation between intake catches and gill-net catches at Fawley Power Station was because, with decreasing temperature, catches at the intake increased due to decreased swimming ability and catches in the gill nets decreased because of reduced activity in the colder conditions. In contrast, the cooling-water intake and trawls in the present study may be influenced by temperature in a similar fashion because all three gears can be regarded as ‘active’ (sensu Turnpenny, 1983) and catches reflect fishes’ escape potential.

The main advantages of the Agassiz trawl for sampling fish and other nekton in estuaries include: (a) large sample unit area; (b) robustness and suitability over many substrates; (c) fixed-opening mouth; (d) successful operation irrespective of the way the trawl lands on the substrate (due to the shape of the trawl); (e) ability to collect quantitative and qualitative data (Hemingway and Elliott, 2002). The Agassiz trawl’s main disadvantages are a low, variable catch efficiency and a tendency to be affected by tide and wind direction. Pelagic trawls share many of the Agassiz trawl’s advantages and

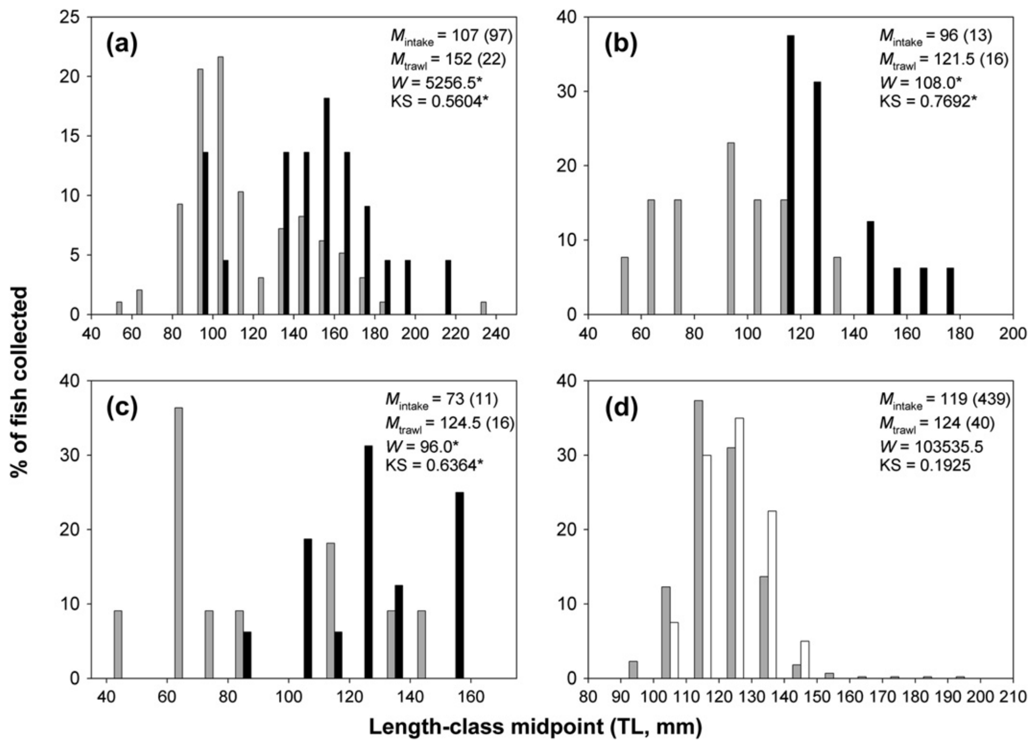


Fig. 6. Length frequencies of fishes collected from the cooling-water intake of Longannet Power Station (▩) and by trawling (Agassiz, black bars; pelagic, □): (a) flounder in July 1999, (b) flounder in April 2000, (c) pogge in January 1999, (d) smelt in July 1999. Box contains median lengths (M), Mann–Whitney W statistic, and Kolmogorov–Smirnov (KS) statistics; *statistically significant difference ($P < 0.05$). Numbers of fish measured indicated in parentheses.

disadvantages, and are notably difficult to maintain fishing at a constant height in the water column in estuaries with powerful tidal currents, similar to the Forth estuary (A.S. Hill, Scottish Environment Protection Agency, personal communication). Trawling is also costly, involving the capital expenses of research vessels and trawls, as well as fuel.

Cooling-water intake screens of power stations are advantageous in providing (a) semi-quantitative data on relative abundance (if pumping records are available); (b) less laborious sampling compared to traditional gears; (c) lower susceptibility to problems of gear damage or river traffic in metropolitan estuaries such as the Thames (Hemingway and Elliott, 2002). In addition, intake-screen sampling is not constrained by weather conditions: sampling has been carried out during gales of $>90$ km h$^{-1}$, for example (P.A. Henderson, PISCES Conservation Ltd., personal communication). It was also apparent from this study that catch composition was considerably more stable than for the two trawls, perhaps indicating greater catch efficiency (albeit for mostly smaller individuals). The main drawback of cooling-water intakes as sampling devices is that they are, literally, fixed stations. This problem may be somewhat reduced in macrotidal estuaries. The tidal excursion in the Forth is often 8–16 km, with many species moving up and down the estuary with tidal currents (Welsby et al., 1964). Thus the fixed station may in effect sample a rather large area, as fish are swept in front of the intake, and more mobile species may be captured with greater frequency (Henderson, 1989). It is therefore very important to standardize sampling programmes to a consistent period of the month to avoid tide-associated biases associated with water movement, exposure of mudflats, and water level in the screen wells (Henderson and Holmes, 1991). Fixed-station sampling must of course be treated cautiously when dealing with long-term data in estuaries that may have experienced improved water quality: Maes et al. (2004) suggested that declines in abundance at a cooling-water intake may reflect movement into previously polluted areas away from the power station. This problem could be overcome, to some extent, in estuaries where multiple power stations are sited along the shoreline (Maes et al., 1998) and sampling is undertaken at all locations. The data in the present study were collected during daylight hours only, as dictated by the trawling programme. There are day–night differences in relative abundance in some estuaries because gear efficiency (both of trawls and intakes) increases with decreasing visibility (van den Broek, 1979); this is not an issue in the Forth estuary because turbidity is high and so visibility is relatively low at all times.

In conclusion, this study provided further evidence that a cooling-water intake is an efficient means to sample estuarine fish populations. As with any gear, the catch represents only a portion of the overall fish assemblage and, in this case, tends to be composed of smaller individuals. Catch composition is not biased towards any particular region of the water column, however, unlike many towed gears. The increasing cost of traditional sampling methods (such as towed gears) because of their reliance on combustion engines, coupled with the likely proliferation of coal and nuclear power stations in the decades ahead, may make cooling-water-intake sampling one of the most practical means of monitoring estuarine fish populations into the long-term future. Commencement of sampling programmes utilizing cooling-water intakes should temporally overlap the final years of sampling with traditional gears, in order to allow time series of relative abundance to be adjusted accordingly.

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