Temporal trends in stock origin and abundance of juvenile herring (Clupea harengus) in the Irish Sea

Noirín Burke, Deirdre Brophy, Pieter-Jan Schön, and Pauline A. King


Celtic Sea herring (Clupea harengus) larvae partly disperse into the Irish Sea, where they mix with the resident stock during their first year of life. This affects the reliability of the use of acoustic estimates of juvenile abundance on the Irish Sea nursery grounds as a recruitment index for use in stock predictions. Otolith microstructure analysis can be used to distinguish between autumn-spawned and winter-spawned individuals. Because winter spawners do not occur in the Irish Sea, this component can be assigned to Celtic Sea immigrants. We used this method to estimate the proportion of winter-spawned individuals in samples of age-1 herring from the western Irish Sea over a 10-year period (1993–2003), and subtracted a corresponding proportion from the acoustic age-1 abundance estimates. The adjusted index for autumn-spawned (supposedly Irish Sea) juveniles was significantly correlated with the abundance of age-3 fish from the same year class in commercial catches and in the acoustic surveys ($p < 0.05$ and $< 0.01$, respectively), whereas the correlations for unadjusted indices were not significant. These findings are discussed in relation to the monitoring and assessment of herring in the two areas.

Keywords: herring (Clupea harengus), otolith microstructure, recruitment indices, stock assessment.

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Introduction

The movements of fish between management areas and the mixing of unit stocks in feeding or nursery areas greatly complicate stock assessments. When components are assessed separately, despite some degree of mixing during their lifetime, estimates of stock numbers and mortality easily become biased, and the accuracy of their assessed states can be difficult to ascertain (Daan et al., 1990). These uncertainties pose particular problems for fishery management, if unit stocks straddle national boundaries and are targeted by fisheries from multiple jurisdictions.

The uncertainty about the mixing of unit stocks has led to the development of a variety of methods for identifying the origin of individual fish. Natural population markers include morphometrics and meristics, otolith microstructure, shape and chemistry, parasite prevalence, gene frequencies, and fatty acid profiles. Artificial tags and otolith-marking techniques can also be used to trace representatives of different populations (Friedland et al., 2003).

Otolith microstructure analysis has been used extensively in fisheries research since the discovery of daily growth markings (Panella, 1971). Otoliths grow throughout the life of the fish, and deposited material is unlikely to be reabsorbed or altered by unfavourable growth conditions (Campana and Neilson, 1985). Their growth rate can be influenced by environmental factors, such as temperature (Fey, 2001), prey density (Feet et al., 2002), and photoperiod (Wright et al., 1991). These properties make otoliths an ideal structure for tracing groups of individuals that experience different growth conditions during their life history. Otolith microstructure has proved to be particularly useful for distinguishing between groups of herring that spawn in different seasons (Moksness and Fossum, 1991; Munk et al., 1991; Mosegaard and Madsen, 1996; Brophy and Danilowicz, 2002; Clausen et al., 2007).

Within the Northeast Atlantic, 11 unit stocks of herring (Clupea harengus) have been defined for management purposes; each characterized by specific spawning times and spawning locations, but there is mixing within and among some of these stocks during various stages of their life histories (Parrish and Saville, 1965). The Irish Sea (ICES Division VIIa North), together with the Celtic Sea and Southwest of Ireland (ICES Divisions VIIa South, VIIg, and VIIj), represent two components that are managed separately, although it is now widely accepted that there is extensive mixing of the two during the juvenile phase. Within the Irish Sea, there are two spawning components: the Manx herring and the Mourne herring. Although most spawning occurs in autumn (the Manx component spawns in a 3–4-week period from September on), a small amount of spawning continues into winter (Dickey-Collas et al., 2001). In the Celtic Sea, spawning takes place in autumn and winter between October and January (Molloy, 1980).

Tagging experiments (Molloy et al., 1993), length distributions and vertebrae counts (Bowers, 1964), and otolith microstructure analysis (Brophy and Danilowicz, 2002) have provided ample evidence that juveniles originating from the Celtic Sea mix with those...
originating from nursery grounds in the Irish Sea. Although there is evidence that a small proportion of juveniles of Celtic Sea origin contribute recruits to the spawning population in the Irish Sea, the spawning assemblages have been shown to consist almost entirely of autumn-spawned fish (Brophy et al., 2006); it has been suggested that juveniles of Celtic Sea origin return to the Celtic Sea to join adult fish from more local nursery grounds (Burke, 2008). The contribution of the migrant component to the total abundance of juveniles in the Irish Sea varies from year to year for unknown reasons (Brophy and Danilowicz, 2002; Burke et al., 2008). As a consequence of this mixing, juvenile abundance estimates from the nursery grounds in the Irish Sea do not provide a reliable recruitment index for the Irish Sea stock, which leads to uncertainty in the medium-term forecasts of spawning-stock biomass.

ICES (2007) has recommended the separation of juveniles caught in Irish Sea surveys into autumn- and winter-spawned fish, based on otolith microstructure and/or length compositions, to produce a recruitment index that is more appropriate for the Irish Sea stock. The estimated hatch dates, based on microstructure analysis, indicate that juveniles in the Irish Sea are either autumn- or winter-spawned (Brophy and Danilowicz, 2002), and no indication of spring-spawned herring has been obtained so far.

We have used otolith microstructure to assess the relative proportions of winter- and autumn-spawned fish present in the Irish Sea over a 10-year time-span. These proportions are combined with assessment data for the Irish Sea stock to produce separate abundance estimates for each component. A similar splitting technique has already been used in the North Sea and the western Baltic for assessing autumn- and winter-spawned components, using otolith microstructure and vertebral counts (Clausen et al., 2007; ICES, 2007). Correlations with abundance estimates of adults are investigated, and the potential for using these split estimates to develop recruitment indices for both herring stocks is evaluated.

**Methods**

**Sampling information**

Herring otoliths collected during the August/September acoustic surveys in the Irish Sea from 1993 to 2003 were selected from the Agri-food and Biosciences Institute Northern Ireland (AFBI) historical archive. During these surveys, length-stratified samples have been collected using midwater trawls, with two individuals taken from each length class where possible, and with a maximum total of 50 individuals. Total length and weight were recorded to the nearest 0.1 cm and 0.1 g, respectively, as well as sex and maturity stage. Sagittal otoliths were removed and cleaned in water before being dried, set in resin in plastic storage blocks, and subsequently used for ageing.

As a first step, only otoliths classified as age-1 by the AFBI (one translucent winter ring) were selected from the historical collection, excluding one set of otoliths for each length class by year (required to preserve the integrity of the AFBI archive). Additional age-1 otoliths were obtained from samples collected during other studies (Brophy and Danilowicz, 2002). Second, it was decided to restrict the analysis to individuals collected in the western part of the Irish Sea, because the numbers available from the eastern part were too small. Finally, years for which the criterion of a minimum sample size of 20 individuals was not met were excluded from further analysis. The total numbers of otoliths examined for each year and year class are given in Table 1, and the locations of the samples are displayed in Figure 1.

Selected otoliths were first photographed then isolated using a coping saw. After heating each piece of plastic containing one pair of otoliths (to soften the resin), the otoliths were removed and stored in plastic Eppendorf caps.

### Otolith analysis

Age readings were confirmed according to visual inspection of the translucent and opaque bands at ×20 magnification using an Olympus™ stereomicroscope. The microstructure was analysed to class individuals as either autumn- or winter-spawned, based on the growth patterns displayed in the larval core, according to the method developed by Brophy and Danilowicz (2002). Otoliths were initially mounted with the sulcus side uppermost in 1.5 ml Eppendorf caps in TAAB™ epoxy resin and polished until light could penetrate the larval core. The resin blocks were

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**Figure 1.** Maps showing the relative proportions of autumn-spawned (open slice) and winter-spawned (closed slice) juveniles by sample site and year. ICES Divisions are indicated in the top-left panel.
flipped and remounted to facilitate polishing on the sulcus side until the larval core was fully exposed.

The core was photographed at ×1000 magnification using an Olympus™ compound microscope with an Olympus™ Camedia digital camera attached. Daily increments were measured along the longest visible axis from the nucleus to the image edge. Otoliths with an average increment width ≥2.3 µm between increments 61 and 70 were classified as winter-spawned, whereas fish with an average of ≤2.2 µm between increments 61 and 70 were classified as autumn-spawned.

Fisheries data
Annual estimates of abundance for age-1 fish from Integrated Catch-at-age Analysis (Patterson, 1998) were obtained from ICES (2007). These were split according to the proportions of autumn- and winter-spawned fish, as classified by otolith microstructure analysis, to produce separate estimates of abundance for each spawning type. Estimates of juvenile abundance (before and after splitting) were investigated for significant correlations with catch-at-age-3 and the acoustic estimate of age-3 in the Irish Sea for the same year class (ICES, 2007), to determine whether the removal of the winter-spawned component would improve the relationship. In addition, the correlation between the abundance of autumn-spawned juveniles in the Irish Sea and the spawning-stock biomass (SSB) in the Irish sea two years previously was examined, as well as the correlation between the abundance of winter-spawned juveniles and the acoustic estimates of abundance of age-3 in the Celtic Sea stock 2 years later.

Results
The proportion of winter-spawned juveniles in the samples analysed fluctuated widely over the 10-year period (24–89%; Figure 1; Table 1). Correcting the Irish Sea acoustic age-1 abundance index for the proportion of winter-spawned juveniles in the otolith samples produced a marked improvement in the relationship with the number of age-3 taken in commercial catches, and the same was true for the acoustic age-3 index (Figure 2; Table 2). No significant correlation was found with the SSB two years previously, or between the abundance of winter-spawned juveniles in the Irish Sea and the acoustic age-3 index or SSB for the Celtic Sea. However, only five data points (1993, 1996, 1998, 2001, and 2003) were available in both cases.

Discussion
The analysis was based primarily on otoliths collected historically during the AFBI acoustic surveys carried out between 1993 and 2004. Although we attempted to make the best possible use of the material available, the analysis was severely limited by sample sizes in all years except 2001 (Table 1). Although no samples from the eastern Irish Sea have been included, because relatively few age-1 fish were available from that area, previous investigations have shown that the abundance of winter-spawned fish increases from east to west (Brophy and Danilowicz, 2002; Burke, 2008). Therefore, we may have overestimated the abundance of winter-spawned fish. If otolith microstructure analysis is to be included as part of the annual sampling programme, we suggest that samples are taken from a wider range of sites when estimating the relative proportions of the two groups in the entire area.

We must also consider the possibility that some of the fish classified as autumn-spawned may have come from the Celtic Sea, because of the extended spawning season there. During certain years, considerable numbers of autumn-spawned juveniles are present in the Celtic Sea (ICES, 2007), and some autumn-spawned larvae may be transported to the Irish Sea, where they contribute to the proportion of autumn-spawned juveniles observed there in the surveys. This would obviously undermine the accuracy of the abundance estimates of juveniles recruiting to the Irish Sea stock. There are also indications that some autumn-spawned herring from the West of Scotland (Division VIa North) use nursery areas in the Irish Sea (ICES, 2007). Nevertheless, although the presence of autumn-spawned or winter-spawned juveniles from other areas cannot be ruled out, the much-improved and significant correlation between the adjusted acoustic abundance-at-age-1 and the acoustic abundance-at-age-3 suggests that these components represent only a minor fraction. This indicates that, in future years, if this
splitting technique were to be carried out more rigorously, and with larger sample sizes, and as part of the routine monitoring of the stock, a reliable recruitment index for the Irish Sea might be produced.

ICES (2007) suggested that identification of winter-spawned juveniles during Irish Sea surveys might also help to improve recruitment indices for Celtic Sea herring. Previous studies have shown that this migrant component is absent in the Irish Sea spawning population (Brophy et al., 2006), and that the adult fish may display natal homing behaviour (Burke, 2008). Our analysis did not yield a significant correlation between winter-spawned juveniles in the Irish Sea and Celtic Sea stock parameters. This may suggest that only a fraction of the juvenile fish of Celtic Sea origin disperses into the Irish Sea, and this fraction is not necessarily constant over the years. In addition, annual survival rates may fluctuate independently among different nursery grounds. Moreover, while the Celtic Sea stock consists of a mixture of autumn and winter spawners, the recruitment index derived here necessarily excludes any contribution from the autumn-spawned component. This introduces another possible source of error in the relationship between juvenile and adult abundance. Therefore, a reliable recruitment index may only be obtained if juvenile abundance estimates from the Irish Sea, based on otolith microstructure analysis, can be combined with annual estimates of juvenile abundance on Celtic Sea nursery grounds.

Accurate recruitment estimates are essential to produce reliable forecasts for fishery management, and splitting techniques are already being used routinely for assessing North Sea autumn- and winter-spawning herring and western Baltic spring spawners (Clausen et al., 2007; ICES, 2007). Apart from resolving specific management questions, monitoring the abundance of winter-spawned juveniles in the Irish Sea may also contribute to the understanding of herring recruitment dynamics in general by helping to evaluate the potential environmental factors causing the annual variability in dispersal (e.g. wind affecting larval drift) or in survival. Such factors warrant further investigation.

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