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Spatial linkages in the early life history of north eastern Atlantic herring populations across the north of the British Isles.

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Summary
There are two ICES management areas for autumn spawning herring spanning the north of the British Isles (Area IVaNorth and area IV). During January and February each year the over-wintering herring (*Clupea harengus*) larvae occurring throughout the North Sea are enumerated for a recruitment index for the North Sea stock. Larvae spawned to the west of the North Sea are probably advected into the northern North Sea from the adjacent west of Scotland (IVaN) spawning grounds, mixing with North Sea-spawned larvae. However, the extent of larval mixing in the North Sea has not been quantified. 'Back-tracking' of larvae from their capture site, otolith micro-chemistry and forward particle tracking from known spawning grounds all indicate a similar pattern of mixing of larvae from both North Sea and west of Scotland spawning grounds in the northern North Sea. There is the potential for a large amount of mixing of larvae from different spawning grounds, even in relatively small areas. The ingress of herring larvae from the west of Scotland highlights the connectivity between these two regional seas areas and has implications for the estimate of the recruitment index for herring in the North Sea.

Introduction
The spawning grounds of autumn spawning herring occur around the east and west coasts of the British Isles. The principal currents are from west to east, therefore it has been known for a long time that herring larvae spawned to the west of the North Sea most probably are advected into the northern North Sea (Heath 1989). However, the extent of larval mixing in the North Sea is not known nor where this mixing occurs.

Particle tracking models have been used quite extensively, either in a forward tracking or back-tracking mode to determine the possible dispersal or origin of larvae. Verifying the results of these particle tracking models has relied on additional information which can provide information on the spatial connectivity of different life history stages. Natal signatures in otoliths can provide crucial information to link individuals to areas, and reveal population connectivity. However, these signals are not always straightforward to interpret. As geotags, the otolith chemical composition should track spatial processes, such as dispersal from spawning areas.

Materials and Methods
Herring larvae are annually sampled between January and early March over the whole North Sea using standard protocols during the ICES 1st Quarter International Bottom Trawl Survey (IBTS) using a 2m ring trawl (MIK) (ICES 2014). All larvae are enumerated and measured (in the case of large numbers of larvae, sub-samples are measured). The larval abundances are used to estimate an O-group index of North Sea herring larvae. A selection of larvae from the northern North Sea, sampled by Norway, in 2009 had their otoliths removed and processed for analyses using Laser-Ablation ICPMS (see Geffen *et al.* 2011). A selection of elements with regularly detectable concentrations was chosen for further analyses. The positions of the larvae chosen for otolith analyses were subject to a 'back-

tracking' algorithm (see Payne *et al.* 2013). Spawning grounds and estimated time of spawning in the North Sea and to the north and west of the British Isles were identified in the particle tracking model and 'back-tracked' trajectories.

The distribution of herring larvae over multiple years were examined in the models by releasing particles from the known spawning grounds from west of Ireland to the English Channel at four one week intervals, at appropriate dates for the known spawning times in each area. The larvae-particles were tracked within a 4km ROMS model (Lien *et al.*, 2014) and their locations 24 weeks after the 10th September, coincident with the completion of the 1st Quarter IBTS MIK survey, along with their spawning ground origins were recorded.

Results and Discussion

The 'back-tracked' drift trajectories of larvae which had been analysed for otolith microchemistry clustered into three broad categories. Clusters 1 and 2 were most likely comprised of larvae that originated from the west of Scotland spawning grounds and possibly even further south on the northwest coast of Ireland. This is dependent on whether larvae are entrained into the rapid west coast of Scotland current. Cluster 3 comprised mainly of larvae spawned in the North Sea management area (example in Fig.1). The otolith microchemistry of individuals, coded by the station and the projected drift trajectory indicate that there is most probably a mixture of individuals from different spawning locations at each station (Fig.2). This is reflected in the potential variability in drift trajectories for each station. Samples of larvae soon after hatching, on the spawning grounds would provide a baseline signature to be able to assign larvae back to their respective spawning grounds.

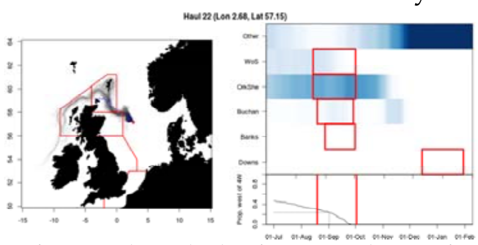

Fig. 1. Back-tracked trajectory and spawning location

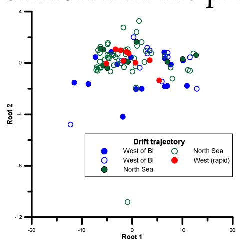

Fig. 2. Otolith elemental composition

The forward projection particle tracking also suggested considerable mixing of larvae at single stations (Fig. 3). These projections also highlighted potential considerable inter-annual variability in the abundance of herring larvae advected into the North Sea from the west of the British Isles and a variable distribution pattern.

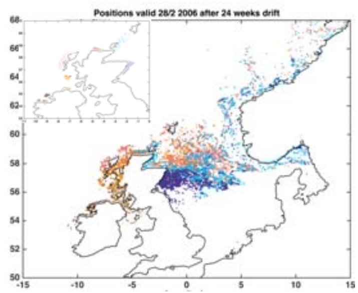

Fig. 3. Predicted herring larvae distributions, 1st March 2006.

The particle tracking models and the otoliths all show a complex mixing of larvae in the northern North Sea. The next challenge is to interpret the field data on larvae distributions and the consequences for stock dynamics and recruitment indices.

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