Distribution and connectivity in Firth of Clyde whiting

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Although the composition of fish communities in the Firth of Clyde has changed radically since the area was opened to trawling, the biomass of demersal fish does not differ substantially from historic levels. The present community, lacking larger species and large individuals of the species present, is composed of an age truncated population of small gadoids, predominantly of one species, whiting (*Merlangius merlangus*). In order to understand how the current system is sustained we examined the distribution and connectivity of whiting to the west of Scotland. Spatial and life-stage connectivity is of key importance to explain the predominance of young whiting in the Firth of Clyde. The use of otolith microchemistry to infer the nature of connectivity between the Clyde and wider west coast will aid in explaining the absence of older, larger individuals. Firstly, understanding the spatial distribution and aggregations of this species is essential to contextualize life-stage connectivity results.

Research surveys from the Scottish west coast (SWC) and Irish Sea (IS) from 2009 to 2015 were used to map whiting distributions at key life-stages. These were identified as mature and age-1 individuals from early spawning season and 0-group recruits from quarter 4 (Nov-Dec). Binomial GLMs were constructed for each demographic group, modelling the probability of a given length class belonging to a particular life stage. Density distributions were modelled with generalized additive mixed effects models (GAMMs) in a delta-gamma approach. Temporally stable variables considered included bathymetry, slope, aspect, distance to shore and sediment type. While temporally variable layers (bottom temperature and salinity) were constructed for relevant time points in each year. A random effect, accounting for variability in gear selectivity, was also included in the optimal models. Geostatistical aggregation curves (GAC) were used to identify variation in space selectivity for these three key life-stages.

Results indicate temperature to be the most influential variable on density followed by sediment type for 0-group fish. The optimal temperature of 13°C had an overall positive effect on abundance although this also varied with salinity and distance from shore. Sand and muddy sand resulted in higher coefficients in contrast to coarser, harder substrates. For age-1 whiting the most important physical variables were distance from shore and the interaction between temperature and salinity. The most influential variable, however, was year. Highest abundances remained within 50km of shore, at temperatures above 8.25°C. The model of mature fish resulted in year as the most influential variable followed by depth and temperature. In the early spawning season mature whiting showed highest abundancies at temperatures above 8.25°C in depths of around 100m. GACs showed differentiation in space use at different life-stages. Early life-stages aggregate readily with 80% of the biomass occupying only around 20% of available space. In comparison mature individuals show a much more dispersed distribution, even in early spawning season.

This study demonstrates the high relative abundance of early life-stage whiting is reflective of preferable environmental conditions experienced close to shore. The most important factor influencing densities at later life stages, however, is the success of previous cohorts. In these groups, year was the most influential variable. This indicates processes other than the environmental variables considered influenced these abundances. In this case it is reasonable to assume that the temporal variable is a proxy for the success of previous recruitment events. Thus, high numbers of young whiting may be expected in the Clyde given its coastal nature. Older, mature individuals occupy space in a more dispersed distribution pattern. The low abundancies of these individuals in the Firth of Clyde may result from this dispersal. Inferences of connectivity from otolith microchemistry at these key life-stages will be able to verify this hypothesis.

Stock assessment of Firth of Clyde whiting using a length-based Bayesian model

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The Firth of Clyde supports a large fishery that once harvested a diverse range of species including pelagic fish, demersal fish, and shellfish. The repeal of a ban on industrial trawling in 1962 marked the start of a period of intense exploitation. Finfish landings rose to a peak in 1973 before steadily declining to negligible levels by the early 2000s. Presently, the Clyde fishery is almost entirely dependent upon high landings of *Nephrops*. Plans to recover the former diversity of the fishery would benefit from information provided by stock assessments. As *Nephrops* is the only species currently subjected to full stock assessments, reliable estimates of trends in the abundance, recruitment, and fishing mortality rates of the Clyde finfish stocks are absent. One of the reasons for this is that most contemporary assessment methods require fishery catch-at-age data or age distributions from survey samples. These data are expensive and difficult to collect, particularly in small regions with limited resources. Catch-at-age data tend to be aggregated over large geographical areas, and age data, in general, are collected only for the most commercially valuable stocks. In order to address this, we developed a new assessment model in which stock structure is represented by length instead of age, and includes time-varying growth rates. Our model is an extension of [1] that requires only data on total annual landings and discards, and survey length-distributions. Since these data are collected for most exploited stocks, even those of relatively low value, our model should be widely applicable. The model is implemented in Stan [2] and uses Bayesian inference through Hamiltonian Monte Carlo sampling for the parameter estimation, and has been tested by applying it to the cod, haddock, and whiting stocks of the west of Scotland (ICES area VIa). We found a good agreement between our results and those of existing age-based models [3] so we then fitted the model to data on Clyde whiting. Our initial findings suggest that Clyde whiting have experienced a high fishing mortality rate since at least 1985; that in any given year the stock comprised mostly of new recruits; that stock biomass has remained stationary while stock numbers have increased; that average growth rate (length-at-age) has declined; and that fisheries for whiting are less size-selective in the Clyde than in ICES area VIa as a whole. The combination of extensive use of fine-mesh *Nephrops* trawling gear and relatively high fishing effort-density is probably linked to the high fishery selectivity at small lengths and high mortality rate of Clyde whiting. The consequent truncation of the stock structure at small lengths appears to have caused stock size to become heavily dependent upon reproductive output in the preceding year. The decline in average growth rate resembles results of a growth analyses based on survey age data [4], and truncation of the stock length structure could be the mechanism driving this decline. As the majority of the Clyde finfish catch consists of discards [5], acquiring accurate discard data for the Clyde is of particular importance for model reliability. Although these results for Clyde whiting provide potentially useful information, the reliability of the model is questionable because the discard data were estimated from discarding rates during 1982-1998 [5]. Up-to-date data on discarding rates are required to increase the reliability of Clyde stock assessment results. With such data, we believe this model could be used to assess the condition of many of the finfish stocks within the Clyde.

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Modelling the exploitation of whitefish and herring in the Firth of Clyde during the nineteenth century

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The Firth of Clyde is and inland sea that has a long history of commercial exploitation of its fish stocks (Heath & Speirs 2012, Jones, Cathcart & Speirs 2015). In recent years historical ecologists have, through the examination of non-traditional sources, begun to piece together a clearer picture of ecosystem change over centuries of anthropogenic influence. One aspect of this long-term approach is that data are being recovered from some surprising sources, and, when placed alongside other evidence, are being used to create models of change through time where previously none would have been thought possible. Using data relating to landings and fishing effort which were gathered by the United Kingdom Fishery Board from 1809 onward, we have been able to calculate catch per unit effort (CPUE) for the period between 1845 and the mid-1880s which, when placed alongside the direct evidence of fishers, lead to some unexpected conclusions. In particular, inshore stocks of commercial whitefish appear to have been in decline by the mid-1850s in the Clyde, many years before the widespread adoption of beam trawling in Scotland. It appears that the most likely reason for this decline is the rapid intensification of fishing from open boats using the traditional techniques of handlines and longlines. The decline of the whitefish fishery was associated with and increased effort for herring, which resulted in an increase in landings, but larger "boom and bust" oscillations in the herring catch during the latter part of the century. In this talk we explore how these patterns can be explained using simple surplus production models fitted to the available historical data. The fitted models suggest that, contrary to conventional wisdom, the pre-industrial fisheries were capable of effecting substantial changes in the Clyde ecosystem well in advance of the introduction of steam trawlers.

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Data Analysis to understand Conditions leading to Fish Kill Events in the Clyde Estuary

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Data analysis and numerical modelling is utilised by SEPA to drive water quality models to assess the dispersion and dilution of pollutants and to investigate the risks posed by these to the marine environment.

Changes in the Clyde Estuary dynamics and its morphology (depth and shape) have resulted in improvements in the water quality observed by four decades of monitoring. These changes in water quality along with proposed changes to discharges into the Clyde led to a comprehensive study to better understand the hydrodynamic processes in the estuary.

Despite these water quality improvements we still observe fish kills in the Clyde. Our investigations involved the collation of data gathered from SEPA's monitoring network complemented by recent water quality and hydrographic survey data.

This work has highlighted several factors which control DO concentrations and have an influence on the river-estuary dynamics. Some of these factors help to improve water quality such as reduced dredging and improvements in sewage treatment. However, there are also factors that contribute to conditions leading to fish kills, such as the operation of the Tidal Weir and long dry periods during the summer months.

Valuing future changes in ecosystem service delivery resulting from South Arran MPA

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The number of marine protected areas (MPAs) globally has increased globally from below 1% in 1990, to 3.41% in 2014 (Thomas et al. 2014). This number is growing annually, driven by major international commitments such as Aichi Target 11 of the UN Convention on Biological Diversity, which calls for 10% MPA coverage globally by 2020. Many of these MPAs are positioned in coastal waters, and likely impact upon the delivery of marine ecosystem services and benefits to coastal communities (Potts et al. 2014). However, few case studies exist that explore the mechanisms through which MPAs influence ecosystem services delivery, and how these services are valued by coastal communities (Ferraro & Hanauer 2015).

Using a case study on the west coast of Scotland, this project will adopt a participatory approach to create a socio-ecological system model of the ecosystem services that are effected by South Arran MPA. This model will be used to inform predictions of the state of ecosystem services 20 years in the future, both with and without the MPA. These scenarios will then form the basis of a deliberative valuation with local communities and stakeholders.

The project is currently in the first stage of developing a conceptual system dynamics model that represents the delivery of benefits from the marine ecosystem to local stakeholders. This model aims to capture the connections, influences and feedbacks between elements of the marine ecosystem and people/ groups who benefit from it. Data for this model are being collected through document analysis and semi-structured interviews with key stakeholders. These data are being coded and combined into a preliminary model using an adapted version of the ARDI (Actor, Resource, Dynamic, Interaction) method for participatory modelling. These adaptations have been made to allow for the inclusion of non-use ecosystem services, and their constituent capital components (Jones et al. 2016; Etienne et al. 2011).

A current working version of this model will be presented here, based on data collected to date. In the next stage of the project, this model will be appraised and refined through a series of group workshops with local stakeholders.

This model will then be used to predict potential future scenarios of ecosystem service delivery, both with and without South Arran MPA. These scenarios will then form the basis of a deliberative valuation process with residents and sea users from around the Firth of Clyde, to ascertain the potential impact of South Arran MPA on local communities over the next two decades.

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Greater lobster densities affect other commercially important crustaceans in a community-led temperate marine reserve

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This study investigated the effects of the Lamlash Bay marine reserve off the Isle of Arran, Scotland, on commercially important populations of European lobster (*Homarus gammarus*), brown crab (*Cancer pagurus*) and velvet swimming crabs (*Necora puber*). Potting surveys conducted over four years revealed significantly higher catch per unit effort (CPUE 109% greater), weight per unit effort (WPUE 189% greater) and carapace length (10-15mm greater) of lobsters within the reserve compared to control sites. However, lobster catches decreased in all areas during the final two years, likely due to low levels of recruitment and increased fishing effort outside the reserve. Nevertheless, catch rates remained higher within the reserve across all years, suggesting the reserve buffered wider declines. Additionally, lobster CPUE and WPUE declined with increasing distance from the boundaries of the marine reserve, a trend tag-recapture data confirmed to be due to spillover. Egg-bearing lobsters were also twice as abundant within the reserve as outside, and the mean potential reproductive output per female was 22.1% greater. It was originally thought that higher lobster densities within the reserve might lead to greater levels of aggression and physical damage. However, damage levels were solely related to body size, as large lobsters > 110 mm had sustained over 218% more damage than smaller individuals. Interestingly, lobster catch rates were inversely correlated with those of juvenile lobsters, and brown and velvet crabs, which may be evidence of competitive displacement and/or predation. However, CPUE and size of velvet crabs remained higher within the reserve for most years of study, suggesting that competition between velvet crabs and lobster may be weak. Combined with our previous work at this location (Howarth et al. 2011; Howarth et al 2015a, b), our findings provide further evidence that temperate marine reserves can deliver fisheries and conservation benefits, but that species interactions need to be considered.

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The Transport of *Nephrops norvegicus* Larvae in the Firth of Clyde

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Nephrops norvegicus is a decapod crustacean of significant commercial importance to the Clyde Sea Area. The distribution of this species depends on the supply of larvae, governed by local hydrodynamic flowfields, as well as on the presence of muddy sediment suitable for the construction of burrows. The transfer of individuals between different geographical areas only occurs during the pelagic larval phase since adult *Nephrops* do not migrate over large distances. *Nephrops* larvae exhibit minimal propulsive swimming and are transported primarily by local oceanographic currents. A high resolution Finite-Volume Community Ocean Model (FVCOM), capable of incorporating the complex bathymetry of the Firth of Clyde, was recently developed at the University of Strathclyde. Here we use the output of this model to predict the trajectories of *Nephrops* larvae released from the Clyde Sea. The length of the larval stage is calculated for each individual according to its development rate and unique thermal history. We show that the pattern of larval dispersal changes throughout the hatching period, but that the upstream regions of the Clyde are consistently more retentive. The results will contribute to the development of a spatial model of the population dynamics of *Nephrops* and the transmission of its dinoflagellate parasite *Hematodinium* sp. to be used to inform the sustainable exploitation of this economically important species.

Juvenile gadoid habitat and growth related changes using underwater stereo-video surveys

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This template is an example of how to prepare an abstract for the 2016 MASTS Annual Science Meeting, to be held on 19-21 October 2016 at the Technology & Innovation Centre, Glasgow.

Please note that abstracts should be broad and applicable to a wide audience.

Most Marine Protected Areas (MPAs) in UK waters have been designed to protect endangered species or features, not to protect fish, and have been contentious due to the denial of fishing rights. This is especially so in the Firth of Clyde, western Scotland, where landings of demersal fish species have declined to near-zero since the 1980's, coincident with an increase in trawling for Norway lobster. There is a suggestion that by-catch and substratum alteration by this fishery might have affected the recruitment of demersal fish, and that additional spatial measures should be established to address this issue. However, there is a lack of detailed information on which seabed areas should be protected so as to benefit demersal fish.

Stereo Underwater Video surveys were collected in the Firth of Clyde between June and September in 2013 and 2014 to predict substratum type within the MPA and determine the habitat and seabed landscape effects of juvenile Atlantic cod *Gadus morhua*, haddock *Melanogrammus aeglefinus*, and whiting *Merlangius merlangus*. *G. morhua* were most abundant in shallow, sheltered areas composed of gravel-pebble containing maerl and heterogeneous landscapes. Ontogenic shifts and density dependence effects on substratum association were also observed. *M. aeglefinus*, and *M. merlangus* predominated in more homogeneous deeper sand and mud. Relative abundances of all three species were positively related to benthopelagic diversity.

This work demonstrates the potential of stereo-video cameras as a non-destructive survey tool under northern-temperate conditions. Our results also indicate that spatial conservation measures to benefit demersal fish should be advised by patterns of benthopelagic diversity as well as substratum type, extent and heterogeneity. The techniques used for this research could be rolled out on a larger scale across the UK to support sensitive seabed and fish monitoring and management measures.

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