Management defined by hydrodynamics – insights for spatial organization of aquaculture

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The Scottish aquaculture industry has been expanding steadily for several decades, and has an objective to double production between 2015 and 2030. While the Scottish government supports this aim, concerns about farm impacts have meant that developments are generally opposed at a local scale, where the planning and consent process takes place. In particular, the spread of sea lice and other pathogens is a persistent concern. Spatial planning to minimize spread between farms and interaction with wild fish populations is therefore a key concern.

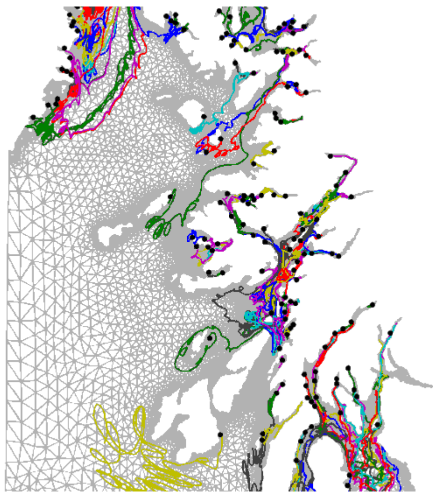
We tackle two specific issues: i) the definition of spatial management units and their effectiveness for parasite control, and ii) determining the best locations of new sites within the existing network.

In modern salmon aquaculture operations, sites are managed within spatial units. In addition to helping control spread of pathogens and parasites, these may also aim to satisfy a range other operational requirements (FRS Marine Laboratory 2000, Code of Good Practice Management Group 2011). The definition of these areas incorporates some appreciation of hydrodynamics, but only recently have sufficiently advanced hydrodynamic models been available to allow description of regional scale dispersal and complex loch topography. It is therefore unclear how effective current management arrangements may be.

We mapped the locations and boundaries of salmon aquaculture sites and relevant management units in the UK. Using a hydrodynamic model of the west coast of Scotland (based upon FVCOM; Chen et al. 2013) we predicted the variation in dispersal of sea lice between aquaculture sites. We compared the effectiveness of management units in terms of within- and between-unit connectivity. Total connectivity between sites varies over time by a factor of two and over a greater range for particular connections between pairs of sites. Even within small units, coordinated management has the potential to reduce external sea lice connectivity by over 75%. Larger management units reduce lice connectivity further (Adams et al. 2016).

A second suite of experiments made more general estimates of connectivity within the region (not only between sites), in order to refine "optimal" management unit definitions, and to suggest the best locations for new sites.

We demonstrate how output from dispersal models might be used in different ways to tackle these challenges, and demonstrate how different localities might be compared for the purposes of assessing future proposed developments.



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Dispersion in Scottish Coastal Waters

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The abstract should be submitted to masts@st-andrews.ac.uk, in an editable format, by 16:00 Friday 7th July 2017.

Models and many measurements show that patches of contaminant spread slowly in coastal waters when small, or after short times, but that the rate of dispersion increases rapidly the bigger the patches are or the longer they have been in the sea. Measurement of the dispersion with dye or drifters can be expensive and time consuming. This work therefore focusses on a few dozen easily available fish farm current records in Scottish coastal waters.

The current records show that wind plays an important part in dispersion, adding to tidal motion. Just as dispersion along the tidal axis is promoted by tidal flow, wind driven lateral motions increase lateral dispersion.

Many current records have been analysed to estimate a spreading coefficient akin to a dispersion coefficient.

The records also show that vertical shear dispersion, caused by different currents at each depth, adds significantly to other dispersive processes. Tracer and drogue measurements quoted in the literature may underestimate dispersion when made in the presence of this shear; the horizontal scale of sheared patches over a few hours can be large relative to local topographic detail.

From the literature and these three analyses, representative values of the dispersion coefficient over time scales of a few hours in coastal waters are estimated to be in the order of a few square metres per second.

Tidal variability in the Fair Isle Gap using High Frequency Radar and Current Meter Measurements

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The Fair Isle Current is a persistent residual current with a clockwise flow direction around Scotland and Northern North Sea transporting water from the Atlantic and Scottish west coast (Dooley 1974). Variability of tidal fluctuation has been investigated using different datasets, such as moored and profiling current meter observations, and High Frequency Radar (HFR) data. The use of HFR, commonly using the Coastal Ocean Dynamics Application Radars (CODAR) system, has improved our knowledge of ocean circulation in many areas in recent years. One of the best data sets in terms of circulation through the Fair Isle Gap (FIG) was collected by the Brahan Project between September 2013 and September 2014. The Brahan Project allowed the extrapolation of wave parameters (Lipa et al. 2014) and, despite the fact that Fair Isle Current mean flow properties are fairly well understood, the HFR data are a substantial resource to improve our current understanding of the circulation in this region.

Harmonic analysis was undertaken to investigate the tidal currents in the region. The FIG tidal pattern is predominantly characterized by semidiurnal constituents, and dominated by M2, S2 and N2 with the diurnal components much weaker (O1 and K1 being the most significant of these). The M2 constituent is the dominant one, with an amplitude between 0.155-0.498 m/s, measured by the HFR system, and 0.205-0.687 m/s, observed by the current meters. Harmonic analysis shows an overall underestimation of tidal current amplitude by the HFR compared to the mooring observations. Root Mean Square Error and Mean Absolute Error better highlight the systematic error between the two datasets.

Phase and inclination have been evaluated with the 95% confidence interval. In particular, M2 phase presents a constant lower value for the mooring, with minimum and maximum error of 1.00° and of 2.20°, respectively. However, at different depths of each location, the phases are similar. As Wright et al. (1999) describe in the amphidromic system, phase decreases from west to east, following a clockwise direction.

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Predicting changes to Scottish Nature Conservation MPA connectivity due to tidal energy device arrays and climate change

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Nature Conservation Marine Protected Areas (NCMPA) have been designated around Scotland for the protection, conservation and restoration of relevant benthic habitats and species. The designation of the NCMPAs took into consideration the ecological 'network' and the biological connectivity between the areas. It is important for NCMPAs to be biologically connected because it prevents genetic isolation and enhances resilience. Planktonic dispersal occurs during the larval phase of benthic species enabling the species to spread and occupy space at distance from the spawning adults. Transport of the pelagic larvae is primarily determined by ocean hydrodynamics including tidal and residual currents, as well as horizontal and vertical mixing. Each species has a pelagic larval duration, during which time the larvae must find suitable habitat to settle.

Both climate change and marine renewable energy have the potential to alter ocean hydrodynamics. As the planktonic phases of benthic species are largely passive and primarily reliant on marine currents for transport, the connectivity between NCMPAs could therefore potentially be impacted. Here we use a particle tracking model driven by hydrodynamic modelling outputs to investigate how connectivity for benthic species at Scottish NCMPAs could be affected in the future due to both climate change and/or large scale tidal turbine arrays.

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Standardizing Biological Modelling of Sea Lice Dispersal

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Are you a student? No

Sea lice are considered the most serious single pathogen of farmed salmon, causing losses, limiting expansion, and spreading to wild salmonids. Therefore sea lice have been a major focus of applied research associated both with salmon aquaculture and with wild salmonids.

An important factor in sea lice management is the planktonic development of larval lice. Planktonic transmission can occur over many kilometers, dependent on both hydrodynamics and lice biology. Understanding this transmission is key to area management of interacting clusters of farms and interaction between farmed and wild fish.

Coupled particle – hydrodynamic models have become a widely used tool to generate information on how transmission occurs, particularly in Norway, Scotland, Canada and more recently the Faeroe Islands.

Although modellers have collaborated closely, different models have been developed for different systems. This can lead to inconsistencies and difficulty in comparing outputs. Therefore a workshop was held, with MASTS support, in Aberdeen (February 2017) with the aim of standardizing approaches, or identifying factors in different environments that require locally specific models. Synergistically, a project has recently begun to model sea lice dispersal in Killary Harbour, Ireland. This aims to use a standarised European model developed in collaboration with Scottish and Norwegian researchers, and with EU funding through NASCO. Standardization is therefore very relevant and strongly supported.

Standardisation is applicable to the modeling methods and to collection of data for validation and applies to both hydrodynamic and particle modelling. However, for reasons of space, in this presentation discussion is limited to the elements of the particle models that represent the sea lice larvae.

Biological processes relate to (a) production, maturation and decay, which are relatively simple rates or times and (b) swimming behavior, which is more complex.

(a) Production maturation and decay processes include egg production and mortality rates and time for maturation

Explicit modeling of egg production is required to model lice numbers. This has not be standardized and substantial uncertainties remain.

Sea lice mortality rate is very sensitive to temperature and salinity, with big declines in lice survival below 29 ppt. However, in full strength seawater a mortality rate of approximately 1% h^{-1} is a reasonable standard rate.

Sea lice larvae mature to become infectious copepodids at a time that depends on temperature; there is good agreement on this relationship. For specific model scenarios a single average maturation time is considered appropriate, e.g. 3.6 d at 10˚C..

(b) Sea lice are only able to swim relatively short-distances, but even this can greatly change distribution patterns relative to passive particles. The simplest modeling represents vertical swimming by maintaining lice near the surface. However, under strong salinity gradients lice may concentrate just below the halocline as this greatly increases their survival. Lice can practice diurnal migration. There is further work required here, and the specific depth lice use has implications for the currents by which they are transported and the formation of concentrated patches, potentially creating relatively high infection pressures at locations distant from lice sources.

The workshop report identifies the requirements for standardised modeling and the Killary Harbour project presents the opportunity to carry this out. Standardisation means that when models are run in different systems differences in outcomes are due to features of the system, not differences in the model.

Acknowledgements

We thank MASTS and all contributors to the Aberdeen workshop. *www.masts.ac.uk/media/36205/nhmsg5-report.pdf*

High-resolution glider observations of tidal flows and frontal dynamics in the northwestern North Sea

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Understanding and predicting the location of seasonal fronts in shelf seas is important for accurately describing regional circulation patterns, for model validation, and for understanding biogeochemical fluxes. A key driver is the mixing caused by tidal currents counteracting the stratification caused by surface heat fluxes and freshwater influence. Here, we discuss the use of ocean gliders to quantify tidal currents and investigate the resulting frontal dynamics. A two-month glider deployment in the northern North Sea repeatedly occupied the JONSIS line, a zonal hydrographic section to the east of the Orkney Islands (0 – 2.23°W at 59.28°N), and provided dive-average current velocities derived from the glider's displacement during each dive. The time series is divided into three spatial bins by longitude, and harmonic analysis is used to determine the amplitude and phase of the M_2 and S_2 tidal constituents in each bin. The amplitude of each constituent decreases offshore, as expected. The phase of each constituent changes little across the section. The offshore decrease in the amplitude of tidal volume transport is considerably less pronounced, an increase in depth largely offsetting the decrease in amplitude. The results are typically within 10% of the amplitude and phase of the M_2 and S_2 tides determined by harmonic analysis of year-long current meter observations from the region, and with predictions of a tidal model. We conclude that gliders may be used to characterise tidal flows in tidally energetic shelf seas. A strong bottom front is observed in the glider temperature and salinity distributions along the JONSIS line. The high vertical and horizontal resolution of the glider data permits the front to be more accurately located than in data from previous ship-based occupations of the section, and the ten repeat occupations provide cross-frontal observations at unprecedented temporal resolution. We use the glider-derived tidal currents to determine whether frontal location is related to the ratio of water depth and the cube of depth-mean tidal speed, as predicted by theory (Simpson & Hunter, 1974). We find that frontal location is consistent in space, but is not well predicted by this theory. Reasons for this, including the influence of horizontal salinity gradients, are discussed, and we compare our observations with output from numerical models. We compare glider occupations with ship-based occupations, and elucidate how we might use gliders to greater effect in future studies of tides and fronts.

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Dispersion and Connectivity – A Regulatory Perspective

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Dispersion and Connectivity – a Regulatory Perspective

As Scotland's principal environmental regulator, SEPA's statutory purpose is to protect and improve Scotland's environment, which includes ensuring compliance with all applicable environmental quality standards (EQS).

Discharges to the marine environment, for example from Sewage Treatment Works, industrial outfalls or fish farms, frequently contain polluting substances at concentrations several orders of magnitude higher than levels deemed to be safe.

Dispersion is the key mechanism by which discharged material is diluted from potentially toxic to acceptable levels. Due to the notorious difficulty in modelling the turbulence that drives dispersion, SEPA has adopted a risk-based approach to assessing the environmental impact of discharges.

For small and/or non-hazardous substances, simple advection-dispersion models based on transport and Gaussian spreading may be adequate. These models offer a very crude approximation of reality so, from SEPA's perspective, it is important that the modelling is conservative such that the effect of the discharge on the environment is not under-estimated.

For more complex dilution studies involving a number of significant discharges (for example microbiological sources near designated bathing waters), numerical hydrodynamic modelling in conjunction with particle tracking or water quality modelling is typically required. For these, field work including dye and drogue studies is usually necessary.

Historically, discharges have been licensed on a case-by-case basis; however, since the implementation of the Water Framework Directive which focusses on the ecological and chemical status of water bodies, a more holistic approach is required.

SEPA has been using particle tracking to derive connectivity matrices and help establish where material present at a given location may come from or end up. This has proved useful in assessing the cumulative impact of multiple fish-farms in a single water body and in identifying locations at risk of the accumulation of benthic impacts.

Results from an investigation into the effects of aquaculture within Shuna Sound will be presented, which suggest that some sites may be affected by medicine from the majority of farms within the water body.

Some test results using the semi-implicit Euler method to integrate hydrodynamic output will also be shown. This yields approximate trajectories without the need for running particle tracking models, and offers the potential of determining larger scale connectivity if applied to output from the Scottish Shelf Model.

Observations and Modelling of Dispersion in Scottish Coastal Waters in Relation to Aquaculture

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The production of farmed salmon is a vital socio-economic activity in remote rural regions of Scotland, and makes a valuable contribution to domestic food production. However, like any farming activity, aquaculture produces waste products and, due to the location of fish farms, these products have to be assimilated by the surrounding marine environment. With the industry planning further expansion over the next decade, the siting of salmon farms in naturally dispersive areas of the coast is becoming more important, and new efforts are being made to quantify dispersion rates in Scottish coastal waters, both to assist in site selection and to improve modelling of the dispersion of particulate and solute waste.

Rates of horizontal eddy diffusion have been estimated at a numbers of sites around the Scottish west coast from both dye release and surface drifter experiments. A selection of those results are presented here. The release experiments took place over typically 2 – 3 hours, providing estimates of the short-term diffusion rates. Results suggest that the short-term diffusion rates are of the order of 0.1 $m^2\ s^{-1}$, which matches the value typically used in models predicting the environmental effects of aquaculture. However, the data also indicate that diffusion rates may increase over time due to the increasing scale of eddies that may affect dispersion, as expected from theory (e.g. Lewis, 1997) and previous observational evidence (e.g. Okubo, 1971, 1974). As models of aquaculture may be required to predict effects of solute medicines for several days following treatment, the accuracy of the models may be improved by taking the increase in diffusion rates with time into account. Further observational work to investigate longer-term diffusion rates is planned.

The observations of diffusion feed into models used by industry to predict dispersion of solute and particulate wastes. Here we compare the predicted dispersion from a particle tracking model (Gillibrand and Willis, 2007) with some of the dye release experiments. The performance of the model is assessed and reasons for discrepancies explored. An innovation incorporating buoyancy into the particle behaviour in the model is described and some exploratory results simulating buoyant plumes are presented.

Finally, some future planned work is described.

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