Farmed Atlantic Salmon (*Salmo salar*) is Scotland’s largest food export with 171kt (Munro & Wallace 2016) produced with an estimated value of £0.64bn. One of constraints to sustainable growth in the sector is the costs associated with controlling the ubiquitous, ectoparasite sea louse (*Lepeophtheirus salmonis*), which is estimated to have doubled since 2009 accounting for 9% farm revenues (Abolofia et al 2017) due to increased medicinal application. As a result salmon farmers are increasingly using cleaner fish such as lumpsuckers (*Cyclopterus lumpus*) and wrasse (*Labridae spp*).

There is a high demand for wrasse with individuals fetching up to £17 per fish. Currently some two-thirds of farms in Scotland are licensed to use cleaner fish with an estimated 1 – 1.5 M (FHI pers. comm.) cohabiting farmed salmon. Due to losses during the production cycles and biosecurity measures, cleaner fish are required to be supplemented on farms during and between cycles. Although there are developments of cultured cleaner fish, with estimated production being some 7t (Munro & Wallace 2016), it is likely that capture caught wrasse will contribute to the supply of wrasse to salmon farms.

Currently, none of the wrasse species used in fish farms are quota species and are not managed. Therefore since 2014 the recording of wrasse is undertaken through vessels being required to complete a FISH 1 form and transactions of wrasse are required to be submitted to Marine Scotland Compliance through the completion of buyers and sellers sales notes. As these forms were developed for all commercial fishing activity as opposed to specifically live wrasse captured, weight is reported per transaction as opposed to number of individuals. Wrasse tend to be recorded under the generic collective “wrasse” species code or the more generic “other demersal species” categorization which may lead to underreporting.

In order to develop an understanding of the fishing activity in Scottish coastal waters a simple analysis of the sales note data was conducted.

Since 2007 the majority of the data entries relate to wrasse caught using traps on the west coast. There have been almost 1150 sales transactions with only 10 pre-dating 2014. Over 120t of wrasse sales have occurred since 2014 which, depending on species composition, equates to between 0.5M – 6M individual wrasse. Last year had the highest biomass recorded at >50t. The median weight per transaction in has declined between 2014 – 2016 from ~101kg to ~27kg whilst the number of transactions has increased from 148 to 624 indicating that practices have altered over this short period.

The dataset demonstrates that the majority of activity takes place outwith the known wrasse peak spawning periods (Skiftesvik et al 2015) with >80% of the biomass caught between August – December which corresponds with the rise in sea lice parasitism on farmed salmon (Murray 2016).

Currently little is known with regards to the potential resilience of each of the wrasse species to commercial exploitation. However, the post spawning demand and size (12 – 24 cm) preference for wrasse by the salmon farming industry, makes it likely that fish are able to mature to a reproductive size and recruitment to take place by larger fish.

Acknowledgments
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References


Tidally averaged mixing parametrization for optimal-detail circulation models of fjords and sea lochs

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The Puget Sound is a fjord on the west coast of the USA near Seattle. It is an important habitat for marine life, but in the last 30 years three species of wild salmon have declined dramatically. This reduction could be explained by the impact of changes in estuarine circulation and bottom up processes on primary production. This context motivates the investigation of long-term changes in circulation due to environmental dynamic conditions and their impacts on plankton.

Our long term goal is to create a new circulation model that runs over decades and to couple it with a bio-chemical model. Here we focus on the development of the physical model. We use a tidally averaged framework to describe the estuarine circulation over a long time-scale. However, this requires us to define tidally averaged eddy coefficients. Here we present a new tidally averaged mixing parametrization for the fjord of the Puget Sound.

This parametrization was established for coastal plain estuaries by MacCready 2007. However, for fjords new constraints arise. For example, due to the deep bathymetry there is a vertical separation between wind and buoyancy-driven effects on the surface layer and tide-driven processes on the bottom layer. Also, the sill at the mouth of the estuary allows additional mixing.

Sutherland et al 2011 created the MoSSea circulation model of the Puget Sound, but only for 2006. It is based on a ROMS simulation with the k-e version of GLS (Generic Length Scale) turbulence closure. We use this high-resolution one year description of the estuarine circulation to study the tidally averaged mixing in relation to environmental forcings.

Our results show a consistent relationship between mixing and tidal velocity, as found by MacCready 2007, at the bottom layer and near the sill. However, the wind stress becomes an important factor for the mixing away from the sills. This dependence of mixing on wind strength shows a route for long-term climate variability to affect phytoplankton population.

References

Insights into the genetic basis of drug resistance of the salmon louse (*Lepeophtheirus salmonis*)

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Caligid sea lice are copepod ectoparasites of marine fish feeding on the mucus, skin and blood of their hosts. The salmon louse (*Lepeophtheirus salmonis*) infects farmed and wild salmonid fishes and represents a major disease challenge for the commercial mariculture of Atlantic salmon. In Scotland alone, preventing or treating sea lice infections costs the industry more than £30 million each year. Control of the parasite at salmon farms involves the use of veterinary medicines as well as an increasing range of non-chemical methods. While resistance has been reported for anti-sea louse drugs including the macrocyclic lactone emamectin benzoate (EMB) and the pyrethroid deltamethrin (DM), little is known about the molecular mechanisms involved. The aim of this study was to analyze the genetic basis of EMB and DM resistance of *L. salmonis* in order to obtain genetic markers of diagnostic value and gain insights into the resistance mechanisms. Reciprocal crosses were performed between two *L. salmonis* strains differing 10-fold in EMB and 140-fold in DM susceptibility. F1 siblings were crossed to produce F2 parasites, which were characterized regarding their drug susceptibility before being sampled for DNA extraction. F2 salmon lice showed a wide range of EMB susceptibilities ranging from fully susceptible to fully resistant. Double digest restriction site-associated DNA (ddRAD) sequencing was used for the discovery and genotyping of genome-wide single nucleotide polymorphisms (SNP). Three QTL regions involved in EMB resistance were identified, suggesting resistance to EMB is multigenic. The inheritance of DM resistance showed a pattern distinct from that observed for EMB. In families derived from a DM resistant P0 dam all F1 and F2 animals were DM resistant while in the reciprocal families no F1 animals and only few F2 animals were DM resistant. Sequencing the mitochondrial genome of three DM susceptible and four DM resistant isolates revealed that resistant *L. salmonis* were carriers of a unique mitochondrial haplotype not found in susceptible parasites. The results provide evidence of roles of maternally transmitted factors in the pyrethroid resistance of *L. salmonis* and suggest a role of mitochondrial genes as determinants of the resistance phenotype. Taken together, SNP markers showing association with EMB and DM resistance were obtained and have the potential to be applied in salmon louse management, supporting fish health professionals in selecting the best treatment and monitoring the success of management measures combating resistance.

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A time series simultaneous equation model for salmon demand and supply: welfare implications of expanding production

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The UK produces the second largest amount (by volume) of aquaculture in the EU, currently dominated by Atlantic salmon (MSEP, 2013). In 2014 the amount of salmon production was estimated in 179,000 ton (Ellis et al., 2016), with a plan to increase it to 200,000 by 2020 (Marine Scotland, 2015). Building on this idea, this research proposes a model to assess economic benefits on producer and consumer and impact of the concentration of the salmon industries on farm-gate price.

Demand and supply are simultaneously modelled using annual time series from 1984 to 2014 by an Auto-Regressive Distributed Lag Model (ARDL) to depict long-run (stationary – non-dependent from time) and short-run (time dependent) effects of salmon consumed in the UK market and the price evolution. Variables used to model the UK salmon consumption are the own salmon price, UK household income, and a price-index of wild fish. Supply models the cost of production via the price of fish oil, labor cost, fuel and electricity prices and a proxy for the concentration of the industry, assuming constant return to scale (we have found that a relative variation in price owing to a unit variation of quantity is close to the unity - 1.047).

Salmon consumption (demand) is inelastic (-0.647), in other words, non-sensitive to the salmon price, showing that salmon cannot be easily substituted. This is also confirmed by the lack of impact of capture fish price on salmon demand. Short-run supply shows impacts of fishmeal (elasticity of 0.468) and electricity (elasticity of 0.321) prices as main drivers of salmon farm-gate price, while labor cost is less relevant (elasticity of 0.287). This means that being equal the amount of salmon produced nearly 47% of price increase can be attributed to feed. The latter result is confirmed by Marine Harvest (2016) that has estimated the UK salmon production cost in £3.39/kg, and feed accounting for 41% of this cost. Moreover, industry concentration is insignificant, showing that it is not influencing the competitive market price (dominated by bigger producers like Norway and Chile). Finally, the supply shows that the real price recorded in the market is very close to the equilibrium (steady state) price modelled, but that a deviation from this equilibrium, caused by a shock in the production factors, cannot be easily corrected (it takes 3.5 years to the price to back to the equilibrium). In ecological words, the market dynamics shows resistance, but limited resilience.

The results of this model support the salmon production expansion by a greater use of production factors and consequently at higher costs. The targeted amount of 200,000 ton can be reached if the industry raised the production by 11.7% over the 2014 production (179,000 ton). The farm-gate price is expected to rise from £4.67 (in 2014) to £5.22/kg (2021), keeping constant the cost of the production factors, and the internal consumption to drop by 5.46%, 7,200 ton less than the 2014 figures (132,500 ton). This change in price would generate a reduction in benefits for the UK consumers of £81.1m that would be transferred to the producers generating a net benefits for society of £9m.

Acknowledgements

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An inexpensive method for larval visualisation

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Are you a student? Yes

Many benthic marine species have small, pelagic larvae as early life stages, and they rely on larval recruitment for their population to persist. Knowledge of population connectivity therefore requires an understanding of the larva’s dispersal from spawning to settlement locations, and is key in managing marine populations1.

Benthic invertebrate larvae were long thought to be passively carried by currents, due to their weak swimming capabilities. However, in recent times, studies have shown that larvae can influence the intensity and direction of their dispersal through vertical migrations, enabled by slow vertical current velocities relative to larval swimming and sinking capabilities2. For instance, larvae modify their vertical position in the water column to feed and avoid predators, and it is also thought that they orient themselves in the water column in such a way that there is a higher probability of survival through physical transport to a suitable environment3.

Hydrodynamic modelling, coupled with particle tracking, has emerged as a powerful tool to include larval behaviour in simulations of larval dispersal. However, an accurate quantification of benthic invertebrate’s larval behaviour is often difficulted by their small size. Thus, larvae have been most commonly observed under microscopes, which strongly limits the vertical size of the container in which they can be observed, or with expensive cameras and video equipment.

Here we present an inexpensive methodology for larval visualisation, using a USB microscope. This method allows to visualise and record the vertical movements of larvae in tall water columns (up to ~70 cm) in both light and darkness. We discuss its potential and limitations based on a case study with Ostrea edulis larvae, and provide detailed account on aspects that should be considered when using this methodology.

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References

Abstract – MASTS Annual Science Meeting

Title: Additional insight on potential reallocation scenarios for artisanal fisheries from a spatial Bayesian belief network

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Without the implementation of careful management plans, new marine activities emerging from Blue Growth initiatives will increase competition for maritime space. In order to make informed decisions about the sustainable use of marine area, managers need to analyse and visualize spatially explicit environmental and socio-economic data to determine where user conflicts are or might emerge, and develop alternative management scenarios. GIS-integrated Bayesian belief networks (BBN) can be used to incorporate information from different sources, as well as different types of information, such as empirical data and expert judgment. Here, we use a BBN to provide additional evidence for the potential reallocation of artisanal fishing effort due to the introduction of a new, non-take fishing area: a proposed, offshore aquaculture site along the Basque Coast. This approach combines discrete, operational fisheries data, continuous environmental data, and expert judgment to create continuous coverage suitability maps for métier fishing activity. Results obtained from the BBN output indicate alternative fishing locations for individual metiers based on environmental suitability, past revenue, and past fishing presence. This case study shows that BBNs may be a relatively simple, yet effective tool for decision makers seeking to resolve user conflicts from a marine spatial planning perspective. Future iterations of this model should explore different discretization methods, as the model results are highly sensitive to these changes.
Further advances in using broadband sonars for sizing fish with and without swimbladders and the detection and survey of demersal fish

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Fisheries acoustics (Simmonds and MacLennan 2005) is a branch of applied biological oceanography aimed at developing and using active hydroacoustic (sonar) systems for the detection, quantification & qualification of aquatic life. The techniques have widespread applications, most notably in the use of surveys of marine resources such as sardine, herring, and anchovy; as well as cod and krill. They are also used to study marine ecology. Acoustic surveys currently provide fisheries-independent abundance indices for the assessment of many pelagic species in the Northeast Atlantic, including North Sea herring and blue whiting.

Current practice is based on the use of single beam, narrowband, multi-frequency echosounders, which enable some identification of the backscattered signal (Fernandes 2009). Further improvements come through collecting data with broadband systems which transmit a signal which sweeps across a band of frequencies. Here we investigate such a broadband system, EdgeTech, a sub-bottom profiler which has been adapted to operate as a broadband echo sounder (Stanton et al. 2010). At low frequencies (1-20 kHz) the resonance peaks of fish with swim bladders may be captured. For fish which do not have a swim bladder, over a wide band, the spectrum rises to a turning point as the physics of the scattering process changes from Rayleigh to geometric scattering. These features may allow for sizing of fish (Holliday 1972).

Following data collection we present some preliminary results in the next step towards measuring fish size remotely. The analysis is based on the mackerel surveys completed in October 2015 and November 2016 and a herring survey in July 2017, all in the North Sea and North East Atlantic Ocean region.

The application of broadband acoustic technology has the potential to transform the way we study marine ecosystems. The higher spectral and spatial resolution, giving an enhanced ability to identify and size organisms, can be applied to several other fields including behavioural studies, e.g. of fish and other objects close to underwater renewable energy sites; and ecological studies of predator and prey.

We hope that in due course of the project we will be able to use the broadband system for echo counting of fish at sea where the method has suffered from the inadequate resolution of conventional systems. The use of the higher spatial resolution of broadband systems has potential to open up the acoustic counting technique for demersal fish which swim close to the bottom such as cod, saithe and hake. Demersal fishermen could use such information to make better informed decisions as to where and when they fish, avoiding fishing in areas where choke species (Baudron and Fernandes 2015) occur.

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References


Habitat enrichment and aggression in larval lumpfish (*Cyclopterus Lumpus*)

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Are you a student? (Delete as appropriate): No

Lumpfish (*Cyclopterus Lumpus*), is a distinctive looking fish with a ventral sucker that allows it to cling to surfaces.

With increased use as a cleaner-fish in salmon aquaculture, and efforts to close the breeding cycle in captivity as an alternative to harvesting wild eggs (e.g. see Imsland et al. 2014, Powell et al. 2017), it is essential to be able to rear the early life stages in habitat that suits their behaviour and enhances survival. Particularly, larvae make use of surfaces for sucker adhesion and this behaviour is linked to aggressive interactions including fin biting that may be a vector for disease transmission and increase stress.

We monitored larval lumpfish behaviour by video to see what impact variations to tank habitat had on aggressive interactions.

Methods

Six tanks (0.4m diameter, 1m height, 1300L volume, black fibreglass smooth surface for adhesion and internal cone of similar material to increase hard surface area) were set up with ~70,000 larval lumpfish (average weight 0.006g) in a flow through system with treated sea water.

Different habitat niches: side, cone, bottom in control tanks and additionally in enriched tanks enrichment and local area around enrichment within each tank were sampled by taking 5min videos from 52 days’ post hatch for five days (GoProTM Hero 3 in waterproof housing).

An ethogram of behaviours in four categories of resting, moving, antagonising and others was produced. Video was split into 10 second clips (GroPro Studio). This allowed calculation of an antagonism index: aggressive interactions per fish per 10s on each habitat niche.

Niche-specific antagonism indices were combined to produce overall estimates of aggressive interactions for enriched and non-enriched tanks.

Results

Antagonism index depended on both local density of the larvae, and the niche they were settled on.

Enrichment reduced overall tank aggression and was observed to be a favourable niche that added variation to the tank to which the larvae reacted positively to. The effect of enrichment was to alter both the behaviour of lumpfish towards each other at a given density as well as to redistribute them within the tank.

It was necessary to consider the different habitats available in the tank rather than just to quantify behavioural interactions at a tank level, video was essential to record both local density as well as to count behaviours. The behaviour and physiology of this species point towards it requiring specific husbandry conditions at all life stages.

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Quantifying extinction risk of data deficient European marine fish species

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The IUCN recently published a red list of European marine fish species (Nieto et al 2015). The report examined more than 1000 species of which around 8% were considered to be threatened according to IUCN criteria such as reductions in abundance and geographical range. However, around 200 of the species considered had insufficient data to make a status determination and are simply classed as “data deficient” (DD). In a worst case scenario, if all DD species were judged threatened, IUCN suggest nearly 25% of all species would be threatened.

An analysis by Fernandes et al (2017) showed that conservation status was associated with size and biological class. In this paper we develop a model to predict the probability, θ, of a species being threatened based on size, depth and biological class. Higher risk is associated with larger size, shallower depth and being of class Chondrichthyes. These traits allow the likely conservation status of DD species to be assessed and hence reduce the upper limit of uncertainty on the percentage of threatened species from 25% to 9%.

In an extension of the model we estimated a probability threshold, θ*, that best assigns each DD species to a threatened category, i.e. when θ>θ*. The classifier identified an additional 42 threatened species. These are mainly large sharks living on the continental shelf where θ is very large. However the model has a high rate of false positives for species with a value of θ close to θ* and hence are likely to be miss-classified. These are the species that the model identifies which would benefit most from further research to establish their true conservation status.

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