# The interaction of hydrodynamic resolution and sea lice behaviour on dispersal dynamics

## Introduction

Lagrangian particle tracking simulations are extensively used to predict the dynamics of the planktonic stages of sea lice, with particular emphasis on transmission from and between salmon aquaculture farms. These models have incorporated much biological complexity, including temperature-dependent growth, salinity-dependent mortality, phototactic swimming, and avoidance of low salinity and high turbulence. However, the simulations at their core rely on hydrodynamic models, and no degree of sophistication of the biological model will overcome a mismatch between real-world hydrodynamics and those used in the model.

Here, we assess the impact of hydrodynamic model resolution on predicted sea lice dynamics. We evaluate the interaction between temporal and spatial resolution of the hydrodynamic model with the uncertainty and variability in lice sinking and swimming behaviours. We simulate lice dynamics in Loch Linnhe, a well-studied sea water loch in western Scotland with developed salmon aquaculture, as well as topographical features that generate dramatic depth-dependent tidal variation in salinity, temperature, and velocity.

## Methods

### Study area

Some background and detail about Loch Linnhe. Relevant aspects include the aquaculture development, topography with particular emphasis on the Corran narrows, the temperature/salinity gradient, and tidal effects on temperature, salinity, and velocity. To align with empirically collected data (see below), we focus on a (series of?) tidal cycle(s) between 1 Nov and 8 Nov.

### Hydrodynamics

The low resolution model, representing the cutting edge for use at regional extents, was the WeStCOMS model. While the domain encompasses western Scotland including the Outer Hebrides, we focus only on Loch Linnhe, categorizing any lice that disperse beyond the study boundaries as ‘emigrants’. The WeStCOMS model is an FVCOM model that uses an unstructured triangular mesh, such that mesh elements are smaller near the coast or complex topographical features, with 10 vertical layers with depths dependent on the bathymetric depth. Calculate some summaries within Loch Linnhe related to element size.

A high resolution model was developed within Loch Linnhe and is nested within the WeStCOMS model. This model includes increased horizontal and vertical resolution to better capture details of water movement that are averaged over in coarser resolution models like WeStCOMS. It also uses an unstructured triangular. mesh, with 30 vertical layers distributed between the surface and the seabed.

Each model was run at two temporal resolutions, with outputs every hour to represent a standard temporal resolution, and every 5 minutes to represent a high temporal resolution.

We also used an empirical dataset that can be described here.

### Sea lice model

Biotracker has been used in several publications. We used a version of this updated to include 3-dimensional dynamics. Particles represent densities of lice rather than individuals, and move horizontally based on water currents and diffusion. Vertical movement is determined by water currents, diffusion, and lice behaviour, such that they sink in response to low salinity or high vertical turbulence, swim in response to light in the absence of sinking triggers, and are passive elsewise. Development is based on temperature, though with a short temporal span it is largely irrelevant here and we can probably just focus on a single stage, with the range of swimming speeds encapsulating the difference between stages. The mortality rate is dependent on salinity, with lower salinity causing increased mortality.

Particle release options:

* Frequency
  + Every 3 hours (even division for both time resolutions)
  + Single initialisation
  + (depends on timespan)
* Vertical distribution
  + Surface or arbitrary depth
  + 3D distribution with uniform spacing (constant density, lower absolute numbers in shallow water)
  + 3D distribution with proportional spacing following bathymetry (denser in shallow water)
* Horizontal placement
  + Aquaculture farms (irrelevant here I think)
  + Subset of mesh element centres or nodes
  + Uniform grid

The goal is not to predict connectivity, but to describe how the model parameters affect the distribution and movement of lice.

Biotracker issues

* Density is updated hourly regardless of time resolution. It’s implemented in a way that would make it very complicated, so consider it one piece of consistency across the two. Also might not really matter if we aren’t focussed on density
* Time translations will need to be part of post-processing. There are way too many mis-matches between the hydro files and the code as well as dependencies in the code to try to set up a different time resolution internally. Max output (mostly) files with 24 time steps, translating to 256 per day, or 337.5s per step. Dt is set to this in run parameters. Output is listed as ‘hours’ when what it means is ‘337.5s’. It’s easier to correct the dates and times in R than reformatting all of the code and hydro files. One consequence is that I still need to rename the hydro files with dates in their names.
* Biotracker interpolates between entries in the hydrodynamic files (stepsPerStep = 30 by default). Should this stay the same for the 1 h vs 5 min runs?
* Mortality: simple option is to implement once per hour, more complicated is to re-calculate salinity equation to scale to 337.5s.

### Sea lice parameters

Differences in the underlying physics of the modelled hydrodynamic landscape may interact with the modelled behaviour. There is a large amount of variation in the swimming and sinking speeds used in the literature. Unfortunately, Brooker 2018 misreads Gravil 1996, dramatically overestimating swimming speeds. Even with a correct calculation, the estimate from Gravil for copepodids is at least an order of magnitude faster than most others. I think it is reasonable to use the range from Johnsen 2016 for slow, median, and fast swimmers (0.001, 0.0005, 0.0001), which is approximately in agreement with recent data from Helena.

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| Simulation parameter | n | Values |
| Spatial resolution | 2 | WeStCOMS, Max’s high-res |
| Temporal resolution | 2 | 1 hour, 5 min |
| Lice swim/sink speed | 4 | 0, 0.001, 0.0005, 0.0001 m/s |
| Lice sink triggers | 2 | salinity, salinity + turbulence |

Behavioural parameters:

* Swimming speed (m/s)
  + cover plausible range – there is an absurd range of values across the literature, which is only partly due to a misunderstanding in a review (Booker 2018 of Gravil 1996).
  + 0, min, median, max
  + copepodid
    - ~~0.0214~~ (Brooker 2018, Gravil 1996)
    - 0.012 (Gravil 1996 calculated)
    - 0.0005 (Johnsen 2014, Kiorboe 2010)
    - 0.0002 (Helena pers. comm.)
    - 0.001 (Johnsen 2016 – ‘fast’ swimmers)
    - 0.0001 (Johnsen 2016 – ‘slow’ swimmers)
  + nauplius
    - ~~0.0125~~ (Brooker 2018, Gravil 1996)
    - 0.00019 (Gravil 1996 calculated)
    - 0.0005 (Johnsen 2014, Kiorboe 2010)
* Sinking speed
  + cover plausible range
  + 0, min, median, max
  + Follow Johnsen 2016, assuming identical swimming and sinking speeds
* Light trigger
  + Ignore – compare day/night, which is integrated into swimming speed (0 = night)
* Salinity trigger
  + Sandvik 2020 found best performance in Norway when sinking was probabilistic between 31 and 23, where they assumed a linear increase in pr(sink) from 0 to 1. This was compared to thresholds at 20 and 25.
* Turbulence trigger
  + Constant (on/off)

### Simulation scenarios

We performed simulations across 5 landscapes (low-1h, high-1h, low-5min, high-5min, empirical) crossed with 4 swimming-sinking speeds (0, slow, median, fast), and [2 sinking triggers (salinity, salinity + turbulence)] for a total of 6[7] x 5 = 30[35] sets of simulations.

### Outputs

The relevant output depends on the precise formulations of the questions we’re asking. Possibilities include:

* Quantities
  + Lice density
  + Vertical distribution
  + Up- vs. down-loch velocities
  + Proportion of up- vs down-loch particles
  + Sinuosity (Total travel / shortest path displacement) – would need to account for different timescales (more points = longer total travel)
* Format
  + Maps of mean/median/sd/CV per element
  + Overall mean/distribution
  + Mean/median/sd within buffer of front (requires mapping the front each timestep, creating a buffer, and subsetting particles within the buffer)

Summaries of depth and density may be sensitive to starting conditions and the amount of time that has passed since lice were released (i.e., hourly release at 1m depth will bias depths toward 1m). This is obvious, but I’m writing it so I don’t forget.