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

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## 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 single (?) tidal cycle 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. The mortality rate is dependent on salinity, with lower salinity causing increased mortality.

Particle release options:

* Frequency
  + Hourly
  + Single initialisation
  + (depends on timespan)
* Vertical distribution
  + Surface or arbitrary depth
  + 3D distribution with uniform spacing (constant density)
  + 3D distribution with proportional spacing following bathymetry (denser in shallow water)
* Horizontal placement
  + Aquaculture farms (irrelevant here)
  + Mesh element centres or nodes
  + Uniform grid

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

Biotracker updates

* Add run parameter for hydro timestep, default to hourly; could change to get .nc dim
  + int currentHour = int currentTime = double Particle.startTime
  + used throughout as iterator
* RunProperties.recordsPerFile1 is set to 25 by default; used in readHydroFields
* dt = 3600 is hard coded in a couple places
* elapsedHours is used for Particle.getReleaseTime to set status
* stepcount iterator is also tied to hours via pstepsUpdater.
* elapsedHours takes into account dt. It’s currently hard coded as += subStepDt/3600.0, which scales it to hours. subStepDt = rp.dt / rp.stepsPerStep
* In theory, could set rp.recordsPerFile1, rp.dt, and update the iterator max to recordsPerFile1-1 instead of 24
* pstepsInterval is based on stepcount, which is based currentHour, which should be renamed
* Start a branch for time resolution – rename iterators since ‘hour’ doesn’t necessarily apply. Also, steps, substeps, etc is very confusing.

### 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
  + copepodid ~ N(0.001, 0.0003) m/s
  + nauplius ~ N(0.0009, 0.0001) m/s
* Light trigger
  + Ignore – compare day/night, which is integrated into swimming speed (0 = night)
* Salinity trigger
* Turbulence trigger

### 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 7 x 5 = 35 sets of simulations.