A project supported by the European Union's INTERREG VA Programme,
managed by the Special EU Programmes Body (SEUPB).

Report for Collaborative Oceanography and Monitoring for Protected Areas and Species (IVA5015)

Deliverable T5.3.1
Full release of connectivity matrices for a range of sites and species behaviours

December 2019

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Executive Summary

Methods were developed to enable marine connectivity calculations to be made using a combination of the best available model outputs covering the INTERREG VA region. This involved adaptation of particle tracking code to accept multiple hydrodynamic inputs and making automatic selection of relevant velocity information for particles within overlap areas. Pre-processing was developed in order to utilise output in multiple formats (FVCOM for the Scottish west coast, and ROMS for the larger Irish domain). Particle trajectories were recorded, in addition to “arrival” at suitable habitat sites, and post-processing carried out in order to estimate connectivity. A range of potential species were identified during workshops early in the project. As exemplars of the modelling approach, particles and habitats representing langoustine (Nephrops Norvegicus L.) and Horse mussels (Modiolus modiolus L.) are considered here.

Outputs are freely available from: https://thredds.sams.ac.uk/thredds/catalog/connmodel/catalog.html.

Contents

1. Input data

Hydrodynamic model outputs from two sources were used in this study.

The first set of model outputs used were those from "WestCOMS", an implementation of FVCOM (Chen et al. 2013) developed at the Scottish Association for Marine Science (Aleynik et al. 2016). This uses an irregular triangular mesh to represent the Scottish west coast at a variable horizontal resolution, as fine as 130 m in the most detailed areas. This allows definition of the complex coastal features such as islands and narrow channels the make up this region, and contain many important habitat features. WestCOMS v1 has been run continuously to provide hindcasts and forecasts since June 2013. A switch to a new version (v2) with an expanded domain was made in April 2019. The WestCOMS domains are shown in *Figure 4*.

The second set of model outputs used were derived from an implementation of ROMS, covering the North-East Atlantic shelf ("NEA ROMS"), including the coast of Ireland (Dabrowski et al. 2014). This model uses a curvilinear grid with a larger horizontal resolution than WestCOMS, but has a much larger spatial domain (*Figure 2*). Simulations have been carried out in hindcast and forecast since 2013.

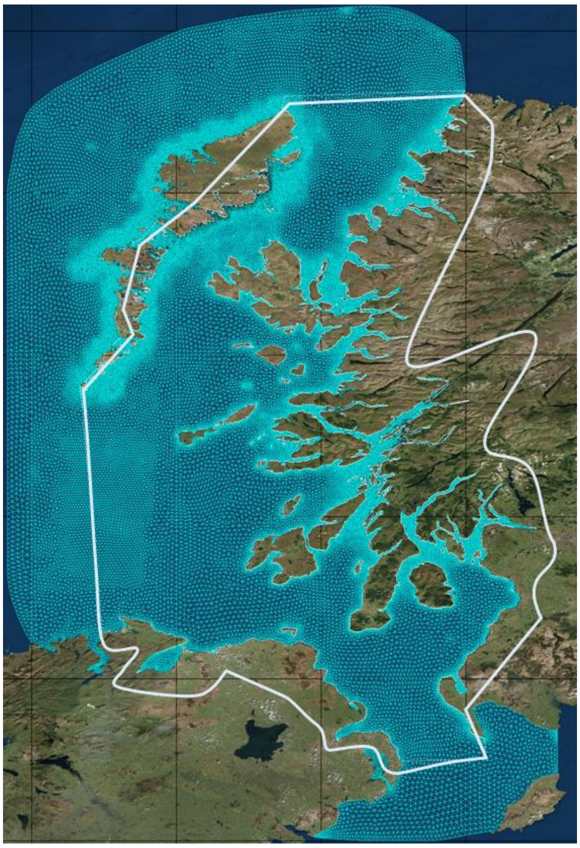

Figure 1: WestCOMS v2 hydrodynamic model mesh. The boundary of WestCOMS v1 is indicated by the solid grey line.

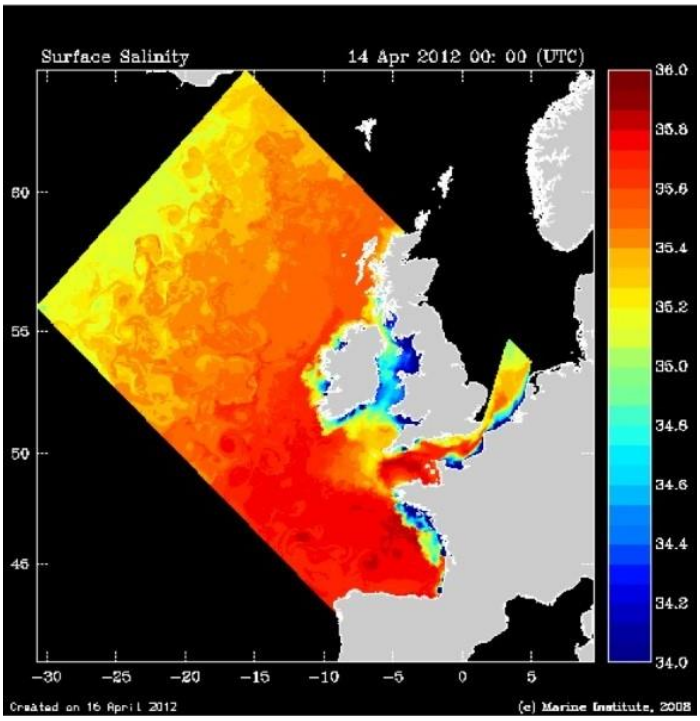

Figure 2: ROMS North East Atlantic domain.

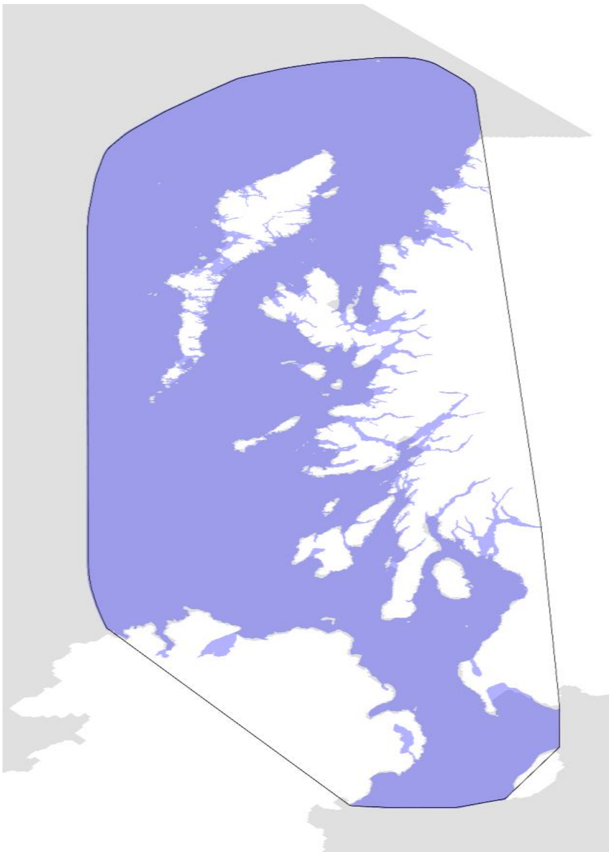

Figure 3: WestCOMS v2 domain (mauve) overlaid on NEA ROMS domain (grey), indicating the added detail in specific areas close to the coast.

2. Pre-processing

In order to use the two different types of model output for particle tracking purposes, it was necessary to harmonise the formats of the data structures.

Outputs from the ROMS model come in two different forms. Operational model outputs covering the last month are publically available on a web server (http://milas.marine.ie/thredds/catalog/IMI_ROMS_HYDRO/NEATLANTIC_NATIVE_2KM_40L_1H/ANALYSIS/catalog.html). These files are individual hourly fields covering the full extent of the NEA ROMS domain, with 40 vertical levels. A second form of the data is a subset that has been prepared by the Marine Institute for SAMS to use as boundary forcing data. This has a smaller spatial domain (but still sufficient to cover the relevant INTERREG VA region), but retains vertical resolution, and is archived by SAMS at 3 hourly resolution (as individual files).

Scripts were developed to enable:

a) Arbitrary spatial sub-setting of the NEA ROMS domain grid, and generation of a triangular mesh representing the same domain.
b) Aggregation of 1-hourly files from the public server to daily files with reduced vertical resolution, including interpolation onto the triangular mesh
c) Aggregation of 3-hourly files from the SAMS archive to daily files with reduced vertical resolution, including temporal interpolation between records to produce fields with hourly resolution, and spatial interpolation onto the triangular mesh.

An example model domain subset is shown in *Figure 4*. A triangular mesh representation of the archived NEA ROMS domain is shown in *Figure 5*, indicating the identification of coastal and open water boundary nodes, and showing a close-up of a portion of the Scottish coast.

3. Particle tracking

Particle tracking code (https://bitbucket.org/tomadams1982/biotracker/) has been developed at SAMS, and previously used to model the spread of various organisms with pelagic larval stages (Adams et al. 2014, 2016).

Under the COMPASS project, the code was adapted to allow the processing of hydrodynamic model output from more than one source, allowing particles to transfer between different spatial domains. This means that, for example, high resolution outputs can be used in areas where they are available, with lower resolution outputs beings used as a secondary option outside the high resolution domain. In the case of the simulations presented here, WestCOMS domains were used as the primary hydrodynamic field (due to their higher resolution in coastal waters), with NEA ROMS outputs being used outside the WestCOMS domain.

Additional capability to represent vertical behaviour of particles was implemented within this project, including swimming, sinking and diffusion.

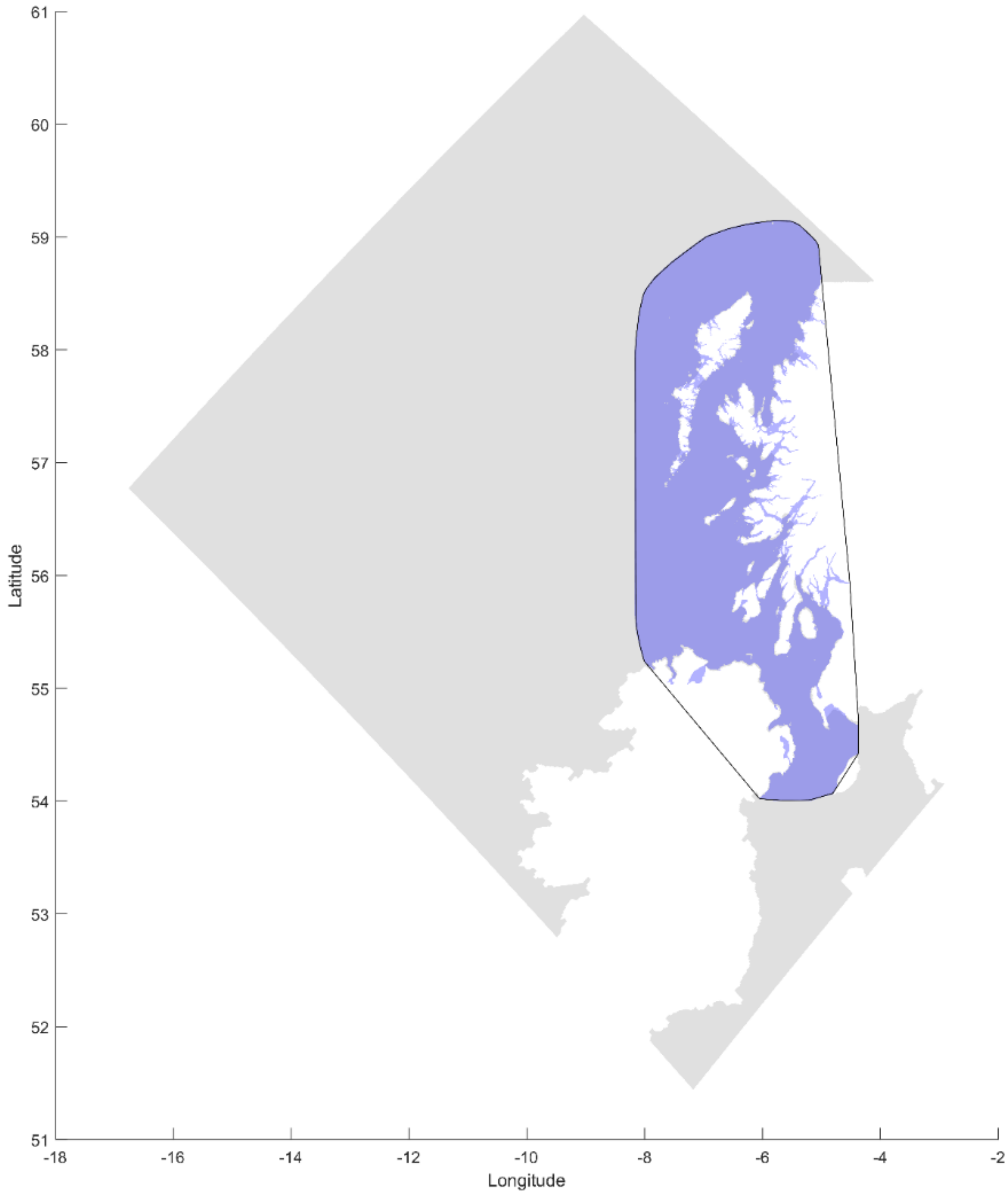

Figure 4: Example model domains, showing a subset on the Irish ROMS domain created using a processing script (grey) and the original Scottish FVCOM domain (mauve).

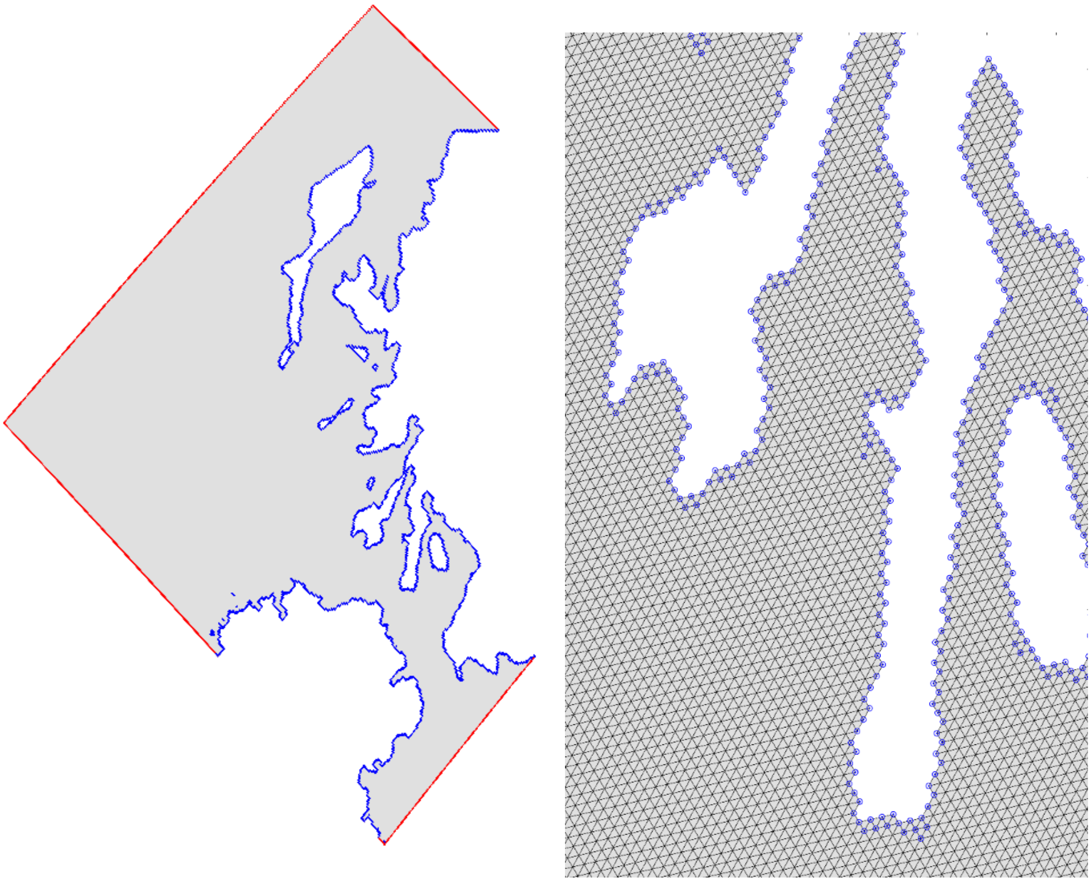

Figure 5: Pre-processing of ROMS model outputs, placing both models on a common (triangular) grid format. The domain here is the subset supplied to SAMS which has been archived since 2013.

4. Species

The dispersal of two species was considered. In terms of larval dispersal, the habitat and larval characteristics are both of interest.

4.1 Langoustine (Nephrops Norvegicus L.)

The langoustine is a key fishery species in waters within the INTERREG VA region, which occupies burrows in muddy seabed sediments.

Nephrops stocks are split into "Functional Units", which are used for the purpose of stock management. These are detailed on the Marine Scotland NMPi website, in conjunction with predictive mapping of suitable habitat locations (http://marine.gov.scot/maps/334). This predictive mapping is based upon modelled extent of muddy sediment in Scottish and adjacent waters, and Vessel Monitoring System (VMS) data from the nephrops fishing fleet. Functional units and habitat areas are shown in *Figure 6*.

Nephrops has a larval duration of between 1-2 months, hatching in May-June (https://www.marlin.ac.uk/species/detail/1672). It potentially has quite a complicated larval behaviour (Phelps 2015), with stage dependent variation in diel vertical migratory behaviour. Stage durations vary according to temperature. For baseline simulations, Phelps used particles with a fixed depth of 24 m, which we followed in our simulations. For comparison, we also ran simulations using particles which had a fixed position at the water surface.

Phelps implemented more complex larval behaviour, consisting of an initial phase where larvae migrate towards the surface, followed by a phase where diel vertical migration (DVM) takes place, and finally a phase where particles sank to the seabed. Another study (Marta-Almeida et al. 2008) implemented and compared a range of behaviours: i) top 5 m ii) top 50 m iii) top 200 m + DVM iv) top 400 m + DVM. These behaviours have not been implemented to date.

Based on predictions of the relationship between development time and temperature (Marta-Almeida et al. 2008), we assumed a pre-settlement phase duration of 40 days (equivalent to a temperature of 10 °C), followed by a settlement window of 10 days. If larvae passed over suitable habitat within this window they were assumed to be able to settle there.

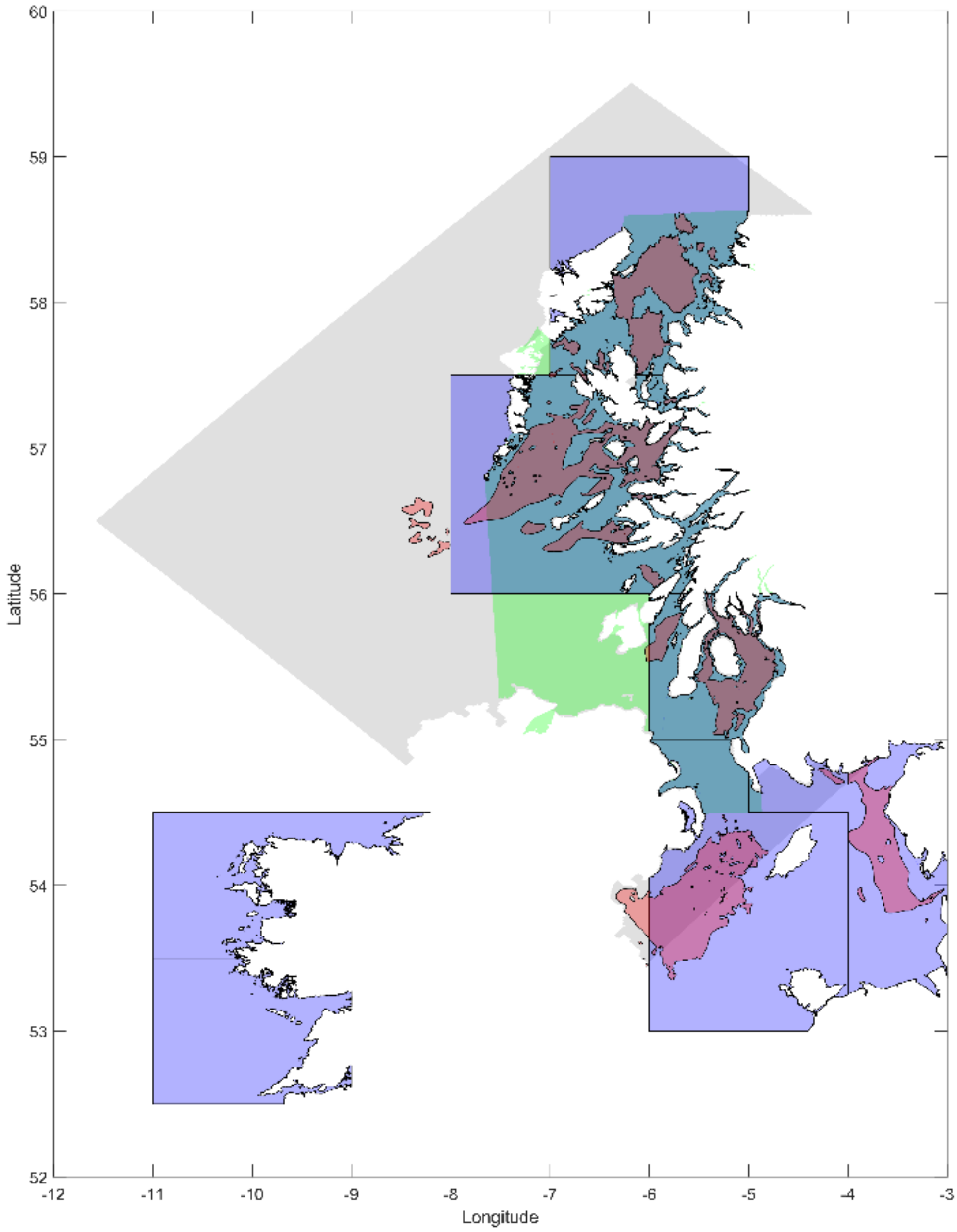

Figure 6: Nephrops functional units (mauve) and predicted habitats (pink) superimposed over model domains.

4.2 Horse mussel (Modiolus modiolus L.)

Horse mussels are a reef-forming bivalve mollusc, which generally occupy coarse sediments between 5 and 70 m in depth, although can also attach to rock (https://www.nature.scot/landscapes-and-habitats/habitat-types/coast-and-seas/marine-habitats/horse-mussel-beds). They are of conservation interest due to their ability to form beds in otherwise featureless environments. These beds provide habitat for a wide range of other organisms, but can be vulnerable to damage, and struggle to reform following disturbance (http://archive.jncc.gov.uk/default.aspx?page=6020).

Habitat locations for this study were obtained from NBN Atlas (https://species.nbnatlas.org/species/NBNSYS0000188548), consisting of point presence observations (*Figure 7*).

Horse mussels spawn in spring and early summer, and have a larval duration of 38 days to 2 months. A previous study implemented a settlement window 30-40 days (Gallego et al. 2013).

In terms of larval behaviour, a range of characteristics have been observed. Some larvae sink in turbulence, in particular when they are in late stages (juveniles sink only at highest turbulence), and regardless of light levels. 16% of juvenile larvae swim vertically upwards with speed 3 mm s^{-1}. However the majority of larvae "hover" at all life stages (Fuchs & DiBacco 2011). Larvae may settle in response to sensing water exhaled by adults (Dinesen & Morton 2014).

For our simulations, a pre-settlement phase of 30 days was implemented, followed by a settlement window of 10 days. Again, if larvae passed over suitable habitat within this window they were assumed to be able to settle there.

5. Simulations

For nephrops, 1000 randomly generated points were placed within each functional unit or element of predicted habitat. Points lying outside of model domains were removed at the beginning of the simulation. Simulations were run using a start date of 01/04/2019, releasing i) 1 particle per site per hour for 24 hours (to average the effect of tidal movements at moment of release), and ii) 1 particle per site per hour for 7 days. For each case, simulations with fixed depth particles at the surface and at 24 m depth were carried out.

For horse mussels, particles were released from each identified habitat location within the model domain, using the same collection of release dates, particle vertical behaviours, and release schedules.

Successful dispersal between two release points was deemed to have occurred when a particle released from one site passed near to another release site, with a default range of 500 m being used. A range of 2 km was also tested for horse mussel simulations.

Connectivity between each possible pair of habitat sites was estimated by summing the density of all particles successfully travelling between two sites, at the moment that they reached the destination site, and dividing by the number of particles released from the source site, producing a probability of dispersal between each specific pair of sites. For nephrops simulations, connectivity values were aggregated by habitat area or functional unit ID, depending on the simulation.

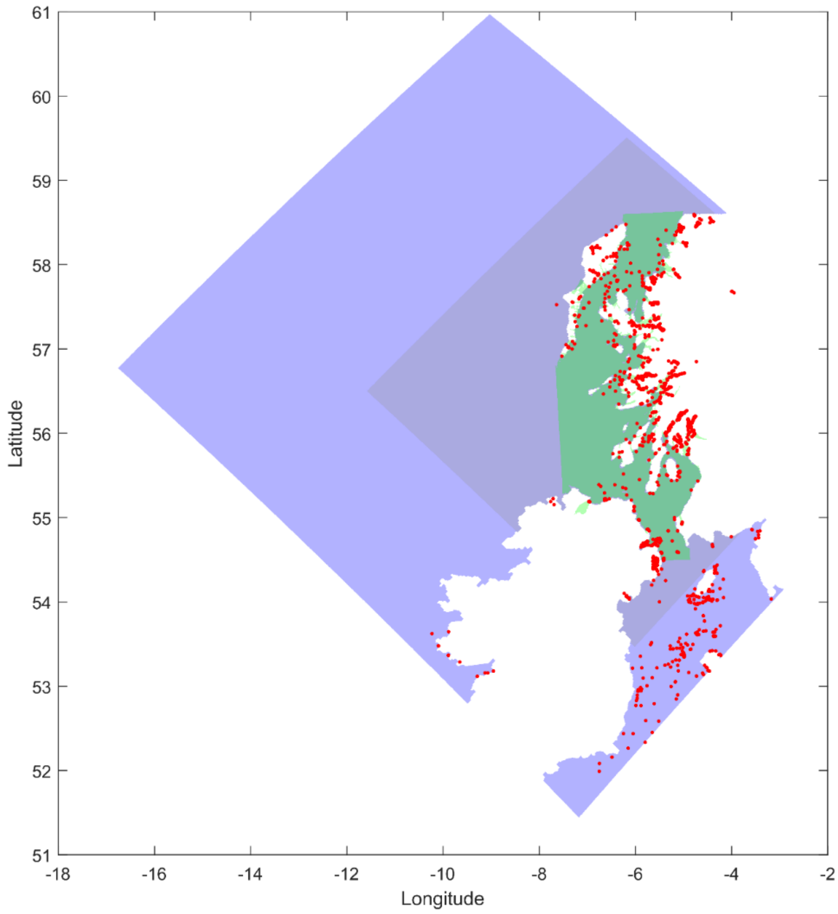

Figure 7: Horse mussel habitat locations within the study region

6. Outputs

Output files are named in the format "connectivity_SPECIES_SITES_BEHAVIOUR_SIMULATIONDATE.nc", for example: "connectivity_modiolus_Habitat_Surface_20190401.nc". SIMULATIONDATE is the numerical date presented as YYYYMMDD.

Files contain several variables:

- ID (release site name/ID)
- lon (release site longitude)
- lat (release site latitude)
- time (simulation start date in modified Julian days)
- Times (simulation start date YYYYMMDD)
- c (connectivity table, listing all predicted non-zero connectivity values [source index, destination index, connection probability])
- nS (number of source sites for each site)
- nD (number of destination sites for each site)
- sS (sum of source connectivity for each site – "influx")
- sD (sum of destination connectivity for each site – "outflux")

Examples of outputs for nephrops habitat and functional units are shown in *Figure 8* and *Figure 9*, with shading indicating the estimated values for each independent unit.

7. References

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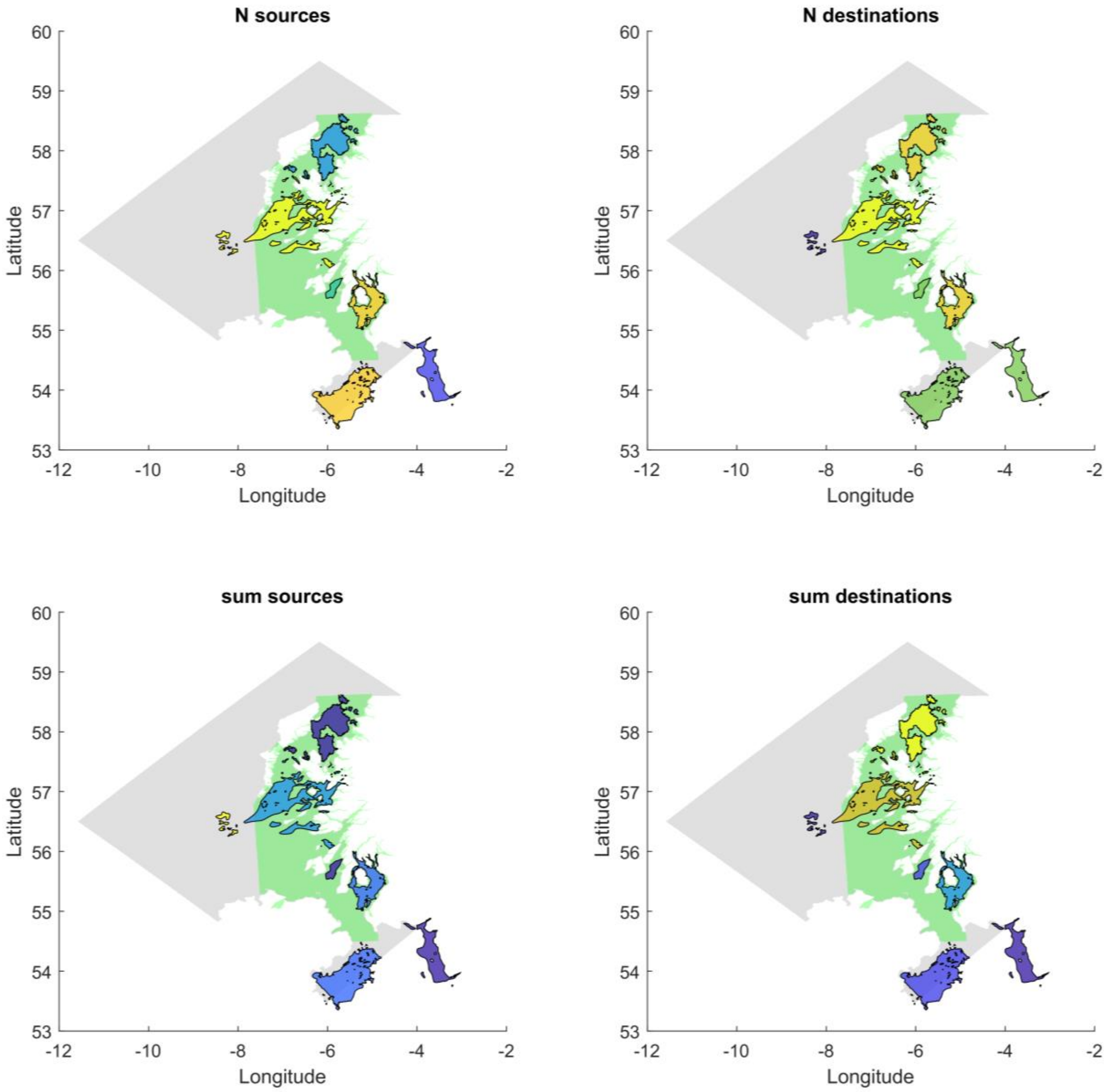

Figure 8: Connectivity metrics for nephrops habitat areas (first arrival only) (April-May 2019) (yellow=high, dark blue=low).

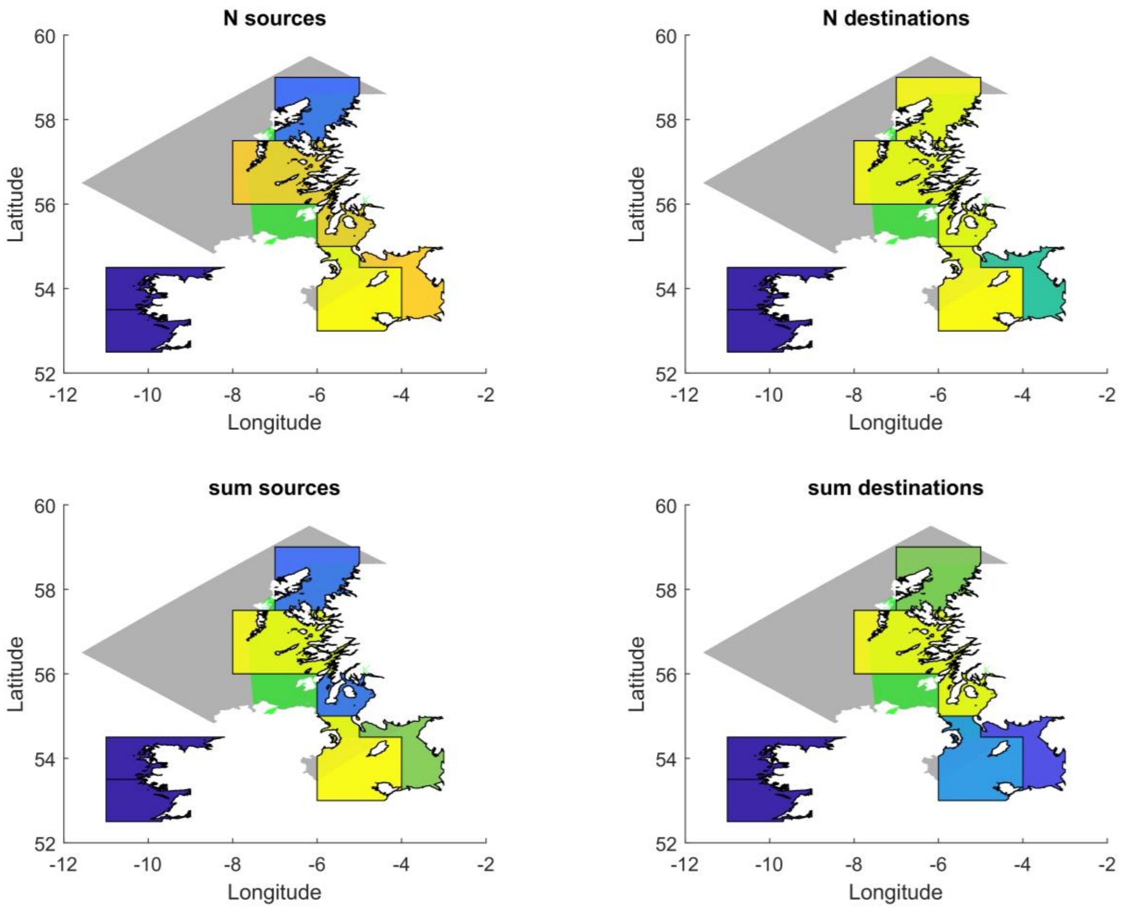

Figure 9: Connectivity metrics for nephrops functional units (April-May 2019) (yellow=high, dark blue=low).