Loch Aline Oyster Larvae Modelling

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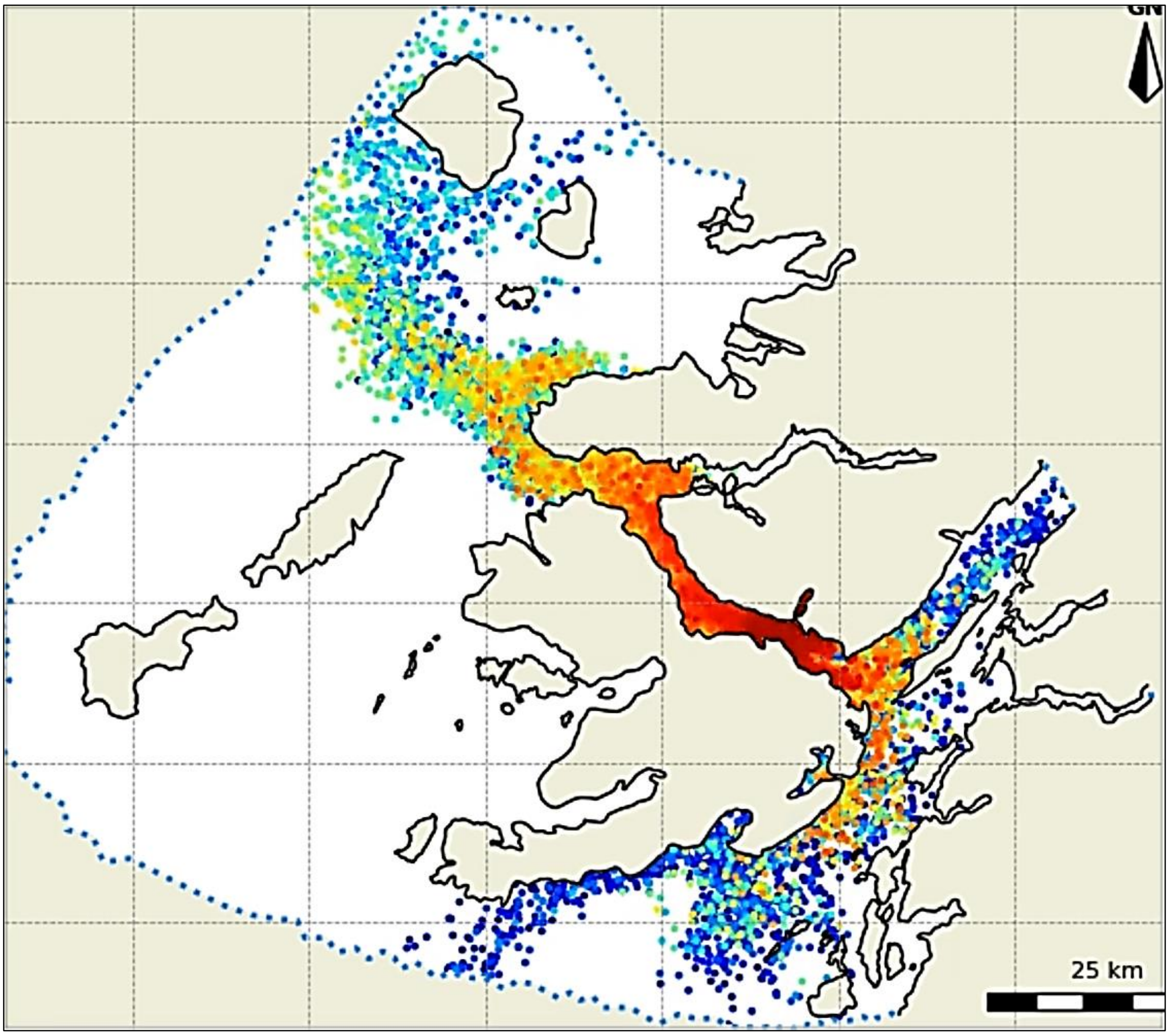

Executive Summary

A multi-stage biological model of oyster larvae (*Ostrea edulis*) has been developed in order to assess their distribution from 2 release sites in Loch Aline. Tidal, wind and freshwater inflow conditions for May 2018 were considered in a 3D model of the sea loch and surroundings.

Virtual "oyster larva" particles were released at each of the 2 sites and allowed to disperse into the marine environment. Particles were introduced into the model continuously at a rate of 20 per hour from each of the 2 sites over the 14-day run period. Each release zone was set as a volume of radius 10 m and depth of 1 m with particles placed randomly within the volume.

Each particle represents a single oyster larva and there were approximately 30,000 particles in the system at the end of the 14-day calculation. The model has the ability to prescribe multiple biological stages (trochophore, veliger and pediveliger), adjust swimming speed and direction, account for seafloor deposition and resuspension, larvae mortality and alteration of swim behaviour based on environmental cues such as changes in salinity. Output is in the form of heat maps of oyster larvae deposition density (#/m^2), larvae distribution in the water column and transport success (percentage of particles released from a site that deposit successfully).

The flow conditions (sea loch currents) driving the oyster larva particles come from a validated hydrodynamic model that has been reported elsewhere [CLAWS_2025] and is presented in summarised form in this document.

The main conclusions of the study are:

1) There is evidence of significant larvae spillage from Loch Aline into the Sound of Mull during the flushing cycle.

2) Larvae that stay in the loch are likely to settle and are widely distributed across the loch area.

3) Larvae exiting the loch into the Sound of Mull appear to be widely distributed both north and south with some distances in excess of 50 km towards the Summer Isles and the south coast of Mull.

4) According to the deposition maps, larvae exiting the loch appear less likely to a deposit than those remaining in the loch. This is likely due to the unfavourable conditions of stronger flow currents in the Sound of Mull and beyond.

5) The non-attaching veliger distribution appears to be wide across the Sound of Mull and south of Loch Linnhe. Maturation from veliger into the attaching pediveliger stage (after 4 days) in these fast-flowing areas means sea-bed attachment is less-likely and significant resuspension is possible for any adhering larvae.

6) Pediveliger dispersion is across a wider area compared with the veliger stage. This is due to the pediveliger stage beginning life from an already widely-dispersed veliger field.

7) Overall, the average model transport success rate over both sites (percentage of larvae particles introduced in Loch Aline successfully attaching) is predicted to be 53%. This degree of transport success is comparable with model predictions for Loch Melfort (50%) but is less than that of Loch Craignish (67%). This suggests that larvae survivability and deposition

success is likely to be very much site-specific, depending on local flushing conditions and the currents and topography that the flushed-out larvae encounter.

8) Due to the specific flushing nature of Loch Aline, and its relatively small surface area and narrow topography (compared, for example, with Loch Melfort and Loch Craignish), it would appear unlikely that changing the release locations would have any significant effect on either the overall larvae transport success or the general deposition patterns within the loch.

About the Report Authors

***Dr Tom Scanlon** BEng PhD CEng MIMechE, Engineering Consultant, MTS-CFD.com*

Tom is a chartered professional engineer with over 25 years' experience in applied computational mechanics. After a first degree in Environmental Engineering at the University of Strathclyde, Tom undertook a Ph.D in Vortex Shedding Flowmeter Pulsating Flow Computational Fluid Dynamics (CFD) Studies at the same university. Subsequently, he was awarded a JM Lessels scholarship from the Royal Society of Edinburgh for a one-year post-doctoral position at the Institute de Mécanique des Fluides de Toulouse, France in the field of numerical oceanography. The ImechE presented Tom with the Alfred Rosling Bennett Premium and Charles S Lake Award in 2003 for CFD in applied aerodynamics. In 2013 Tom returned from an EPSRC-funded sabbatical in the USA, where he carried out fundamental research in rarefied gas dynamics at the University of Michigan and the Lawrence Berkeley Laboratory in California. From 1994-2017 he was a Senior Lecturer in the Department of Mechanical and Aerospace Engineering at the University of Strathclyde specialising in heat transfer, fluid mechanics and applied CFD. His work is reported in over 50 refereed journal and conference publications. He is currently a director at the engineering consultancy firm MTS-CFD.

***Dr Matt Stickland** BSc PhD CEng FIMechE, Engineering Consultant, MTS-CFD.com*

After a first degree in Aeronautical Engineering at the University of Manchester, Matt worked for BAE Systems (Military Aircraft) at Warton in Lancashire in the Wind Tunnel Department working on projects which included EAP, EFA (Typhoon), Tornado and HOTOL. After leaving BAE in 1990 Matt worked for YARD Consulting Engineers in Glasgow modelling the heat and fluid flows in Advanced Gas Cooled reactors during on-load refuelling. In 1991 Matt accepted a senior lectureship in the Department of Mechanical Engineering at the University of Strathclyde where his research interest covered both experimental and computational heat transfer and fluid dynamics. He was awarded a PhD for his research into 3D imaging and its application to fluid flow visualisation. For his research in the field of experimental and computational fluid dynamics he was awarded the 2003 AR Bennett Premium/CS Lake Award and the 2004 T A Stewart-Dyer Prize/Frederick Harvey Trevithick Prize from the Institute of Mechanical Engineers. In 2022 Matt left the University of Strathclyde to take a directorship with the Engineering consultancy firm MTS-CFD. Matt is a Chartered Engineer and a Fellow of the Institute of Mechanical Engineers. He has published his research in over 100 papers in refereed journal and conference proceedings.

1 Introduction and Motivation

Rewilding efforts in Scottish sea lochs and estuaries have seen a significant focus on the restoration of native oyster populations, particularly the European flat oyster (*Ostrea edulis*). These initiatives aim to rejuvenate marine biodiversity, enhance water quality, and support local ecosystems. One notable project is taking place in Loch Aline, where the community marine conservation charity Caolas (https://www.caolas.org/) are actively involved in reintroducing native oysters. Such projects are part of broader restoration efforts aimed at creating sustainable marine habitats and promoting ecological resilience. These projects not only strive to bring back the once-abundant oyster populations but also seek to foster a greater understanding and appreciation of marine conservation among local communities.

In order to assess the distribution of oyster larvae from 2 release sites in Loch Aline, Caolas has commissioned the development of a detailed hydrodynamic and biological model of the area. The model simulates water levels and flows (i.e., currents and tides), which govern the transport and fate of oyster larvae emanating from the release sites – see [CLAWS_2025] for further details of the hydrodynamic model.

The use of hydrodynamic modelling to drive particles representing marine zooplankton is increasingly common [Johnsen_2020], [Asplin_2020], [Smyth_2016], [North_2008]. Marine Scotland and SEPA [SEPA_2025] are working on similar projects in Scotland. The integrated biological model presented in this report draws on the methods and assumptions used by Scottish and Norwegian modellers working for government agencies, as well as other peer-reviewed research.

In order to represent the oyster larvae, virtual "larva" particles were released at each of the 2 sites and allowed to disperse into the marine environment. Each particle represents a single larval stage. A modelling technique similar to the current SEPA screening approach [SEPA_2025] for salmon lice has been adopted, where the biological effects of oyster larvae production, maturity and mortality have been included. Larval swimming behaviour was also included in the model based on the criteria presented in [North_2008].

In this report the model outputs are presented in three ways, to categorise how the oyster larvae are likely to be distributed throughout Loch Aline and beyond:

1. Oyster larvae deposition density (#/m^2) for veligers and pediveligers, averaged over a 14-day period in May 2018, shown as a heat map.
2. Oyster larvae density (#/m^2) in the water column averaged over a 14-day period in May 2018, shown as a heat map.
3. A graph of transport success for larvae released from each of the 2 sites. Transport success is defined as the percentage of all particles released from a site that successfully deposit on the sea floor as pediveligers.

Animations of the larvae dispersion are also available as part of this study.

2 Hydrodynamic model

2.1 *Reduction of the full West Coast model*

The flow conditions (sea loch currents) that drive the oyster larva particles come from a validated hydrodynamic model that has been reported elsewhere [CLAWS_2025]. The extent of this full "West Coast" model is shown in Figure 1. The model has been developed by MTS-CFD to assess the impact of aquaculture-derived sea lice on wild Atlantic salmon and sea trout. The hydrodynamic model contains the influence of wind forcing on the loch surface and stratification through the salinity and temperature fields. It offers general insight into the spatial and temporal variation in the flow environment around the West Coast of Scotland and the hydrodynamic model also provides a suitable basis for modelling oyster larvae dispersion.

Figure 1 *Computational domain for the hydrodynamics of the West Coast of Scotland. Red zone highlights the sub-model area for Loch Aline.*

In order to reduce the size of the West Coast model to one more focused on Loch Aline, a subsection of the mesh around the area of interest is created and a hydrodynamic sub-model is created. The resulting mesh is shown in red in Figures 1-3.

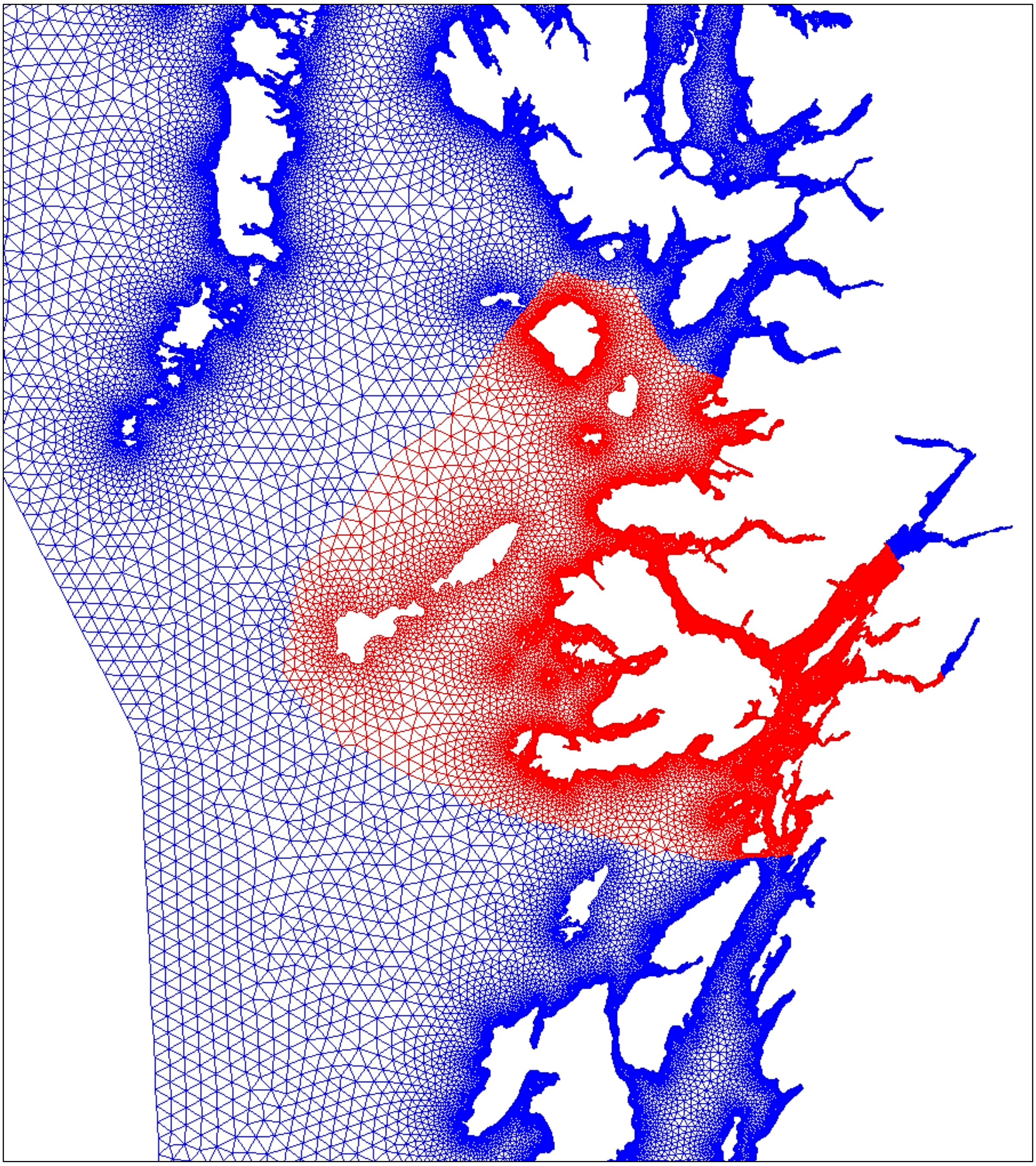

Figure 2 *Zoomed hydrodynamics mesh of the West Coast of Scotland. Red zone highlights the sub-model area for Loch Aline.*

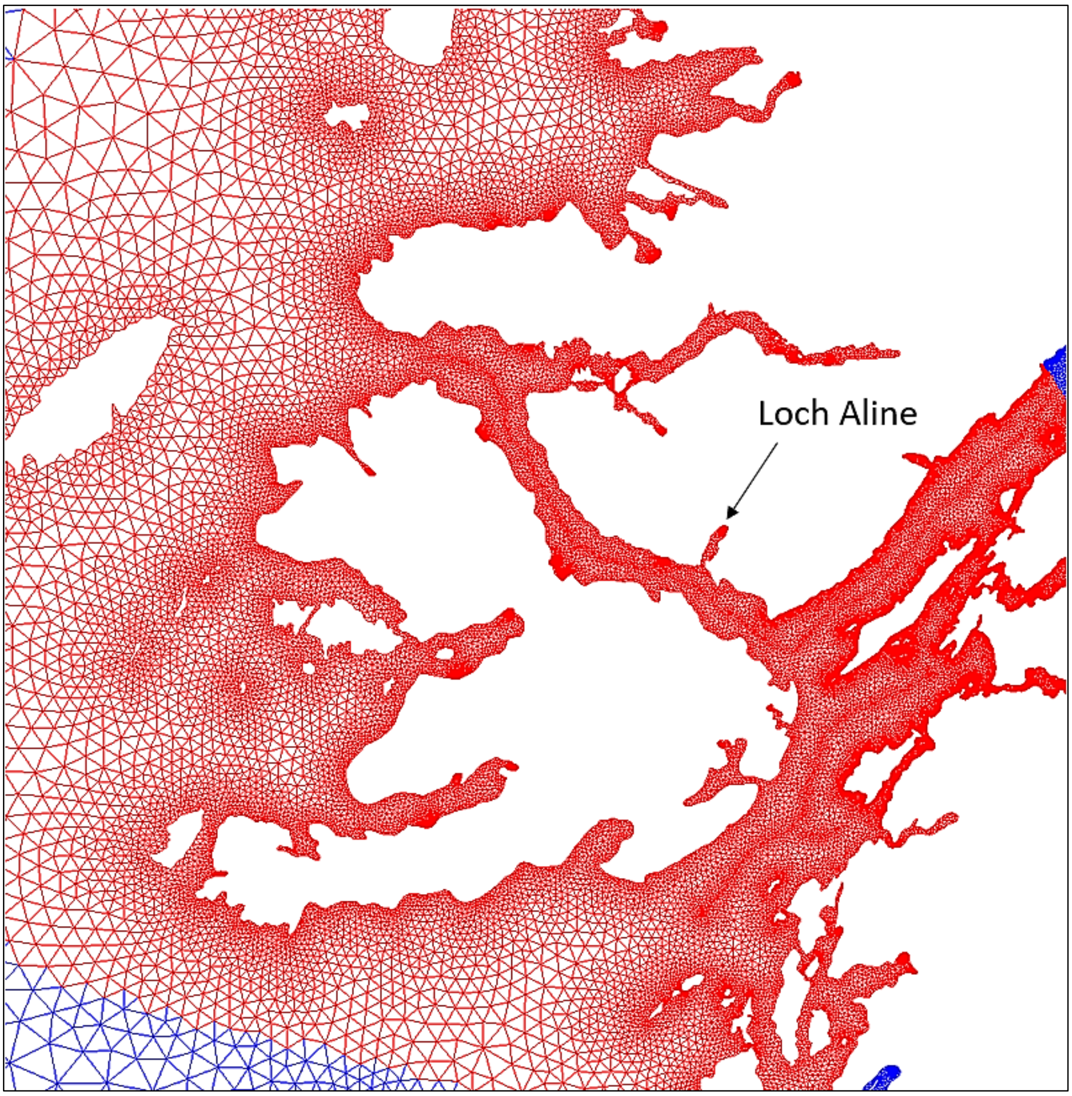

Figure 3 *Further-zoomed hydrodynamics mesh of the West Coast of Scotland. Red zone highlights the sub-model area for Loch Aline.*

2.2 *Bathymetry*

The bathymetry data for the hydrodynamics model have been collected from a range of different sources including publicly available data sets provided by Marine Scotland for the Scottish Shelf Model [SSM_2025], digitised Admiralty charts and bathymetry information from the UK's Digimap Ordnance Survey Collection [DOSC_2023]. The bathymetry in the area around Loch Aline is shown in Figure 4.

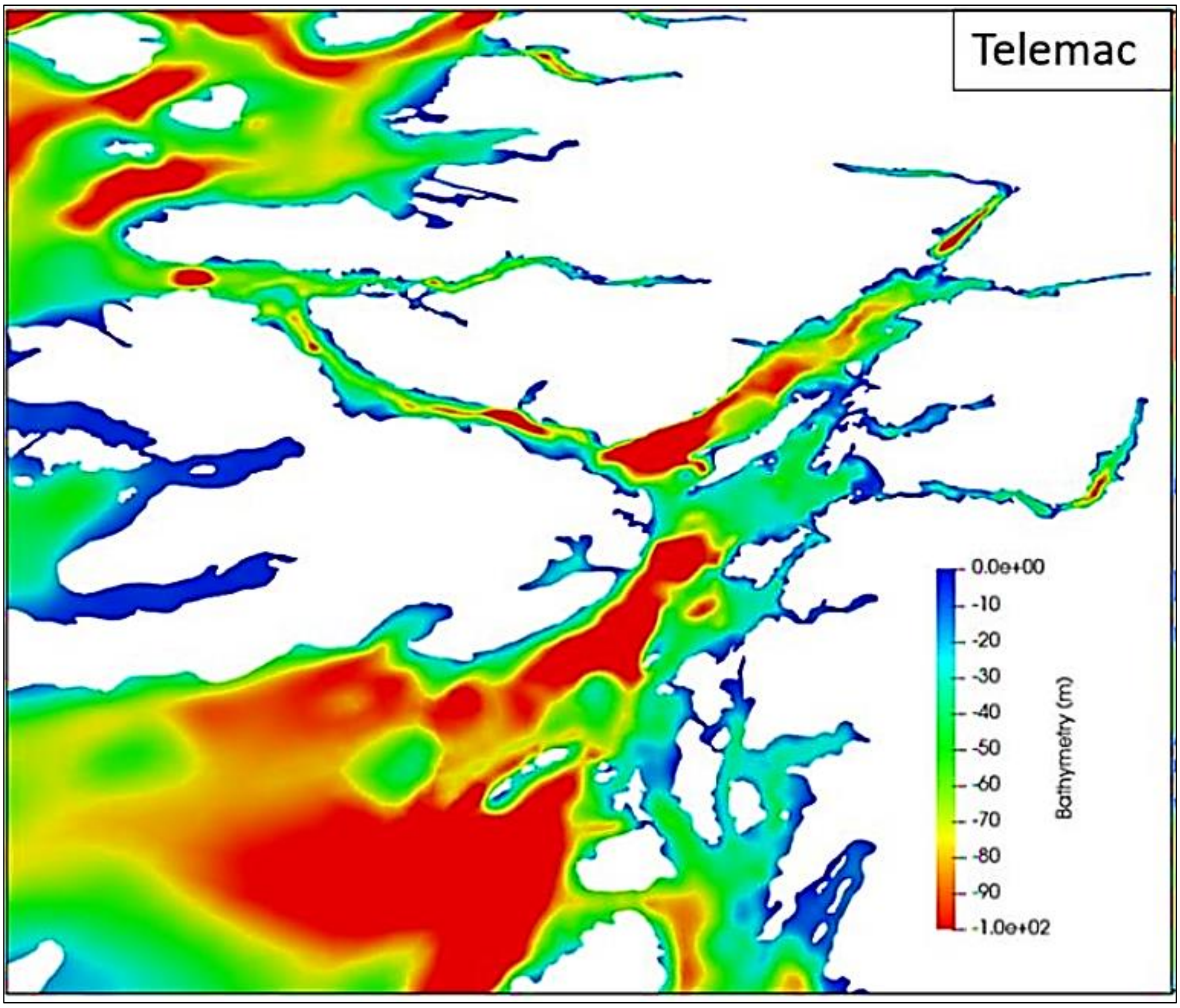

Figure 4 *Sea bed bathymetry in the vicinity around Loch Aline.*

2.3 *Meteorology*

Wind forcing on the loch surface is included in the hydrodynamic model based on weather data at 6-hourly intervals covering the period of May 1-15, 2018 [ERA_2025].

2.4 *Freshwater effects in Loch Aline*

Freshwater inflows at the head of Loch Aline means that the loch exhibits a degree of stratification. The vertical density gradients produced, combined with air-water heat exchange and tidal forcing, can result in complex flow patterns within the loch which need to be adequately captured in order produce realistic flow fields to transport the larvae particles. The freshwater inflow rates are derived from published data [G2G_2018].

Figures 5 shows a snapshot of the near-surface salinity field in Loch Aline.

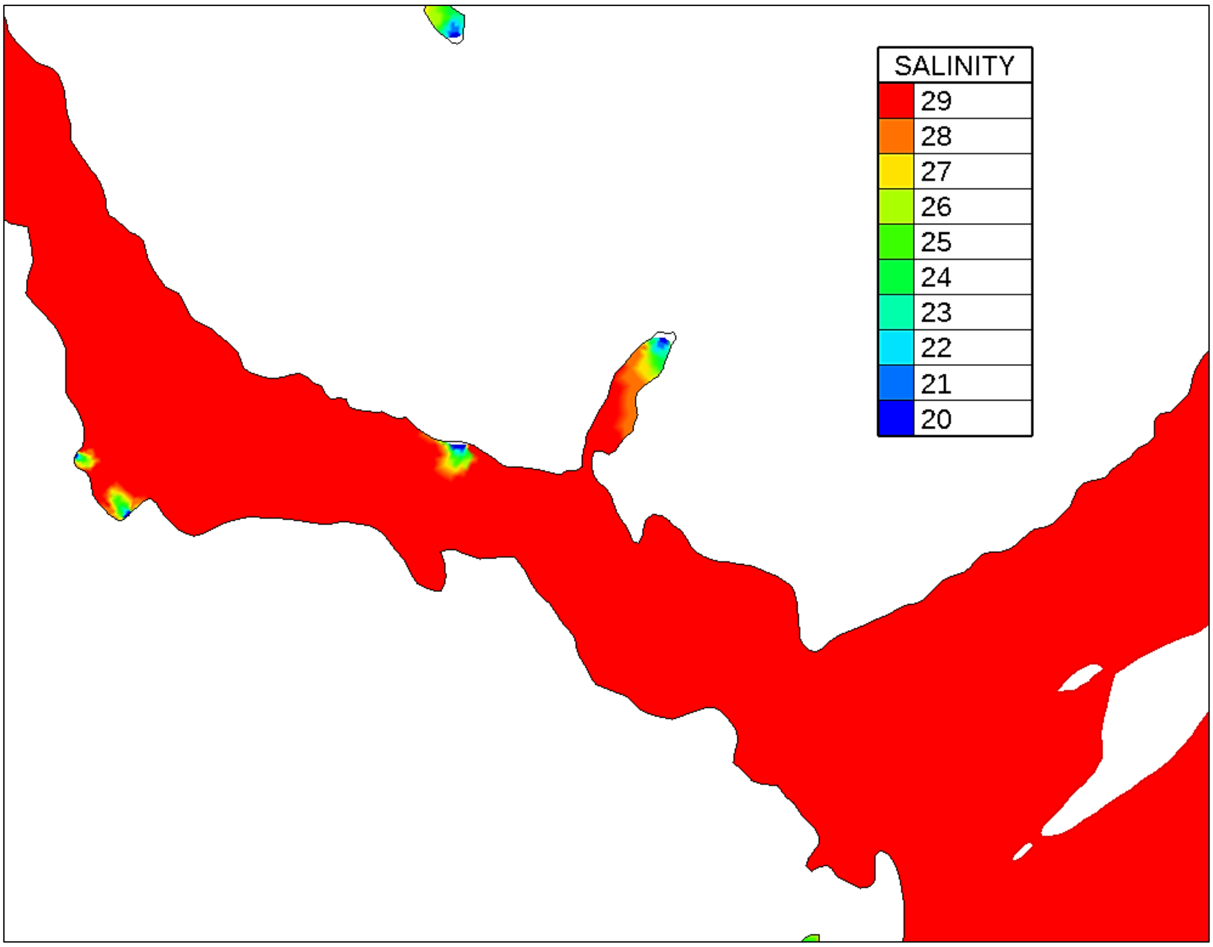

Figure 5 *Snapshot of near-surface salinity contours (PSU) in Loch Aline.*

2.4 *Flow fields*

Figures 6 and 7 show snapshots of the near-surface flow patterns in Loch Aline on a flood and ebb tide and highlight the complexity of the flows due to the competing effects of tides, wind and freshwater stratification.

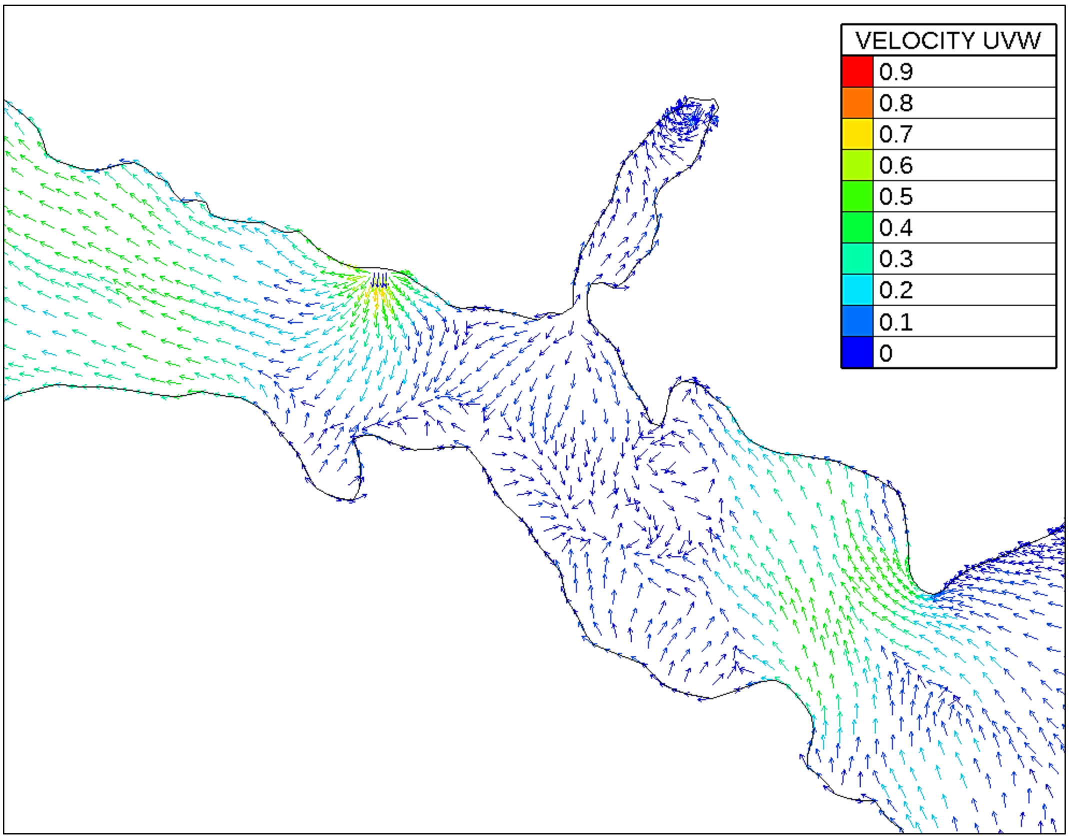

Figure 6 *Snapshot of near-surface flow patterns in Loch Aline on a flood tide.*

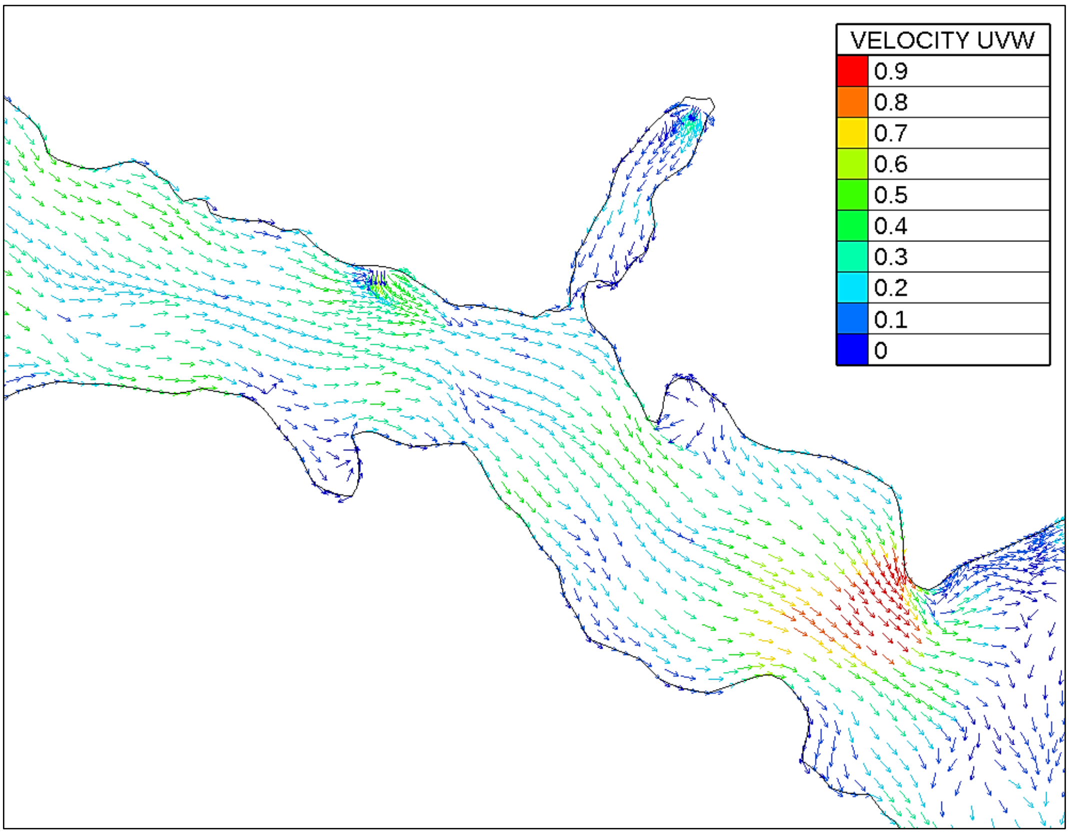

Figure 7 *Snapshot of near-surface flow patterns in Loch Aline on an ebb tide.*

3 Oyster Larvae Model

3.1 *Model description*

The integrated biological model presented in this report draws on the methods and assumptions used by Scottish and Norwegian modellers working for government agencies, as well as other peer-reviewed research [Johnsen_2020], [Asplin_2020], [Smyth_2016], [North_2008]. A methodology similar to the current SEPA screening model for salmon lice [SEPA_2025] has been employed. In this approach, oyster "larva" particles are released into the marine environment from 2 release sites in Loch Aline. Each particle represents a single larva. The location details and model names of the 2 release sites are shown in Figure 8.

Figure 8 *Location details of the 2 release sites with their lon/lat position.*

Particles were released continuously at each site at a rate of 20 per hour during the 14-day period from May 1-15, 2018. Initial particle positions were randomly distributed within a volume of radius 10 m and depth 1 m, centred at the lon/lat location of each site. At the end of the 14-day calculation there were approximately 30,000 particles in the system.

In addition to transport by sea currents, particles were given a random movement component, both vertically and horizontally at each time increment to represent turbulence on a subgrid scale. Particles were dispersed in the horizontal using a dispersion coefficient of 0.1 m^2/s and dispersed in the vertical using a dispersion coefficient of 0.001 m^2/s. This is considered a conservative vertical mixing approach [SEPA_2025] for the West Coast of Scotland. The particle integration method used was 4^{th} order Runge-Kutta.

Particles begin their lives as upwards-swimming veligers and are transported by sea loch currents during a user-defined maturation time period. Upwards swimming directs the veligers to the relatively faster-moving water surface layers and affords greater dispersion across the loch and beyond. Veligers do not possess the ability to deposit on the loch/sea bed.

Subsequently, particles transform into the pediveliger stage after the maturation period of veligers is reached. Pediveligers have the ability to change swim direction to downwards after a user-set time period and can also sink when a user-defined time period is achieved. Downward swimming/sinking allows the pediveligers to approach the sea bed. When contact is made, the particles will attach at that location, however, they have the ability to be resuspended into the water column if a critical threshold of near-bed shear-stress is reached. For details of the resuspension calculation, see [CLAWS_2025]. Pediveliger particles lose their ability to resuspend after a user-defined time period and are considered to be permanently attached. Pediveligers that fail to attach will expire after a user-defined time period.

3.2 *User-defined settings*

The user-defined settings for each biological stage are shown in Table 1.

Table 1 *User-defined parameters in the oyster larvae model*

Biological stage	Parameter name	Parameter value	Comments
Trochophore	Maturation time to veliger	0 day	Time for passive trochophore stage to mature into upward-swimming veligers
Veliger	Maturation time to pediveliger	4 days	Time for upward-swimming veligers to mature into downward swimming or sinking pediveligers
Veliger	Upward swimming speed	3 mm/s	Based on the paper of [North_2008] but is relevant for oyster species (*Crassostrea virginica*)
Veliger	maximum number of swimming days allowed	4 days	Set to be equivalent to the maturation time to pediveliger
Pediveliger	mortality after day	13 days	Pediveligers expire after 13 days of the 14-day calculation
Pediveliger	Downward swimming or sinking speed	3 mm/s	Based on the paper of [North_2008] but is relevant for oyster species (*Crassostrea virginica*)
Pediveliger	downward swimming after day	6 days	Pediveligers can begin their downward descent to search for a suitable habitat e.g. hard substrata
Pediveliger	sinking after day	7 days	Equivalent to downward swimming but included for completeness
Pediveliger	deposited particles attached permanently after day	10 days	Successfully-deposited particles can no longer resuspend and are permanently attached

Swimming behaviour based on the environmental cue of salinity changes is possible in the oyster larvae model but was not included for the runs presented in this report.

3.3 *Model outputs*

Model outputs are presented in three ways, to categorise how the oyster larvae are likely to be distributed throughout Loch Aline and beyond:

1. Oyster larvae deposition density (#/m^2) for pediveligers averaged over a 14-day period in May 2018, shown as a heat map.
2. Oyster larvae density (#/m^2) in the water column averaged over a 14-day period in May 2018, shown as a heat map.
3. Graphs of transport success for larvae released from each of the 2 sites. Transport success is defined as the percentage of all particles released from a site that successfully deposit on the sea floor as pediveligers.

4 Results

4.1 *Average deposition and larvae density heat maps*

Figure 9 shows the heat map of the average normalised pediveliger deposited concentration (#/m^2) across Loch Aline. The deposition values are normalised with respect to the largest average concentration found in the system.

The results from Fig.9 show that the deposition concentrations are distributed widely across the loch with some spillage deposition in the Sound of Mull. Although there is likely to be significant numbers of larvae leaving the loch they are unlikely to deposit in the Sound of Mull due to the unfavourably strong currents there.

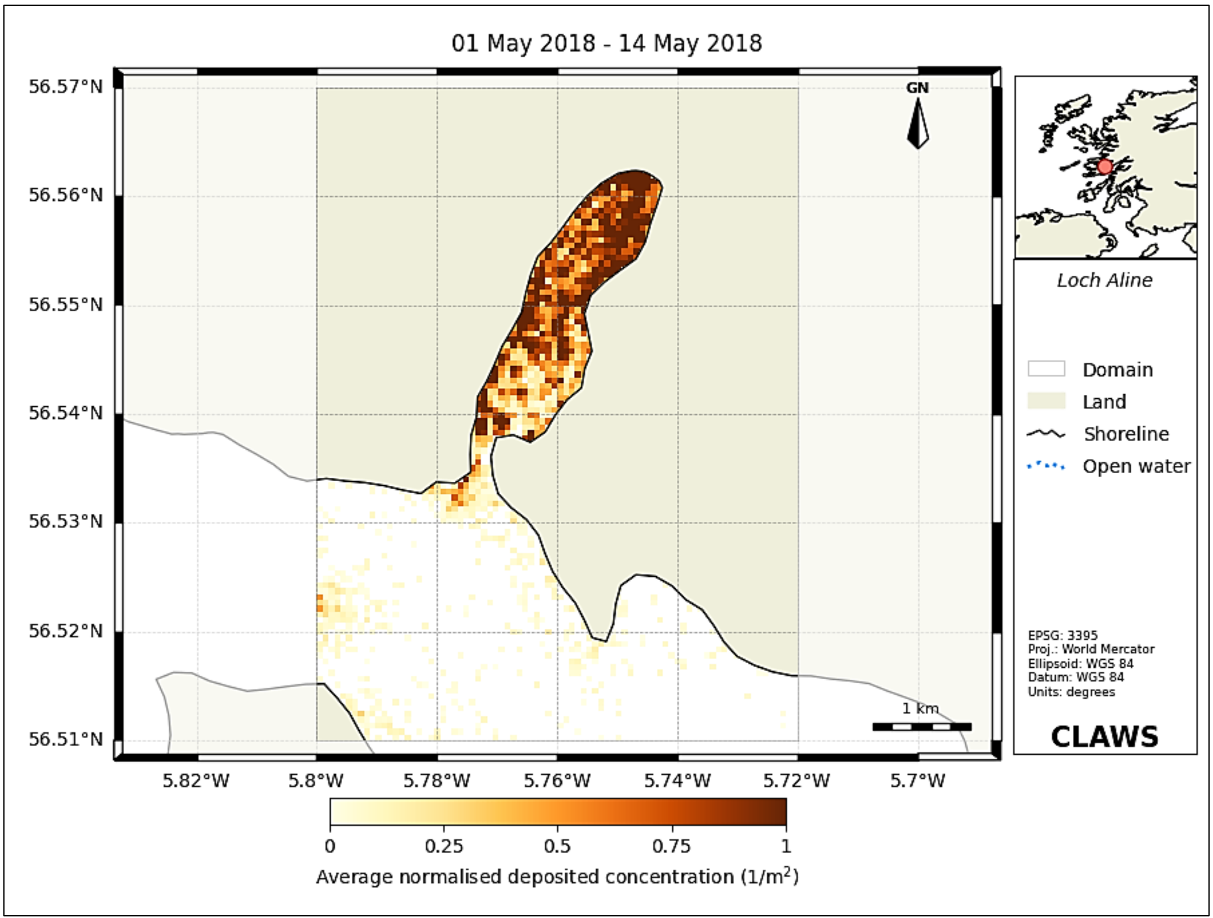

Figure 9 *Average normalised pediveliger deposited concentration (#/m²) in Loch Aline over the 14-day period from the 1st-15th May 2018.*

Figures 10 and 11 show the average oyster veliger and pediveliger densities (#/m²) in the water column, averaged over the 14-day period from the 1st-15th May 2018. These images serve to highlight the wide dispersion of the oyster larvae both north and south with some distances in excess of 50 km towards the Summer Isles and the south coast of Mull. The dispersion distances are also highlighted in the box plot of Figure 12.

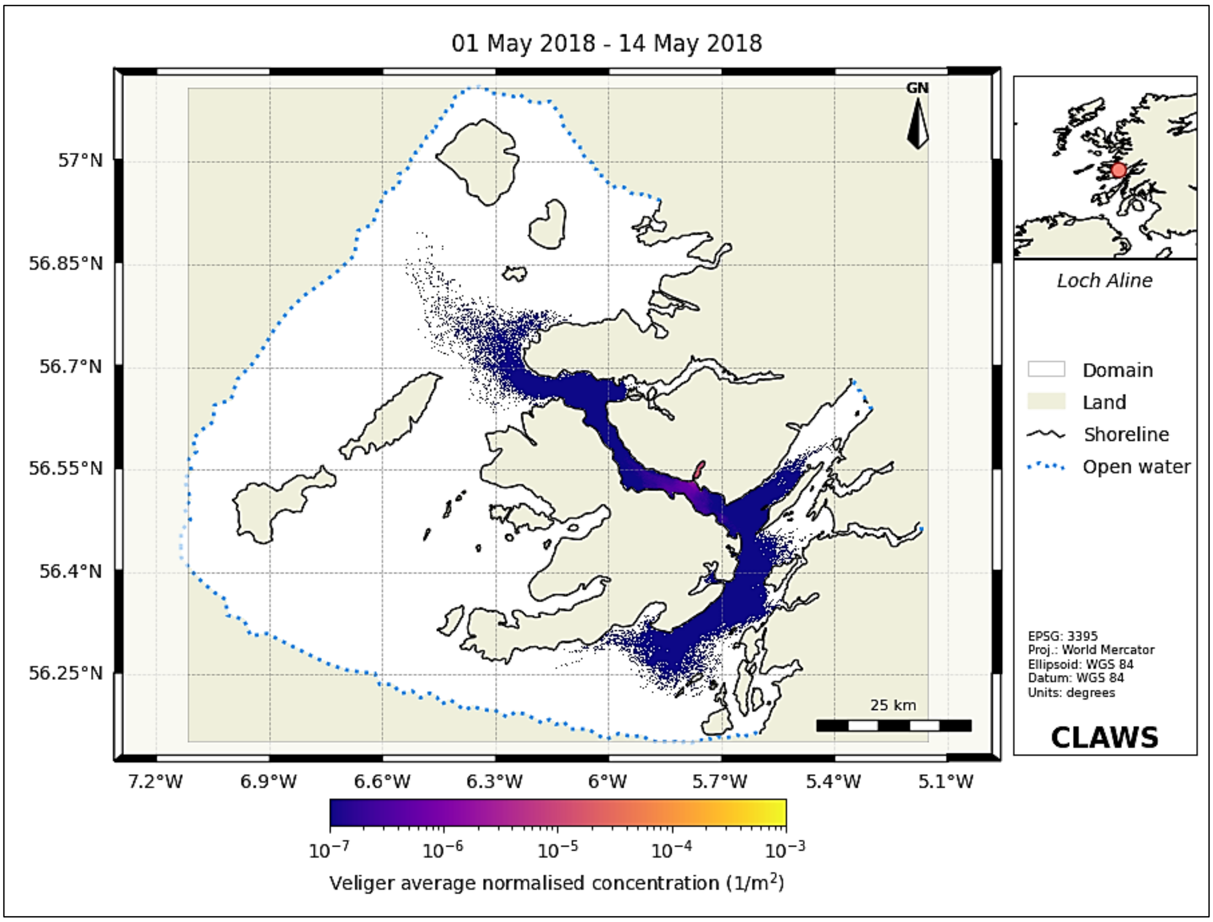

Figure 10 *Average veliger concentration (#/m^2) in the water column over the 14-day period from the 1^{st}-15^{th} May 2018.*

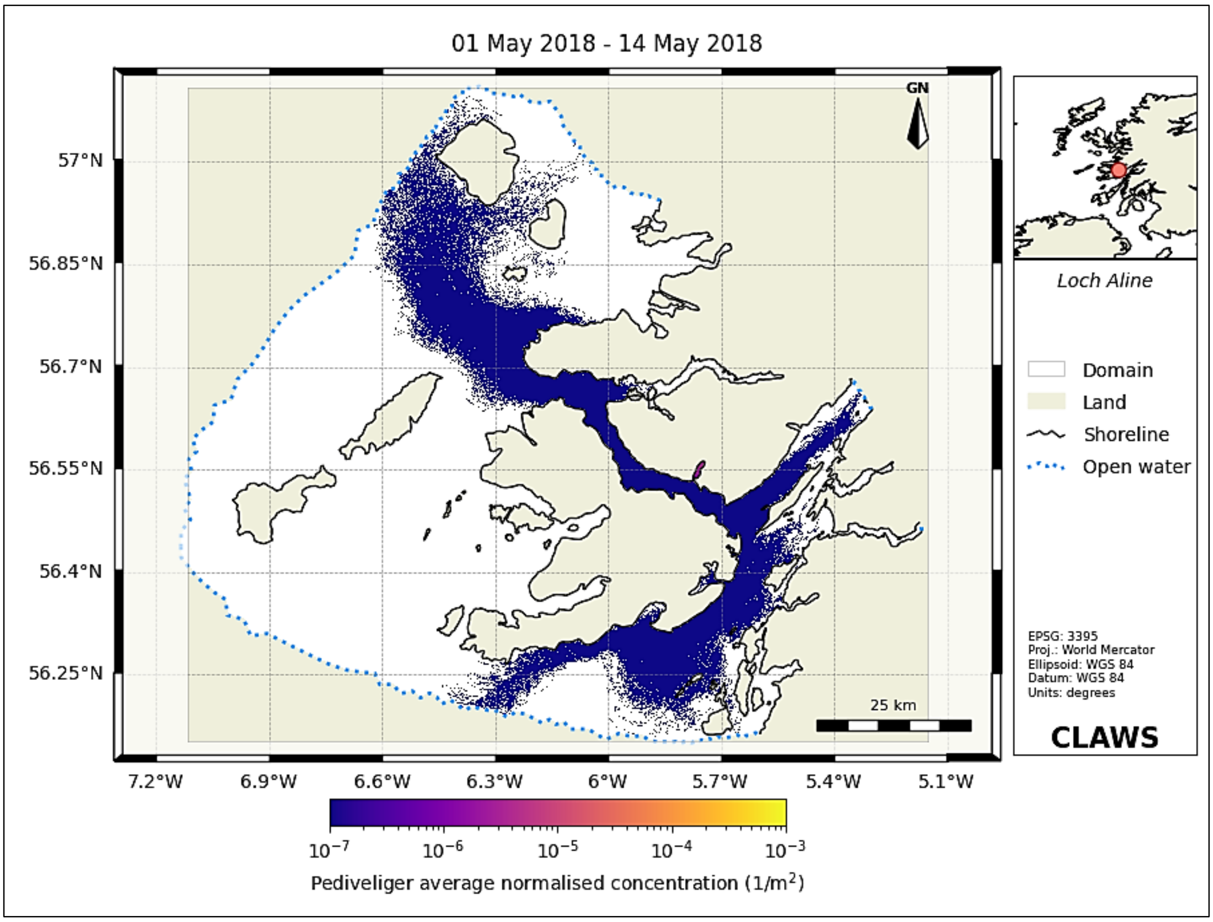

Figure 11 *Average pediveliger concentration (#/m^2) in the water column over the 14-day period from the 1st-15th May 2018.*

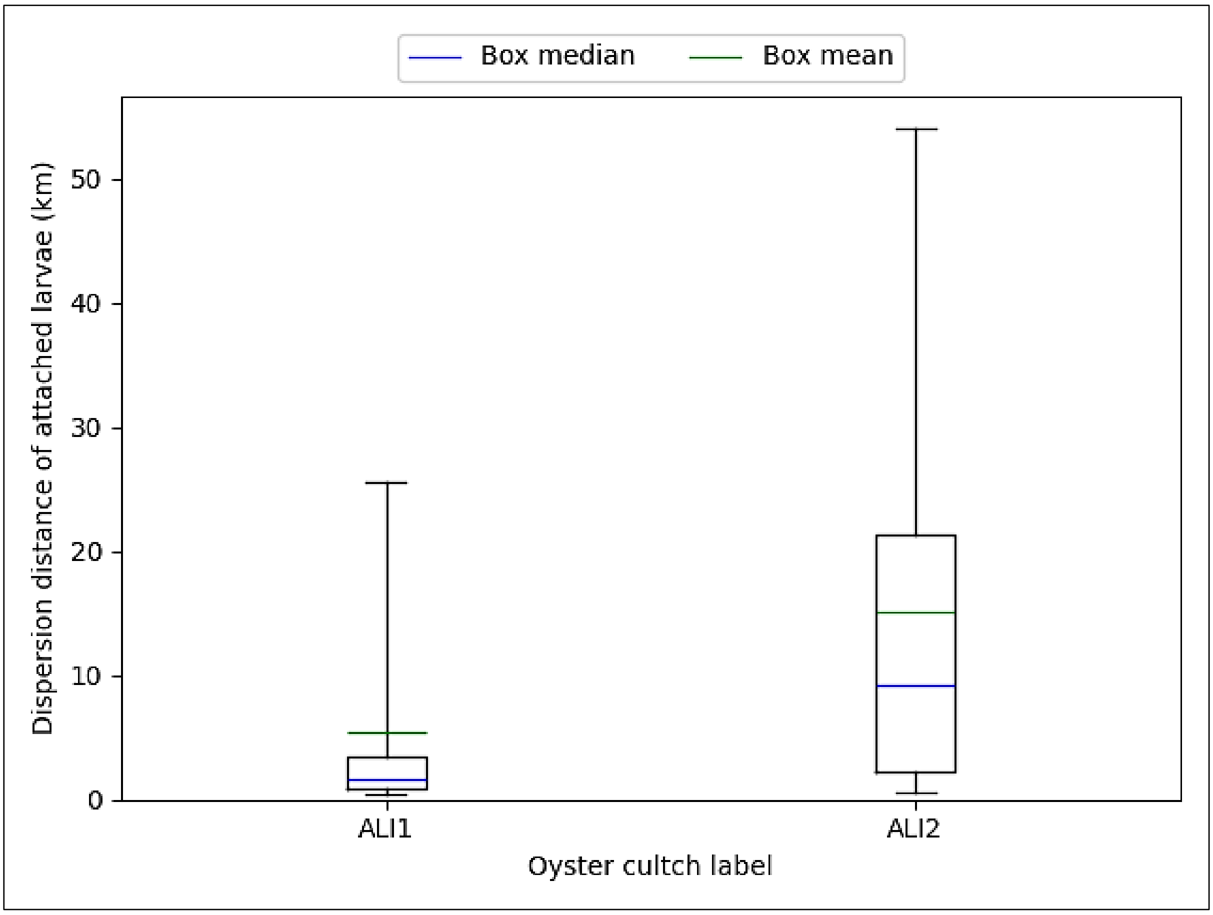

Figure 12 *Box plot showing predicted dispersion distances of pediveliger larvae from sites ALI1 and ALI2 (see Figure 8 for site locations).*

Pediveliger dispersion appears across a wider area compared with the veliger stage. This is likely due to the pediveliger stage beginning life from an already widely-dispersed veliger field

4.3 *Further data output*

Figure 13 shows the plot of transport success for each of the 2 release sites. Transport success is defined as the percentage of all larva particles leaving a site that successfully deposit on the sea floor. Overall, the average model transport success rate over both sites is predicted to be 53%. This degree of transport success is comparable with model predictions for Loch Melfort (50%) but is less than that of Loch Craignish (67%). This suggests that larvae survivability and deposition success is likely to be very much site-specific, depending on local flushing conditions and the currents and topography that the flushed-out larvae encounter.

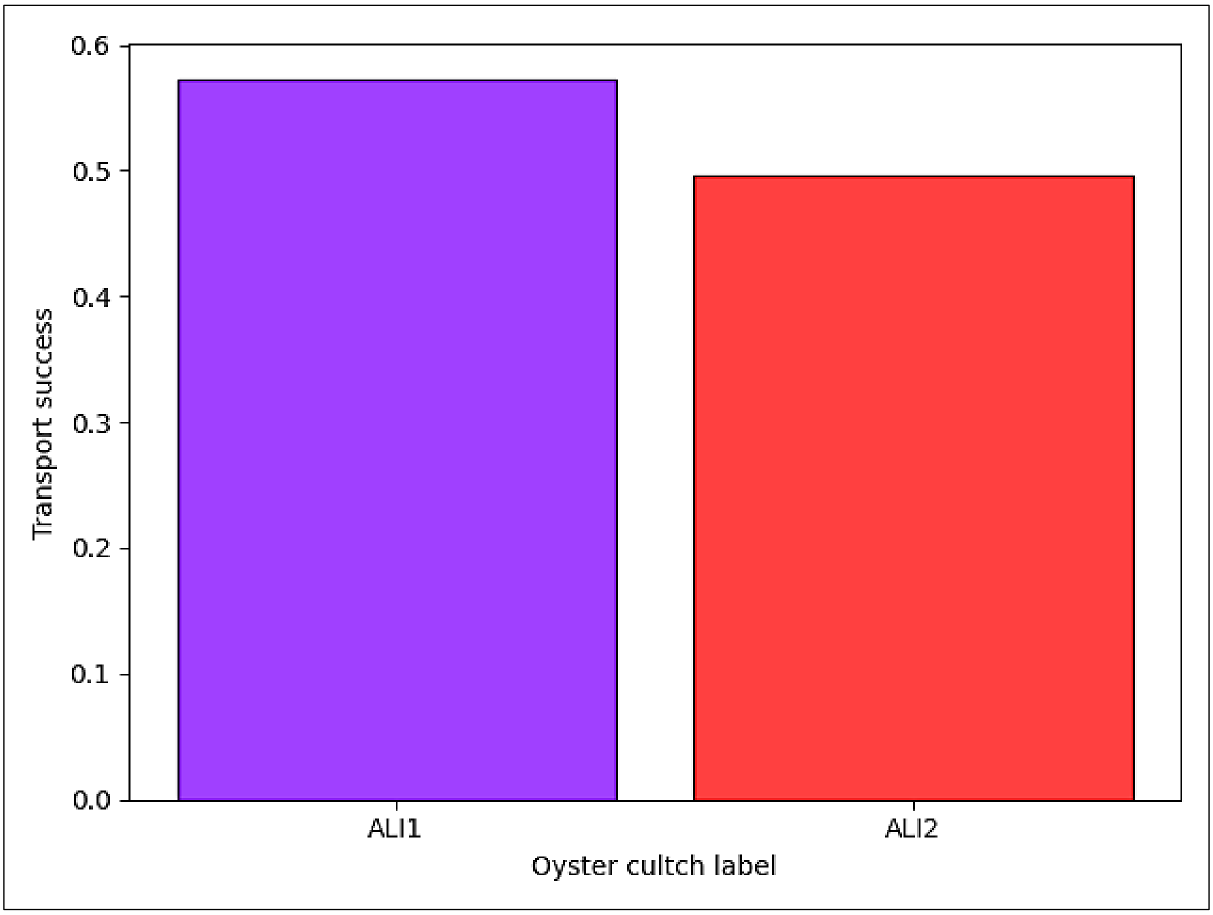

Figure 18 *Bar chart of transport success for the 2 release sites in Loch Aline. (see Figure 8 for site locations).*

4. Conclusions

A multi-stage biological model of oyster larvae (*Ostrea edulis*) has been developed in order to assess their distribution from 2 release sites in Loch Aline. Tidal, wind and freshwater inflow conditions for May 2018 were considered in a 3D model of the sea loch and surroundings.

Virtual "oyster larva" particles were released at each of the 2 sites and allowed to disperse into the marine environment. Particles were introduced into the model continuously at a rate of 20 per hour from each of the 2 sites over the 14-day run period. Each release zone was set as a volume of radius 10 m and depth of 1 m with particles placed randomly within the volume.

Each particle represents a single oyster larva and there were approximately 30,000 particles in the system at the end of the 14-day calculation. The model has the ability to prescribe multiple biological stages (trochophore, veliger and pediveliger), adjust swimming speed and direction, account for seafloor deposition and resuspension, larvae mortality and alteration of swim behaviour based on environmental cues such as changes in salinity. Output is in the form of heat maps of oyster larvae deposition density (#/m^2), larvae distribution in the water column and transport success (percentage of particles released from a site that deposit successfully).

The flow conditions (sea loch currents) driving the oyster larva particles come from a validated hydrodynamic model that has been reported elsewhere [CLAWS_2025] and is presented in summarised form in this document.

The main conclusions of the study are:

1) There is evidence of significant larvae spillage from Loch Aline into the Sound of Mull during the flushing cycle.

2) Larvae that stay in the loch are likely to settle and are widely distributed across the loch area.

3) Larvae exiting the loch into the Sound of Mull appear to be widely distributed both north and south with some distances in excess of 50 km towards the Summer Isles and the south coast of Mull.

4) According to the deposition maps, larvae exiting the loch appear less likely to a deposit than those remaining in the loch. This is likely due to the unfavourable conditions of stronger flow currents in the Sound of Mull and beyond.

5) The non-attaching veliger distribution appears to be wide across the Sound of Mull and south of Loch Linnhe. Maturation from veliger into the attaching pediveliger stage (after 4 days) in these fast-flowing areas means sea-bed attachment is less-likely and significant resuspension is possible for any adhering larvae.

6) Pediveliger dispersion is across a wider area compared with the veliger stage. This is due to the pediveliger stage beginning life from an already widely-dispersed veliger field.

7) Overall, the average model transport success rate over both sites (percentage of larvae particles introduced in Loch Aline successfully attaching) is predicted to be 53%. This degree of transport success is comparable with model predictions for Loch Melfort (50%) but is less than that of Loch Craignish (67%). This suggests that larvae survivability and deposition success is likely to be very much site-specific, depending on local flushing conditions and the currents and topography that the flushed-out larvae encounter.

8) Due to the specific flushing nature of Loch Aline, and its relatively small surface area and narrow topography (compared with Loch Melfort and Loch Craignish), it would appear unlikely that changing the release locations would have any significant effect on either the overall larvae transport success or the general deposition patterns within the loch.

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