The role of sea lice dispersion models

Lars Asplin,

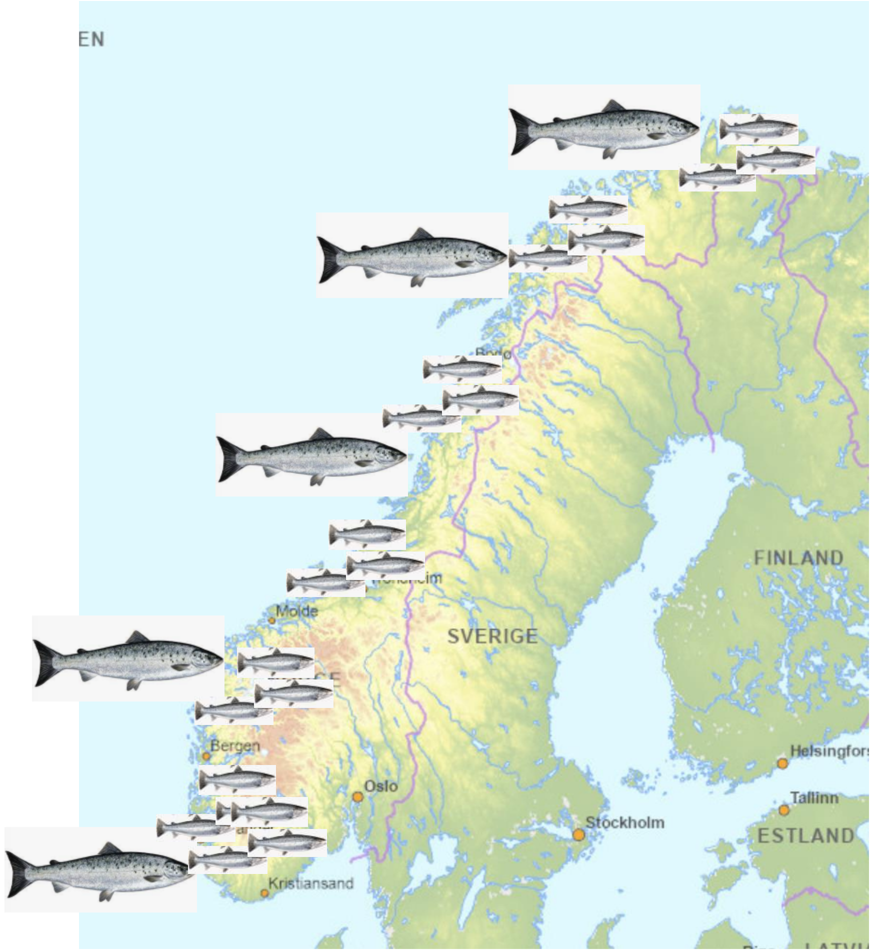
TWG SLUG work-shop,
September 7, 2023, Pitlochry, Scotland.

The salmon lice – naturally occurring parasite on salmonids

A limited number of potential hosts.

Lice strategy:

- Many offspring.
- Large dispersion.
- Adaption to find fish.



The salmon lice – aquaculture industry introduces ~1000 times more potential hosts for salmon lice.

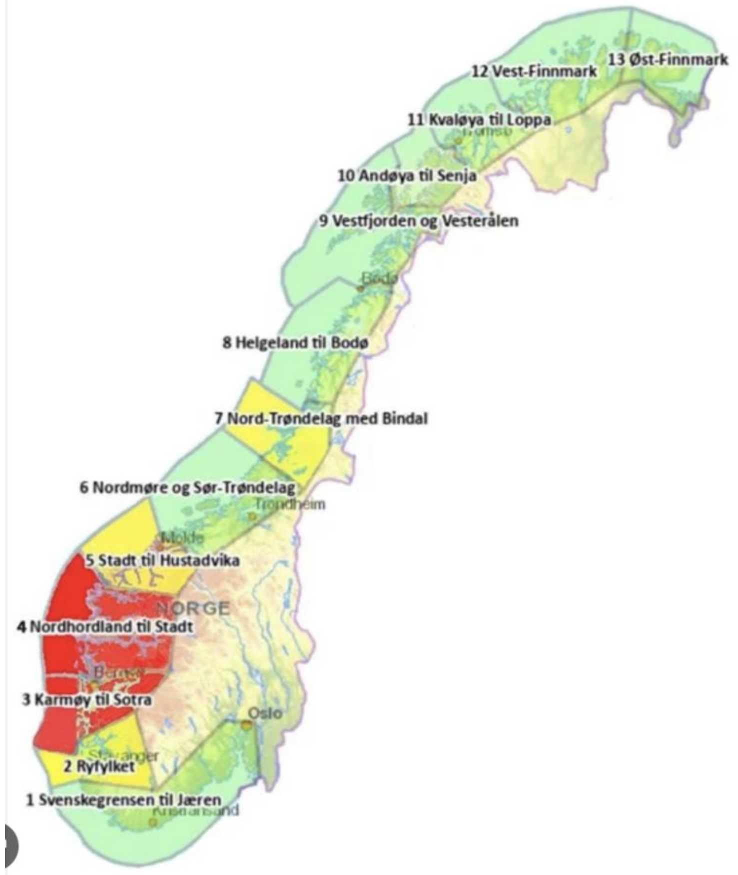
The Norwegian Traffic Light System.

A way to manage the salmon industry.

National ambition to increase aquaculture by a factor 5.

Salmon aquaculture shall be environmentally sustainable.

Wild fish population mortality from salmon lice is the present measure of sustainability.



The Traffic Light system – initially one model should decide the traffic light color.

This idea (from the Ministry) created a lot of fuzz.

In 2016 we had numerous “ugly” meetings.

We eventually realized that the problem is too complicated to solve by a single method.

An expert group will assess all available relevant data.

The expert group has 11 members from various institutions.

Both empirical data and model results are used for the estimation of infection pressure in 13 production zones along the Norwegian coast.

Every second year, an assessment is submittet to a steering group (containing 3 persons) that finalize the recommended traffic light for the coming two years.

The Ministry of Commerce and Fisheries decide the traffic light color in each production zone based on the recommendations.

The salmon lice dispersion model has an important role in the Traffic Light System.

Lice infection pressure is depending on a 1-3 weeks planktonic phase where the first 3-5 days are non infective.

Currents can vary substantially during such a time period.

The salmon lice dispersion model has an important role in the

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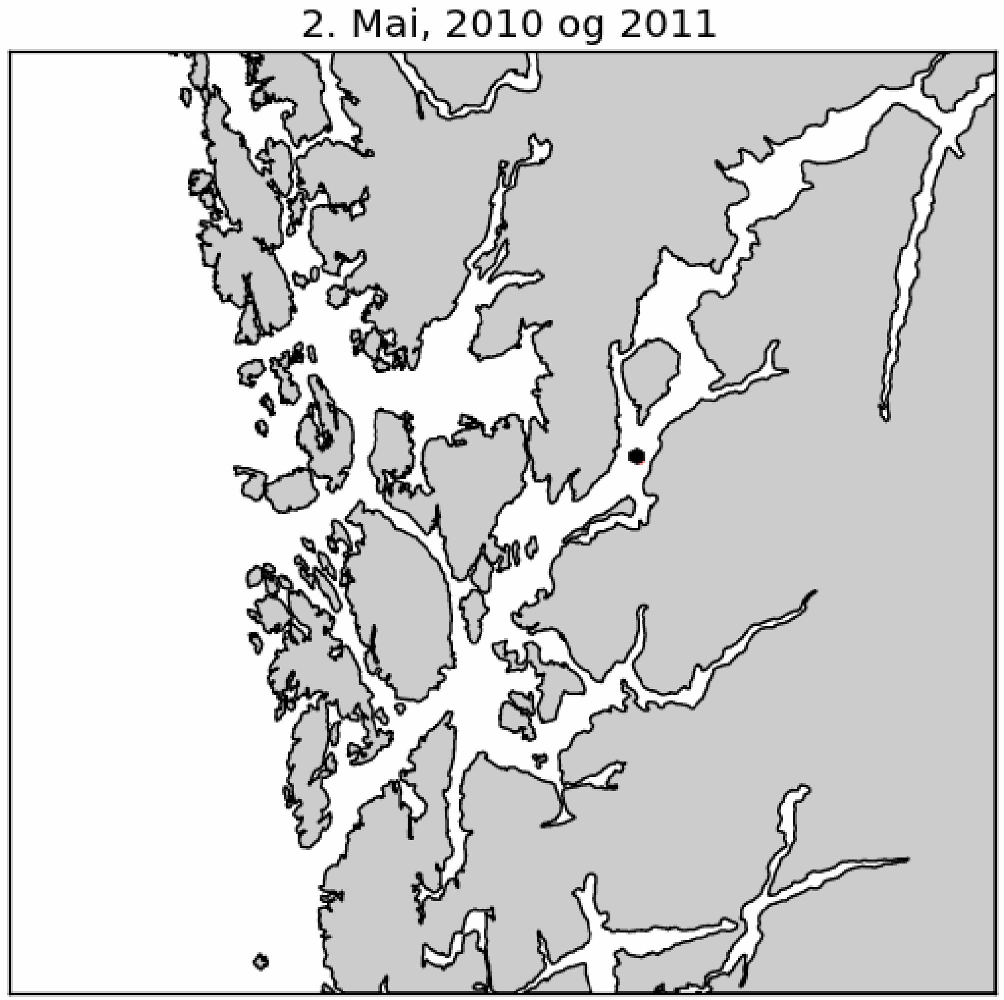

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Animation:
Ingrid A. Johnsen

The salmon lice dispersion model has an important role in the Traffic Light System.

Lice infection pressure is depending on a 1-3 weeks planktonic phase where the first 3-5 days are non infective.

Currents can vary substantially during such a time period.

The inhomogenic distribution of plankton (patching) is complicating things big time!

Only dispersion models including a realistic physical environment can supply sufficient information.

Effort should be put into developing such models, including ways to interpret and utilize model results.

Caveat: The model results are (usually) not what empirical data show. (calculate the DOSE, measure the RESPONSE).

Too high spatial resolution in modelling set up is often not needed to describe the infection pressure sufficiently.

Continuous model results validation (including the current model) is necessary!

Many potential sources for uncertainty in salmon lice dispersal modelling.

1. The source term of lice nauplii.
2. The physical environment (current, salinity, temperature).
3. The planktonic lice behaviour.
4. The planktonic lice mortality.

Also: How fish are infected? How populations are affected?

To understand and use the model results, these potential uncertainties should be quantified as far as possible.

The Technical Working Group SLUG (Sea Lice Uncertainty Group).

Based on a long term collaboration with FRS/MSS/Marine Directorate in Aberdeen.

International collaboration with scientists having similar challenges is fruitful.

The TWG SLUG was established last year with the aim to present the work at the SeaLice 2024 conference in Glasgow next September.

STRENGTH OF KNOWLEDGE IN SEA LICE DISPERSION MODELLING AND HOW TO COMMUNICATE THIS.

Knowledge Strength Working Group: Terms of Reference 1

SPECIFIC OBJECTIVE

- Develop paper on **Strength of knowledge in sea lice dispersion modelling and how to communicate this.**
- Specific questions addressed
  - What is the purpose of the modelling?
  - What are the causes of uncertainty in model outputs?
  - How can modellers maximise knowledge strength derived from models?
  - How can uncertainty be communicate for effective decision making by different audiences?

WHAT IS THE PURPOSE OF THE MODELLING?

- The purpose must be agreed between model users and model builders
  - A practical question in a practical way
- This purpose determines where knowledge strength should be maximised

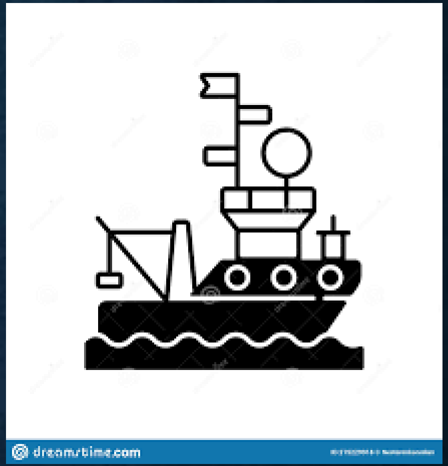
- Screening models
  - Must be applicable with limited local data as aim is to see if more modelling effort and data are required
- Detailed management models
  - Give specific local outputs for managing specific sites, will need local data for forcing and validation
- Scientific models
  - Assess processes in detail e.g. DVM models for incorporation or parameterisation of other models

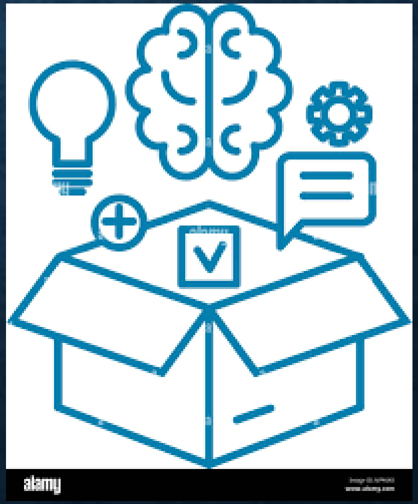
WHAT ARE THE CAUSES OF UNCERTAINTY IN MODEL OUTPUTS?

Cause of uncertainty	**Example**	**Nature**	**Solution**
Computational implementation	Number of lice a model particle represents	No, or impracticable, natural value.	Increased computational resource
Model structure: processes and variables incorporated	Diurnal Vertical Migration	Biological or physical processes included	Fundamental biology, model complexity
Parameter values: process rates	Swimming speed	Specific process value average and variation	Observational data (lab or field)
Forcing values	Lice inputs from farms	Specific process value average and variation	Surveillance data

HOW CAN MODELLERS MAXIMISE KNOWLEDGE STRENGTH?

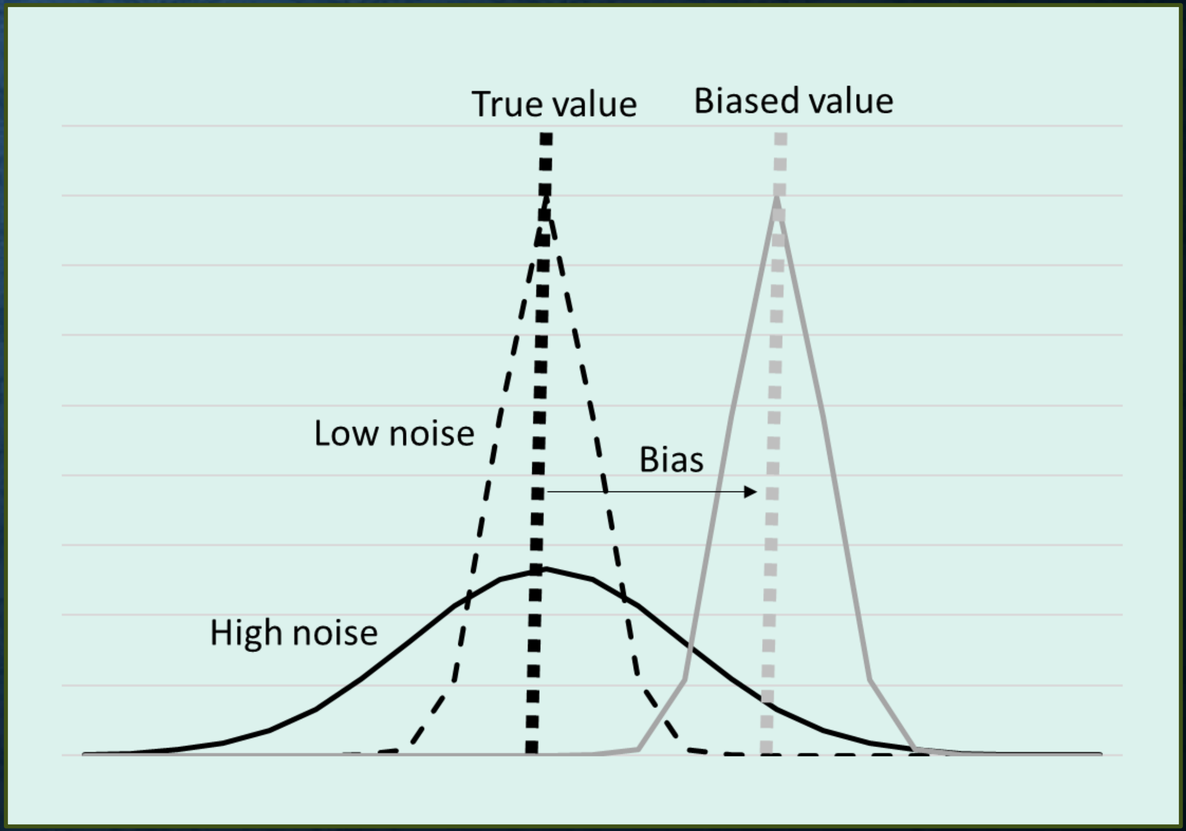
- Power
  - More computation resources
  - More data/science
  - Costly
- Wisdom
  - Understand uncertainty in the modelling
  - Sensitivity and scenario analysis
  - Describes but does not remove uncertainty





NOISE AND BIAS

- Noise = Scatter around true value
    - Noise is in observations
    - More data will reduce this
    - Stochastic models
- Bias = Systematic distortion away from true value
    - Bias either observations or model
    - Multiple independent data sources/models



HOW CAN UNCERTAINTY BE COMMUNICATED TO DIFFERENT AUDIENCES FOR USEFUL DECISION MAKING

- Need to provide important information for decision makers
- Need for clear narrative
- Need for modelling to be able to be scrutinised by other scientists
- Need to be accessible to users

Usable
Ensure model outputs are usable for practical policy advice

Understandable
Ensure that implications of model uncertainties are presented in ways that different audiences can understand

Assessable
Ensure the process is documented so can be assessed by appropriate external experts
Use peer review through publication and presentation at scientific conferences

Accessible
Ensure results are published online, open access science publications
Inform stakeholders of developments as they occur

Severity/Consequence

Likelihood		Slightly harmful (1)	Harmful (2)	Extremely harmful (3)
	Highly unlikely (1)	Trivial risk (Score 1)	Tolerable risk (Score 2)	Moderate risk (Score 3)
	Unlikely (2)	Tolerable risk (Score 2)	Moderate risk (Score 4)	Substantial risk (Score 6)
	Likely (3)	Moderate risk (Score 3)	Substantial risk (Score 6)	Intolerable risk (Score 9)

AIM

- To create paper based on this outline
- Make outputs accessible to stakeholders
- Take advice from stakeholders on how to maximise knowledge strength
  - Power and wisdom (more data, knowledge gaps)
- Take advice from stakeholders on best ways to present uncertainty constructively
  - Addressing different audiences effectively
  - Specific request for ideas in breakout session 1

SLUG ToR 2

Risk assessment of sea lice dispersion modelling

September 2023

Contents

Context

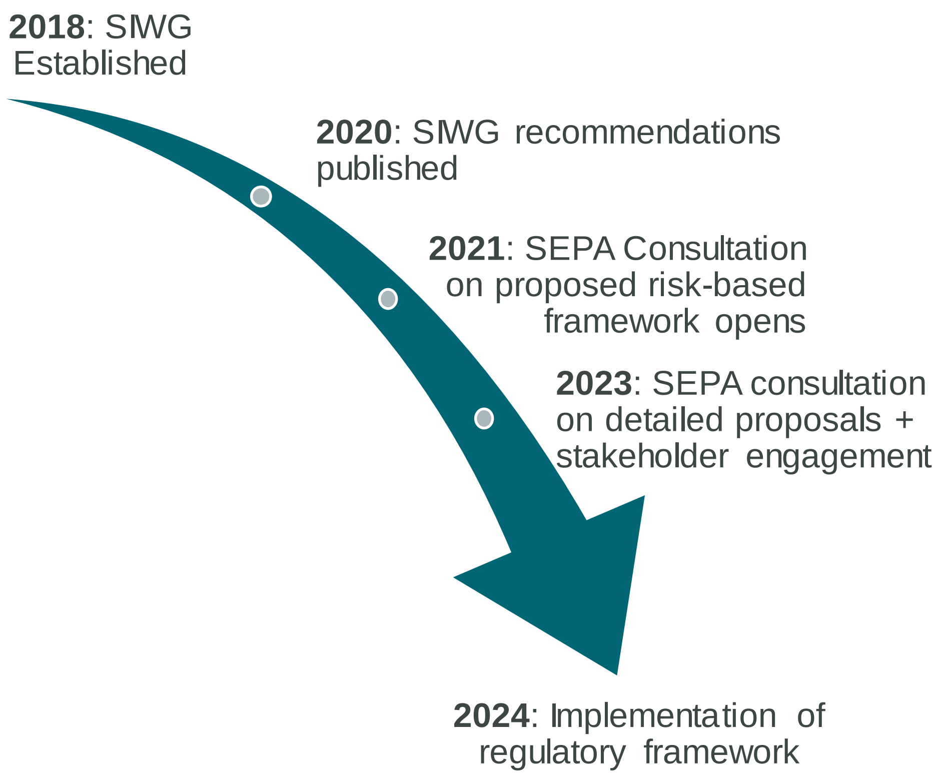
Background

Risk that sea lice from fish farms negatively impact populations of wild salmon and sea trout.

Number of lice on farmed fish, lice dispersal, wild salmon migration and resilience important factors.

Salmon Interactions Working Group (SIWG) established to consider risk management to wild salmonids.

SEPA responsible for managing risk to wild salmon from sea lice under CAR.



Regulatory framework

Defined Wild Salmonid Protection Zones (WSPZ).

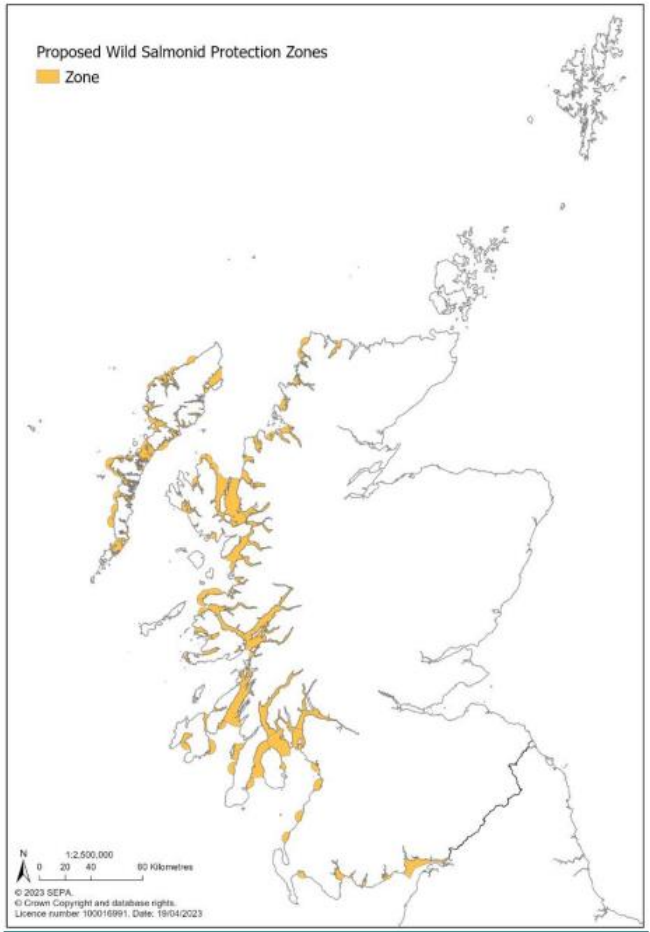
Protect wild salmon post-smolts between 1st April and 30th May.

Risk-based screening ensures requirements on developers are proportionate and beneficial.

Initially apply conditions to permits of existing significant contributor sites.

Adaptive in response to scientific evidence and experience of operation.

Ongoing engagement and collaboration is part of this.



Consultations & engagement

Initial consultation in 2021.

Detailed consultation closes 15th September.

Engagement meetings throughout this process with stakeholders (industry, Coastal Communities Network, wild fisheries, researchers and other regulators).

Range of questions raised from broad array of perspectives.

[Detailed proposals for a risk-based, spatial framework for managing interaction between sea lice from marine finfish farm developments and wild salmonids in Scotland - Scottish Environment Protection Agency - Citizen Space (sepa.org.uk)]

Frequent questions

Broad themes

Spatial and temporal distributions
- Salmonids
- Sea Lice
- Effects on exposure risk

Migration routes
- What pathways taken?
- Variability

Model uncertainty
- Different models
- Minimum performance
- Resolution
- Complexity

Physical processes
- Frontal structures
- Wind scenarios
- Instantaneous vs residual
- Temperature/ salinity

Lice characteristics
- Relevant behaviours
- Infection pathways
- Lice stages

Evidence & validation
- **Data**
- What level of performance is acceptable
- Examples of good practice

Sea trout
- Evidence
- Risk vs wild salmon
- Impact on other species
- Data

Evidence mapping

An example

Previously used by Diadromous Fish ScotMER Receptor Group for evidence gaps related to the health, distribution, and impacts on Diadromous fish.

Similar themes: spatial & temporal distributions, migration pathways, evidence and monitoring, feasibility.

DF.02-2022	Survival and progression rates in relation to passing through marine renewable areas	What is the survival rate of fish passing through marine renewable developments? Is there increased mortality when migrating through marine renewable developments? e.g. due to shifts in predator distributions What is the rate of passage through marine renewable developments? Does passage rate change when transiting a renewable development and does this increase risk of predation? Are fish attracted to developments for new feeding opportunities? Does predation risk increase if more time is spent at a development? Does construction activity (e.g. Pile Driving) effect survival of migrating fish?

Diadromous Fish ScotMER Receptor Group - gov.scot (www.gov.scot)

Evidence mapping

Initial draft

Informed by consultations and engagement meetings.

Following the diadromous fish example.

Looking to identify and prioritise evidence gaps associated with risk assessment of sea lice impacts on wild fish.

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Sea Lice Dispersal Modelling Knowledge Strength & Uncertainty Evidence Gaps

Information			
ID	Evidence Gap	Key Research Questions	Ta Gr Pr Fe
SLUG.02-2023	Survival and progression rates of fish in relation to passing throu	Where are data available to adress this question? What is the	S Ac S S O
SLUG.03-2023	Spatial and Temporal Distribution - Sea Lice	What is the spatial and temporal distribution of sea lice from aquaculture farms in this region? Where are data available to adress this question? What is the level of variance arround these data?	
SLUG.04-2023	Survival and predation of sea lice in the water column	What is the survival rate of sea lice in the pelagic life stages? Where are data available to adress this question? What is the level of variance arround these data? Is there evidence of predation on sea lice in the marine	
SLUG.05-2023	How much impact does uncertainty between different models ha	What is the impact of differences between hydrodynamic mod What is the minimum level of performance required to achieve What level of complexity in hydrodynamic representation is rec Do different particle tracking models give radically different res What depth range should be considered for accurate risk ass What particle/ concentration resolution is necessary for adequ What level of complexity in particle behaviour is required to ac	S

Aim for the meeting

Identify evidence gaps, feasibility, and priority

Outcomes

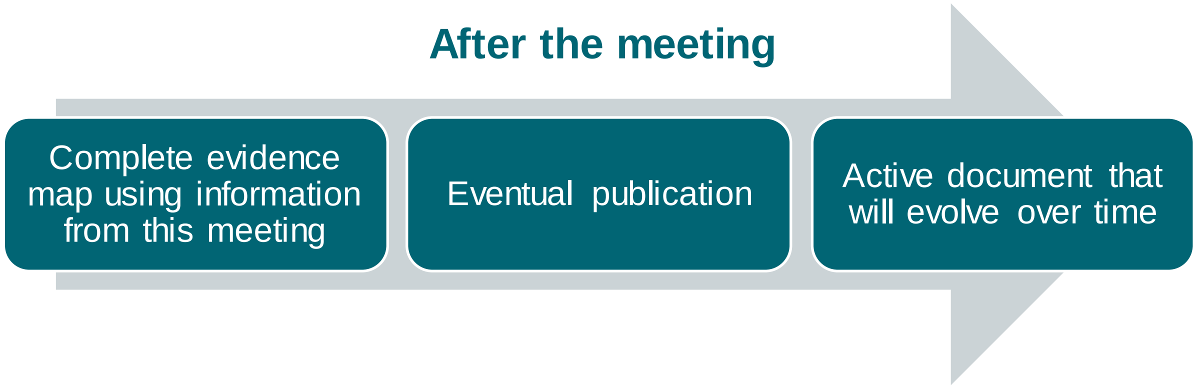
Evidence map

Understanding of relevant uncertainties

What is feasible to address?

What is essential for risk assessment?

Prioritisation for future research



Thank you

Contact details

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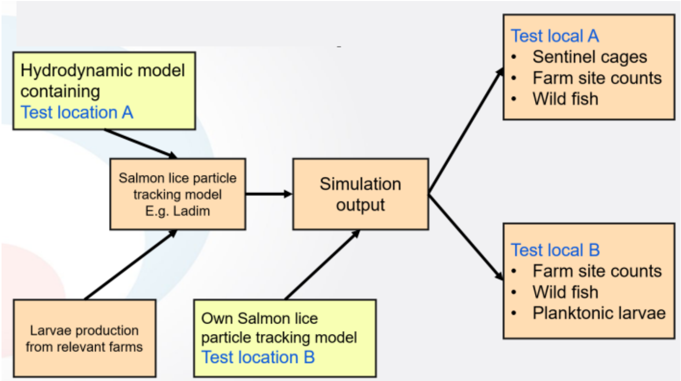
sepa.org.uk

Benchmark test for salmon lice dispersion modelling

06-sep-2023

Tróndur Kragesteen, Tróndur Johannesen, Birgitta Andreasen, Sissal Vágsheyg Erenbjerg og Gunnvør á Norði



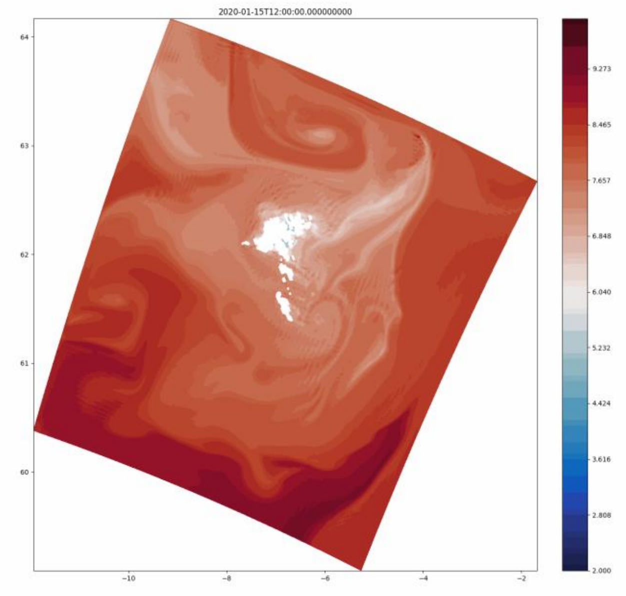
Why a benchmark test?

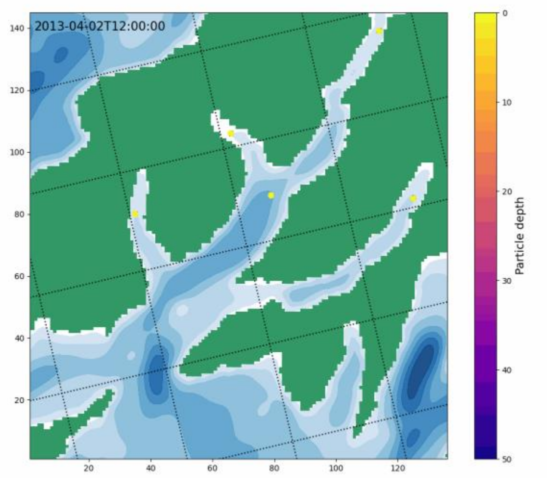
Is my model good or bad or useful?

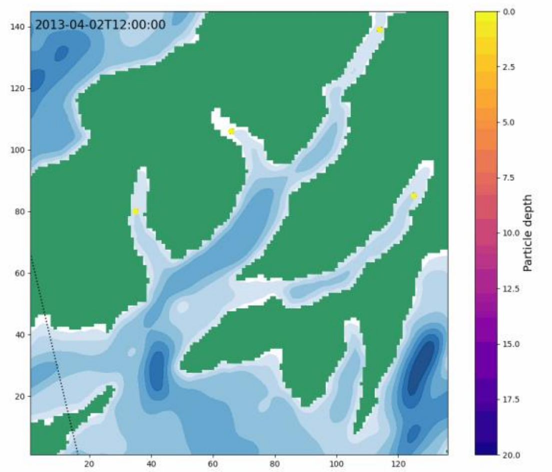
Is the model better or worse?

Benchmark Test starter pack

1. **Sufficient hydrodynamic model**
2. **Particle tracking model**
3. **Lice farm source’s**
   - **Farm position**
   - **Lice counts**
   - **Number of fish**







How to validate

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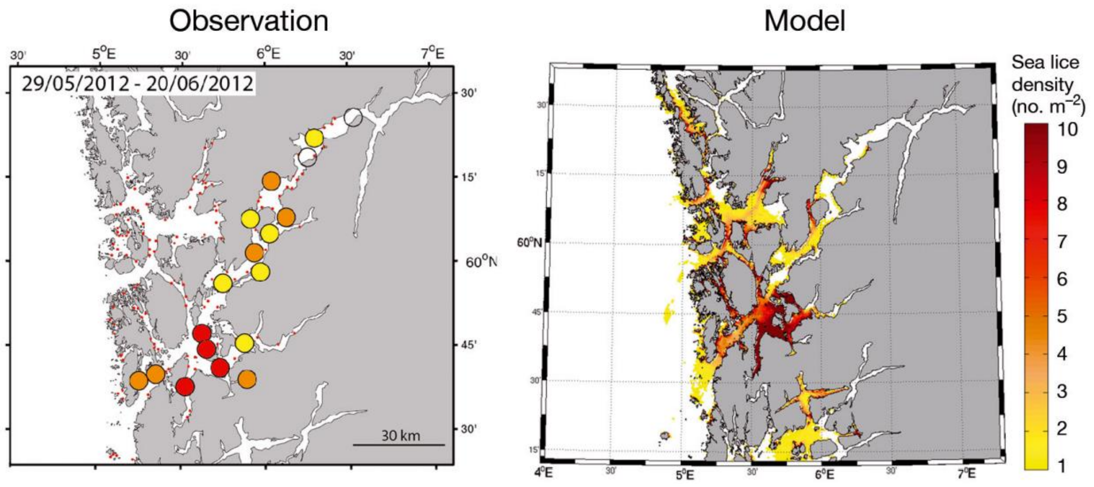
- Test location/area
  - know the sources of lice within system
  - Isolated farm networks

- Validating data
  - Sentinel cages
  - Farm site
  - Wild fish
  - Planktonic lice trawls

Sentinel cages:

- Applied Norway and Scotland
- Small cage with 30 salmon
  - Diameter: 0.8 m
  - Height: 0.9 m
  - located a 0.5 m depth
- Reset every 14 days



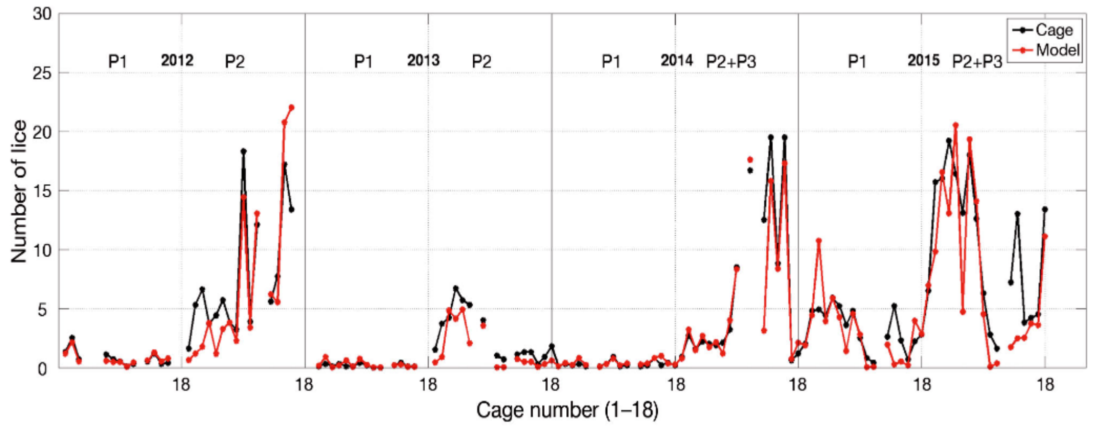


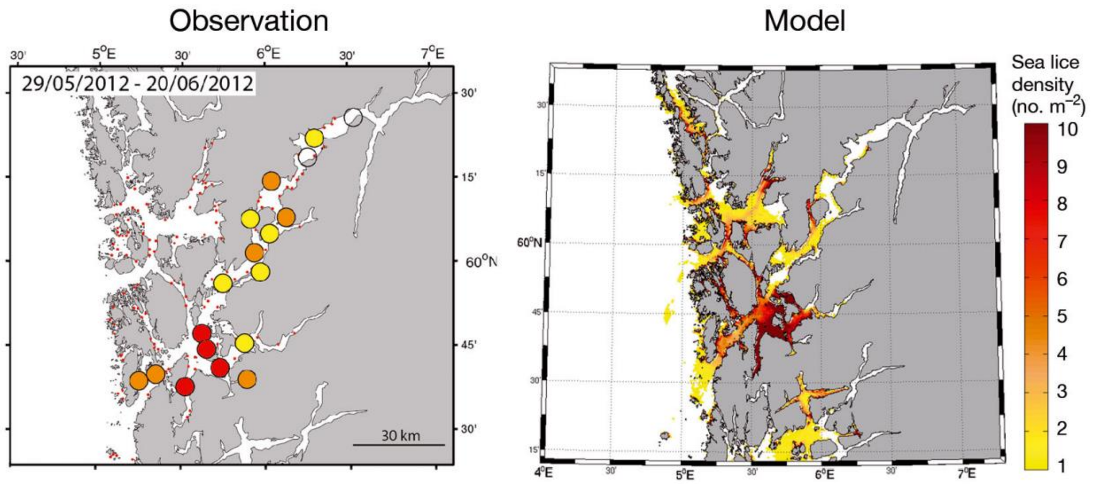
Fig. 5. Spatiotemporal series of cage data (black) and model data (red) over the tested periods (2012–2015; see Table 1). Number of lice: mean number of lice per fish from the cage data, and number of lice m^{-2} from the model (integrated over same period as the cages were deployed in the sea). Numbers on the *x*-axis show the repeating cage numbers from the first period in 2012 to the last period in 2015

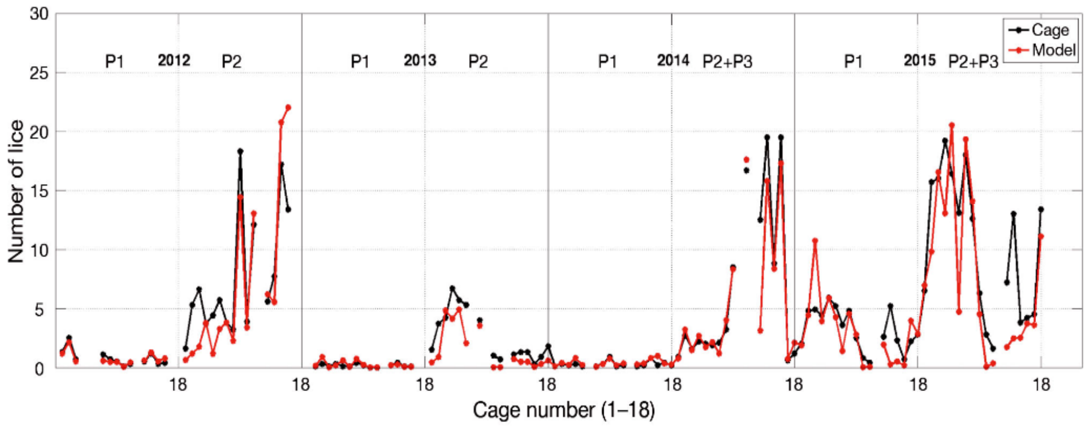
Sandvik et al., 2016

Sentinel cages:

Drawbacks:

- Infection success is still uncertain
- Expensive to maintain
- Fish welfare ethics
- Can not be deployed anywhere





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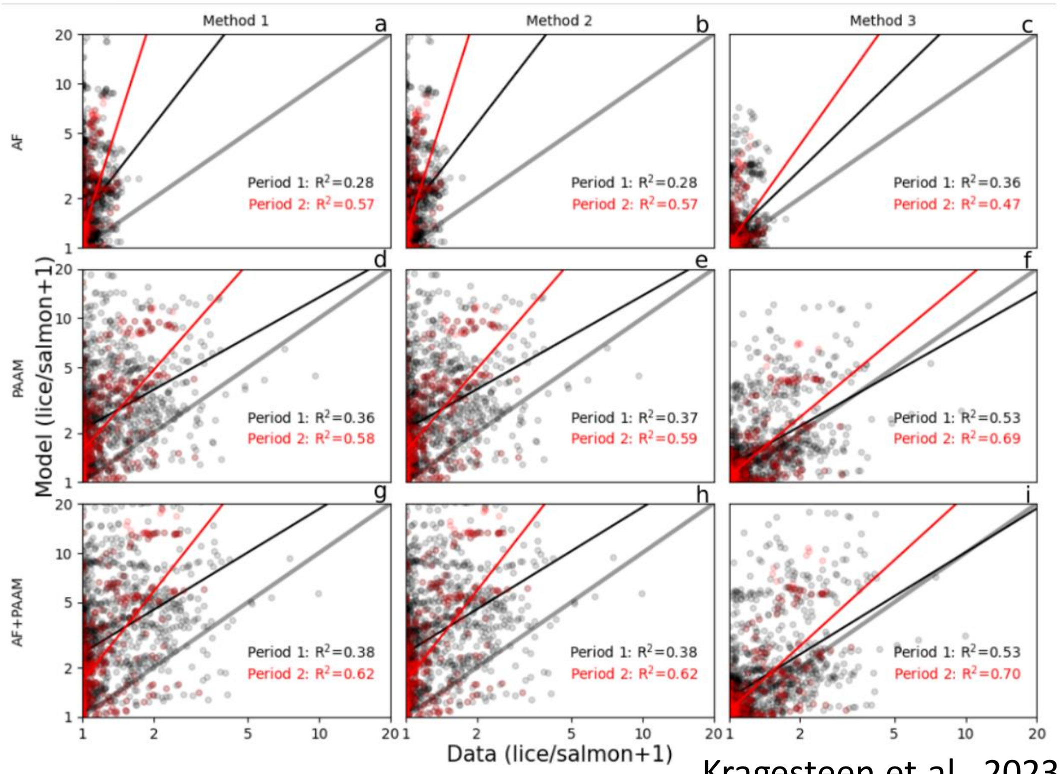
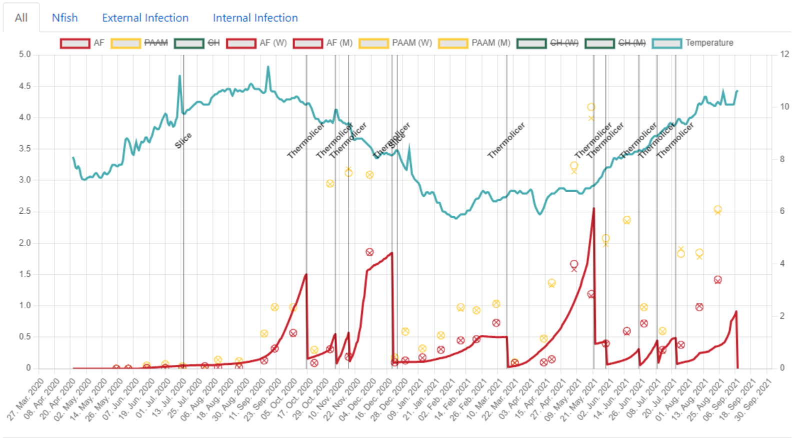
Sandvik et al., 2016

Farm site lice counts:

- Population dynamic model is required
- Large "sentinel" cages
- First 100-150 days can be suitable

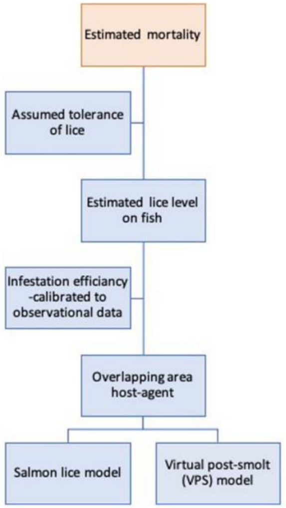


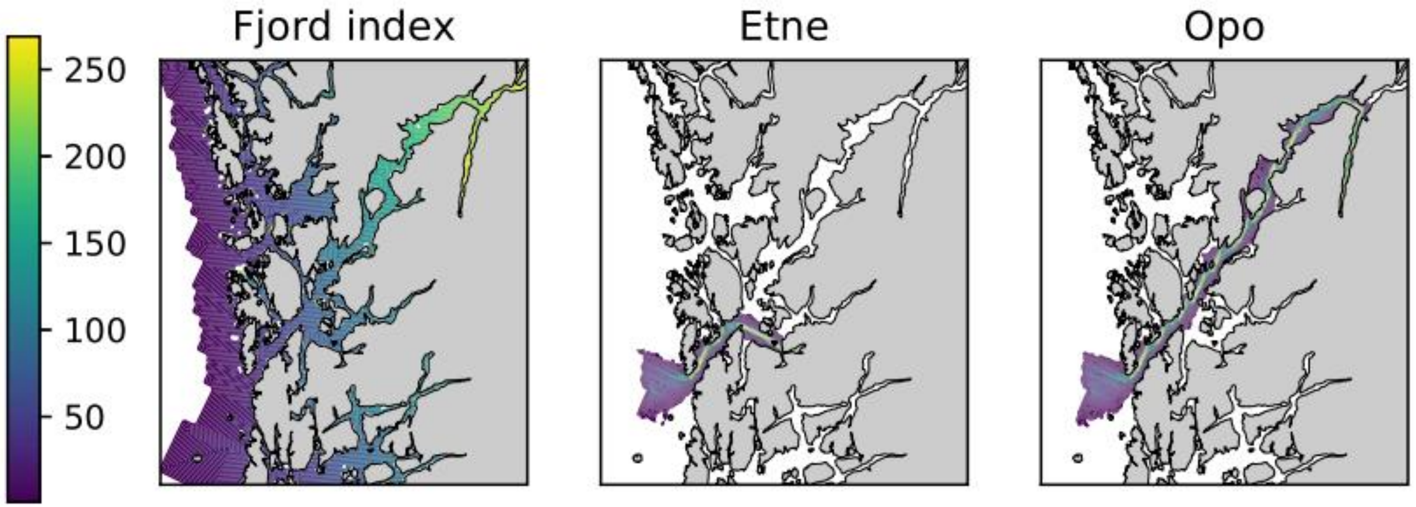
Kragesteen et al., 2023



Wild fish catches:

- Done systematically in Norway
- Is a significant indicator in the “Traffic light system”.
- Requires an additional model of how salmon migrate.





Johnsen et al., 2021

Planktonic sea lice trawls

- Time series of copepodid densities
    - Faroe Islands and Scotland
- Large samples needed
- Time consuming to identify
- Open water densities low and variable
- Further innovation could make planktonic sampling more feasible

Penston et al. 2009

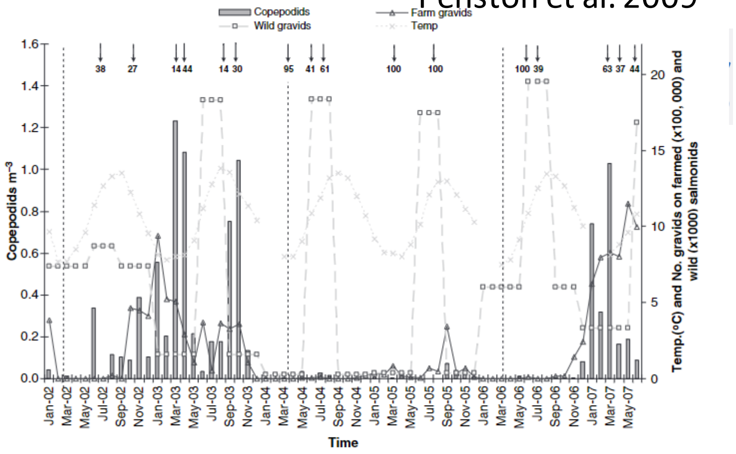
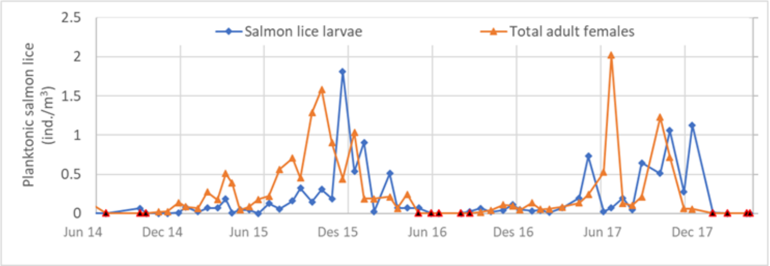


Figure 2 The estimated numbers of gravid *Lepeophtheirus salmonis* on farmed salmon (dark line with triangle) and the upper estimate of gravid *L. salmonis* on wild salmonids (light line with square) in the Loch Torridon area and the mean *L. salmonis* copepodid densities (bars) recovered in the water column at stations A, C and E, between January 2002 and June 2007. Sea surface temperature is indicated by the cyclical dotted line. The vertical dashed line indicates when the farms restocked and the arrows indicate applications of emamectin benzoate on at least one of the farms. The numbers associated with the arrows represent the percentage of the total farmed biomass treated for that month.

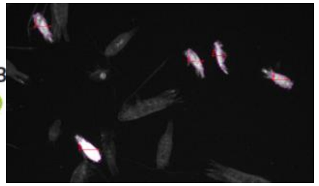


Example of timeseries in Faroe Islands (unpublished)

Received: 26 November 2020 | Revised: 12 January 2021 | Accepted: 13 January 2021
DOI: 10.1111/jfd.13345
ORIGINAL ARTICLE
Journal of Fish Diseases WILEY

Illuminating the planktonic stages of salmon lice: A unique fluorescence signal for rapid identification of a rare copepod in zooplankton assemblages

Cameron R. S. Thompson[1] | James E. Bron[2] | Samantha B
Sussie Dalvin[1] | Mark J. Fordyce[4] | Tomasz Furmanek[1]
Rasmus Skern-Mauritzen[1]



Test bench setup

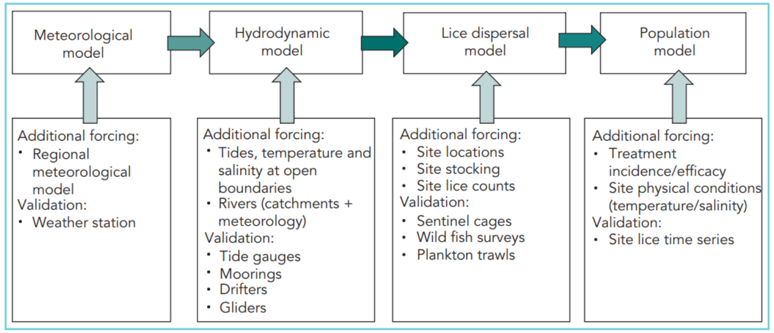
Larvae production from relevant farms

Salmon lice particle tracking model
E.g. Ladim

Simulation output

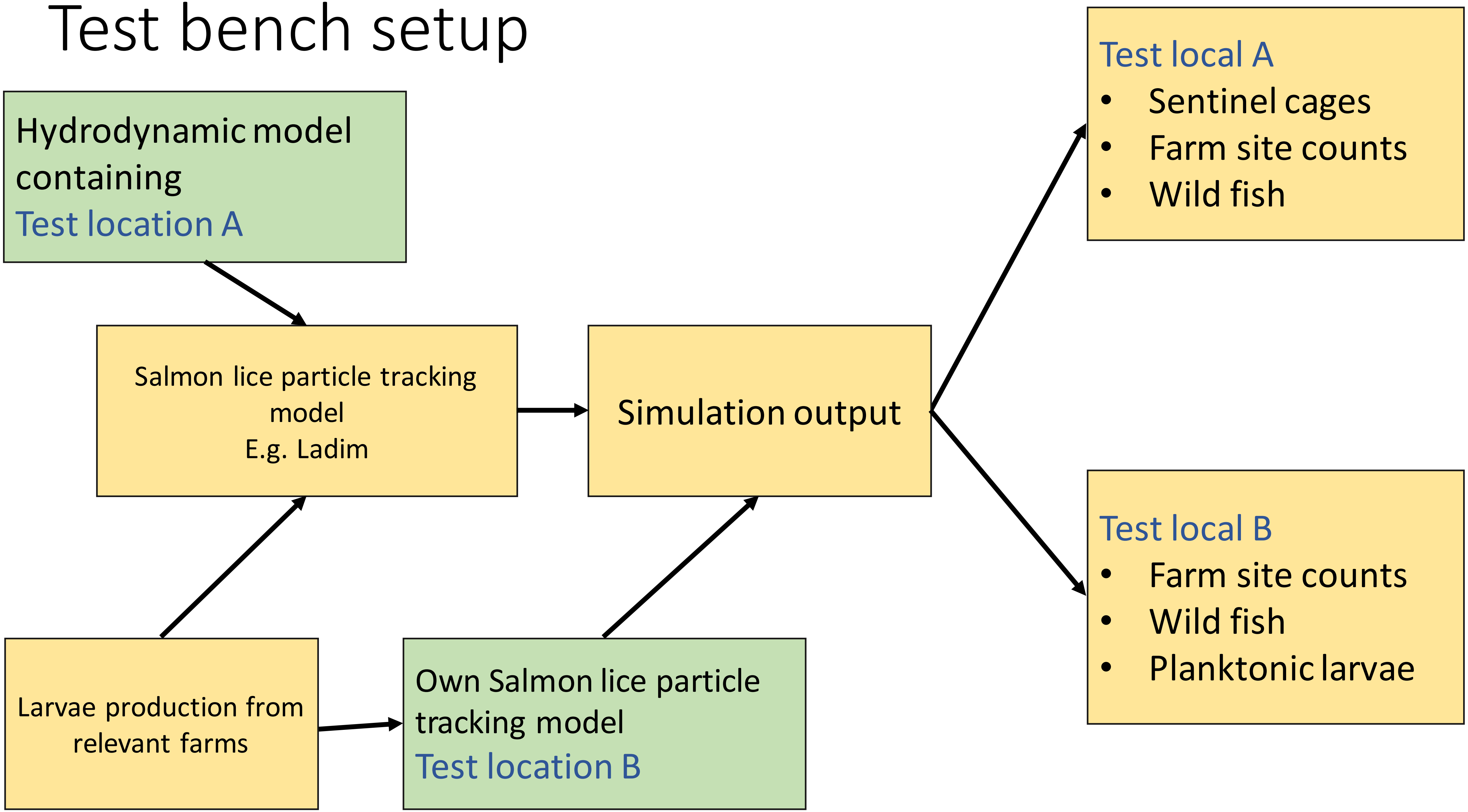
Test local A
- Sentinel cages
- Farm site counts
- Wild fish

Test local B
- Farm site counts
- Wild fish
- Planktonic larvae



Murray et. al., 2022

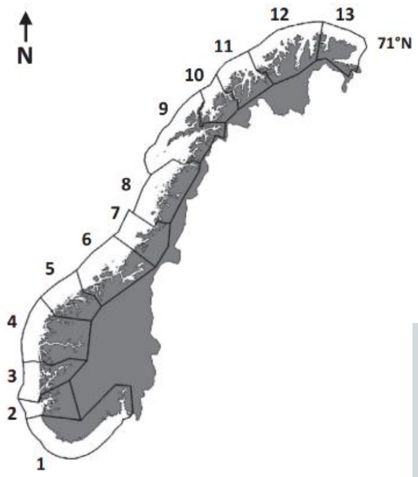
Test bench setup



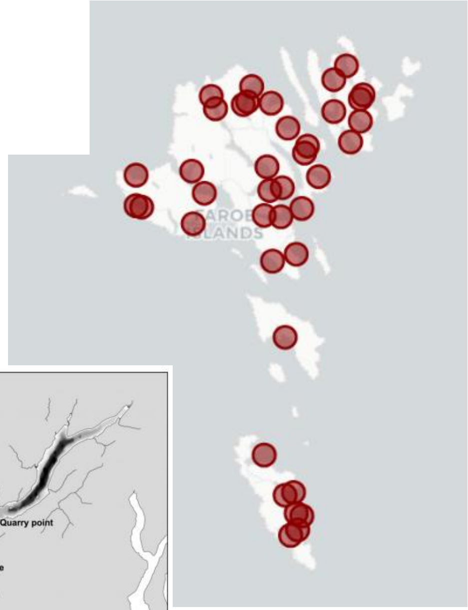
Test locations

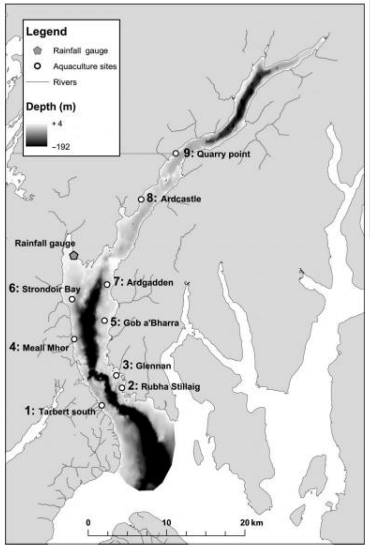
Some examples:

- Production zone 2 or 3 in Norway
- Faroe Islands
- Loch Fyne in Scotland?



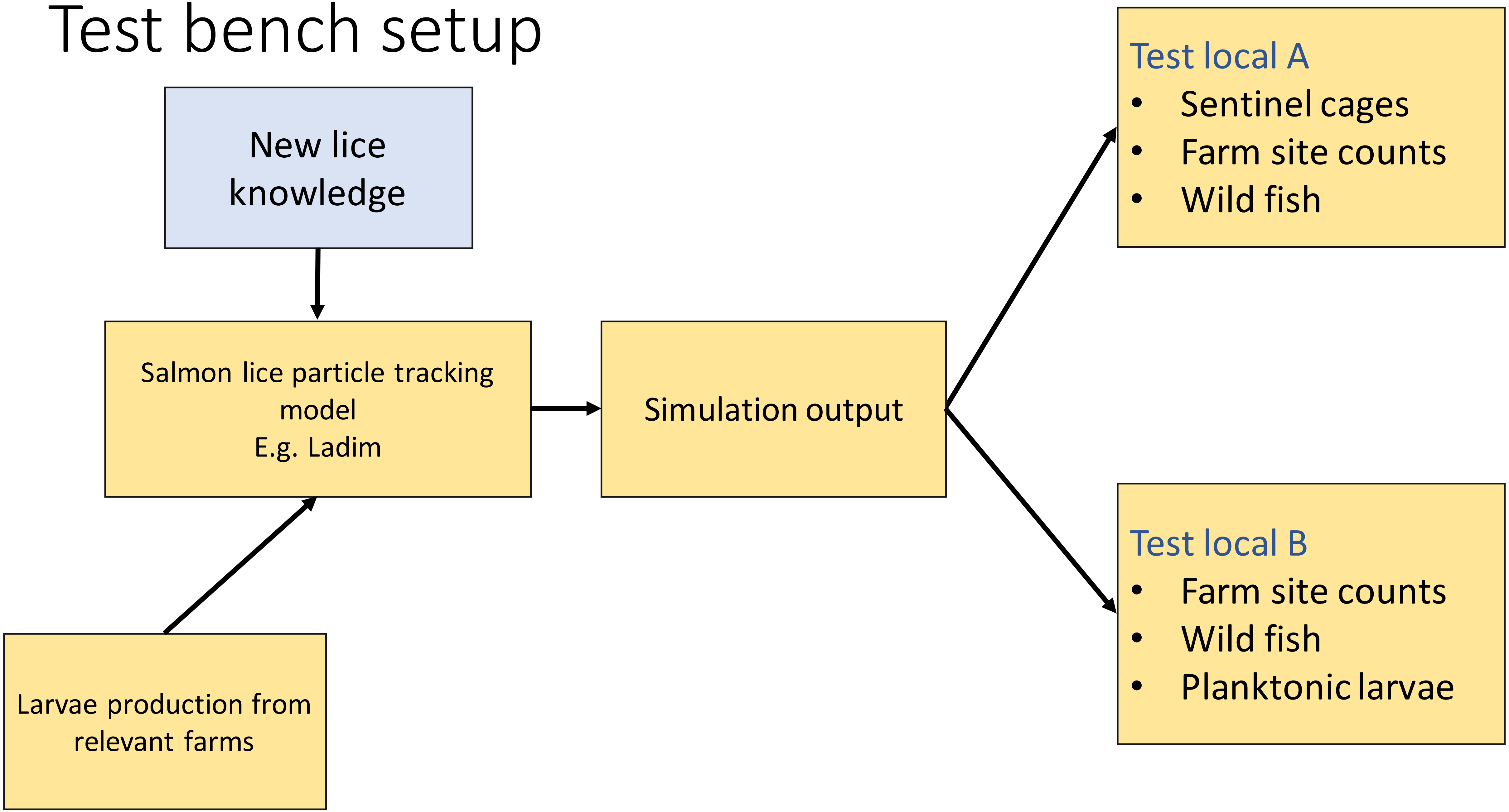
Overton et. al., 2019





Adams et. al., 2012

Test bench setup



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The end... ☺

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Francisco Bravo, PhD

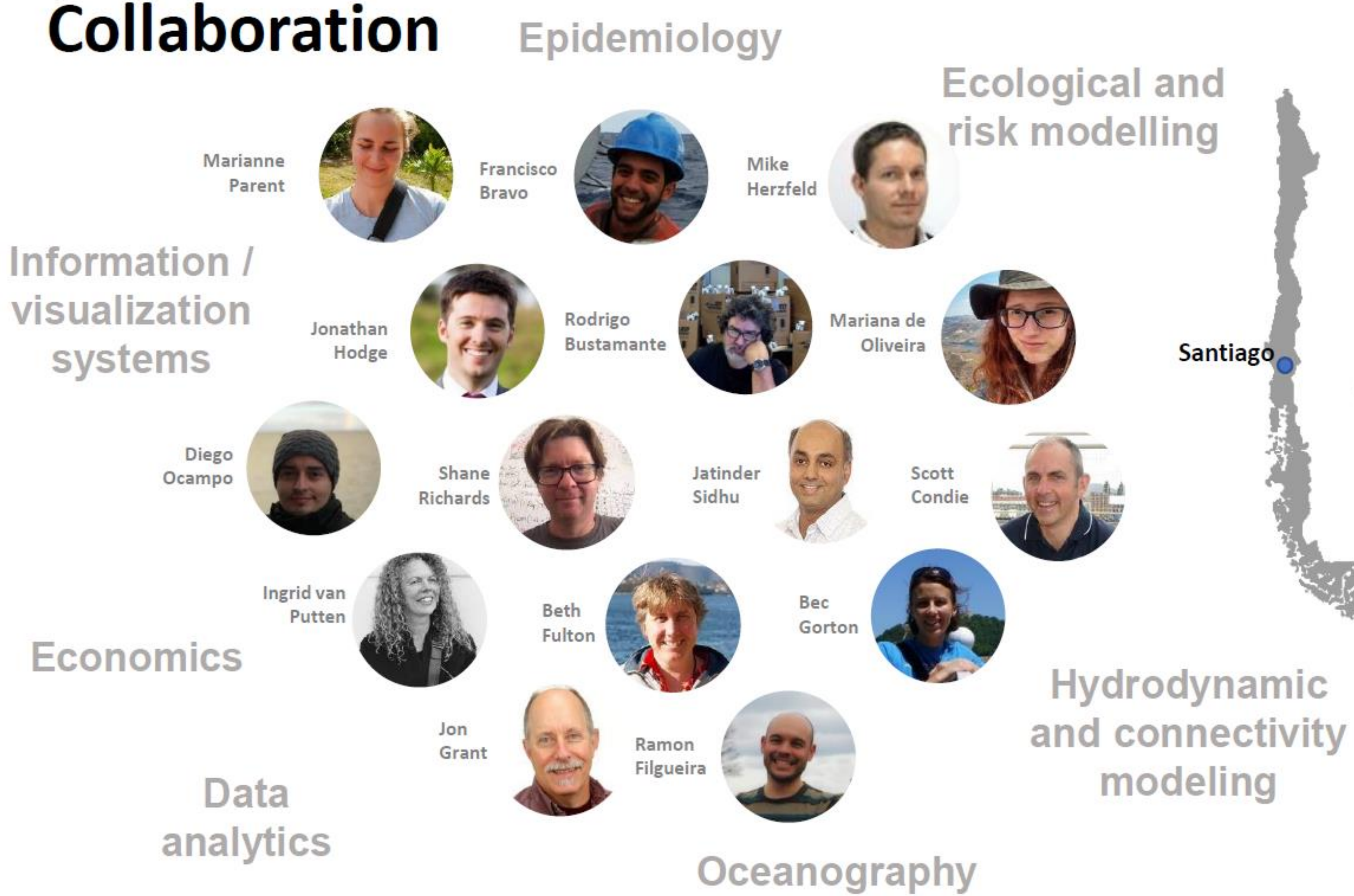
Marine Biologist and oceanographer

Research interests:

- Numerical modeling of marine-coastal socio-economic and ecological systems
- Industry-environment interactions in coastal zones
- Coastal, estuarine and marine sediment biogeochemistry + benthic ecology

CSIRO Chile

Collaboration



SalmonChile Intesal

SERNAPESCA

{epi³lab}

DALHOUSIE UNIVERSITY

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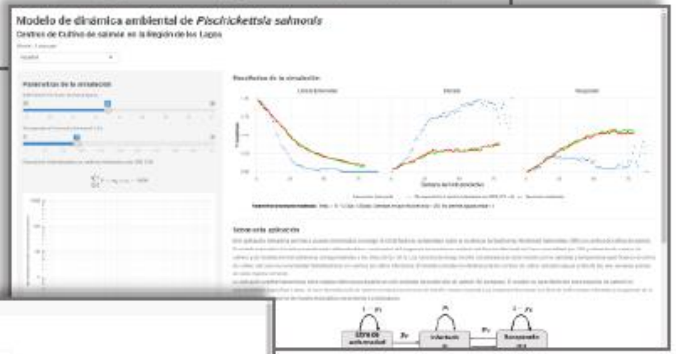
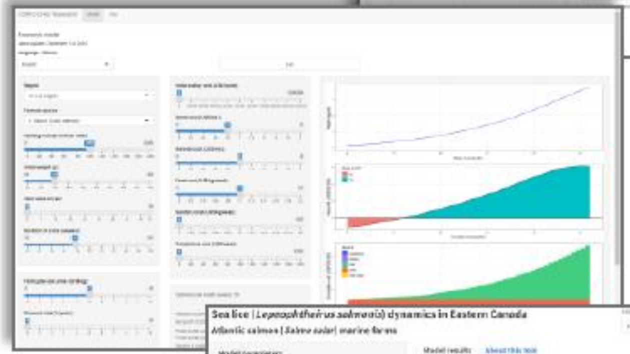
https://www.csiro.cl/bigdata-salmonicultura/

Dynamics of salmon diseases at the sanitary neighborhood level

Environmental Dynamics Model of *P. salmonis*



Bioeconomic performance



Sea lice dynamics in Eastern Canada

Key elements of previous modelling work in aquaculture

1. **Developed at the level of farm and farming cycle, but feasible to integrate into larger scales** (i.e. group of farms).
2. **Standalone models but feasible to integrate with real-time monitoring systems.**
3. **Empirically validated with industry data.**
4. **Risk-based approach** (probability of undesired events where end-users choose risk level to take).
5. **Discriminate the role of environmental conditions and farming practices**

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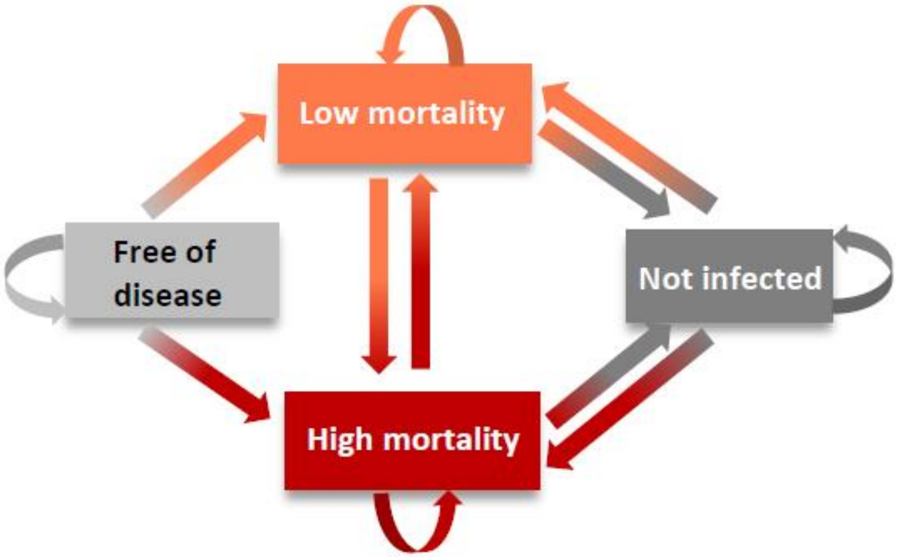
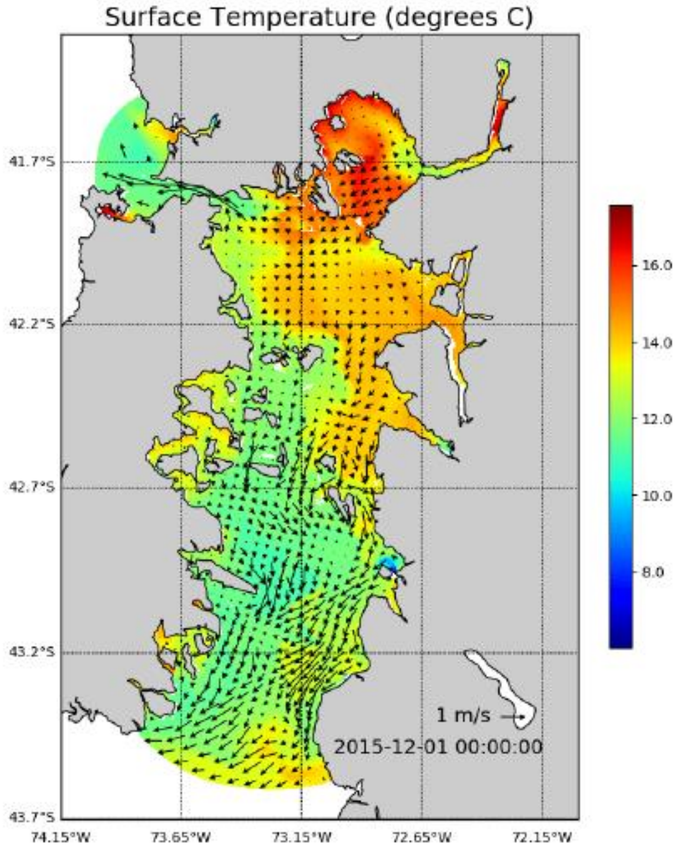
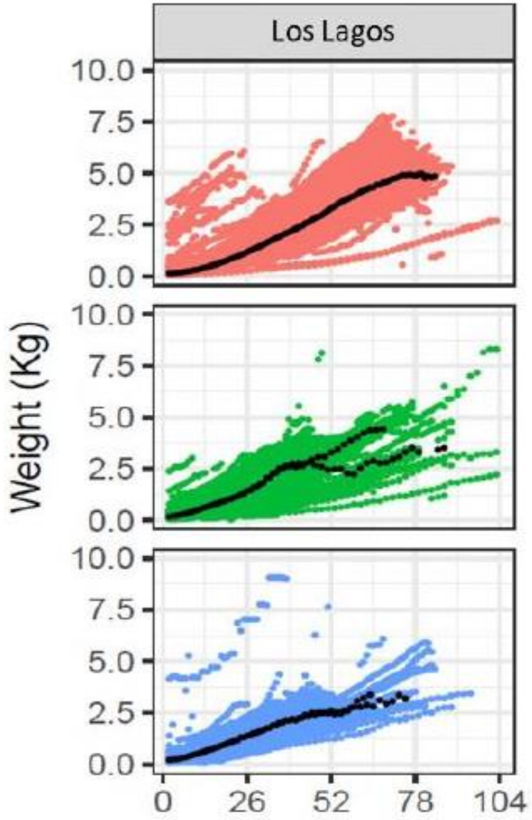
Modelling approaches

Probabilistic / Stochastic



Deterministic / mechanistic





CSIRO Chile

Sealice dispersal modelling

Euclidean distance among sites

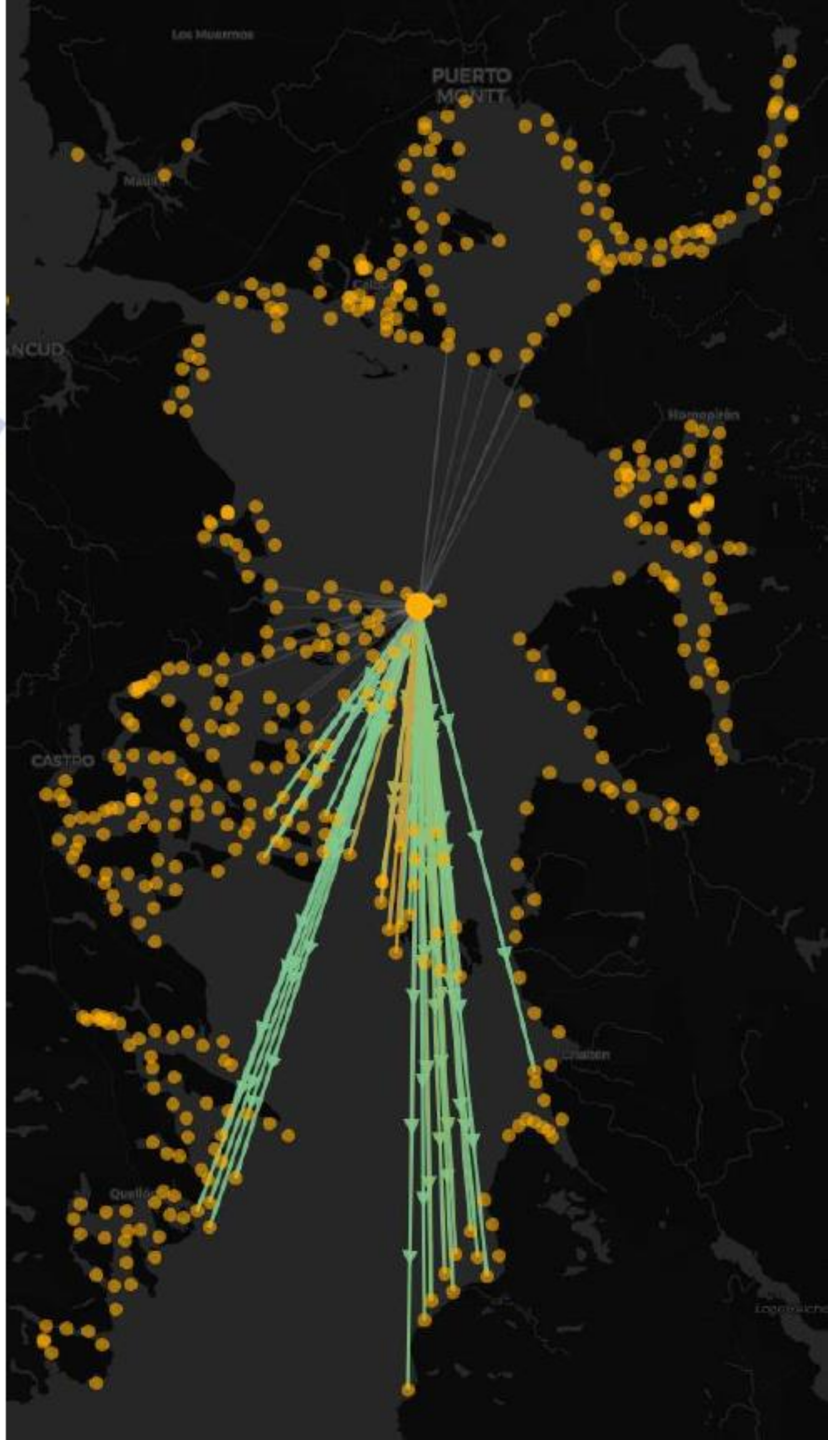
Seaway distance and Kernel density estimates

Theoretical hydrodynamic connectivity

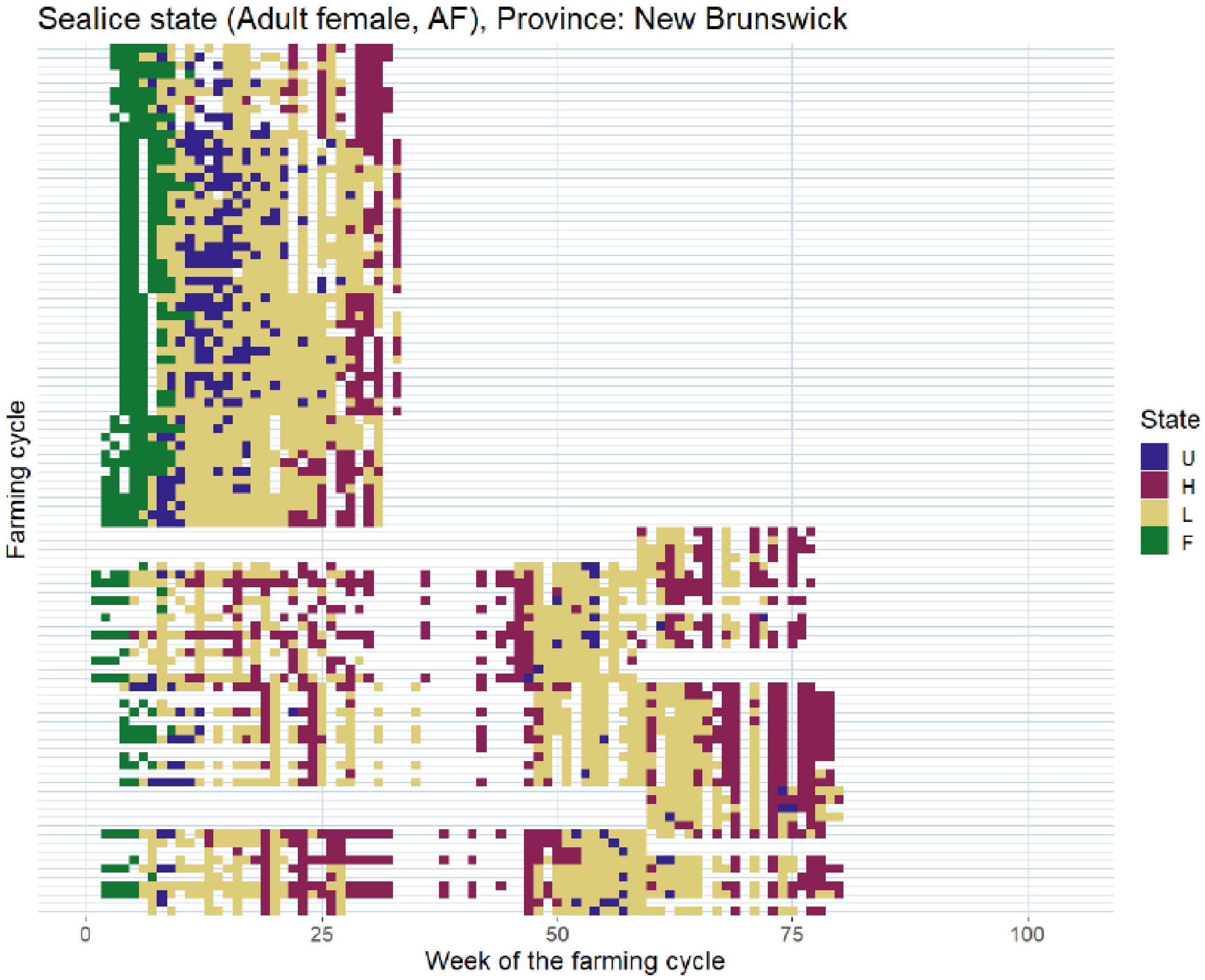
- Particle dispersal models with no active behaviour

Realized hydrodynamic connectivity

- Active behaviour included in particle dispersal models
- Filtered by actually spreding farms

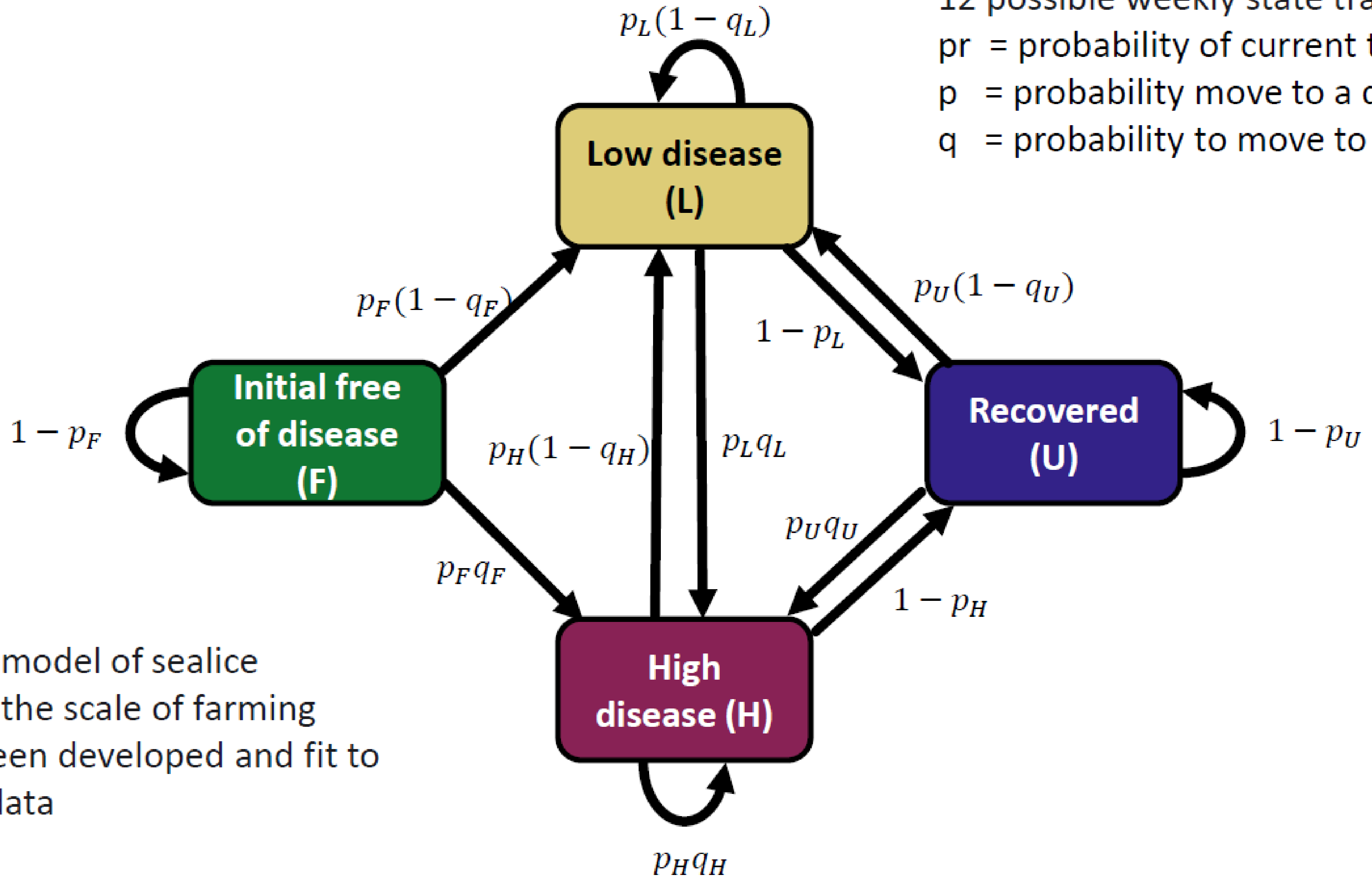


The Fish-iTrend database



The Fish-iTrend database

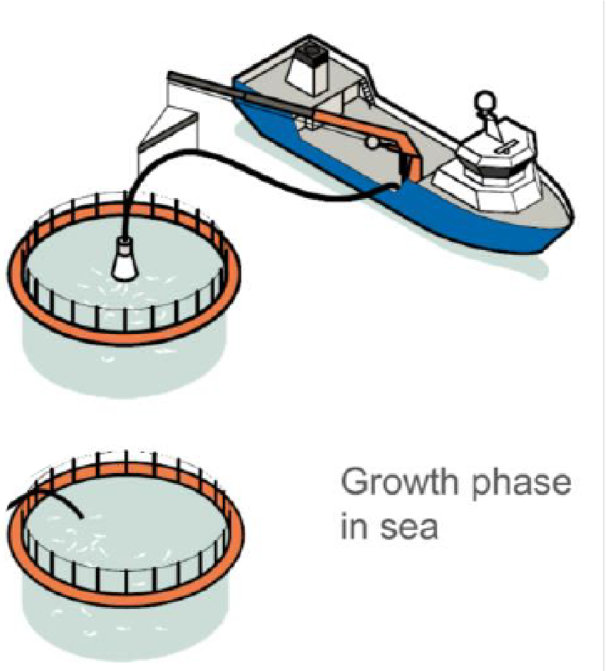
4 disease states (boxes)
12 possible weekly state transitions (arrows)
pr = probability of current transition
p = probability move to a disease state (L or H)
q = probability to move to the high disease state



A predictive model of sealice dynamics at the scale of farming cycles has been developed and fit to Fish-iTrend data

Sea lice dynamics and modelling

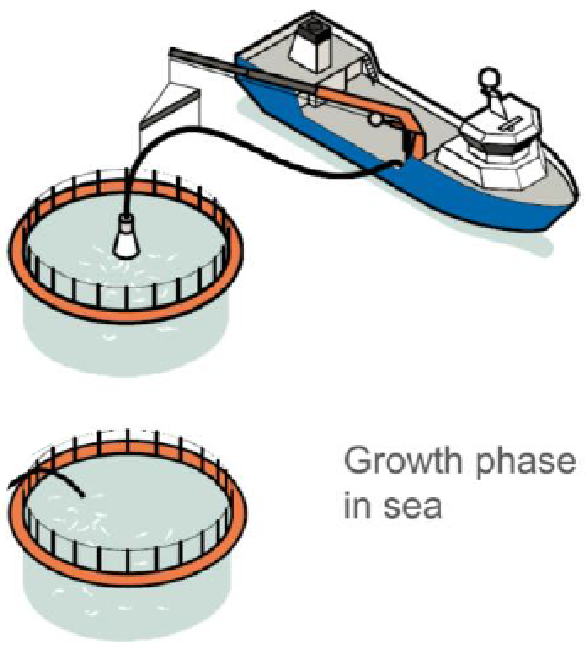
Covariates incorporated so far:	- Week of the year when the fish cage are stocked - Waterborne transmission of sealice based on Gaussian kernel density estimate (KDE) of seaway distances among sites. - Sea surface temperature (MUR-SST) - Sea surface salinity (Copernicus-SSS) - Active treatment (yes/no) in response to high infestation
Other covariates to incorporate in second round:	- Bay Management Area (BMA) practices / regulations. - Number of active cages (with fish on cages). - Co-ocurrance of CHAL (chalimus, stages I and II), PAAM (pre-adult and adult males), and Caligus. - Fish density (ind m^{-3}, Kg m^{-3}, Ton $cage^{-1}$). - Age or size of fish at stocking. - North Atlantic Oscillation or similar index for year effects. - Type of sealice treatment (Boat, In-Feed, Skirt, Tarp) - Proxy of smolt quality?

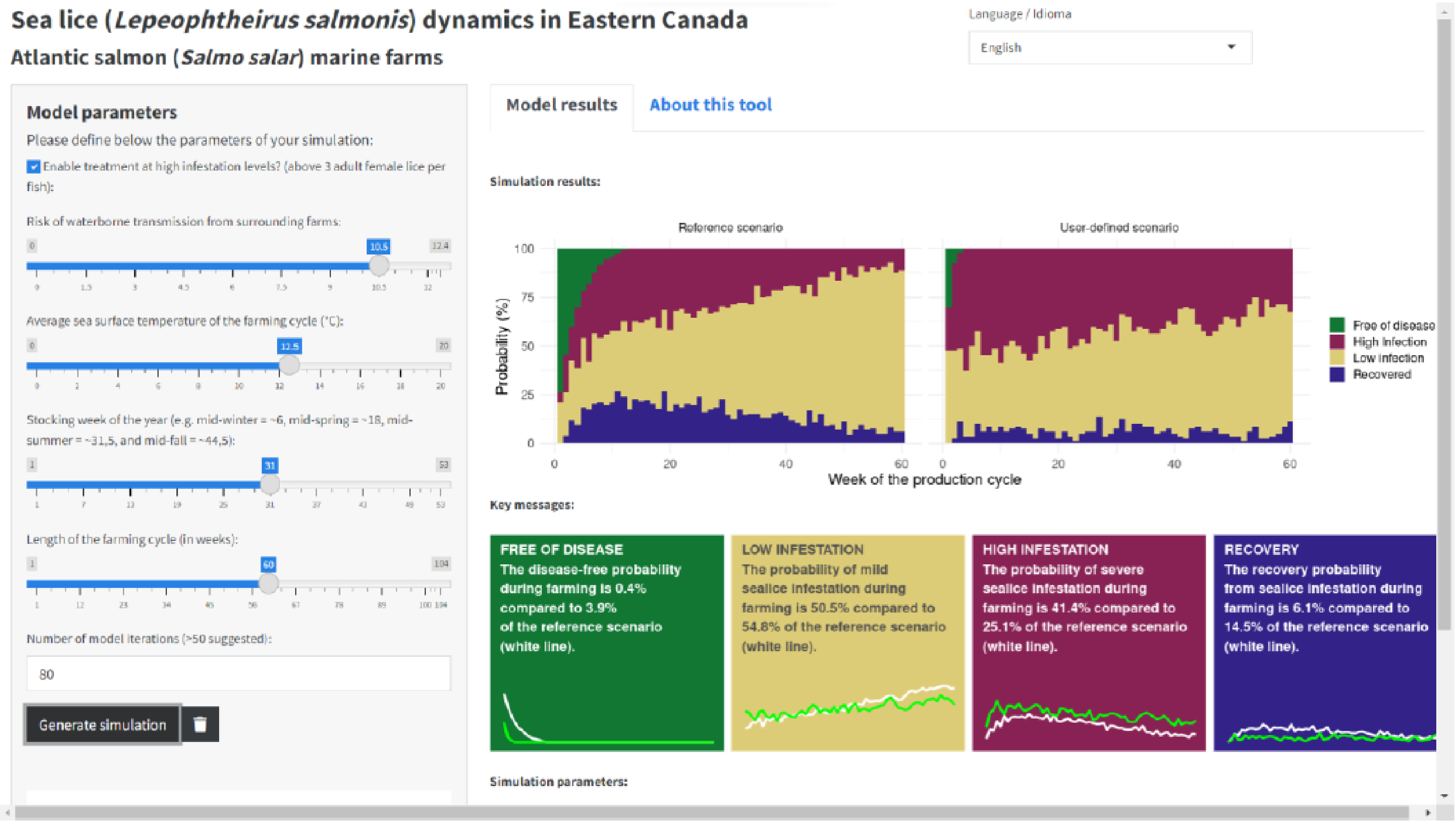


Chile

Sea lice dynamics and modelling

Covariates incorporated so far:	- Week of the year when the fish cage are stocked - Waterborne transmission of sealice based on Gaussian kernel density estimate (KDE) of seaway distances among sites. - Sea surface temperature (MUR-SST) - Sea surface salinity (Copernicus-SSS) - Active treatment (yes/no) in response to high infestation
Other covariates to incorporate in second round:	- Bay Management Area (BMA) practices / regulations. - Number of active cages (with fish on cages). - Co-ocurrance of CHAL (chalimus, stages I and II), PAAM (pre-adult and adult males), and Caligus. - Fish density (ind m^{-3}, Kg m^{-3}, Ton $cage^{-1}$). - Age or size of fish at stocking. - North Atlantic Oscillation or similar index for year effects. - Type of sealice treatment (Boat, In-Feed, Skirt, Tarp) - Proxy of smolt quality?





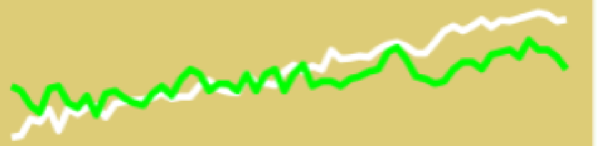
Sea lice (*Lepeophtheirus salmonis*) dynamics in Eastern Canada
Atlantic salmon (*Salmo salar*) marine farms
Language / Idioma
English
Model parameters
Please define below the parameters of your simulation:
Enable treatment at high infestation levels? (above 3 adult female lice per fish):
Risk of waterborne transmission from surrounding farms:
Average sea surface temperature of the farming cycle (°C):
Stocking week of the year (e.g. mid-winter = ~6, mid-spring = ~18, mid-summer = ~31,5, and mid-fall = ~44,5):
Length of the farming cycle (in weeks):
Number of model iterations (>50 suggested):
80
Generate simulation
Model results
About this tool
Simulation results:
Reference scenario
User-defined scenario
Probability (%)
Week of the production cycle
Free of disease
High infection
Low infection
Recovered
Key messages:
FREE OF DISEASE
The disease-free probability during farming is 0.4% compared to 3.9% of the reference scenario (white line).
LOW INFESTATION
The probability of mild sealice infestation during farming is 50.5% compared to 54.8% of the reference scenario (white line).
HIGH INFESTATION
The probability of severe sealice infestation during farming is 41.4% compared to 25.1% of the reference scenario (white line).
RECOVERY
The recovery probability from sealice infestation during farming is 6.1% compared to 14.5% of the reference scenario (white line).
Simulation parameters:

Model predictions

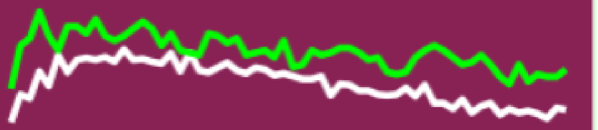
What do we get from the model? → **Probabilities through time of being in different disease states**

FREE OF DISEASE
The disease-free probability during farming is 0.4% compared to 3.9% of the reference scenario (white line).

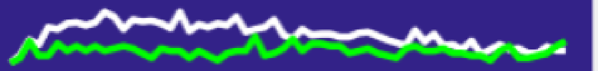
LOW INFESTATION
The probability of mild sealice infestation during farming is 50.5% compared to 54.8% of the reference scenario (white line).



HIGH INFESTATION
The probability of severe sealice infestation during farming is 41.4% compared to 25.1% of the reference scenario (white line).



RECOVERY
The recovery probability from sealice infestation during farming is 6.1% compared to 14.5% of the reference scenario (white line).



Simulated conditions (green line)
Reference conditions (white line)

For more information:

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w www.csiro.au/

Thanks you
Questions?

Empirical estimation of *L. salmonis* dispersal in the Bay of Fundy, NB

Stakeholder Workshop – Knowledge strength in sea lice dispersal modelling

Marianne Parent, BSc, DVM, MSc, PhD candidate

September 7th, 2023

CVER

UNIVERSITY of Prince Edward ISLAND

Fish-iTrends; ACFAA-NAIA-AANS LIU:

Acknowledgements

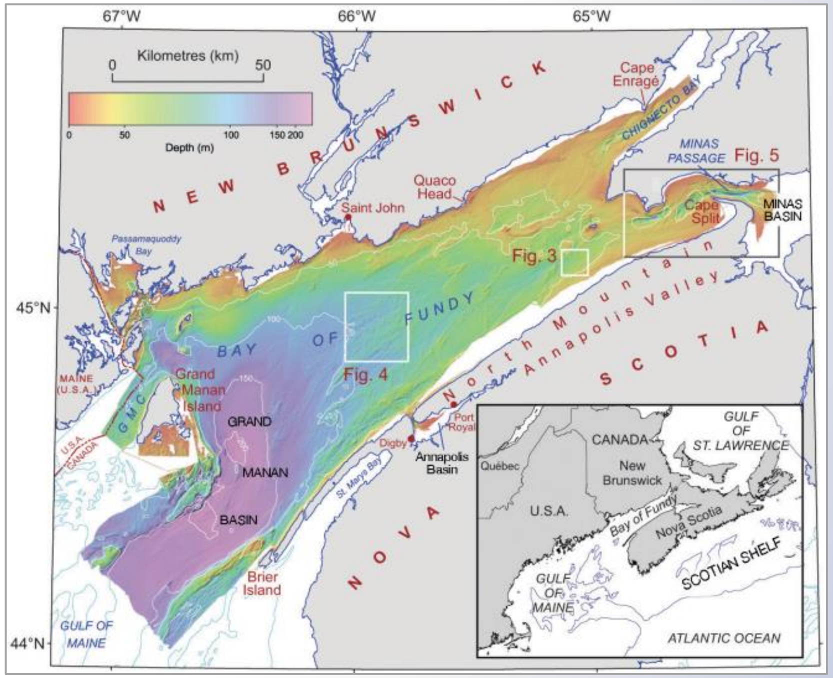
Connectivity & dispersal

- Mitigation is improved by knowledge of connections among sites (Adams et al., 2015; Samsing et al., 2017)
  - Connectivity occurs as sites share same ecological resource (Le Corre et al., 2017)
  - ‘Disconnecting’ sea lice populations by removing habitat patches (i.e., farms) to epidemiologically significant distances (Samsing et al., 2017)
- Estimation of dispersal distance
  - Maximum peak of dispersal kernels (Samsing et al., 2017)
  - Infestation pressure (Kristoffersen et al., 2014, 2018; Elghafghuf et al., 2020 ; Parent et al., 2021)
  - Hydrodynamic model combined with particle-tracking model (Cantrell et al.; 2018; Harrington et al., 2022)

Data Sources

- Fish-iTrends data management system
  - 2009-2018
- Sea surface temperature: remotely-sensed (UK Met Office)

- Regional depth map (bathymetry map) from Fisheries and Oceans Canada
  (Greenberg et al., unpublished)



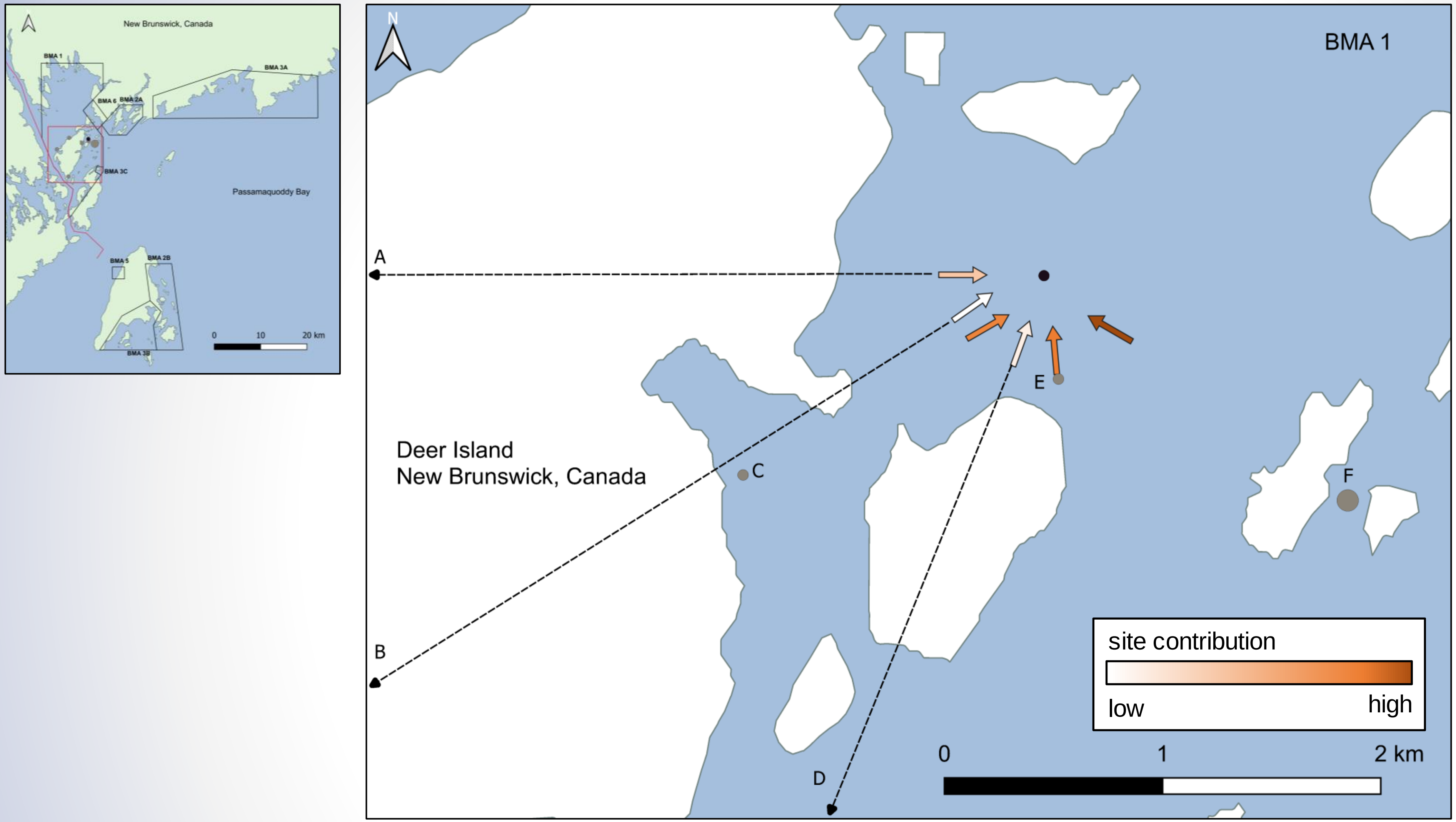
(Todd & Shaw, 2014)

Infestation pressure

- Measure that represents the dose of exposure of infectious stages of sea lice to potential fish hosts
- Temporally weighted average abundances with a time lag within a site (internal: IIP) and among sites (external: EIP)
    - IIP: contributions from AF & PAAM
- EIP were spatially weighted
    - Kernel density estimation of seaway distance at 100 m resolution

External infestation pressure

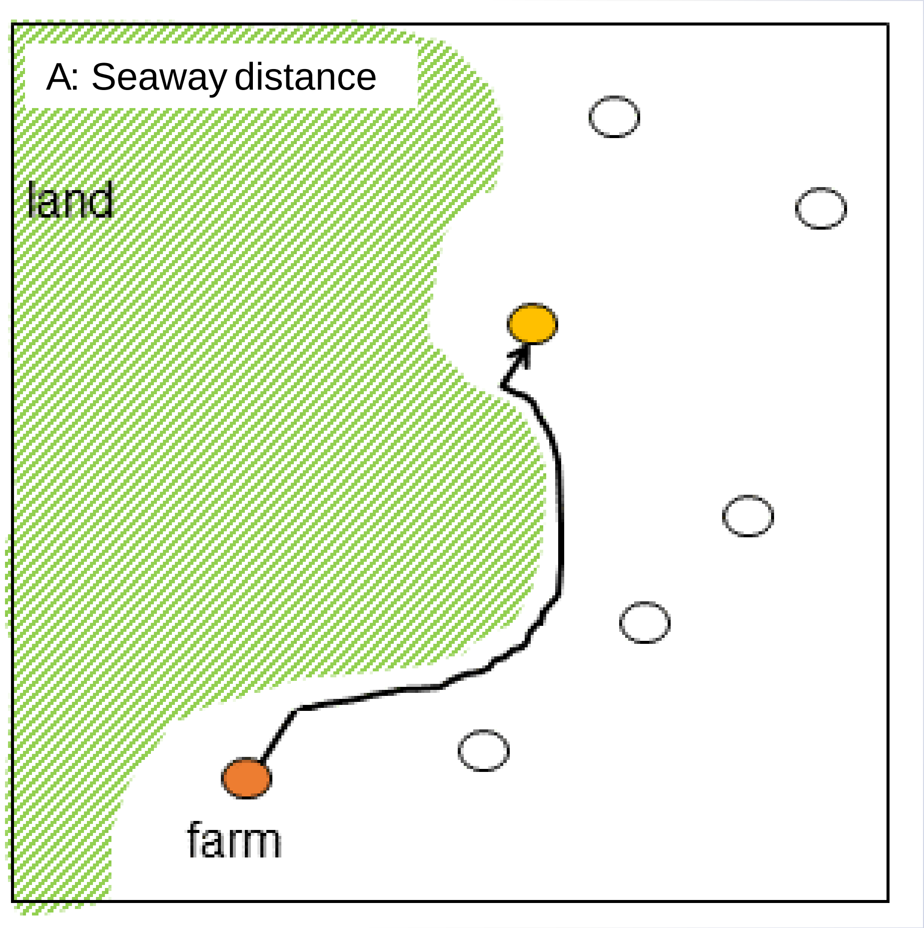
- EIP predictor in multivariate linear mixed models
  - Segment approach (Parent et al., 2021)
    - Standardized estimated coefficient 0.11, 95% CI 0.09-0.14
  - Time series regression:
    - Standardized estimated coefficient 0.05, 95% CI 0.02-0.08
  - Greater seaway distances have lower EIP

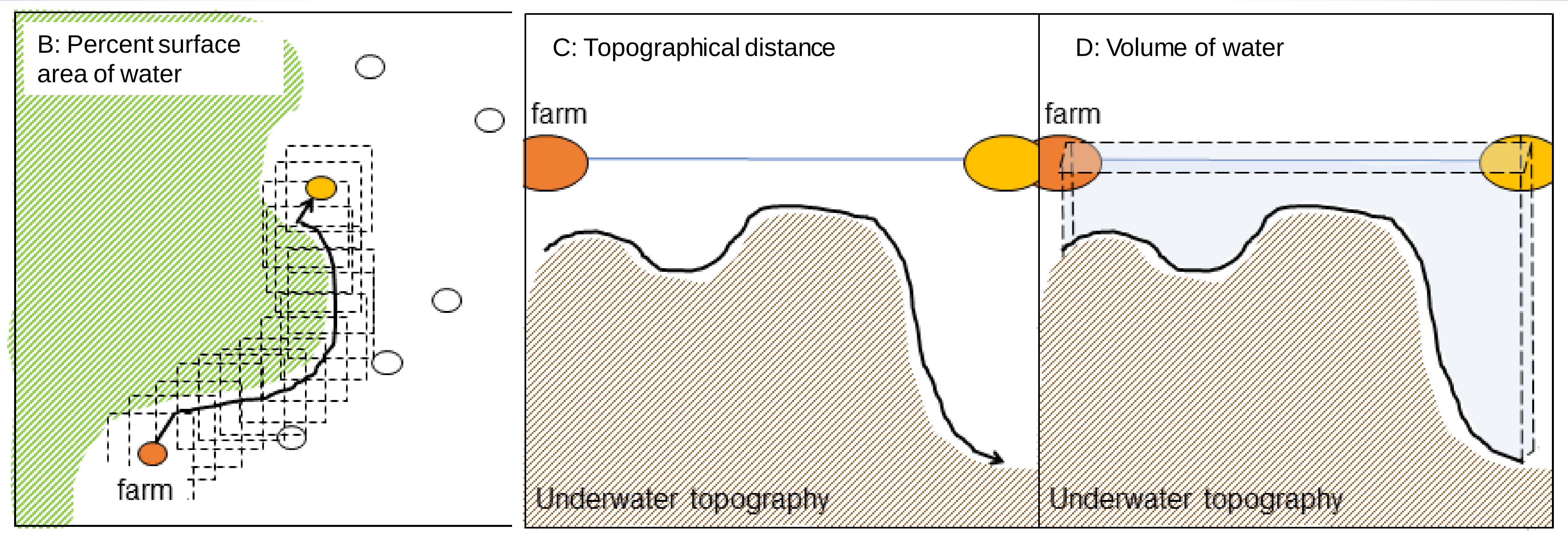


Site contributions (arrows) from neighbouring sites (grey circles) to the external infestation pressure of a selected site (black circle). Site contributions of F are twice the contributions of other sites (A-E). Dashed arrows (A, B and D) point to sites beyond map bounds at seaway distances of 6.5 km, 13.8 km and 10.0 km, respectively.

Connectivity measures

- For all pairs of sites:
  - Seaway distance (25 m grid resolution)
  - Percent surface area that is water
    - Area with radius of 250, 500, and 1000 m
  - Topographical distance
    - Unadjusted
    - Adjusted by factors of 10, 100, 500 and 1000
  - Volume of water
    - Unadjusted
    - Area with radius 250, 500, and 1000 m





Depictions of the methods for the generation of connectivity matrices. Additional matrices were produced by increasing the covered area to 250 m, 500m, and 1000 m (B and D), and multiplying by a factor of 10, 100, 500, and 1000 (C).

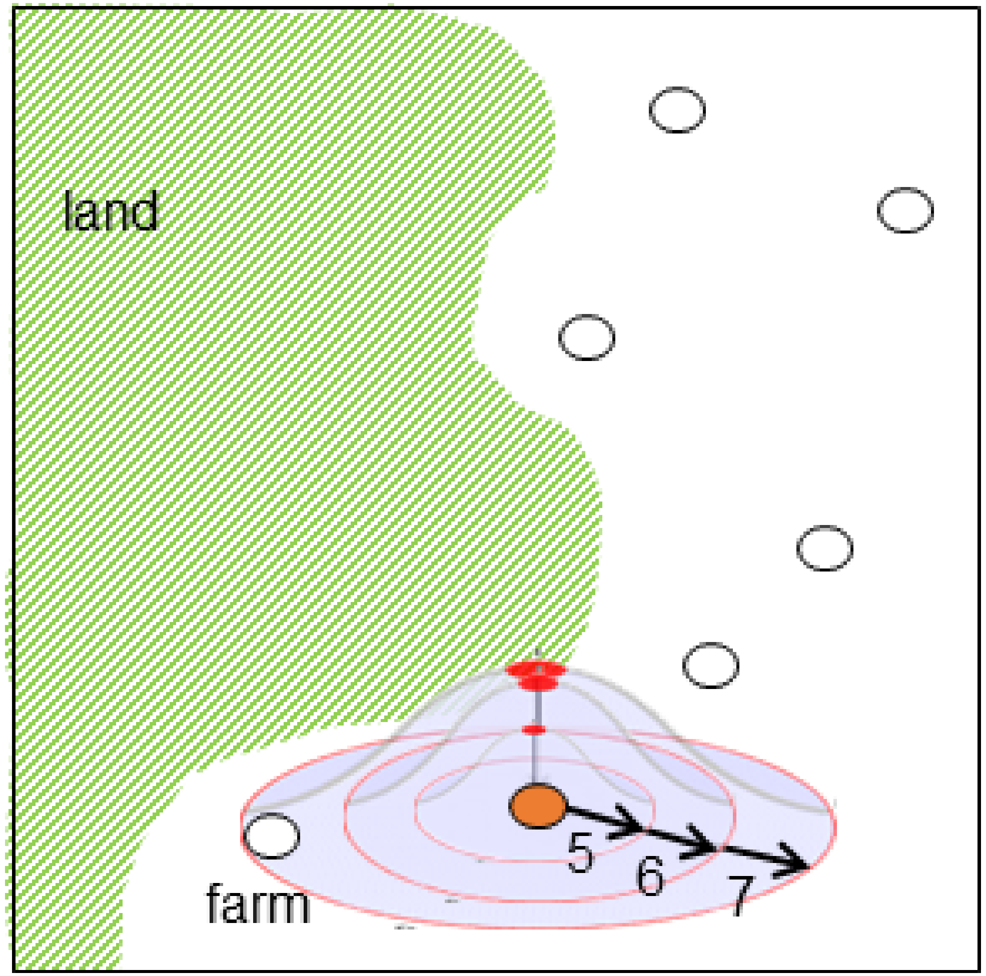
Conclusion

- Dispersal of sea lice occurs throughout Bay of Fundy
- Empirically determined dispersal distance
  - 10 km seaway distance
  - 7-8 km percent surface area of water
  - Not a maximum, highest likelihood that sea lice travel that dispersal distance

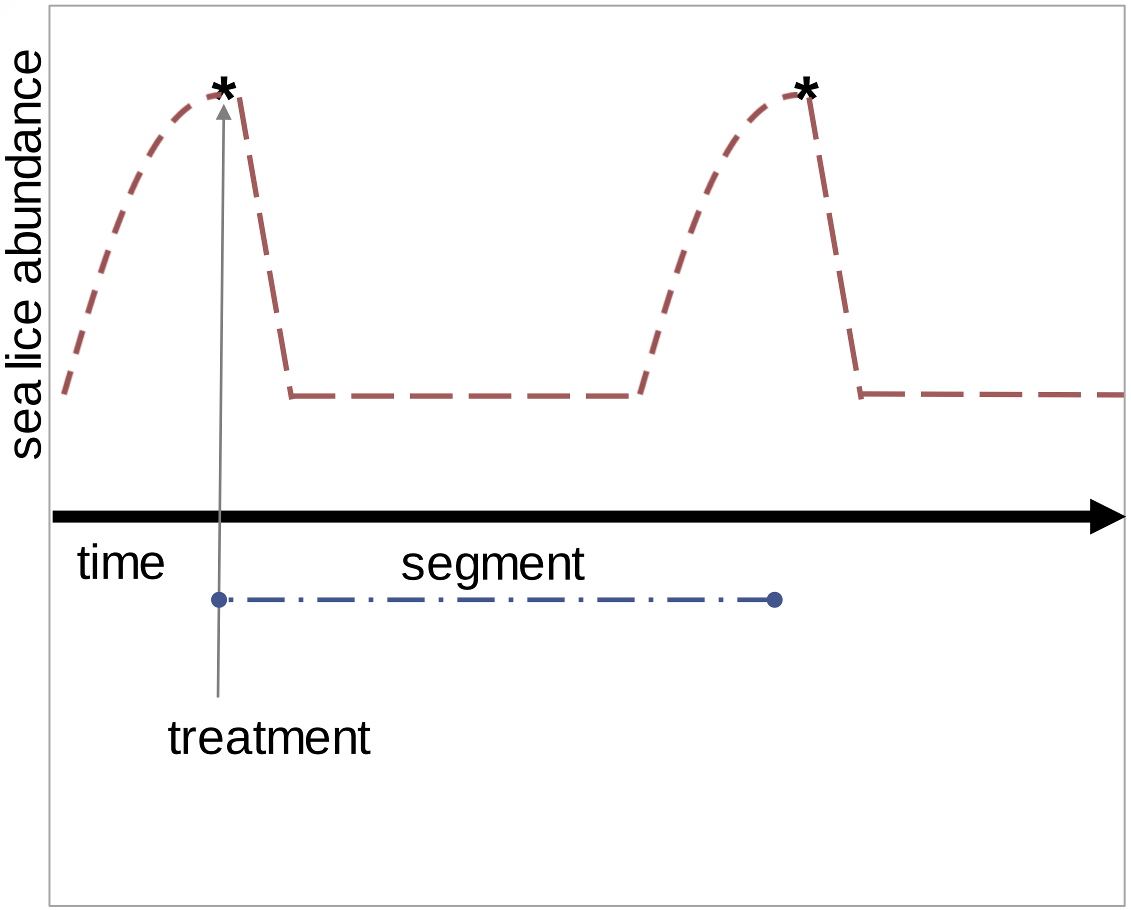
Thank you!

Comments? Questions

Extra slides



Estimation of the probability density function of the connectivity measures among sites with bandwidths of 5 to 15 km, here demonstrated 5 to 7 km.



A segment was defined as the first observation after a topical treatment followed by all additional observations until the following treatment and limited to a single cohort of salmon (share the same fish group identifier, cage, site, and production cycle).

On Uncertainty in Sea Lice Dispersal and Connectivity Modelling

Philip Gillibrand

philip.gillibrand@mowi.com

Introduction

- Sources of uncertainty in sea lice dispersal models
- Communicating uncertainty in sea lice dispersal modelling
- Coupled hydrodynamic and particle tracking models
- Potential for accumulation of errors

Particle Tracking Methods

- Lagrangian advection schemes unconditionally stable but not necessarily accurate
  - Careful selection of time step, or adaptive time step, required
  - RK4 standard choice: 4^{th} order accuracy, relatively efficient
  - Euler: 1^{st} order accurate

- Random walk methods for diffusion
  - Correction required to "naïve" scheme for variable diffusivity (Hunter et al., 1993; Visser, 1997)
  - Necessary in stratified Scottish waters?

- Adequate number of particles
  - $Relative\ concentration\ error\ \varepsilon_i = \frac{\sigma_i}{\mu_i} = (\alpha_i \mathrm{N})^{-1/2}$ (Allen, 1982; Hunter et al., 1993)
  - Should be able to simulate uniform distribution

- In Scottish coastal waters, boundary conditions important (interaction with coastline)

Sources of Uncertainty in Sea Lice Dispersal Modelling (1)

- **Physical**
  - 3D velocity
  - Temperature
  - Salinity
  - Turbulence (vertical eddy diffusivity)
- **Numerical**
  - Grid resolution (horizontal and vertical)
  - Number of particles
  - Interaction with boundaries
  - Accurate coding
- **Data**
  - Sources
  - Calibration and evaluation

"Solutions"

Physical: Calibration and validation against data; Uncertainty in performance elsewhere

Numerical: Sensitivity testing

Data: Best practise monitoring and field sampling

Sources of Uncertainty in Sea Lice Dispersal Modelling (2)

- **Biological**
  - Stage development rates and lifespan
  - Senescence (ability to infect)
  - Natural mortality
  - Upward swimming speeds
  - Sinking rates
  - Swimming triggers
  - Response to low salinity water
  - Depth limit
  - ***Predation***

“Solutions”

Laboratory experiments

Calibration against data?

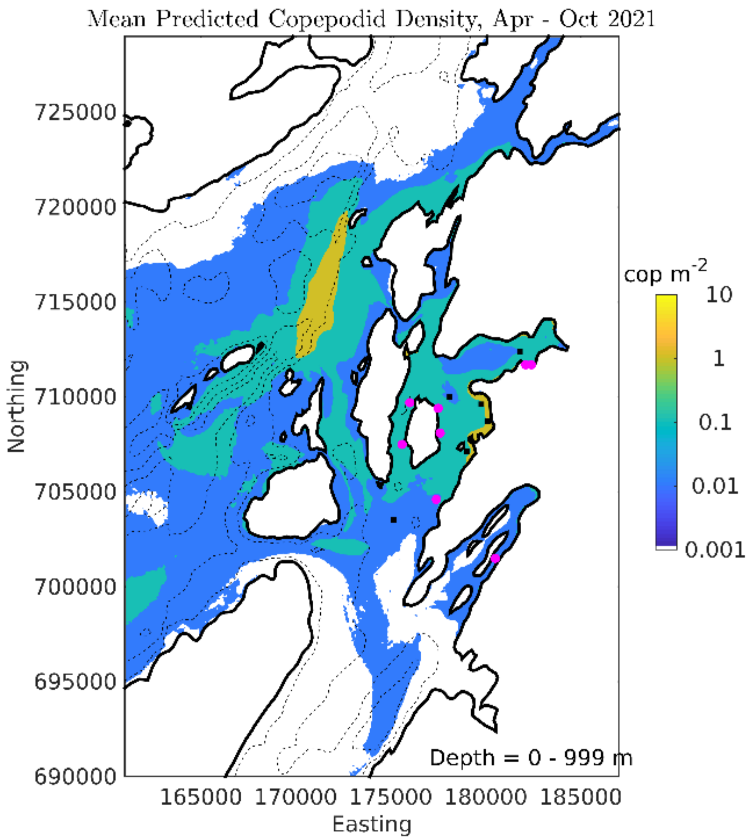
  - Diffusivity (horizontal and vertical)
  - Effect of wind forcing, Stokes drift

Calibration against data?

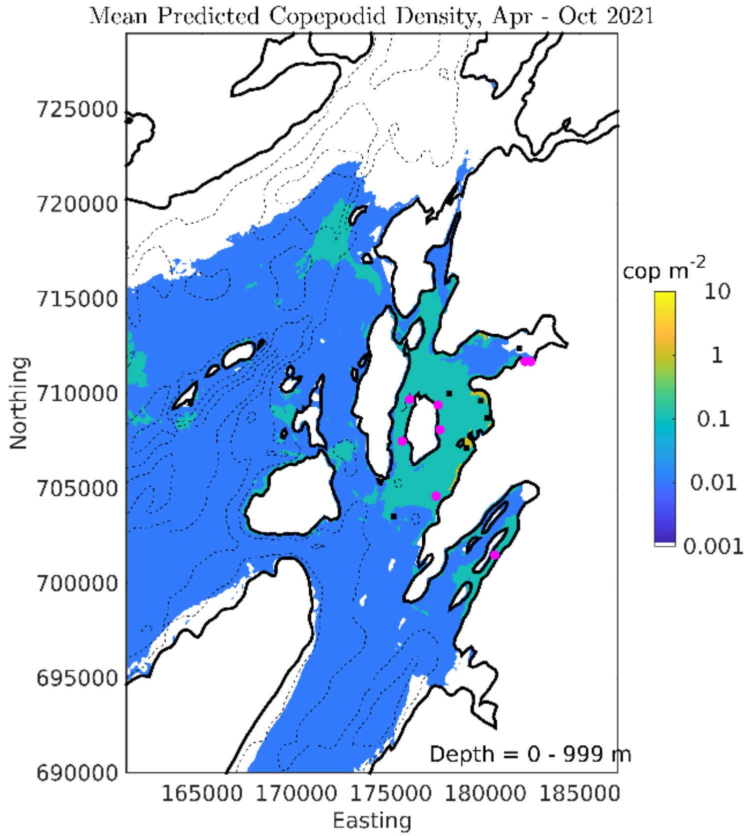
MOWI

Effects of Hydrodynamic Model Forcing (SPILLS project, WP1)

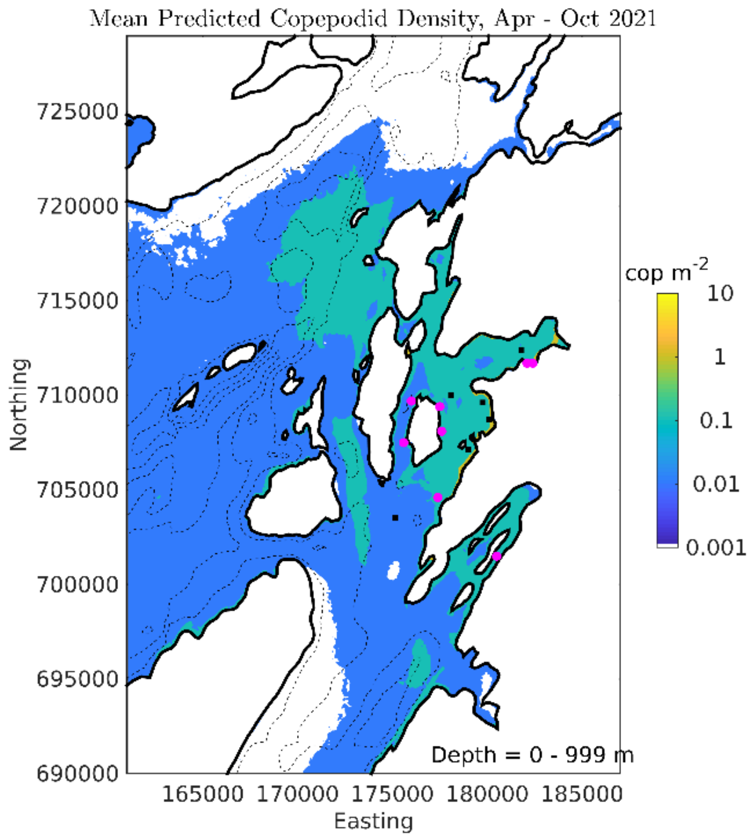
6-month mean infective lice density distributions



HD Model 1



HD Model 2

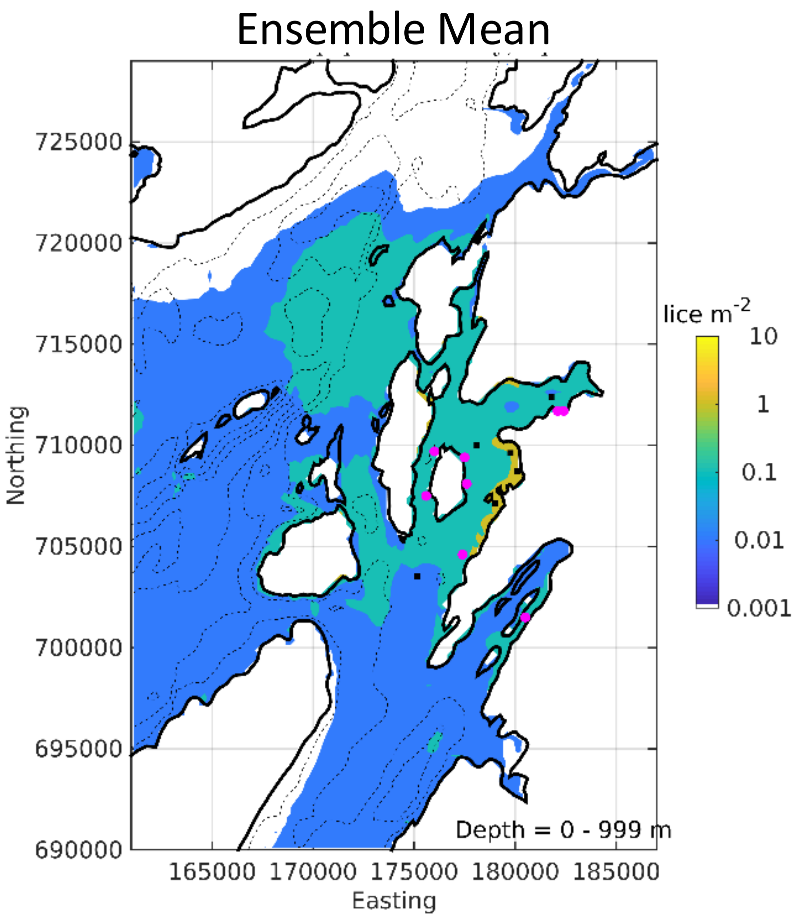


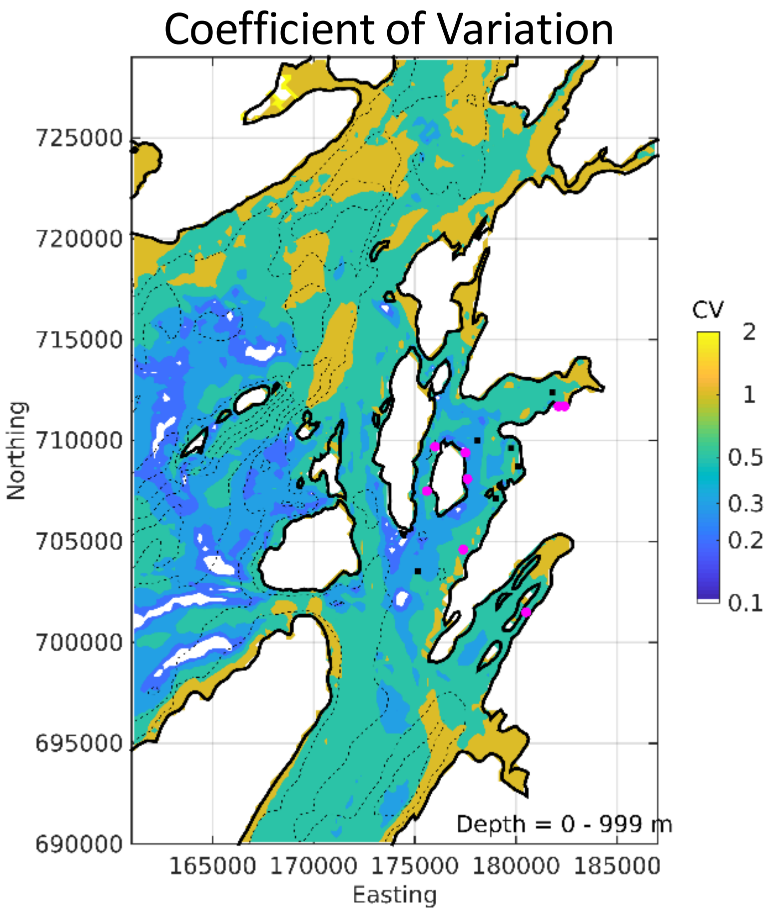
HD Model 3

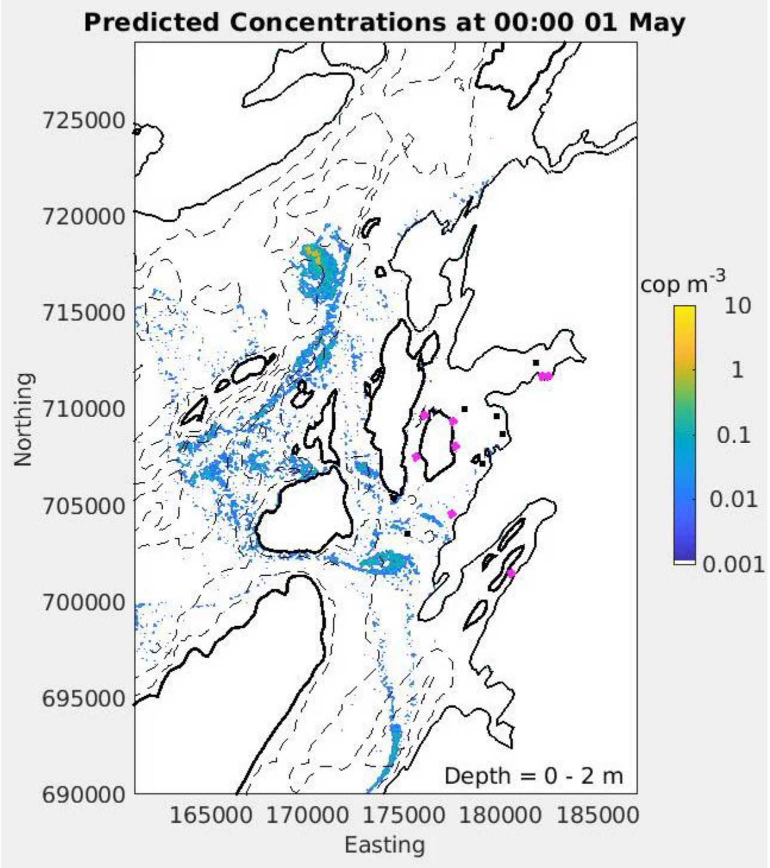
MOWI

Ensemble Mean and Coefficient of Variation (SPILLS project, WP1)

5 model runs







$$\text{CoV} = \frac{\sigma}{\mu}$$

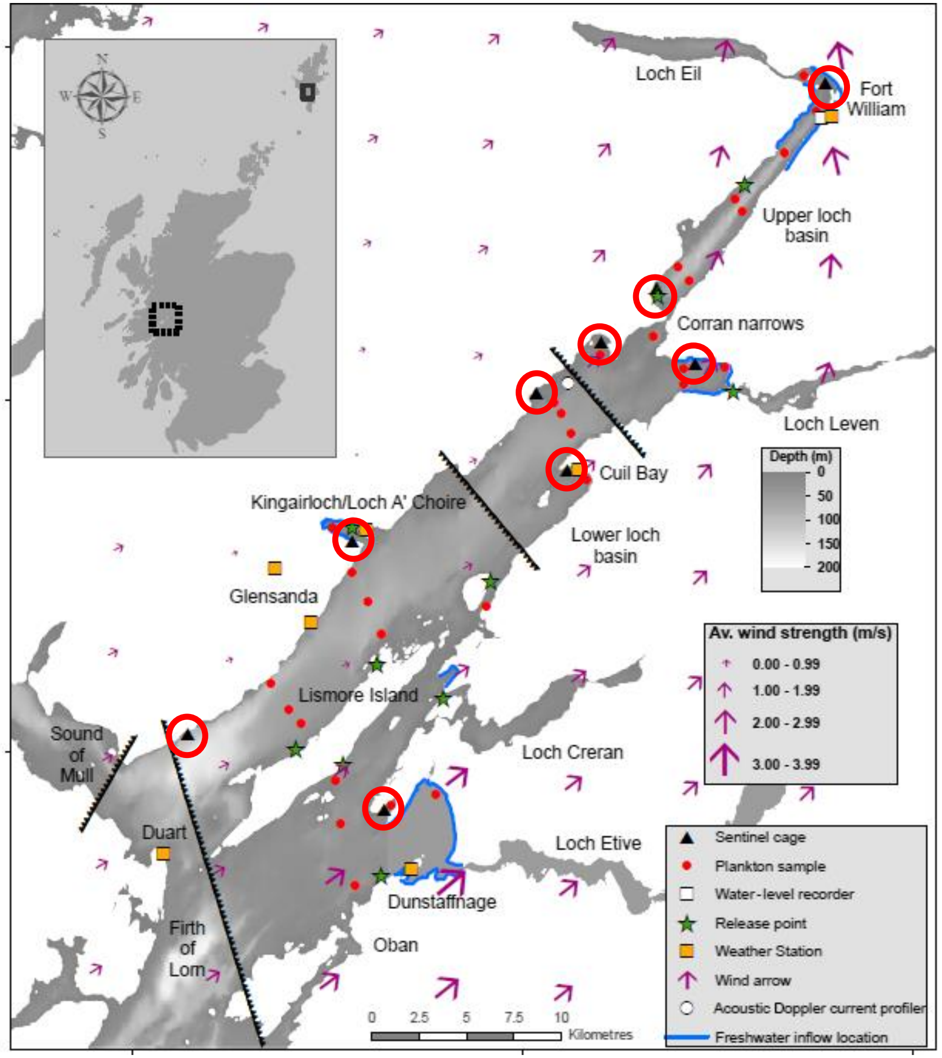
Evaluation of Models against Sentinel Fish Lice data (SPILLS project WP4)

Loch Linnhe, 2011 – 2013
Spring & Autumn sentinel cage deployments
~ 1 week per deployment
2 deployments per season
~ 50 fish per cage
11 active farm sites
Estimated lice numbers

Modelling of infection pressure vs mean lice count per sentinel cage fish

Infection Pressure

$$IP = \int_0^T \rho_I . dt$$



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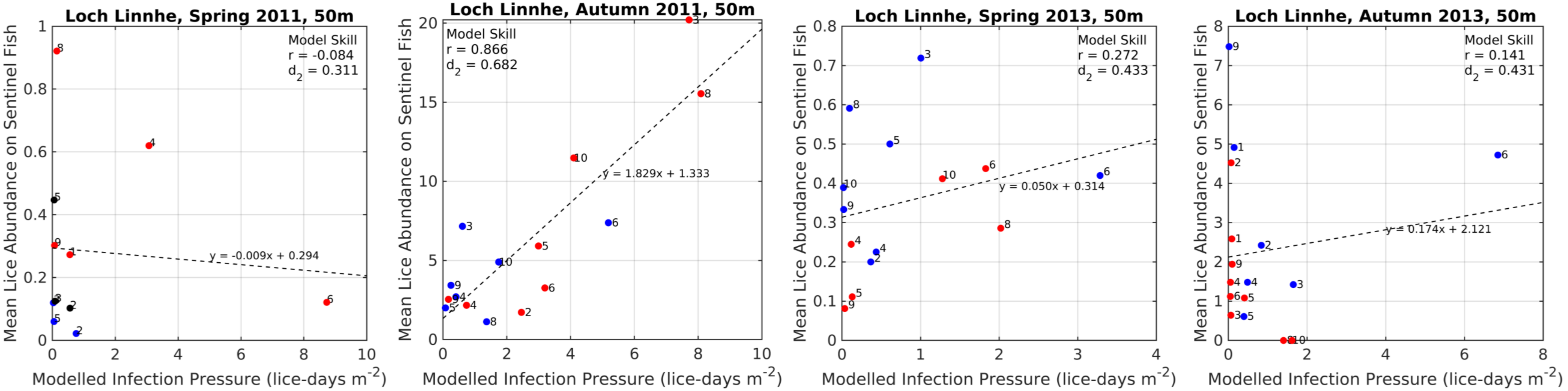
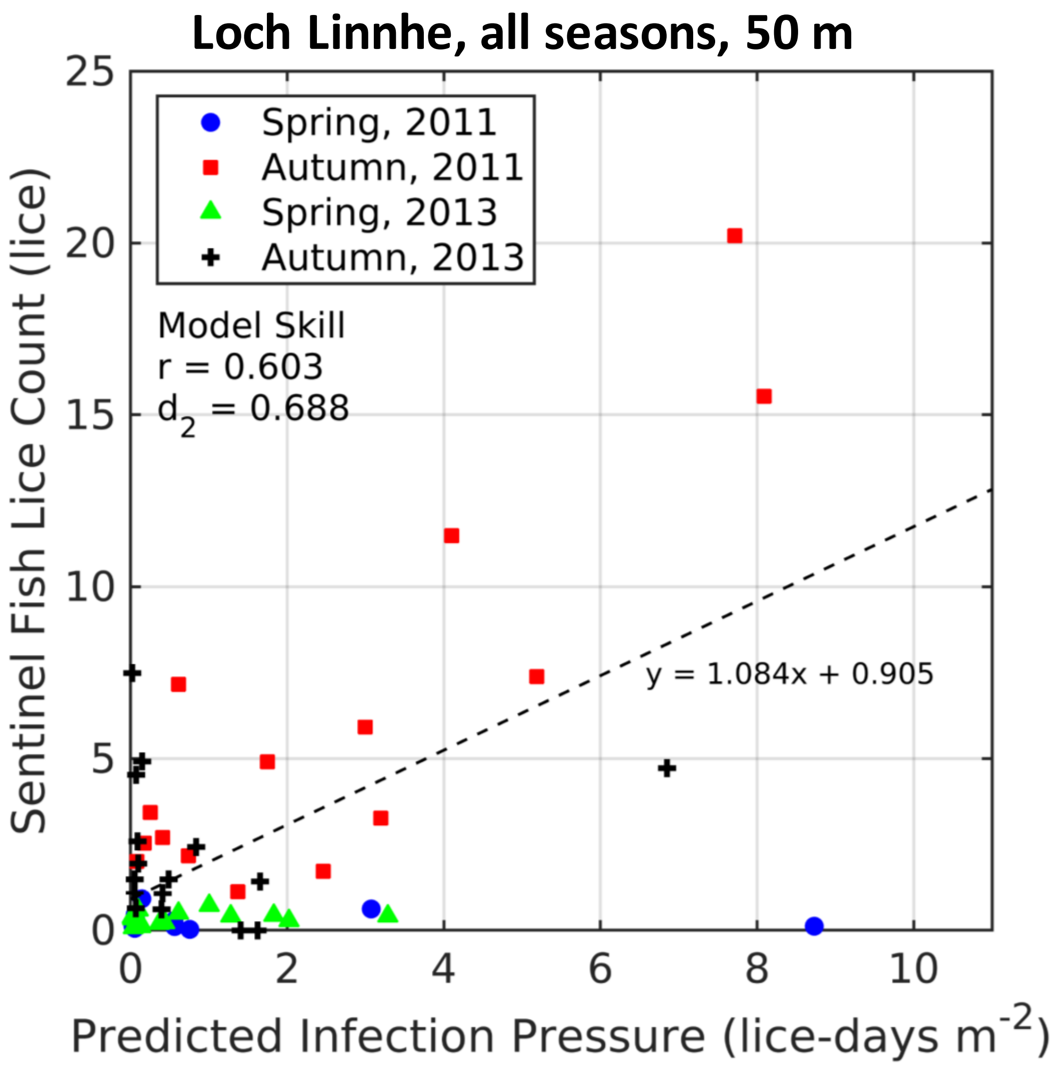
Evaluation of Models against Sentinel Fish Lice data (SPILLS project WP4)



HDM: WLLS (SSM), *courtesy R. Murray, SG Marine Directorate*
PTM: UnPTRACK, *Gillibrand (2022)*

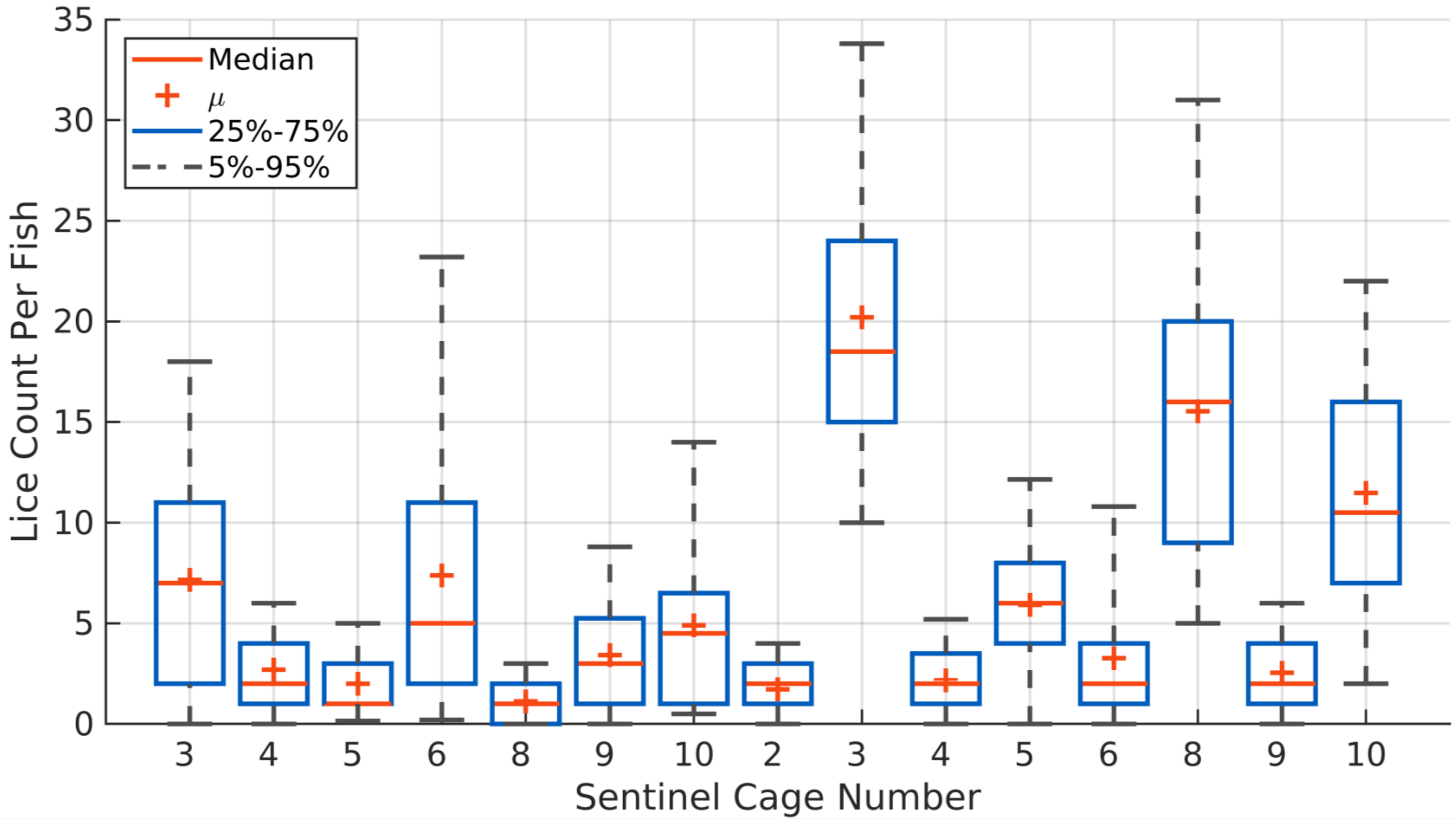
MOWI

Evaluation of Models against Sentinel Fish Lice data (SPILLS project WP4)



Variability in Sentinel Fish Lice Data (SPILLS project, WP4)

Loch Linnhe, Autumn 2011 (50 fish per cage)



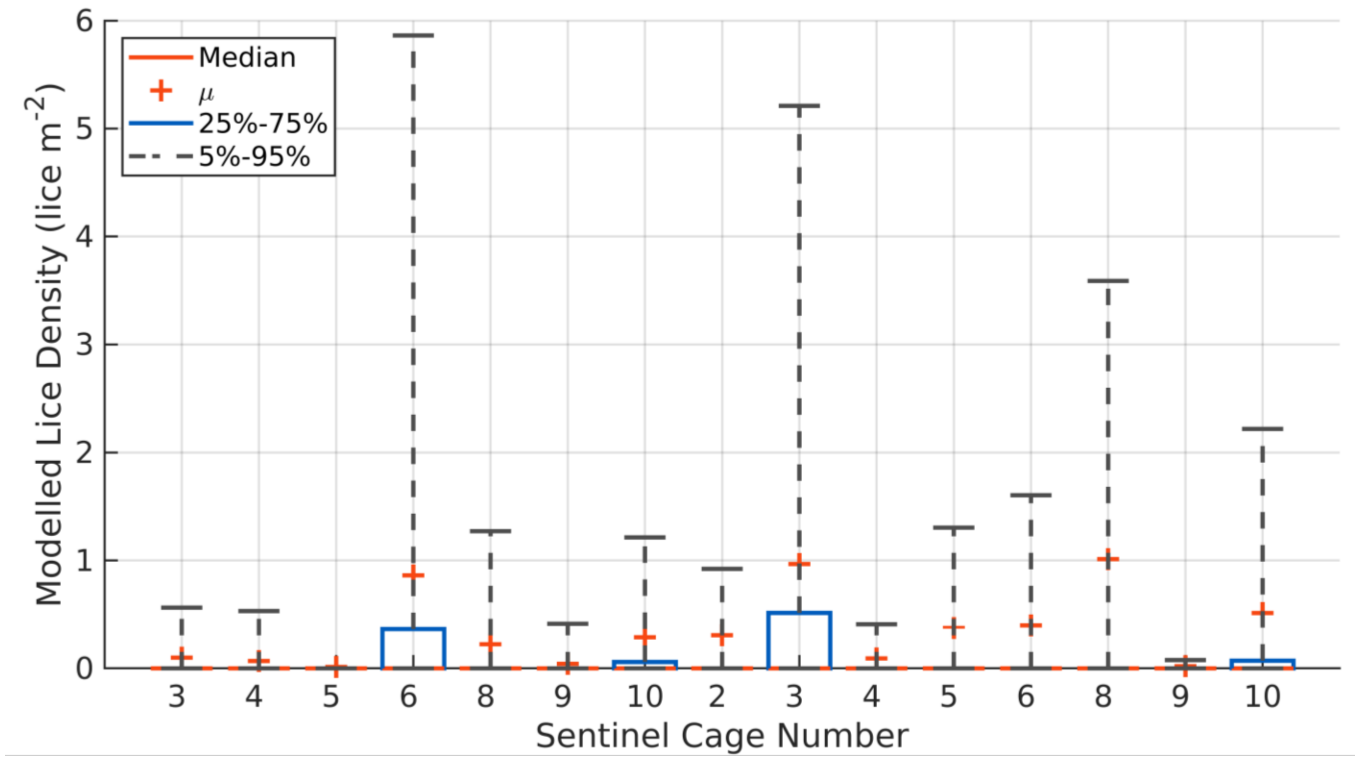
Variability in Modelled Time Series (SPILLS project, WP4)

Loch Linnhe, Autumn 2011

Modelled infective lice density

Median = 0 in all cases

Zero percentage = 62% – 97%



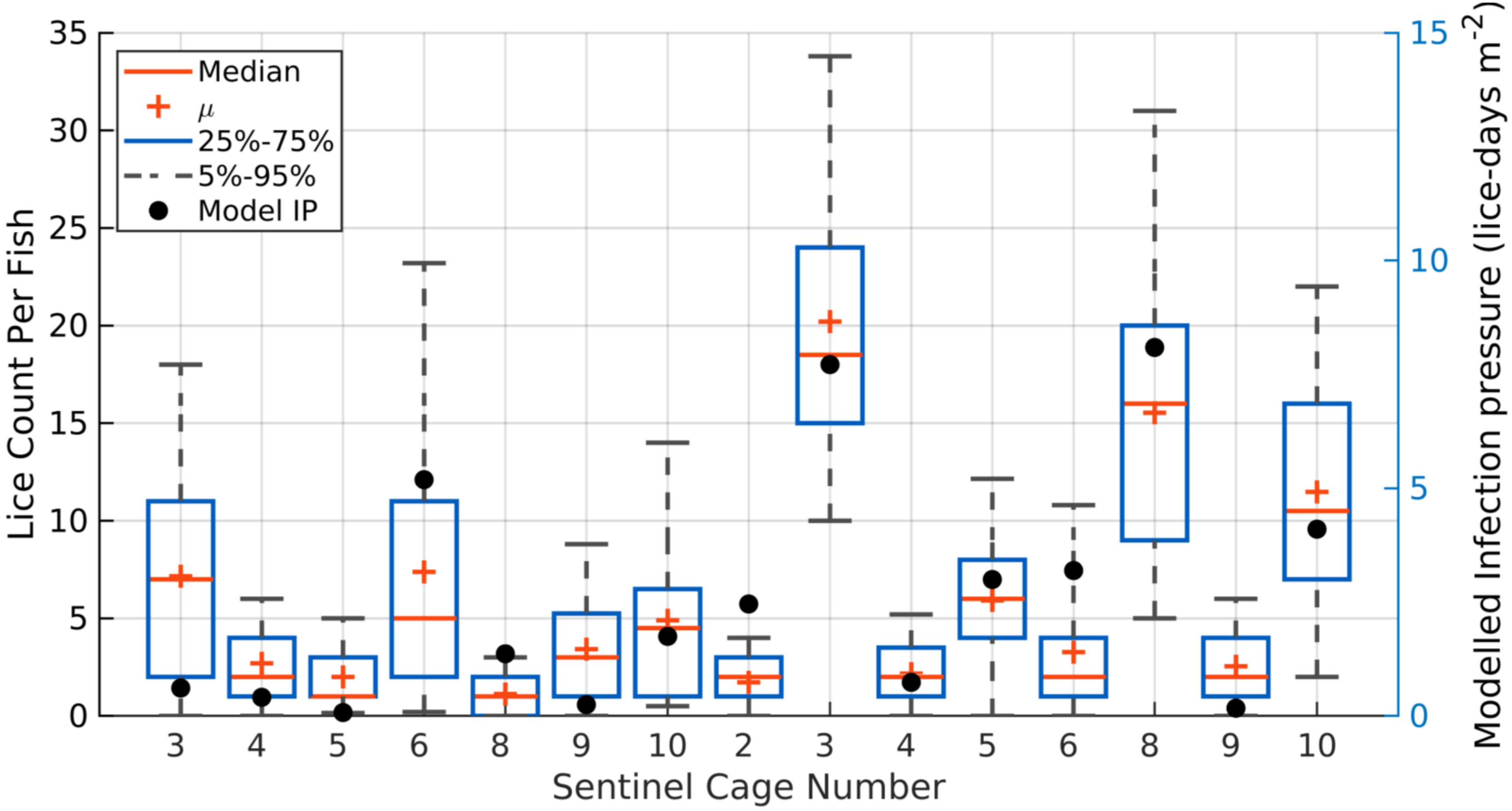
MOWI

Variability in Sentinel Fish Lice Data vs Model (SPILLS project, WP4)

Loch Linnhe, Autumn 2011

Infection Pressure

$$IP = \int_0^T \rho_I . dt$$



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Recent Projects and Proposals

- **Off-Aqua: Assess offshore aquaculture**
  - SAMS, University of Stirling, University of Exeter
  - Morro et al. (2021), Szewczyk et al., (in review)
- **SealiceELS**
  - Sea lice larval biology and behaviour (SAMS, Mowi), paper in prep (Stollberg et al., in prep)
- **Sea lice holocam**
  - University of Aberdeen, SAMS, Mowi
  - Identifying and quantifying sea lice in the environment using holocam technology
- **SUPER-DTP PhD proposals**
  - Sea lice larval biology and behaviour (Kim Last & Helena Reinardy, SAMS; Mowi, SSF).
  - Structure of Scottish salmon lice populations and their genetic adaptations (U. Stirling, SAMS)

Conclusions

- **To minimise uncertainty***
  - Appropriate grid resolution and model choices
    - Number of particles, time step, boundary conditions etc.
  - Thorough calibration of hydrodynamic model, inc. tides & residual flows
  - Demonstration of basic PTM competency (Brickman test, well-mixed condition)
  - Use of data gathered following best practice guidelines
  - Appropriate choices of biological characteristics and behaviour

- **To communicate uncertainty**
  - Full and open disclosure of modelling methods, data used and results
  - Calibration of model versus available data
  - Sensitivity testing
  - When possible, an ensemble of model runs with assessment of uncertainty and variability is ideal

* Murray et al., 2022. In: *Sea Lice Biology and Control*

Thank you

philip.gillibrand@mowi.com

Phillip Gillibrand, Oceanography and Modelling Manager

“All models are wrong,
but some are useful”

George Box

MOWI

References

Allen, C.M. Numerical simulation of contaminant dispersion in estuary flows. Proc. Royal. Soc. London (A), 381, 179-194, 1982.

Brickman, D., Ådlandsvik, B., Thygesen, U.H., Parada, C., Rose, K., Hermann, A.J. and Edwards, K. Particle Tracking. In: Manual of Recommended Practices for Modelling Physical-Biological Interactions during Fish Early Life, Ed. by E. W. North, A. Gallego, and P. Petitgas. ICES Cooperative Research Report No. 295, 27-42.

Gillibrand, P.A., 2022. UnPTRACK User Guide. Mowi Scotland Ltd., June 2022, 33 pp. https://github.com/gillibrandpa/unptrack/blob/master/unptrackUserGuide.pdf

Hunter J.R., P.D. Craig and H.E. Phillips. On the use of random walk models with spatially variable diffusivity. J.Comput. Phys., 106, 366-376, 1993.

Morro, B., Davidson, K., Adams, T.P., Falconer, L., Holloway, M., Dale, A., Aleynik, D., Thies, P.R., Khalid, F., Hardwick, J., Smith, H., Gillibrand, P.A., Rey-Planellas, S., 2022. Offshore Aquaculture of Finfish: Big expectations at sea. Reviews in Aquaculture, 14, 791-815.

Murray A.G., Shephard, S., Asplin, L., Adams, T A., Ådlandsvik, B., Gallego, A., Hartnett, M., Johnsen, I.A., Jones, S.R.M., Moriarty, M., Nash, S., Pert, C.C., Rabe, B., Gargan, P.G., 2022. A standardised generic framework of sea lice model components for application in coupled hydrodynamic-particle models. In: *Sea Lice Biology and Control*., Treasurer, J., Bricknell, I., Bron, J. (Eds.), pp 167 – 187.

Stollberg, I., Last, K., Gillibrand, P.A., Reinardy, H.C., in prep. Characterisation and Early-Stage Development of Sea Lice (Lepeophtheirus salmonis) from Scottish Salmon Farms.

Szewczyk, T.M., Morro, B., Díaz-Gil, C., Gillibrand, P.A., Hardwick, J.P., Davidson, K., Aleynik, D., Planellas, S. R., submitted. Interactive effects of long-term wave exposure and other stressors on fish welfare on Atlantic salmon (Salmo salar) farms. Submitted to Aquaculture.

Visser, A.W., 1997 Using random walk models to simulate the vertical distribution of particles in a turbulent water column. Mar. Ecol. Prog. Ser., 158, 275 – 281.

Fish Tracking

Sept 2023

Salmon and sea trout tracking

science

- Provide behavioural data to inform monitoring strategies and model potential impacts

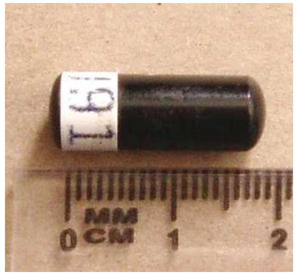
- Salmon
  - ❖ Understand how fast salmon migrate through a particular area
  - ❖ Determine whether they are using any preferred migration routes

- Sea trout

- Understand habitat usage and how it changes in relation to sea lice pressure
  - ❖ Area
  - ❖ Depth
  - ❖ Salinity

Acoustic Tracking- Fish tagging

- Salmon/sea trout smolts tagged using internally implanted acoustic tags.
- Fish released in the river and allowed to migrate to sea

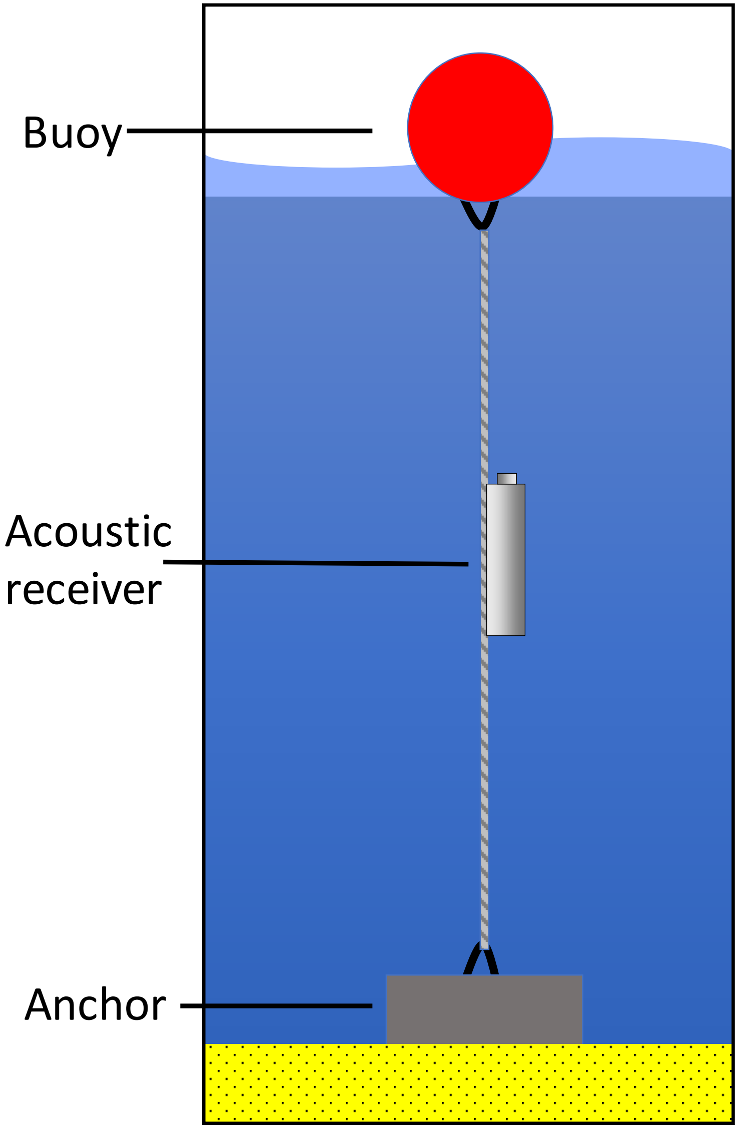



Fyke net


Screw Trap

Method: Acoustic tracking

science



- Acoustic tags transmit signal over 100's of meters which are detected using specialised receivers.
- Information on tagged salmonid movements collected using networks and curtains of receivers.

Potential limitations of approach

science

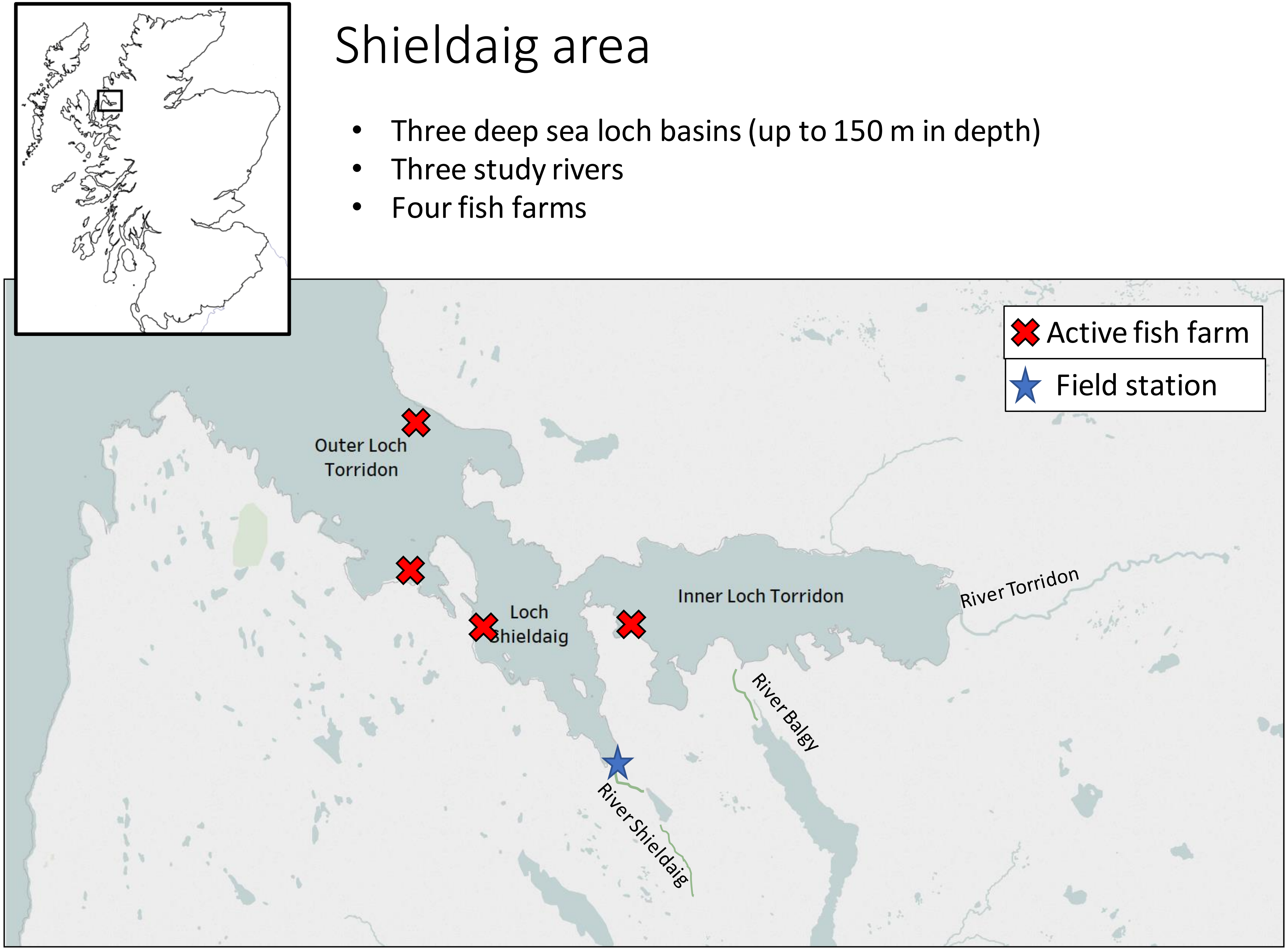
- Tags/ receivers can fail
- Tags can be ejected by fish
- Predation events
- Requires the use of fish over a threshold size (e.g. 130mm or more)
- False positives
- Tag collisions and false negatives
- Requires correct environmental conditions for detections
- Observer effects

However, tag and receiver technologies are continually improving:

more powerful tags, better hydrophones, predator tags, smaller tags

Shieldaig area

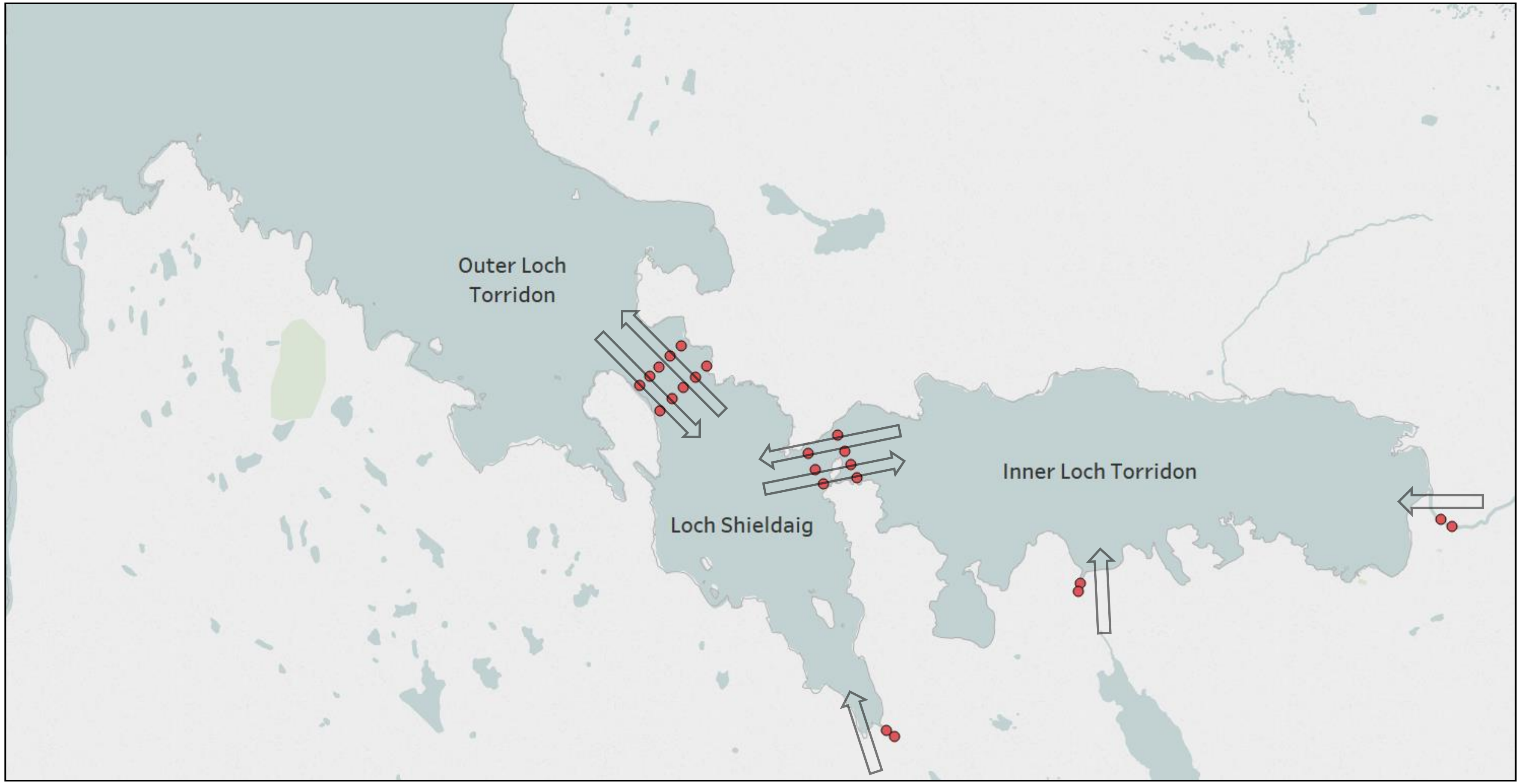
- Three deep sea loch basins (up to 150 m in depth)
- Three study rivers
- Four fish farms



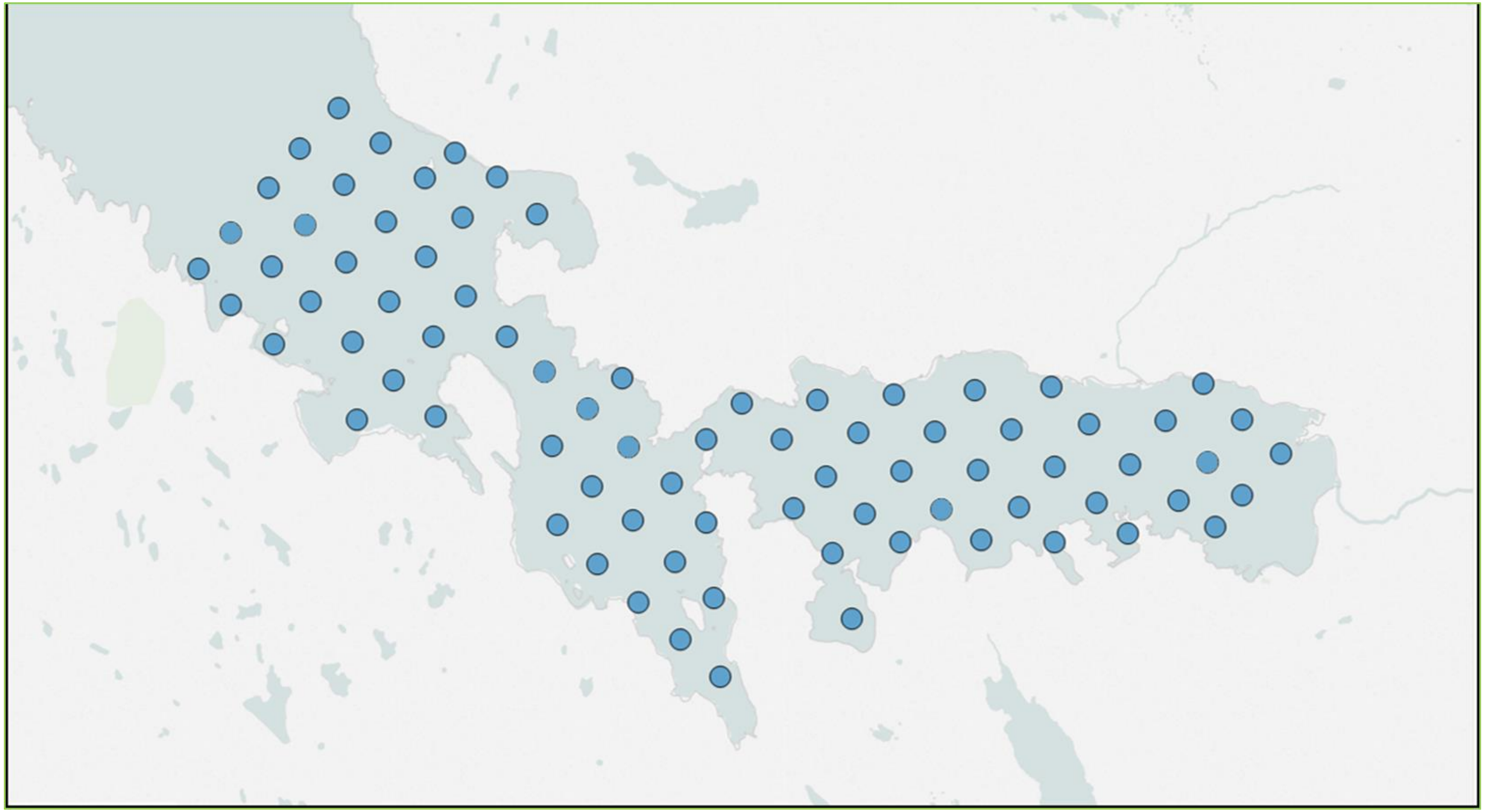
Typical gate-style array for the area

Provides information on

- timing of sea entry
- timing of movement between basins
- variation in migration times through area

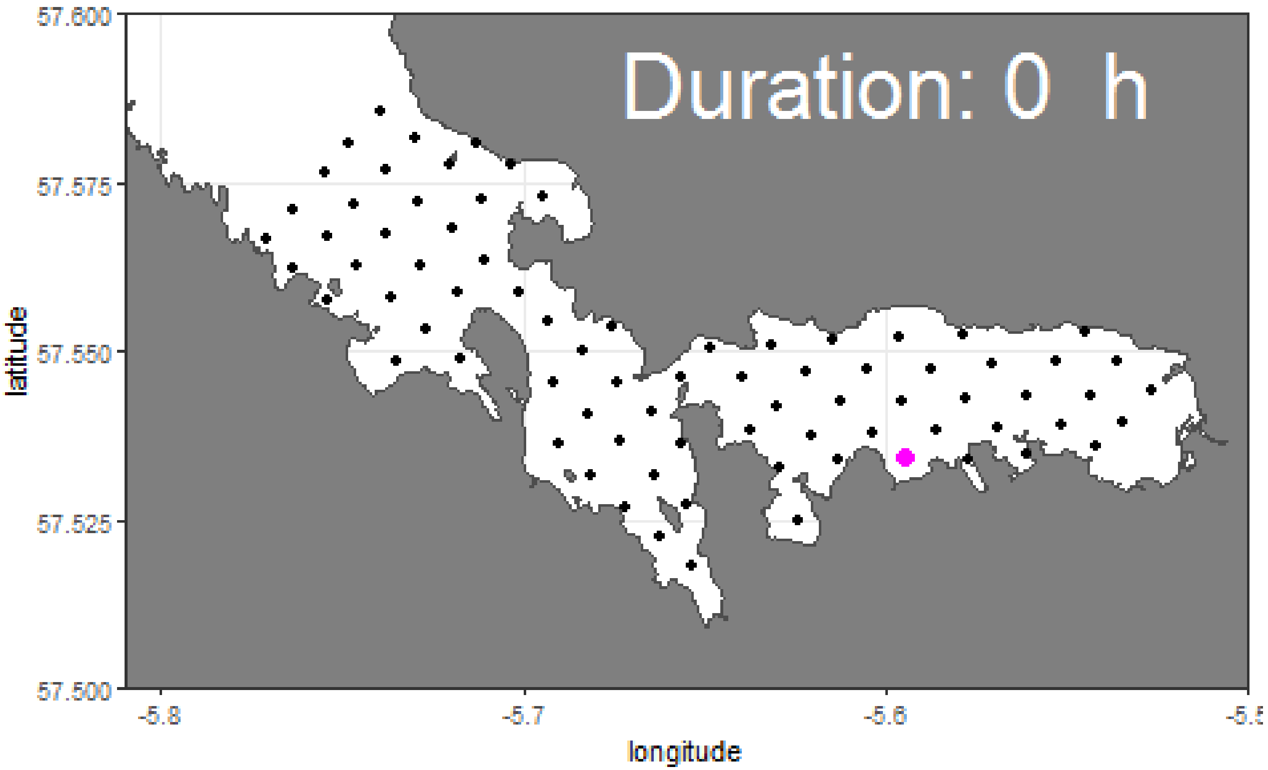


Grid array



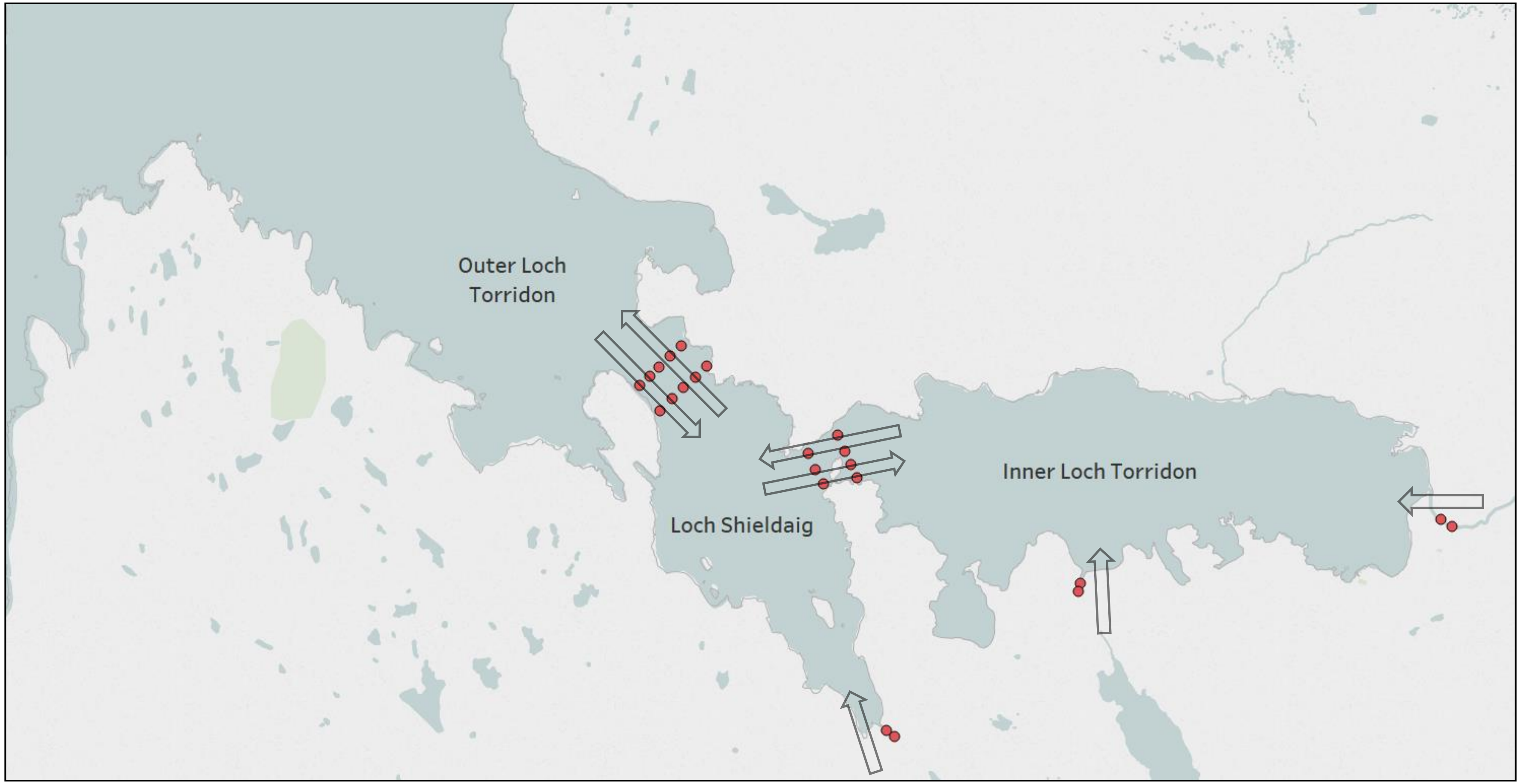
Salmon 3146 (River Balgy). Example of migration.
Interpolated migratory route of tag (black dots are location of receivers)
Pauses on final detection location before tag left array

Duration of milling behaviour affects migration speed from monitored region



Sea trout-Typical gate-style array for the area

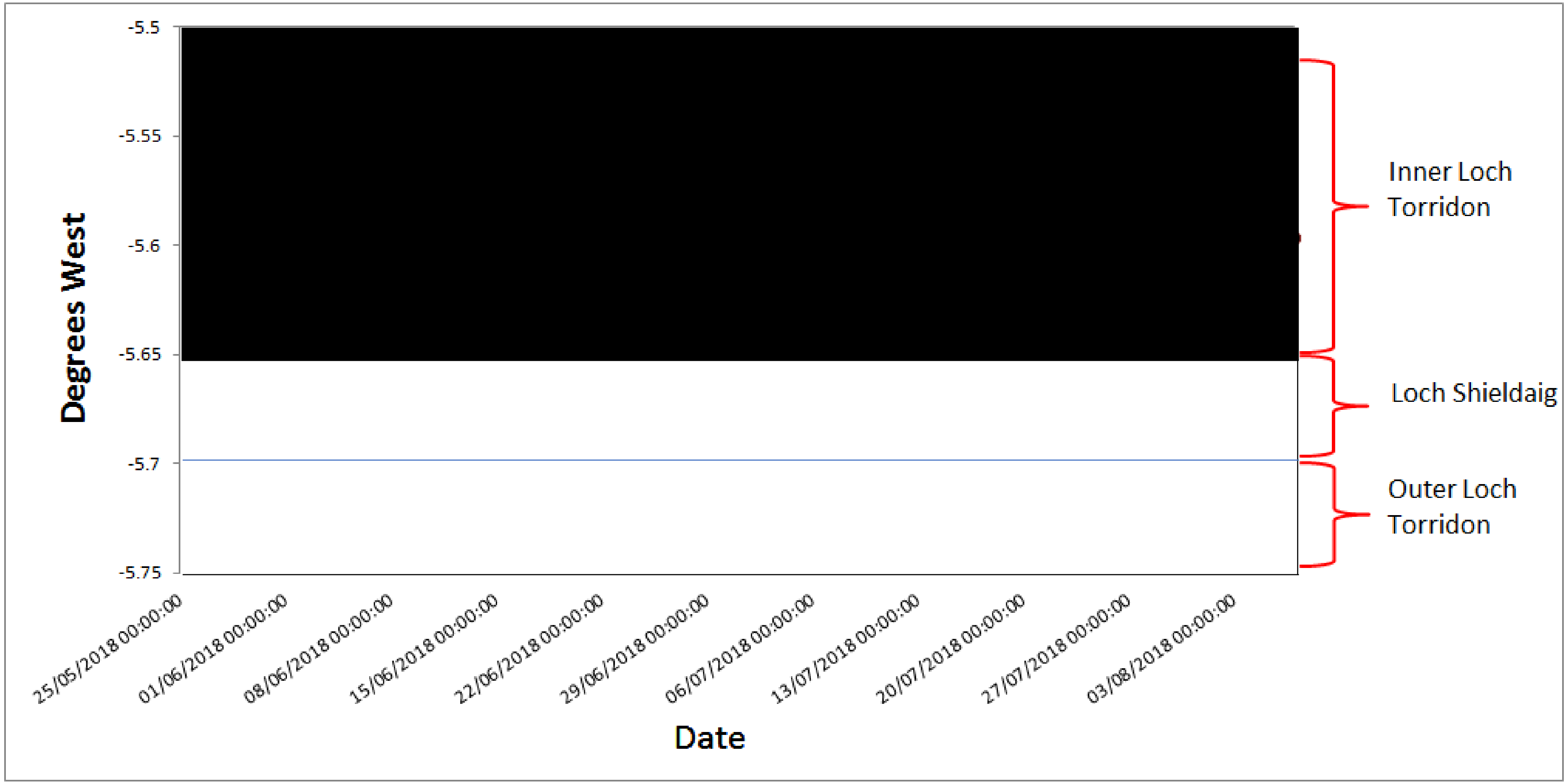
- timing of sea entry
- timing of movement between basins
- black boxes in between



Position of a Torridon sea trout, late May to early August….

Gate design: tag somewhere in the black box of Inner Loch Torridon. Alive or dead? Missed? Failed? Shed?

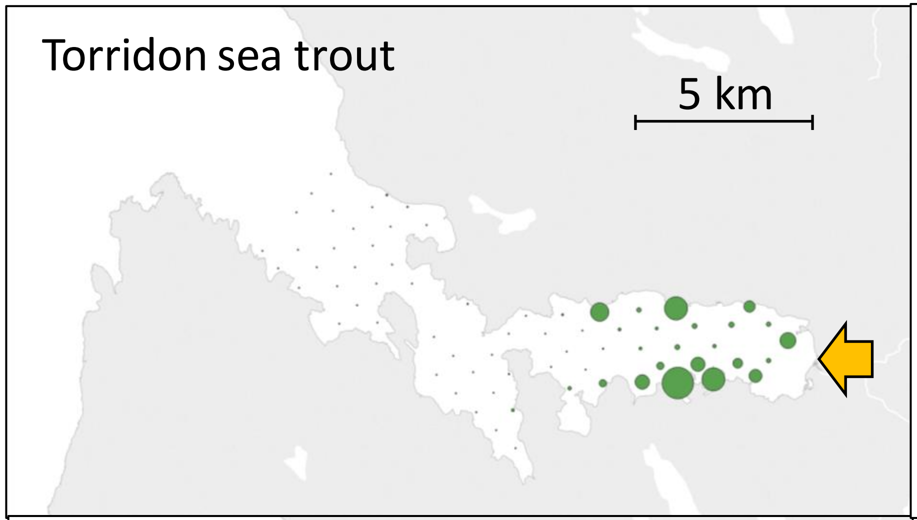
Grid design: tag swimming around Inner Loch Torridon, showing particular location preferences

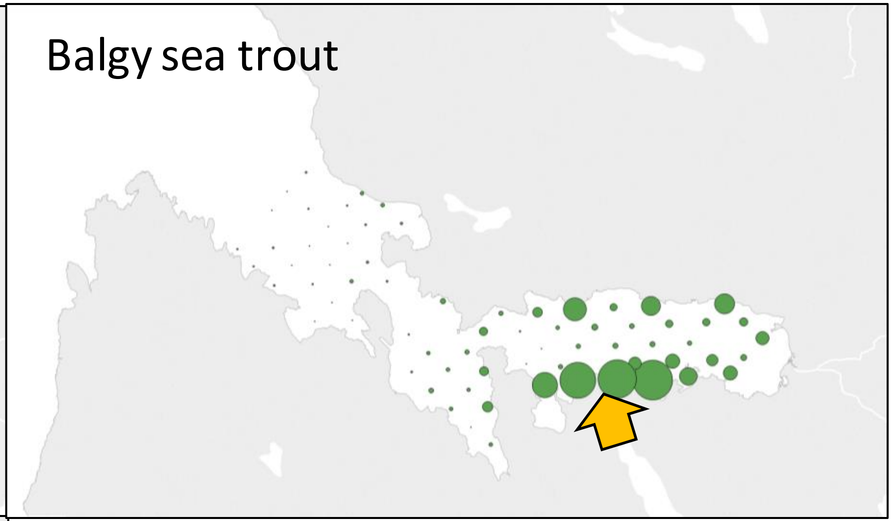


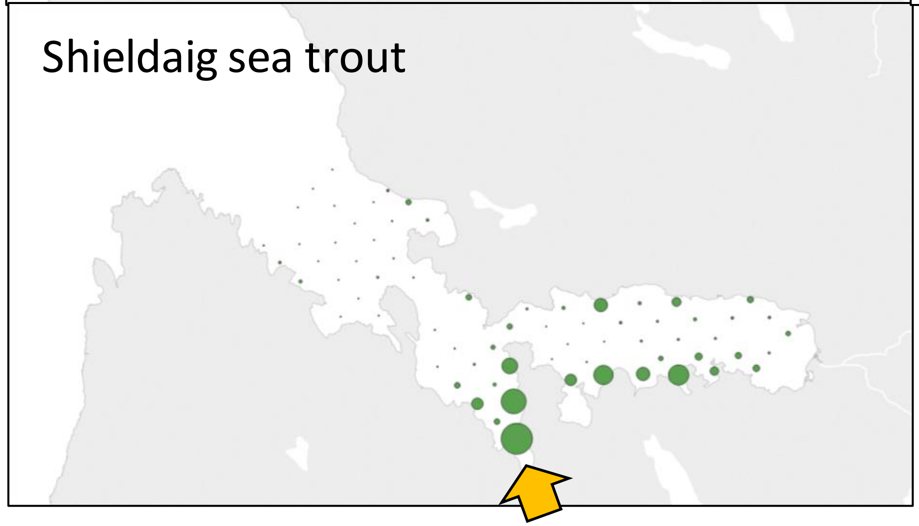
Acoustic tracking- final thoughts

- Salmon
    - Gate type arrays can be used.
    - There is evidence of “milling” behaviours. Causes unknown.
    - Migration times can be calculated.
    - A slow migration time does not necessarily mean a slow swimming speed.
- Sea Trout
    - More challenging than salmon
    - Will require a combination of extensive receiver arrays coupled with genetic and behavioural studies to inform sampling strategies.
- Technological advances

Sea trout detection frequency







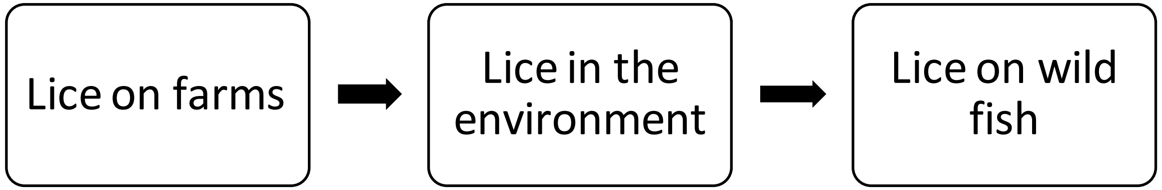
Using acoustic tagging can we can start to build up a picture of trout habitat usage

Addressing uncertainty in sea lice dispersal models – investigating different sea lice surveillance techniques

Berit Rabe, Alexander G. Murray, Stephen C. Ives, Meadhbh Moriarty, David J. Morris

Background

- "A gap analysis on modelling sea lice infection pressure from salmonid farms (III): Surveillance to inform model applications for sea lice infestation management" – paper in progress
- To help address uncertainty in sea lice dispersal models we investigate pros/cons of surveillance techniques for:



- Produced detailed tables for:
    - Surveying plankton in the water column
    - Collection methods for:
        - Infestation pressure on fish – captured fish
        - Infestation pressure on fish – free swimming

Surveying plankton in the water column

	What data collection methods do we need to assess environmental infection pressures caused by sea lice?
Overarching	**Surveying plankton in the water column**
Positives	• Sampling all planktonic stages • Importance of all plankton stages: it allows age of larvae to be identified • Fixed area/depth sampling, possibility of programming to allow synchronous sampling strategies • Little to no ethical/conservation considerations
Negatives	• Catchability unknown • Zero inflated - lots of data needed (therefore time consuming for analysis) • Labour intensive - laborious processing of samples requiring specific expertise • Large potential for identification errors depending on expertise • Time intensive in general • Larval lice decay rapidly • Potential for lice damage, lice escape after collection • Misses out on attached stages • Small area sampled, potential for resampling, short time frame - might miss patches of plankton • Nets/pumps can clog - clogging can go unnoticed during tows or deployment • Sea state/sampling weather dependent (on different time scales) • Caligus copepodids and naupllii difficult to positively identify without suitable microscopy ie using maxiliped spurs, subtle difference in carapace can be used but requires experienced viewer • Boat sampling requires considerable expense re training, maintenance and certification

Surveying plankton in the water column

Options	**1: Plankton pump Fixed deployment**	**2: Plankton pump Towed deployment**	**3: Plankton tows**
Positives	• Identify depth of lice • Allows targeted measurements in both space and time of specific water volumes • Complementary CTD monitoring possible	• Spatial coverage • Large transects can be achieved and subdivided • Different depths can be examined • Combining techniques of pumping and towing • Complementary CTD possible	• Spatial coverage • Can be deployed on any boat e.g. commercial, ferries etc. • Smaller boat is more appropriate due to displacement of water • Can be done from shore • Vertical and horizontal tows possible • Can sample intertidal foraging areas
Negatives	• Labour intensive deployment (requires anchor point) • Potential for retrieval to be delayed by unexpected weather change, leading to spoiled samples • May require frequent cleaning in summer due to biofouling • If battery powered efficiency varies over time so difficult to quantify • Clogging issues • Time intensive in general • Larval lice decay rapidly • Potential for lice damage • Misses out on attached stages	• Damage to sea lice • Requires a larger boat with lifting capacity eg derrick • Need to maintain constant depth which can be challenging • Potentially difficult to deploy and retrieve	• Spatial integration required • Need to maintain constant depth which can be challenging • Net can clog reducing effective sampling • Tidal state can influence quality of sample, eg foot churned debris • Lots of samples over a long time period required

Infestation pressure on fish – captured fish

	What data collection methods do we need to assess direct infection pressure on fish caused by sea lice?
Overarching	**Infestation pressure on fish – captured fish**
Positives	• Samples attached stages • Can attach other instrumentation for environmental monitoring (i.e. CTD)
Negatives	• All parasitic stages missed • Only picks up copepodids at surface • Supply of hatchery smolts required (consideration) • Immune status of fish regarding infection success (consideration) • Negative welfare impacts on fish • Sea state dependent

Infestation pressure on fish – captured fish

Options	1: Fixed Sentinel Cages	2: Towed Sentinel Cages
Positives	• Well-established methods • Provides data on actual infestation pressure at a point • Integrates data over deployment time (i.e. 1 week) allowing estimation of infestation pressure • Majority of attached stages can be retained and enumerated • Dislodged samples in euthanizing anaesthesia can be retained and enumerated • PCR can be used to identify small attached • Can be combined with CTD for complementary data	• Spatial coverage • Fish swimming at reasonable speed • Integrates data over space allowing estimation of infection pressure • Method can be deployed at short notice as doesn't require the same permissions and moorings installation • Majority of attached stages can be retained and enumerated • Dislodged samples in euthanizing anaesthesia can be retained and enumerated • Mirrors experience of migrating fish • PCR can be employed to detect small attached stages • Can be combined with CTD for complementary data
Negatives	• Stationary fish less indicative of typical wild fish • Fixed locations only therefore it is unclear what area this is indicative of the infestation pressure. • Requires larger vessel with lifting capacity to put moorings in place • Deployment and retrieval dependent on sea state • Fish constrained • Expensive in terms of time and processing • Requires moorings and permissions • Usually only a small number of locations in a system is sampled (may not be representative of salmonid presence) • Limited to accessible area • Due to fish welfare issues only a small sampling period permissible • Risk of dislodging infesting animals • All fish euthanised at point of sampling • Cannot be used in intertidal areas • Risk of predator damage • Risk of loss from storm damage / collisions etc.	• Short deployment period • Fixed depth (possibly limited towing distance) • Fish constrained • Use of farmed fish rather than wild • Careful monitoring of natural swimming speed is required • Requires small, manouverable, suitable vessel equipped with navigation equipment to maintain slow speeds • Requires vessel with lifting capacity • Deployment and retrieval dependent on sea state and tides • Methodology not fully established • Deployment difficult • Movement of cage must closely follow pre-established migration route, speed of escapement and timing of salmon smolts and prior evidence distribution of infective sea lice • Expensive in terms of time and processing • Usually only a small number of locations in a system is sampled (may not be representative) • Limited to accessible area • Due to fish welfare issues only a small sampling period permissible • Risk of dislodging infesting animals • All fish euthanised at point of sampling • Cannot be used in intertidal areas

Infestation pressure on fish – free swimming

	What data collection methods do we need to assess direct infection pressure on fish caused by sea lice?
Overarching	**Infestation pressure on fish – free swimming**
Positives	• Samples attached stages • Locally-relevant studies • Integrates infection pressure over time (provided the sampling location is representative)
Negatives	• All planktonic stages missed • Negative welfare impacts on fish • Can Caligus be easily identified?

Infestation pressure on fish – free swimming

Options	1: Sweep Netting (sea trout targeted)	2: Fixed Netting (Fyke) (both species)	3: Pelagic Trawling (salmon target, sea trout sometime caught)
Positives	• Well established method • Wider spatial coverage • All stages of lice development • Long record, national coverage • Fish health/fish condition can be assessed • Involves local fisheries trusts • Capture is involuntary thus no bias	• Well established method • Longer sampling/deployment time • All stages of lice development • Fish health/fish condition can be assessed • Fish health/fish condition can be assessed • Can involve local fisheries trusts • Less damage to fish • Lower risk of dislodging lice than alternatives • Methodologies for tidal and marine sampling exist	• Larger spatial coverage • Collects wild salmon during their **natural migration** • Each fish only sampled once • Can provide information on infestation pressure
Negatives	• Usually only one location in a system is sampled (may not be representative) • Limited to accessible areas • Time and spatially dependant • Possibility of resampling same fish, adding unknown bias • History of fish unknown • Risk of dislodging lice • Damage to bycatch • Usually requires small boat use and skilled crew • Handling causes stress	• Fixed location/low spatial coverage • Limited to accessible areas • Time and spatially dependant • Possibility of resampling same fish, adding unknown bias • History of fish unknown • At risk to predator damage • Net may need to be removed during spates/storms to prevent fish mortality • Net can damage fish, and potentially dislodge lice if the fish rubs up against the net • Handling causes stress	• Boat required • Difficult to capture enough salmon • Can result in large wild fish mortality • Risk of dislodging lice • Handling causes stress

Conclusions

- Assessment of **efficient use of surveillance** in support of management of sea lice impacts on wild salmonids
- Opportunities and values for surveillance depends on the stage of the sea lice life cycle
- Data collated as part of a well-designed surveillance monitoring is important for the purpose of supporting management decision making
- Model improvements (and therefore reduction of uncertainty) can be directed as more data becomes available from ongoing surveillance

Model complexity and hydrodynamics

Andy Dale, Tim Szewczyk, Dmitry Aleynik

Knowledge strength in sea lice dispersal modelling

2023 September 7

SAMS Scottish Association for Marine Science | A partner of UHI

OFF AQUA

OFF AQUA

Hydrodynamic modelling

Dima Aleynik

Max Holloway

Coupled sea lice model

Tom Adams

Tim Szewczyk

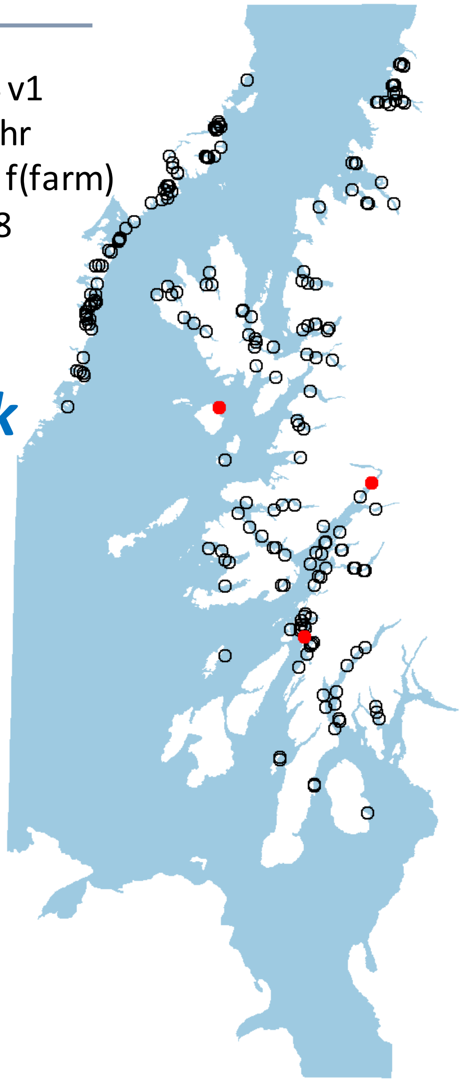
Observational physics

Andy Dale

John Beaton

Sea lice dispersal Pt I: WeStCOMS domain

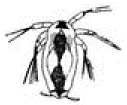
- WeStCOMS v1
- 5 particles/hr
- $density_{init} = f(farm)$
- 2015—2018



2D: Particles at 1m depth

3D: Vertical currents, diffusion, behaviour

- Salinity < 20 psu or high turbulence → ***Sink***
- Else light > threshold → ***Swim up***
- Else → ***Passive***



Nauplii
(non-infective)

40 degree-days

Sink: 2e-4 ± 4e-5 m/s
Swim: 2e-4 ± 4e-5 m/s
$Thresh_{Light}$: 2.06e-5 μmol/m²/s

Copepodid
(infective)

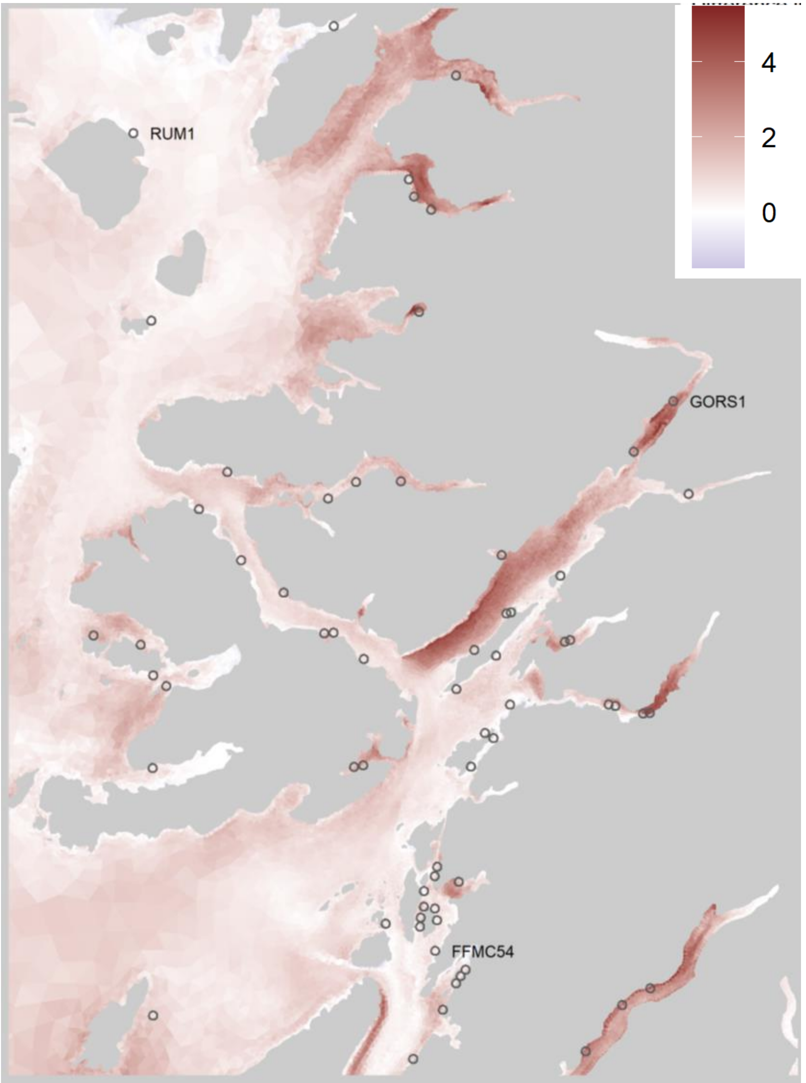
150 degree-days

Sink: 5e-4 ± 1e-4 m/s
Swim: 5e-4 ± 1e-4 m/s
$Thresh_{Light}$: 0.392 μmol/m²/s

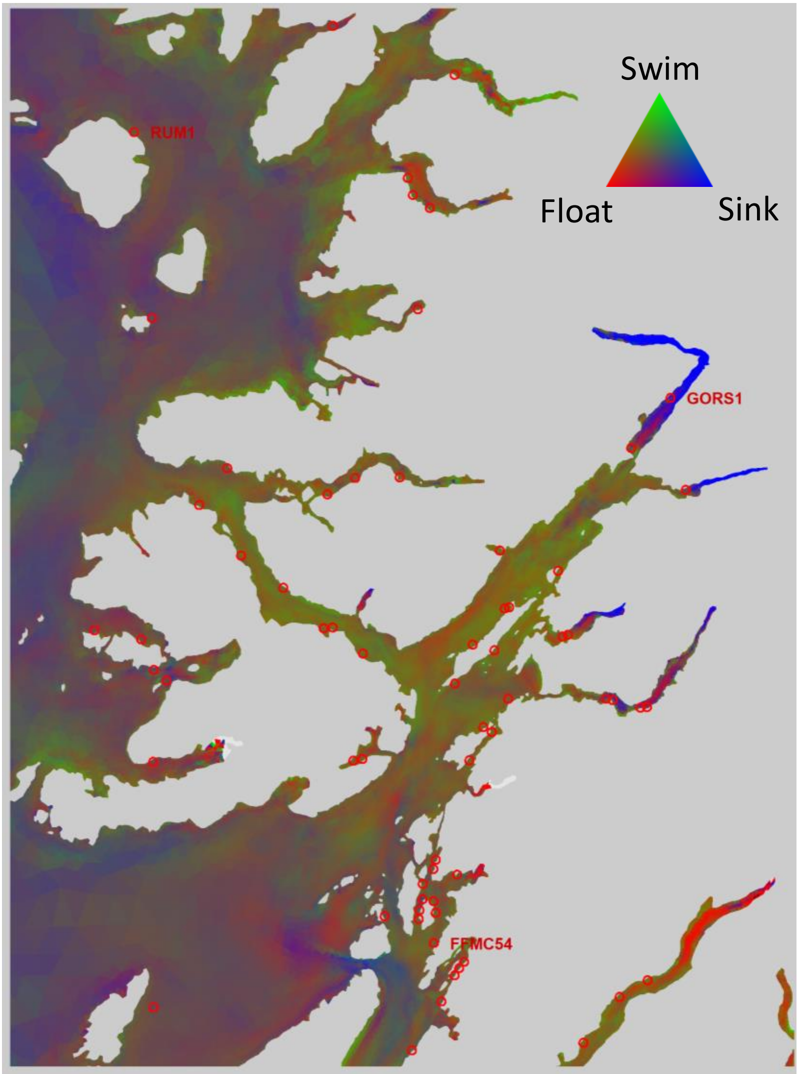
Bricknell 2006; Johnsen et al. 2014, 2016; Myksvoll et al. 2018; Samsing et al 2019; Sandvik et al. 2020

3D: Greater lice retention nearshore, uploch

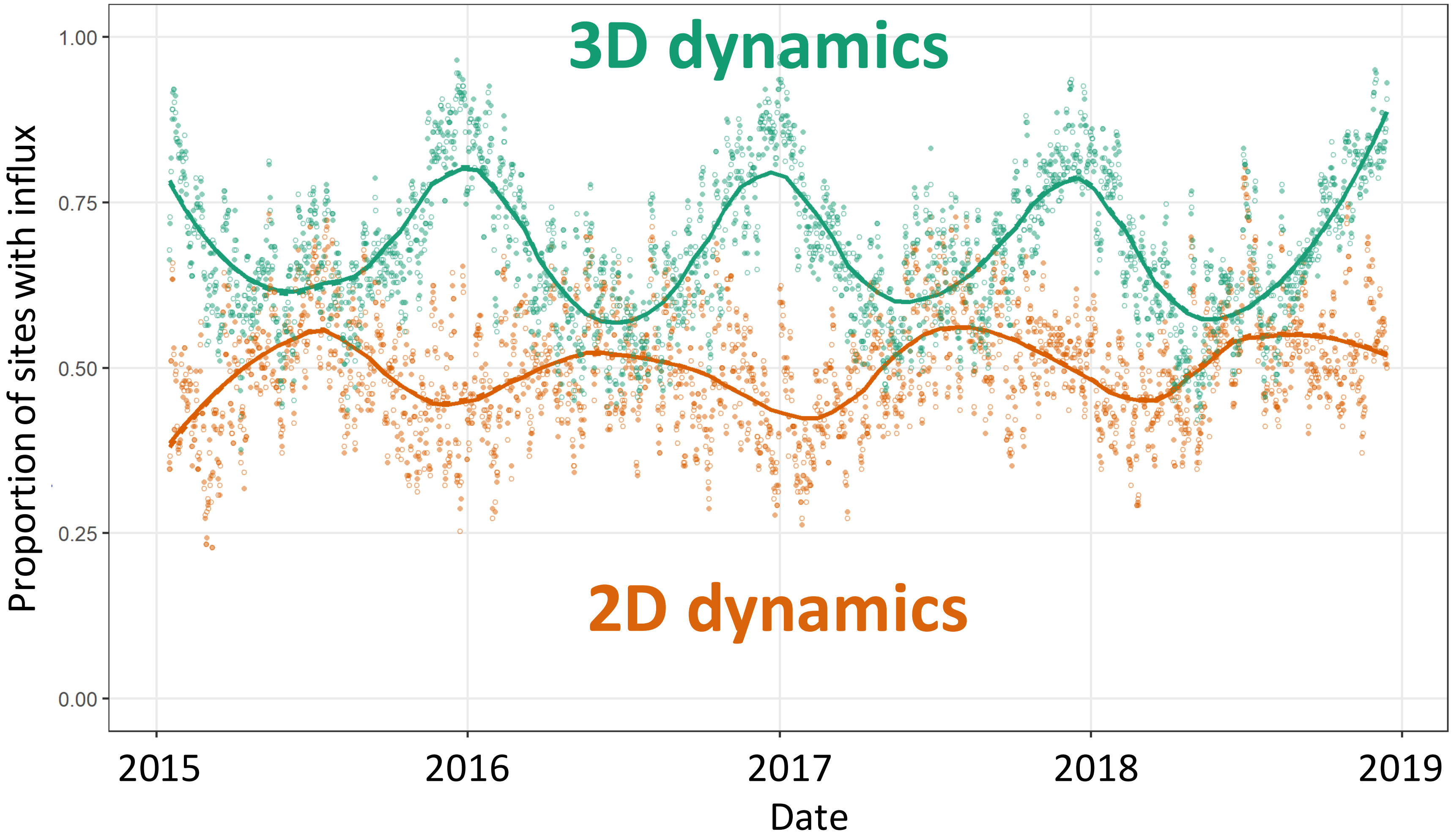
Difference in lice density 3D vs 2D



Relative proportion of activity types

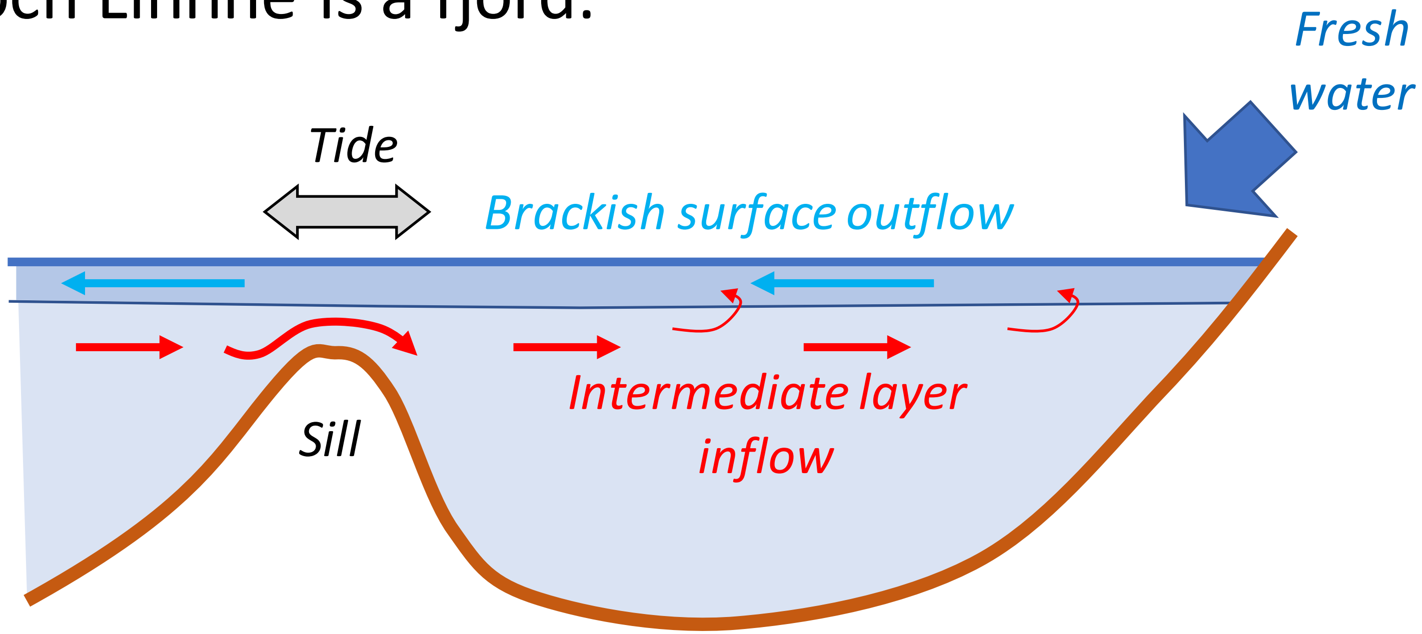


3D: Greater **prevalence**, early winter peak

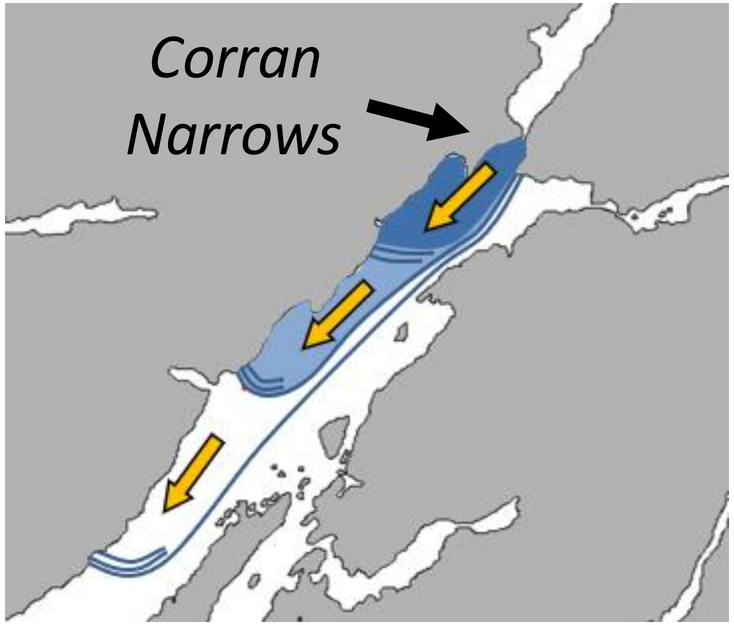


Why is this? .... Loch Linnhe as a case study

Loch Linnhe is a fjord:



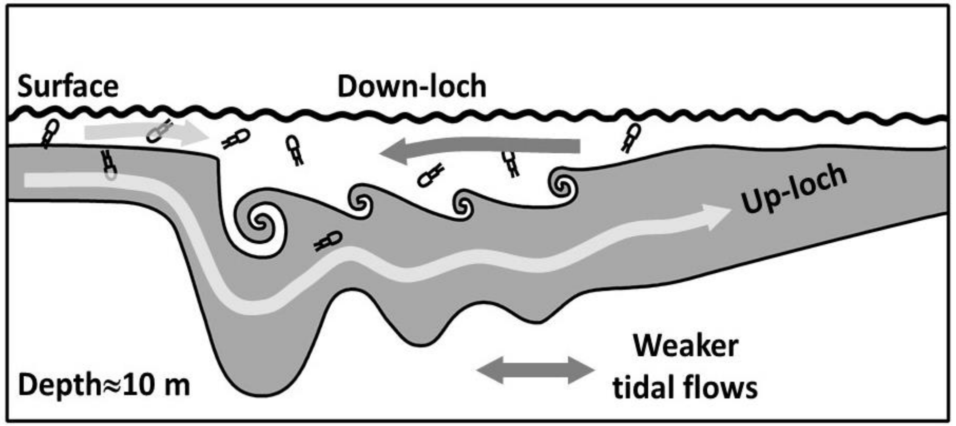
In fact, Loch Linnhe is a broad fjord:



So, the fjordic circulation is not uniform across the loch and tends to 'lean' on boundaries.

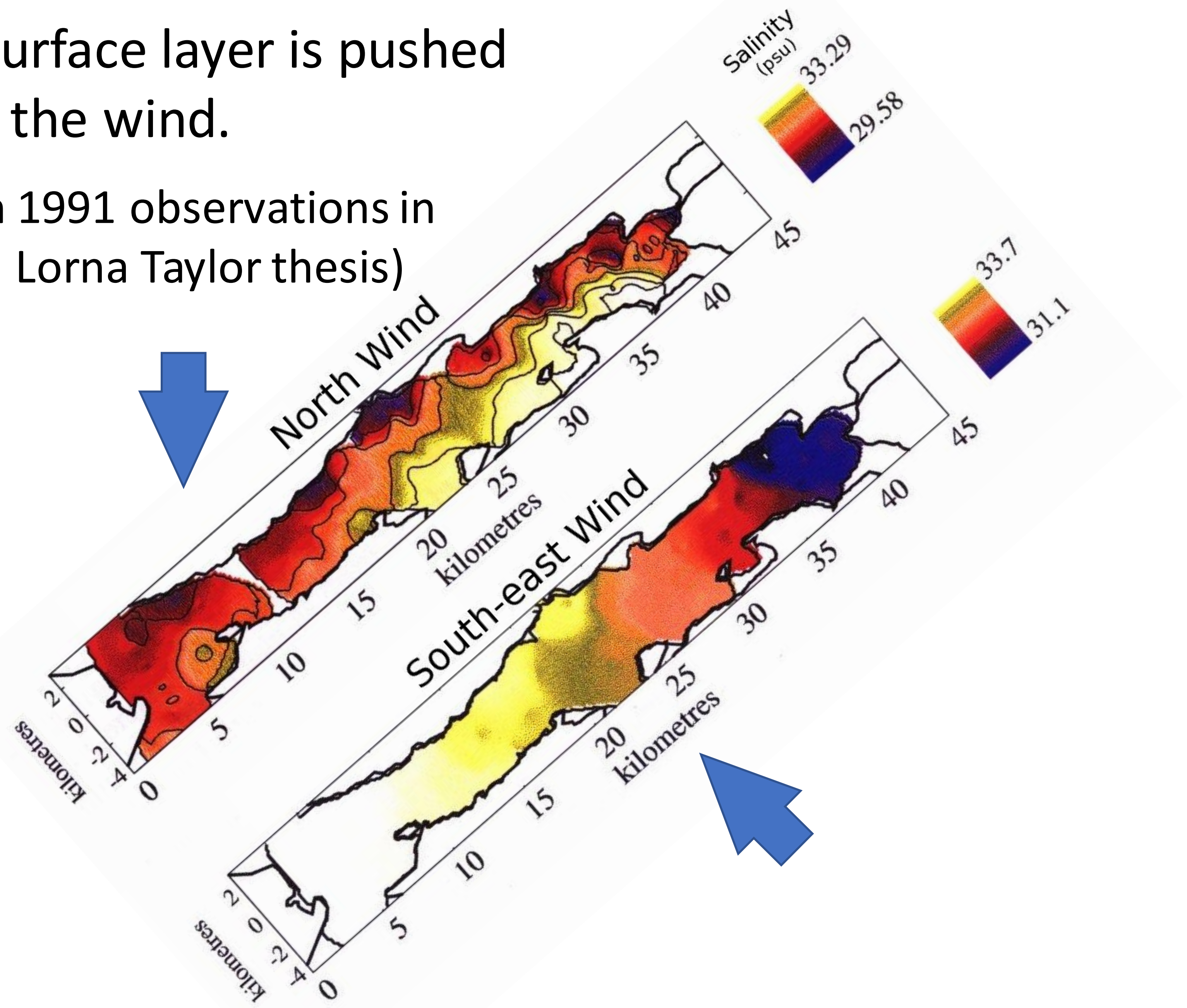
And circulation is tidally pulsed through sills/constrictions:

Cartoon of a propagating tidal bore interacting with sea lice.

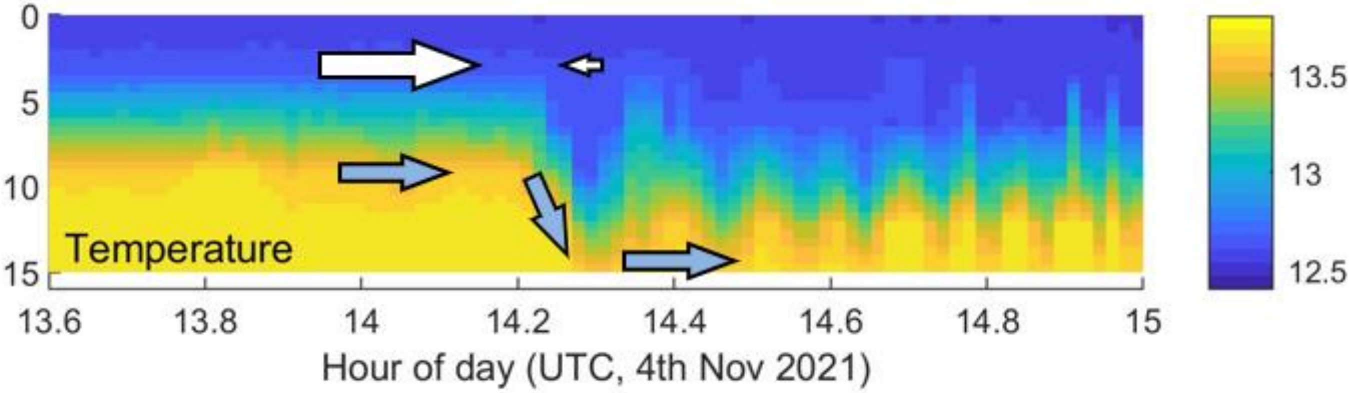


Also, the surface layer is pushed around by the wind.

(Mike Heath 1991 observations in figures from Lorna Taylor thesis)



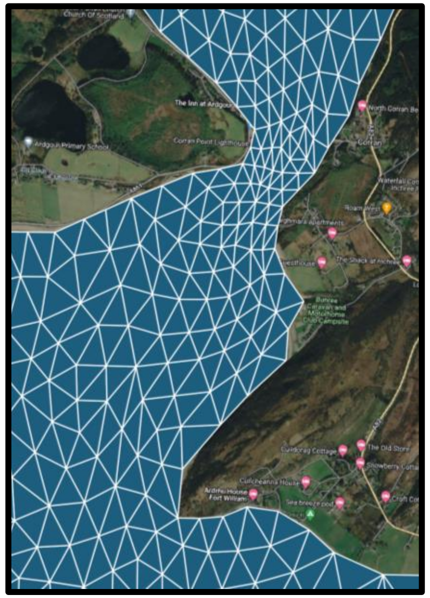
In OffAqua we got some lovely new observations of finescale, tidally-pulsed physics.



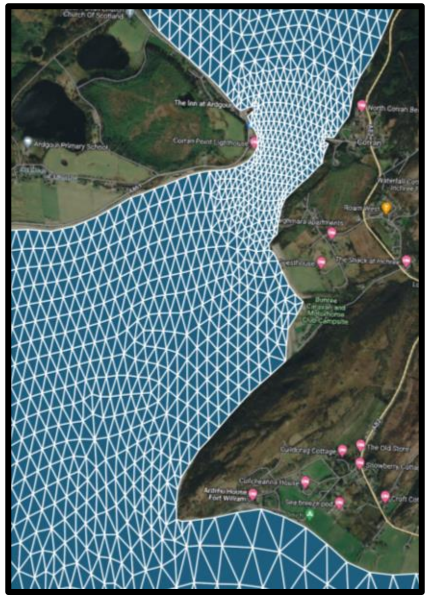
Sea lice dispersal Pt II: Hydrodynamic resolution

Are hydrodynamics adequately resolved relative to lice behaviour?

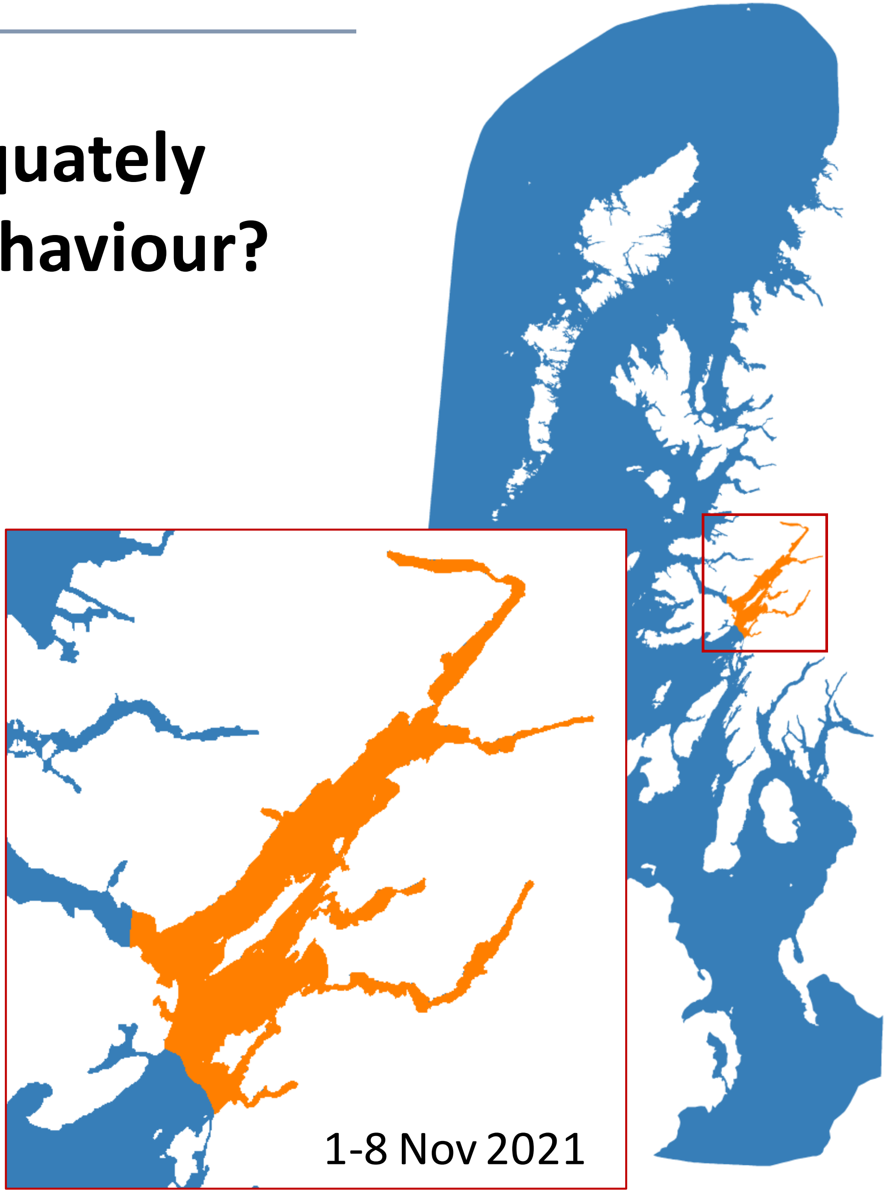
WeStCOMS2



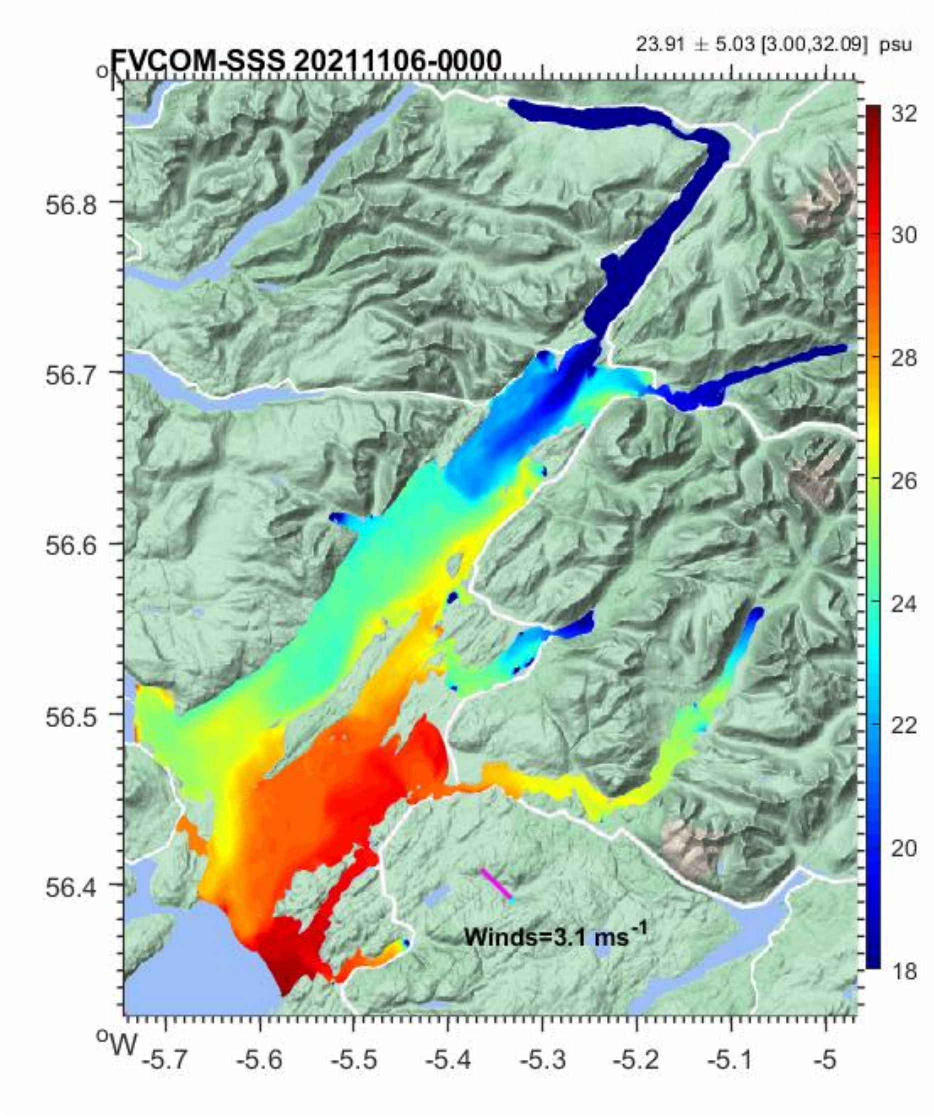
Linnhe7



x temporal: *1 hour* vs. *5 min*



New, high resolution Linnhe7 model



Lice dispersal simulations

Varying three aspects of the coupled model system

		2 Temporal resolution	
1	**Spatial resolution**	WeStCOMS2 1h	WeStCOMS2 5min
		Linnhe7 1h	Linnhe7 5min

3

x **Lice Speed**

0.01 cm/s
0.05 cm/s
0.1 cm/s

Particle positions

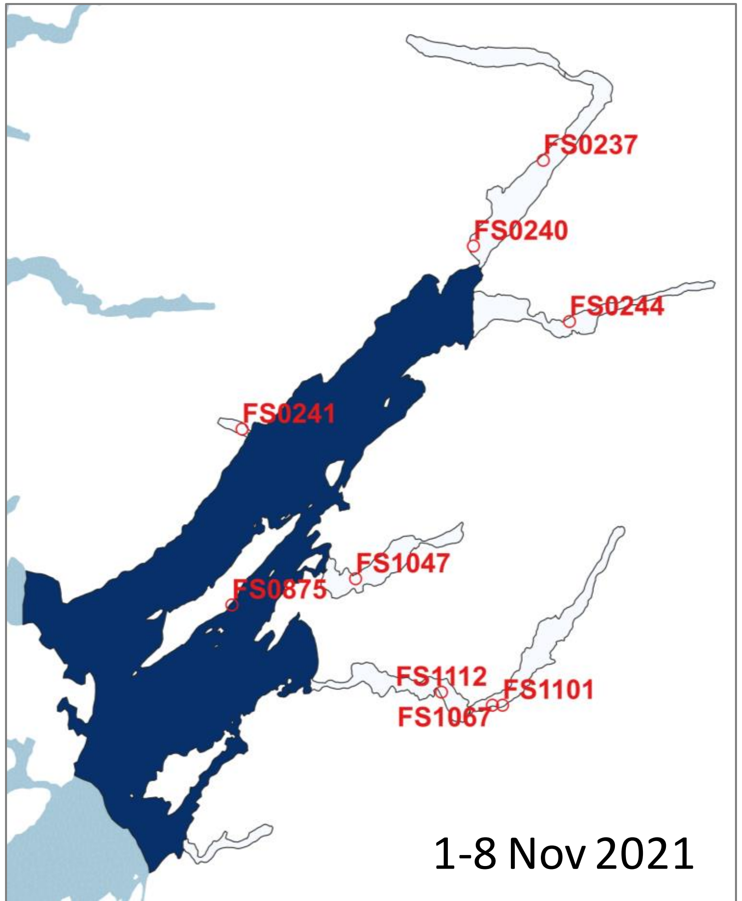
- 2.5 min updates, hourly analysis
- 9 active farms

Lice parameters

- Mortality: 0.01 hr^{-1}
- p(sink) ~ salinity [32=0 – 23=1]
- K_H: 0.1, K_V: 0.001 m^2/s

Focus

- Tidal pulse from Corran Narrows



Sandvik et al (2020)

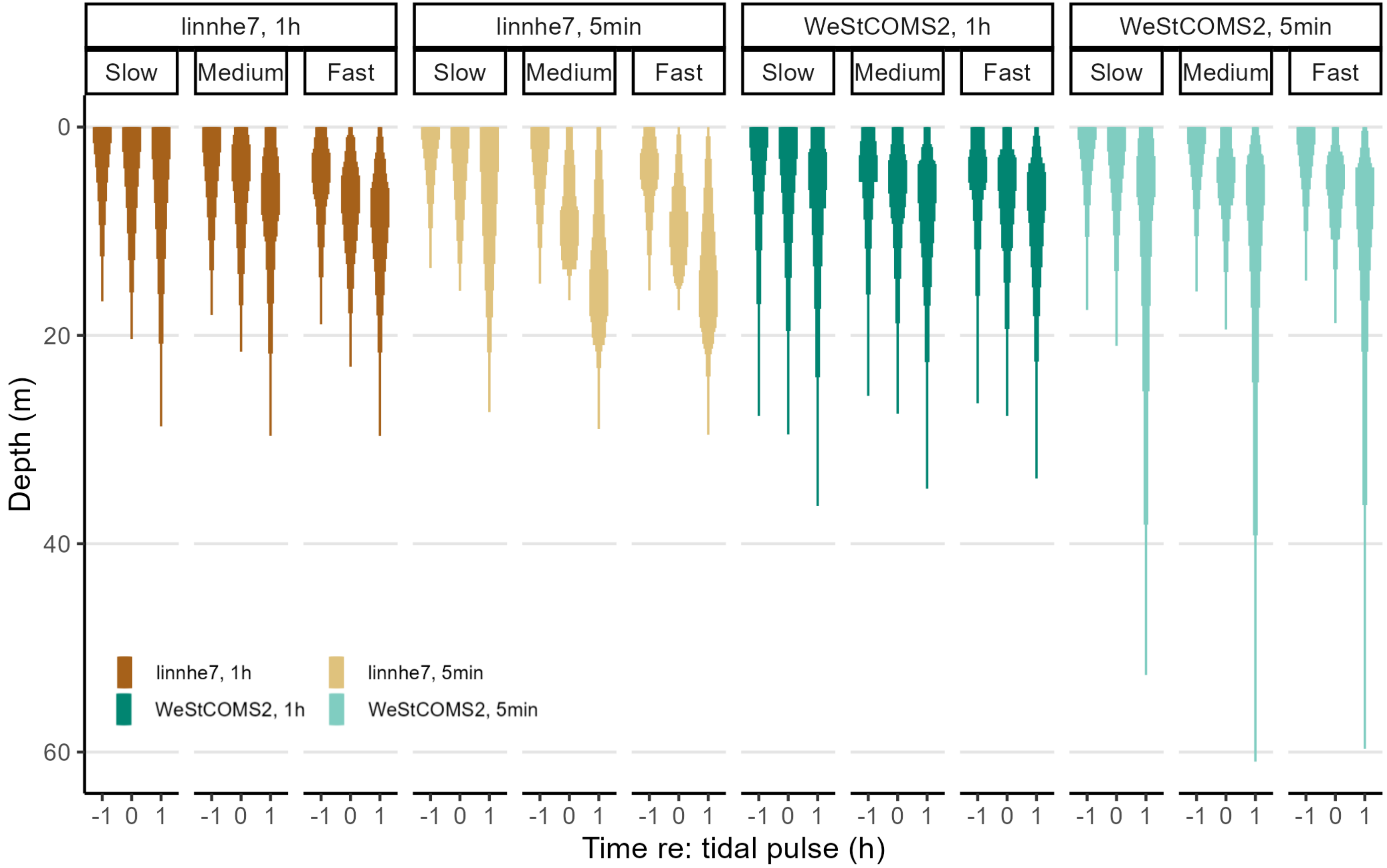
Vertical distribution and tidal pulses

Particles move deeper through tidal pulse

- Deeper with higher res, faster lice

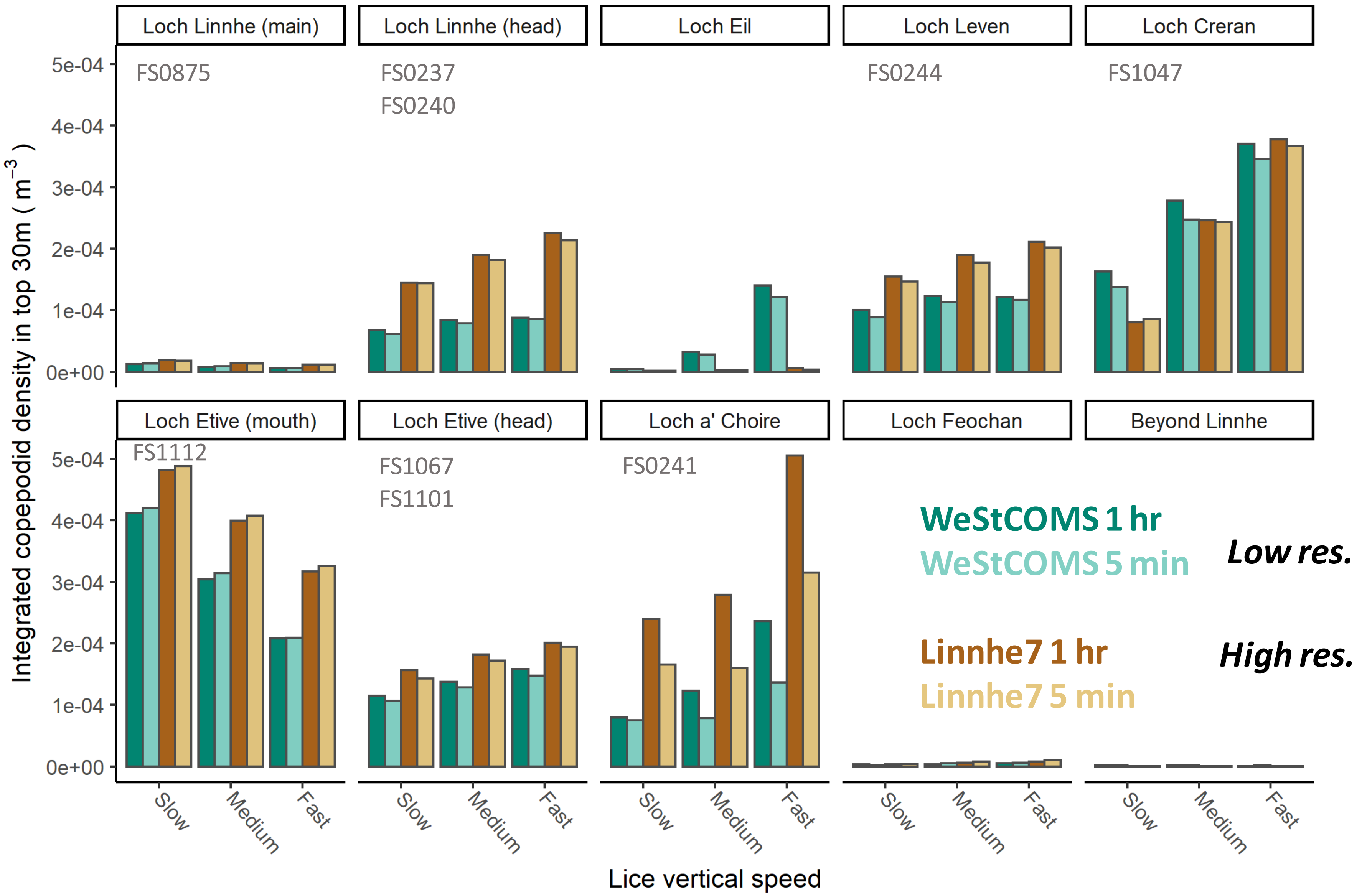
WeStCOMS 1 hr
WeStCOMS 5 min

Linnhe7 1 hr
Linnhe7 5 min



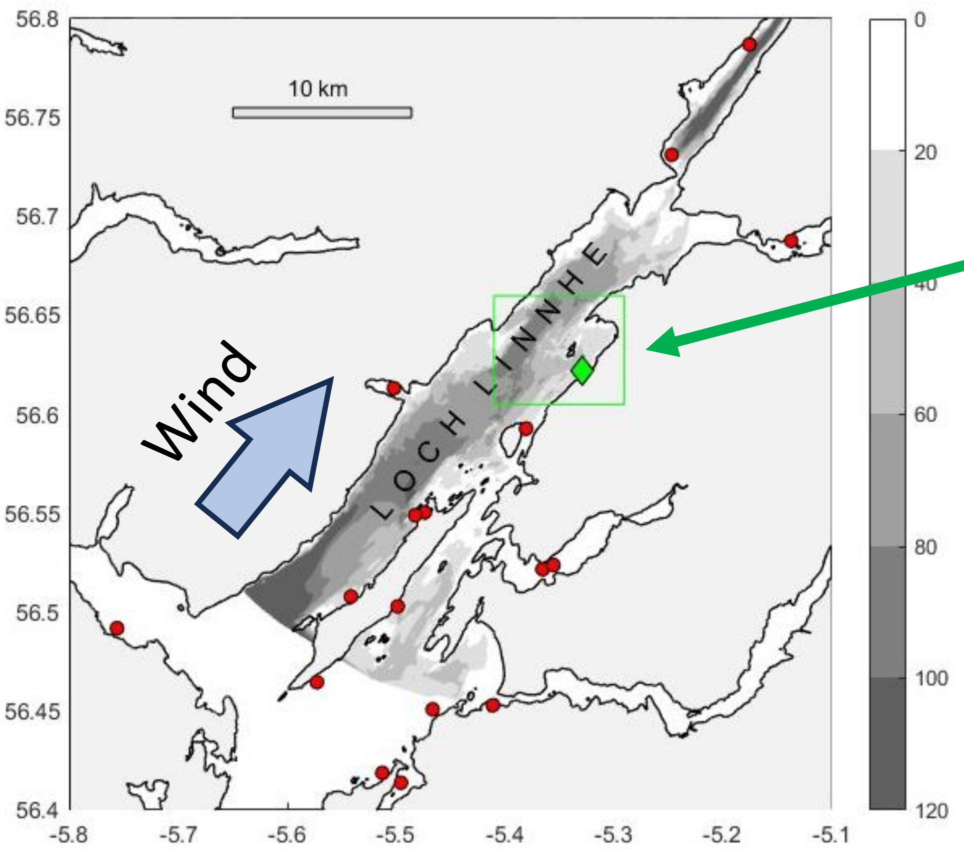
Copepodid density

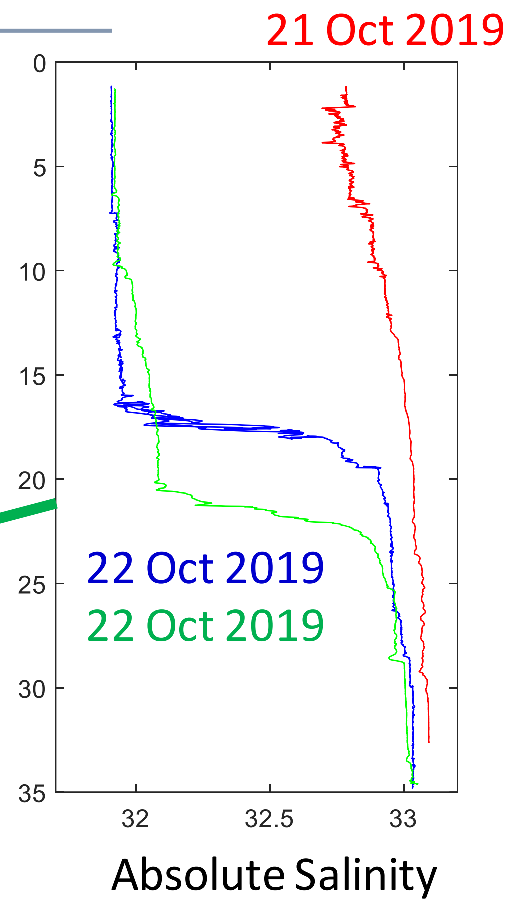
Higher in sheltered areas with high spatial res, faster lice



The key role of wind-induced variability

SARF-funded dispersion work on the eastern side of Loch Linnhe experienced a period of up-loch winds from the SW.

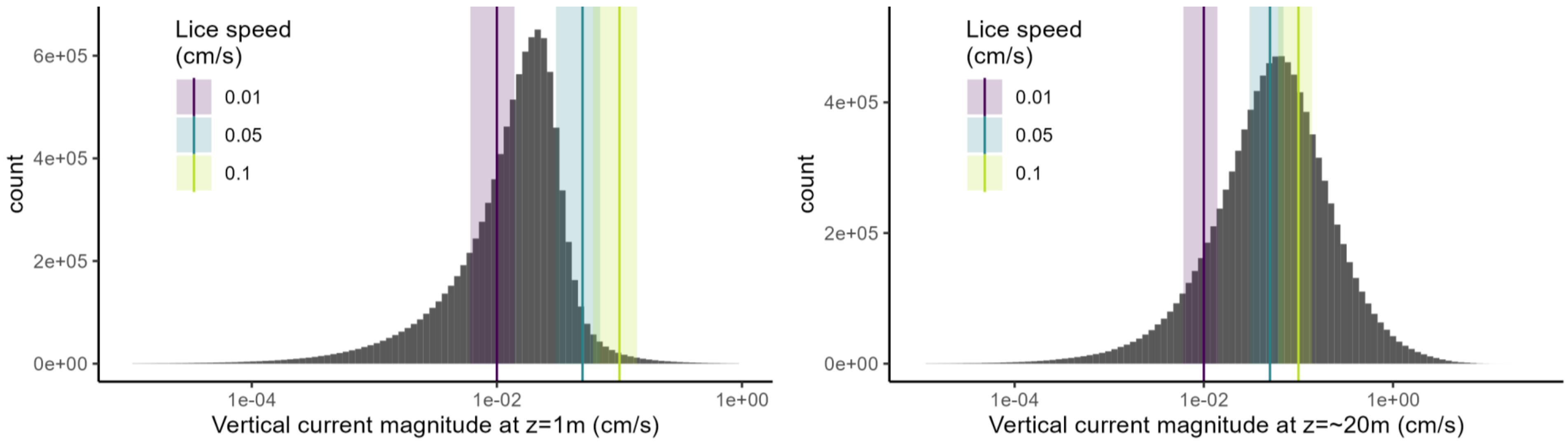




Overnight, fresher water arrived to a depth of 20+ m (wind-driven downwelling).

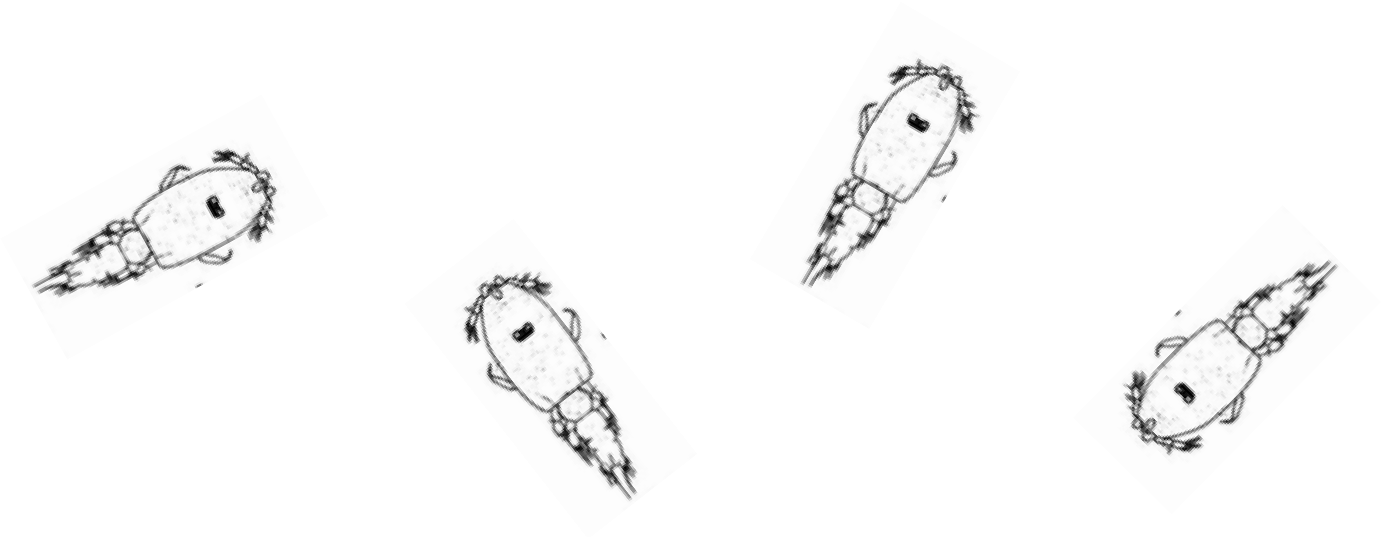
Summary – part 1

- Vertical dynamics alter distribution of lice, driving increased pressure in sheltered locations
- Higher resolution hydrodynamics cause increased retention of lice in sheltered locations
- Often, vertical currents > measured lice speeds
- Resolving vertical dynamics is essential



Summary – part 2

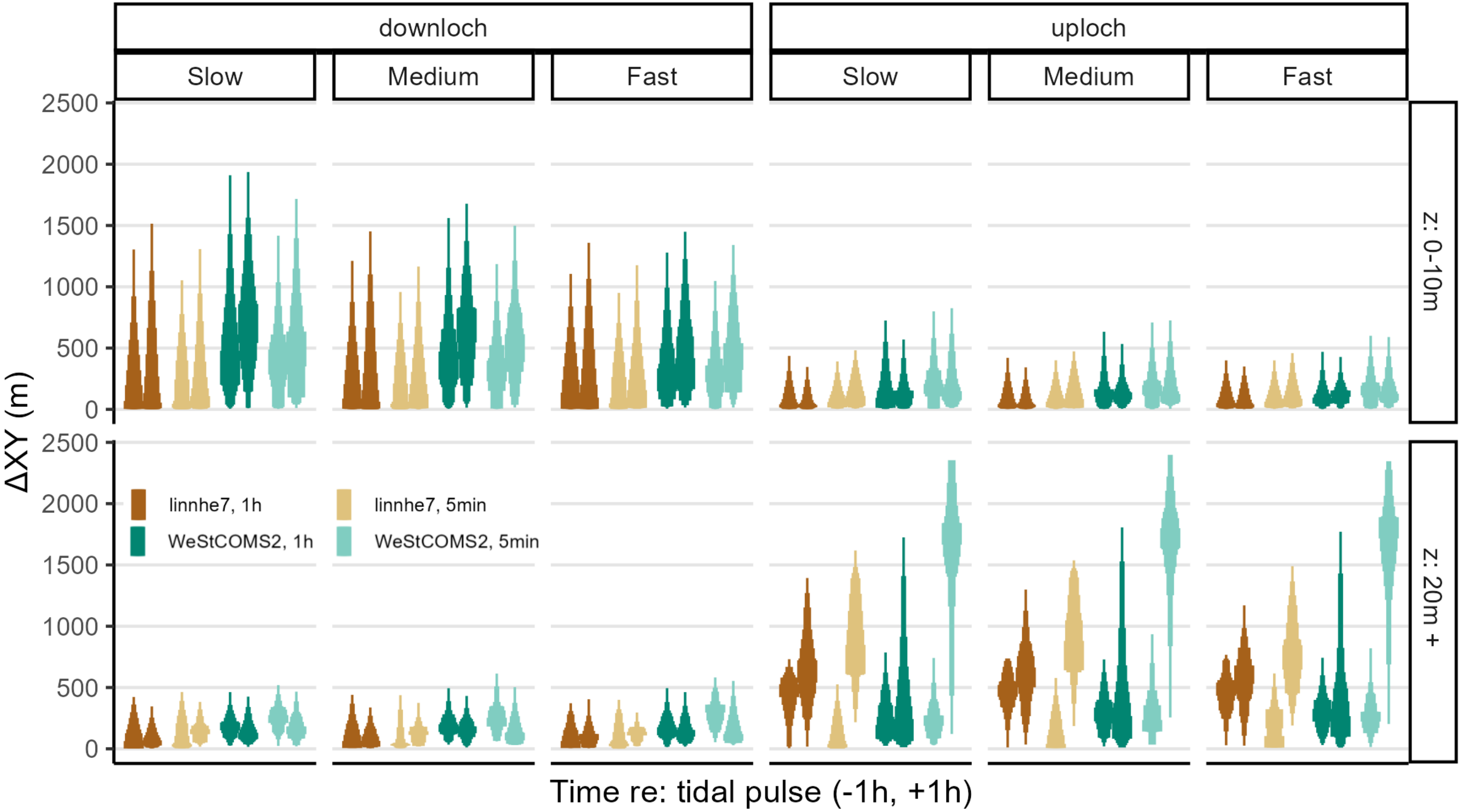
- Coupled hydrodynamic-lice simulations have not yet converged with respect to resolution. Important physical processes often have short length- and timescales and complex dynamics.
- Wind-driven variability in coastal waters can be large and is vital to simulating dispersal of lice.

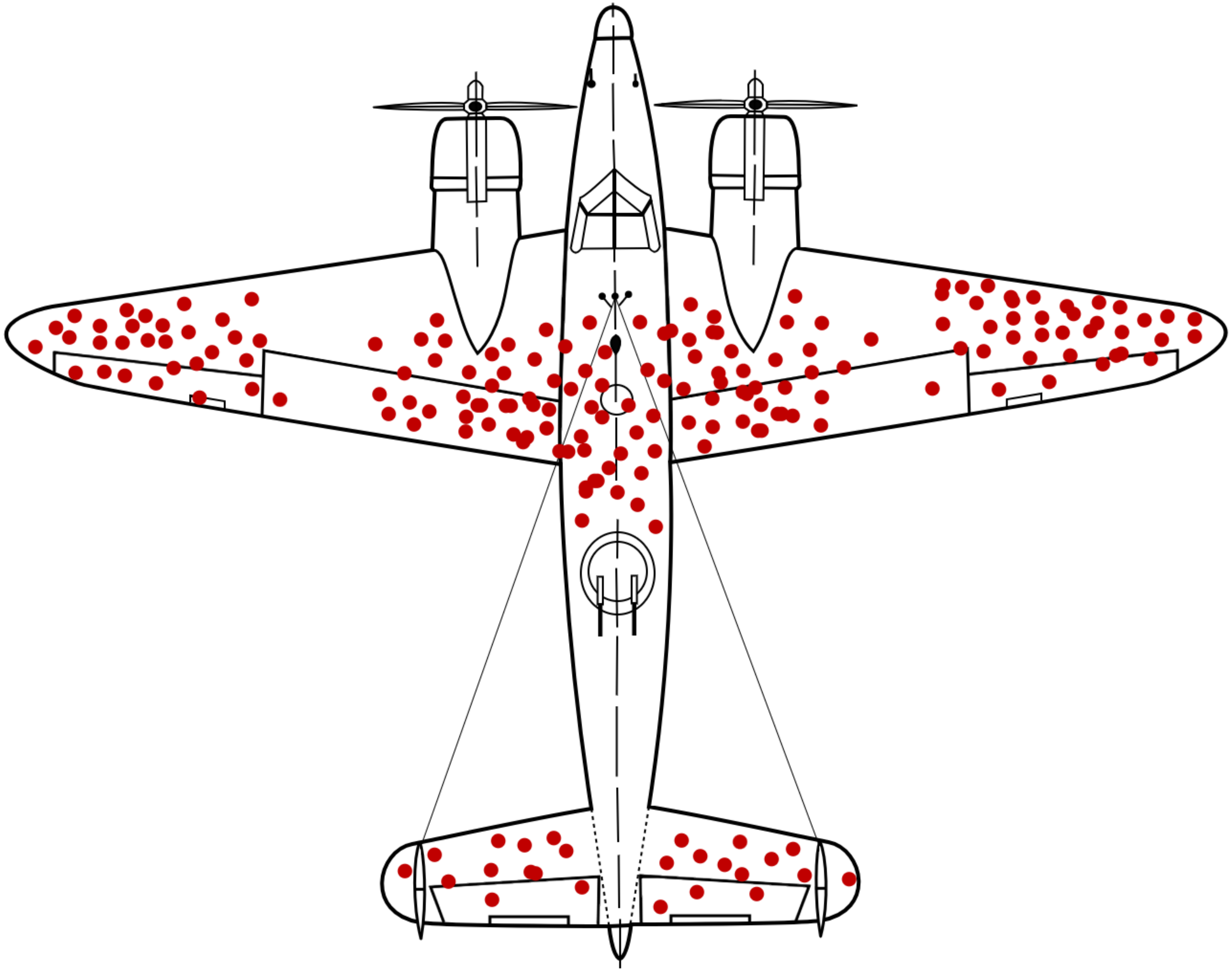


Horizontal movement and tidal pulses

Deep, uploch-ward particles move furthest

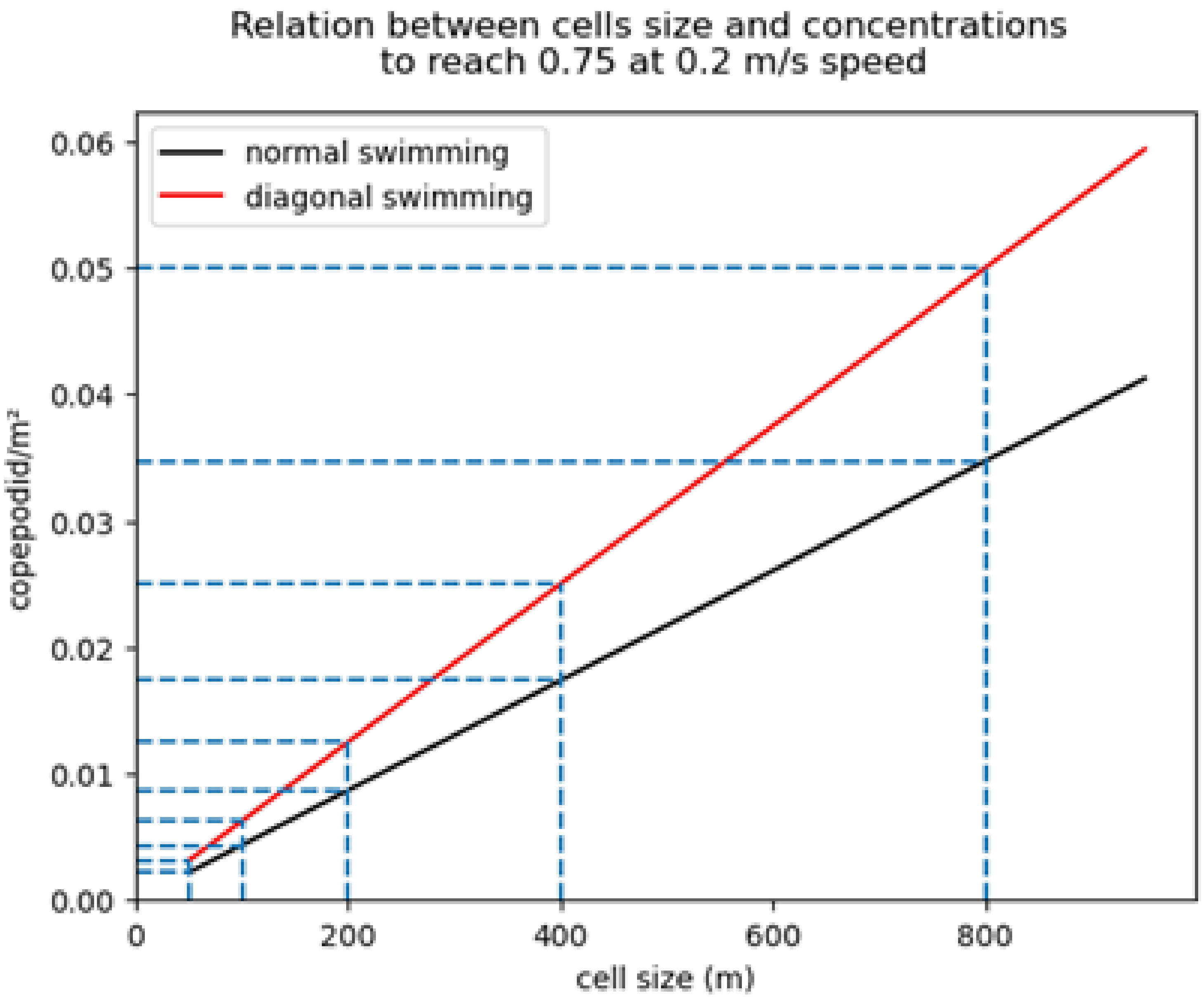
- Further with 5 min res, high spatial res





Survivorship bias > image from
https://en.wikipedia.org/wiki/Survivorship_bias

Julien Moreau
The NW Edge



This is oversimplified of course using the time it takes for a fish to cross a cell perpendicular to the edge and in diagonal and scale it to a daily concentration. But the idea is to show that the way the data are usually presented is not directly interpretable to assess a risk without some other complex considerations.

This paper on the different of order between counting on wild post-smolt and sentinel cages explains the concept further. https://doi.org/10.3354/aei00443

Julien Moreau
The NW Edge

West Scotland Coastal Modelling System:

WeStCOMS

Weather, Ocean circulation and Wave

Operational Forecasts

Dmitry Aleynik

Stakeholder Workshop - Knowledge Strength in Sea Lice Dispersal Modelling

Freshwater Fish Laboratory, Faskally, Pitlochry

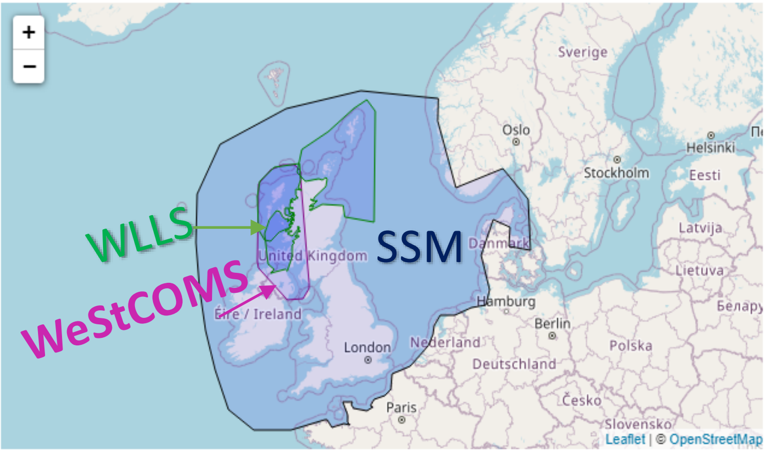
7th September 2023

WeStCOMS summary and access links

National Partnership for Ocean P... ×

coastal.miraheze.org/wiki/Main_Page

Map indexing coastal hydrodynamic models listed on this wiki



To create a new coastal model page, just type in a title/name below, click create, and start editing. If you would like to index your model using the map above, please email Rory O'Hara Murray rory.murray @ gov.scot a rough ASCII comma separated boundary using WGS84 format.

Type your page title here

Create new coastal model page

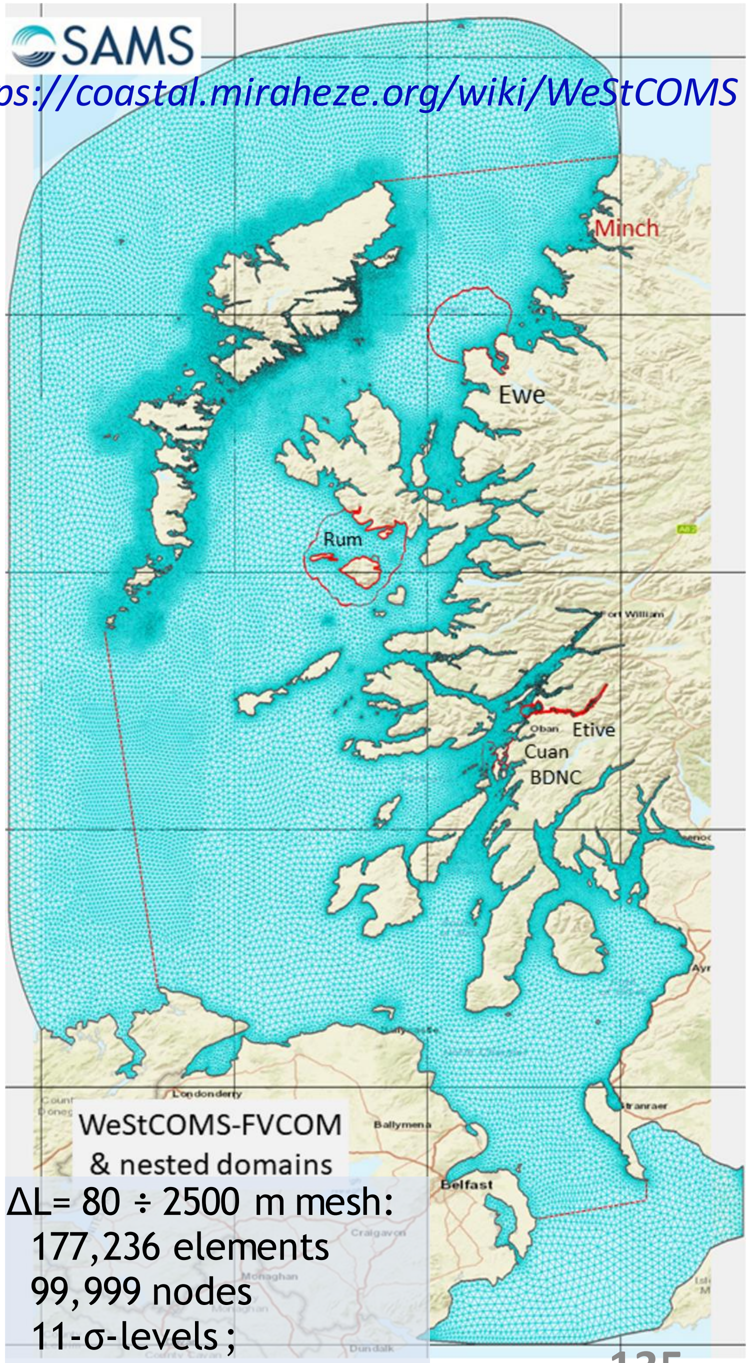
Note that not all model domains may be shown on the map above. Recently added models are provided in the list below, and a full list of model domains can be found through the following page:

Index to all Coastal models

Recently added coastal model pages

- 9 September 2020: Scottish Shelf Model - Pentland Firth and Orkney Waters
- 9 September 2020: Scottish Shelf Model
- 9 September 2020: Scottish Shelf Model - East Coast Lewis and Harris
- 9 September 2020: Template:Coastal models
- 9 September 2020: Scottish Shelf Model - Wider Loch Linnhe System
- 9 September 2020: North West European shelf - GETM-BFM
- 9 September 2020: North Sea GETM-BFM
- 26 May 2021: WeStCOMS
- 27 September 2022: Regional Ocean Acidification Modelling - Global NEMO-MEDUSA

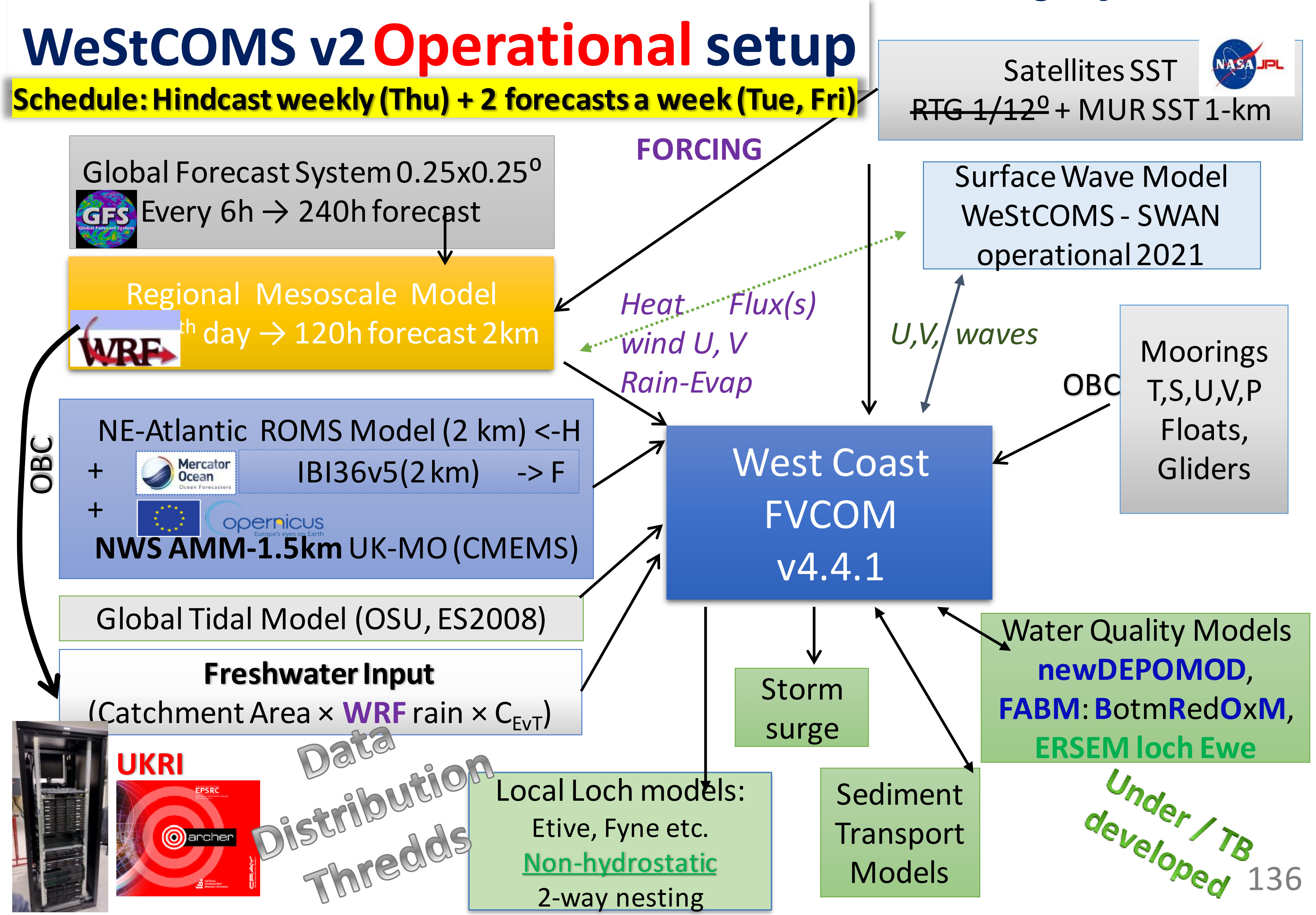
https://coastal.miraheze.org/wiki/WeStCOMS

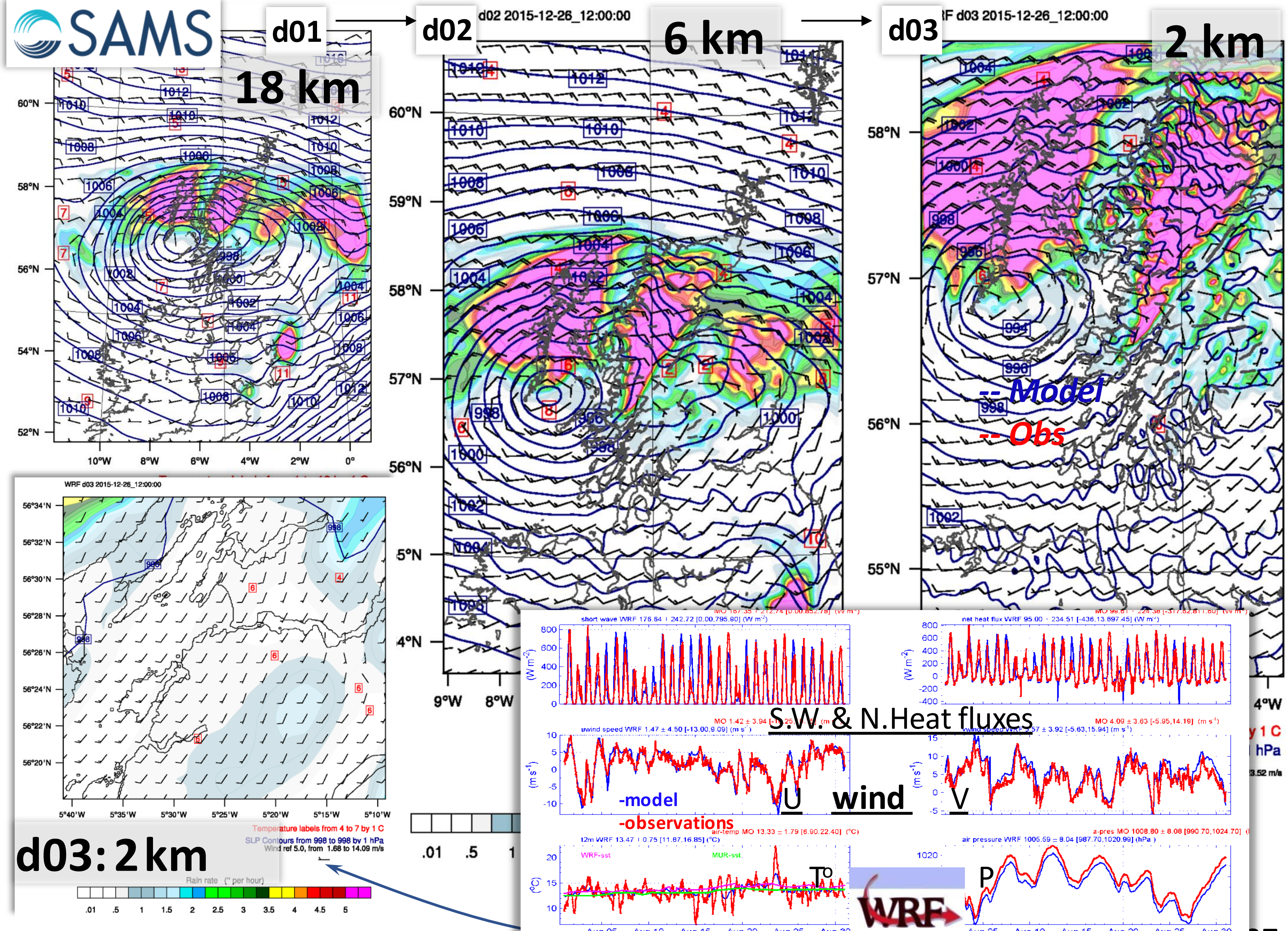


WeStCOMS-FVCOM & nested domains

$\Delta L = 80 \div 2500$ m mesh:
177,236 elements
99,999 nodes
11-σ-levels ;
$\Delta T_{BT} = 0.5$ sec

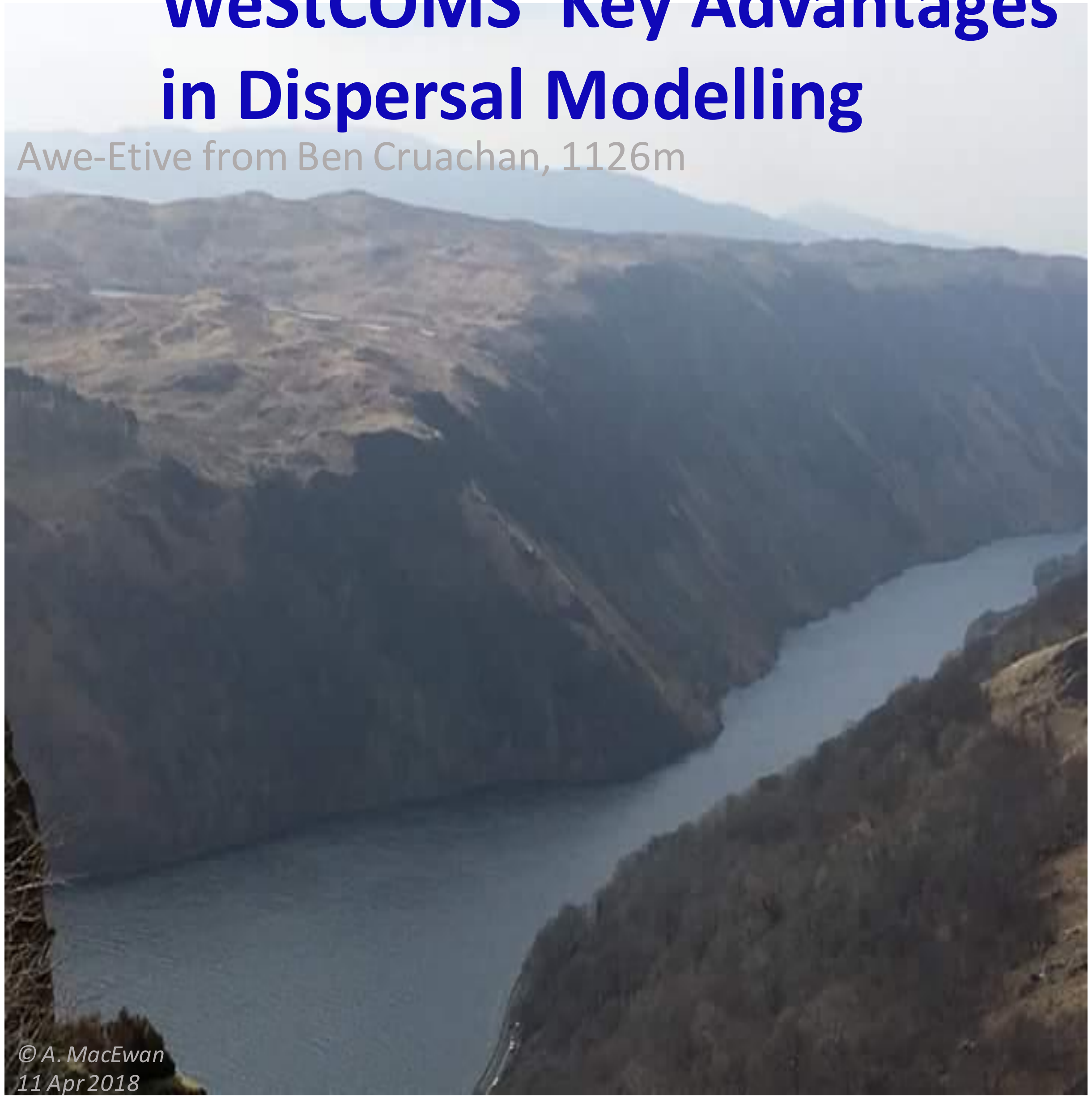
West Scotland Coast Ocean Modeling System





NCEP, ECMWF, etc grids are ~ 50 ÷ 25 km

WeStCOMS' Key Advantages in Dispersal Modelling



Adequate hydrodynamic systems response to external forcing is achieved due to:

1. Resolution of meteo-field tiles 2 x 2 km is comparable with terrain
2. Correct freshwater discharge, derived from WRF rainfall over the river' catchments
3. Improved quality of open boundary forcing with sufficient (1.5 -2.5 km) resolution CMEMS-AMM15, NEA-ROMS
4. SWAN waves module enables Stockes drift corrections for the motion of objects in upper layers

SAMS

inter-& intra-annual variability

UK 56%

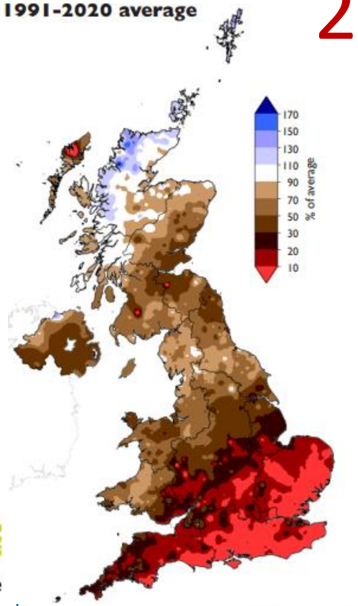
Scotland 81%

July 2022 rainfall
as % of 1991-2020 average

2022/07

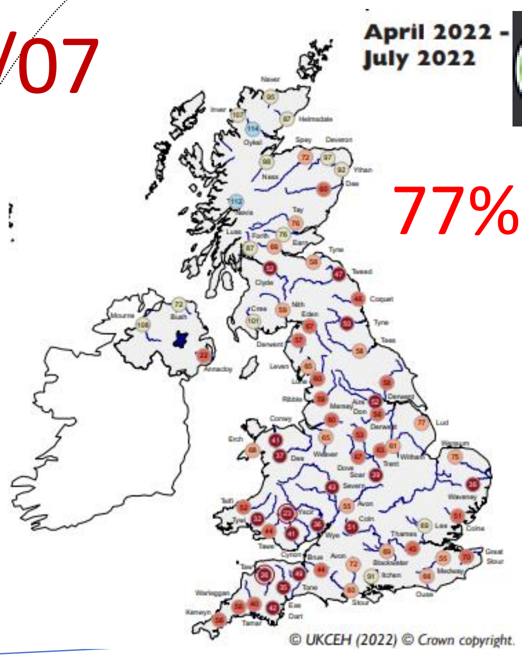
Percentages are from the 1991-2020 average.

Region	Rainfall	Jul 2022	Jun22 – Jul22	RP
United Kingdom	mm	46	105	
	%	56	66	8-12
England	mm	23	68	
	%	35	52	10-20
Scotland	mm	84	158	
	%	81	80	2-5



April 2022 - July 2022

Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL



77%

<25%

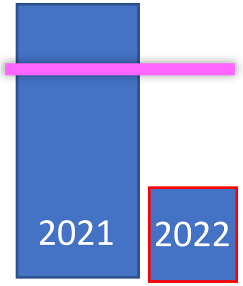
River flow

Rainfall

July 2021 rainfall
as % of 1981-2010 average

2021/07

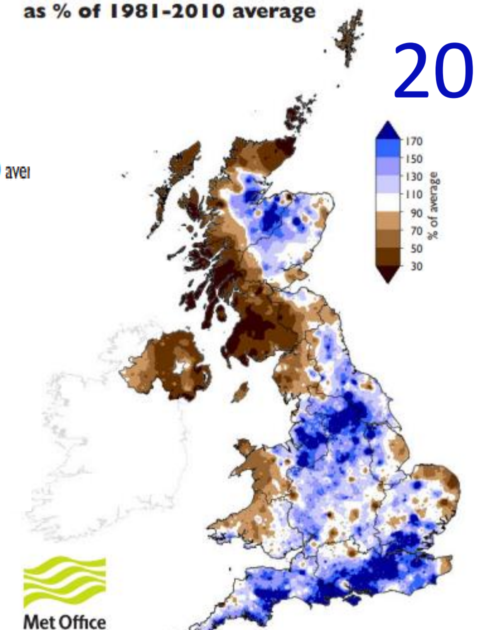
UK



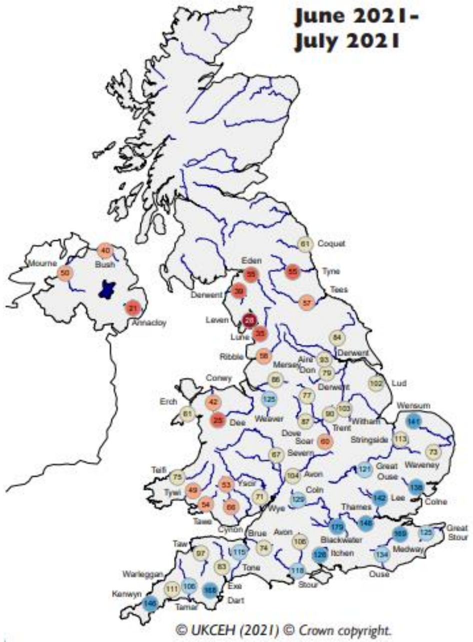
128% 56%

Percentages are from the 1981-2010 aver

Region	Rainfall	Jul 2021
United Kingdom	mm	73
	%	96
England	mm	78
	%	128
Scotland	mm	66
	%	71

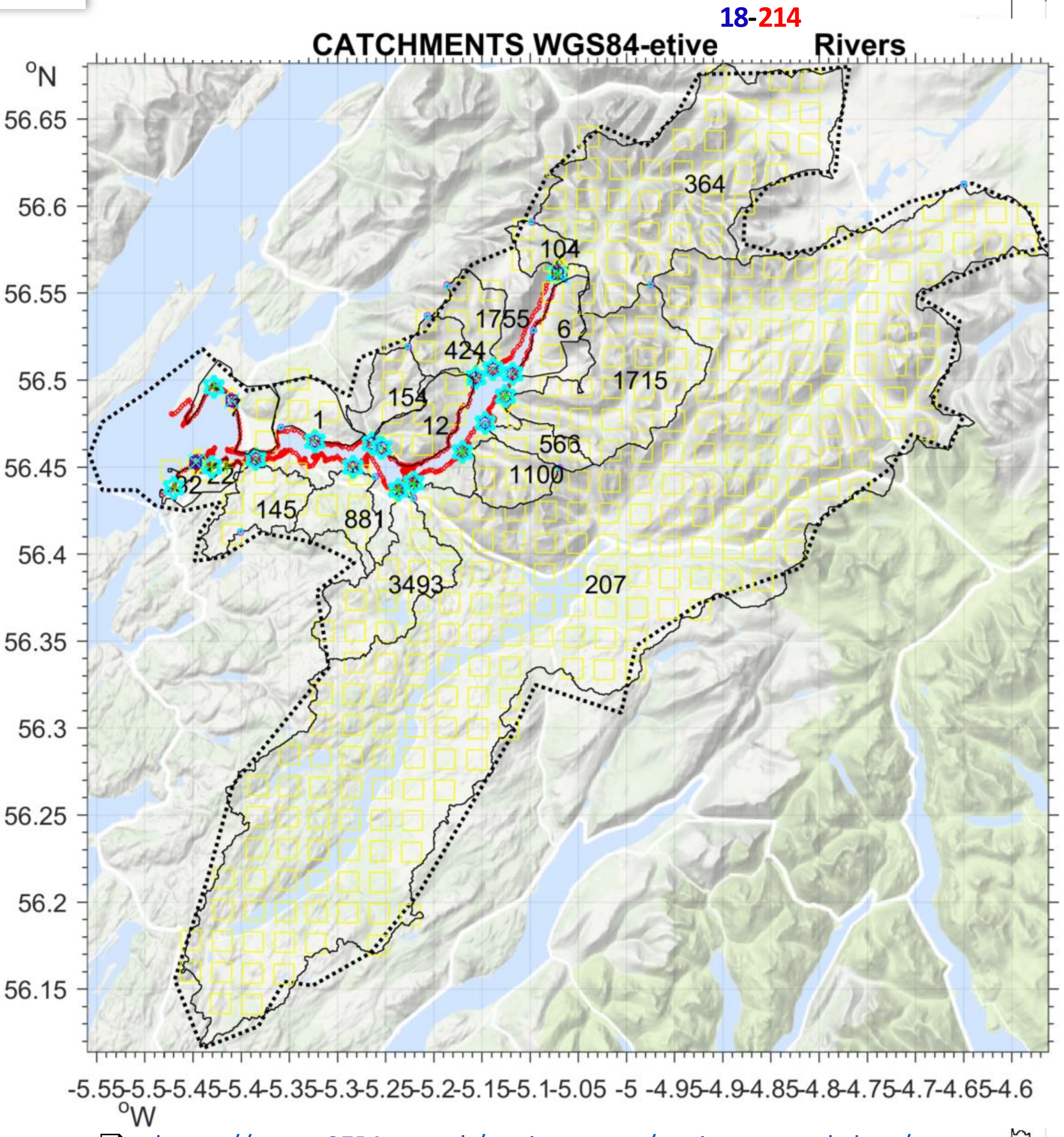


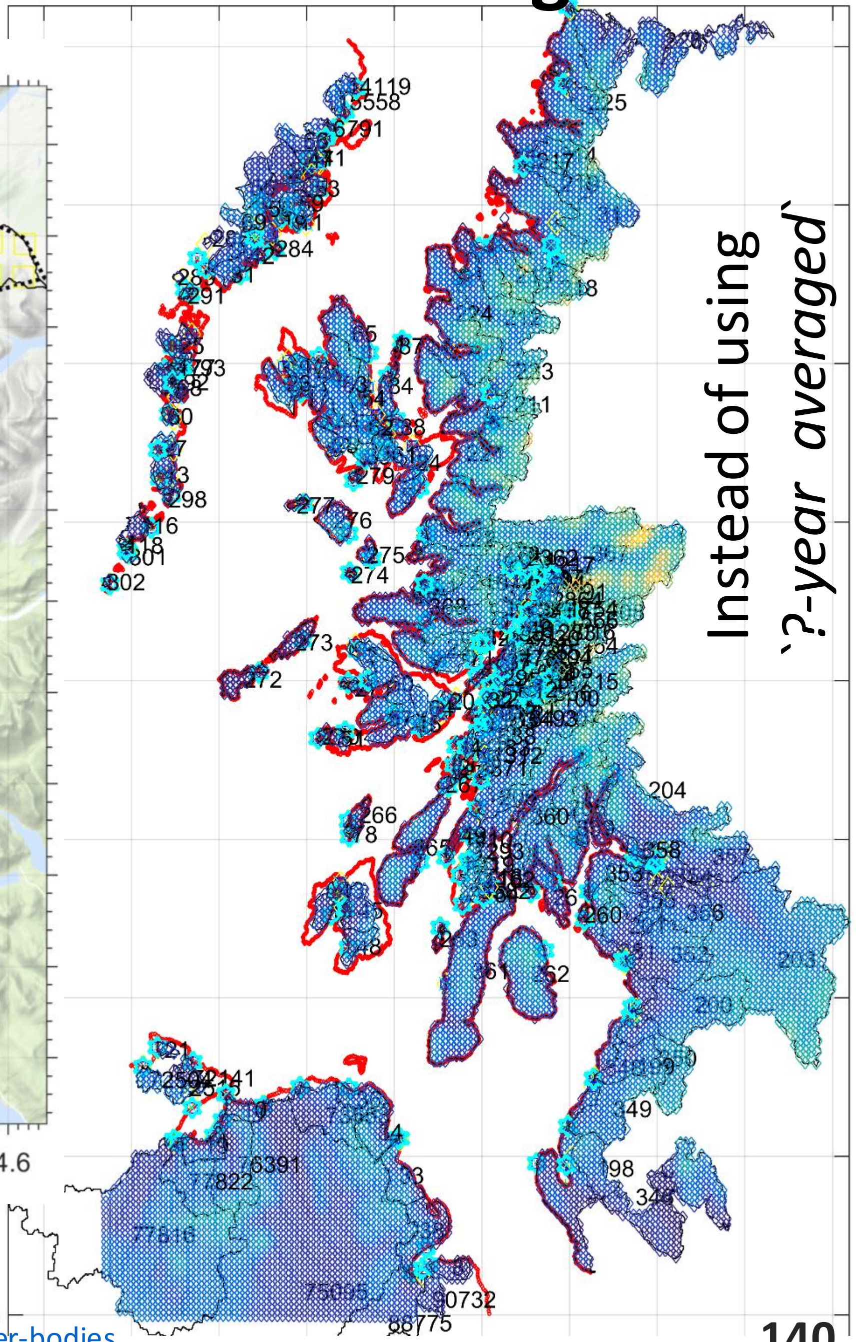
June 2021- July 2021



> 150 %

WRF: Actual Freshwater discharge

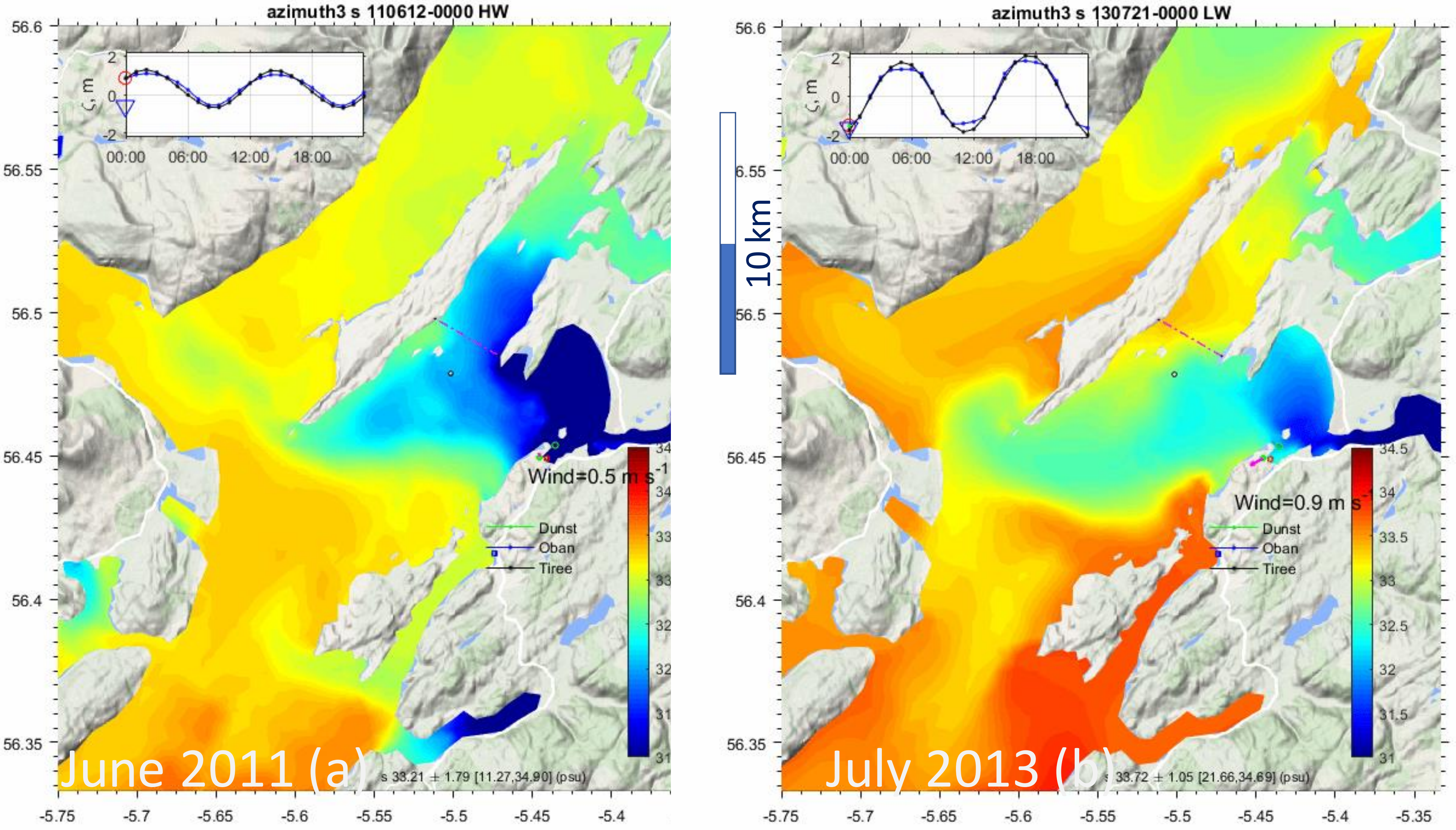




Instead of using `?-year averaged`

- https://www.SEPA.org.uk/environment/environmental-data/
- http://hydrosheds.cr.USGS.gov
- http://gis.EPA.IE/geonetwork
- https://www.opendatani.gov.uk/dataset/northern-ireland-river-water-bodies

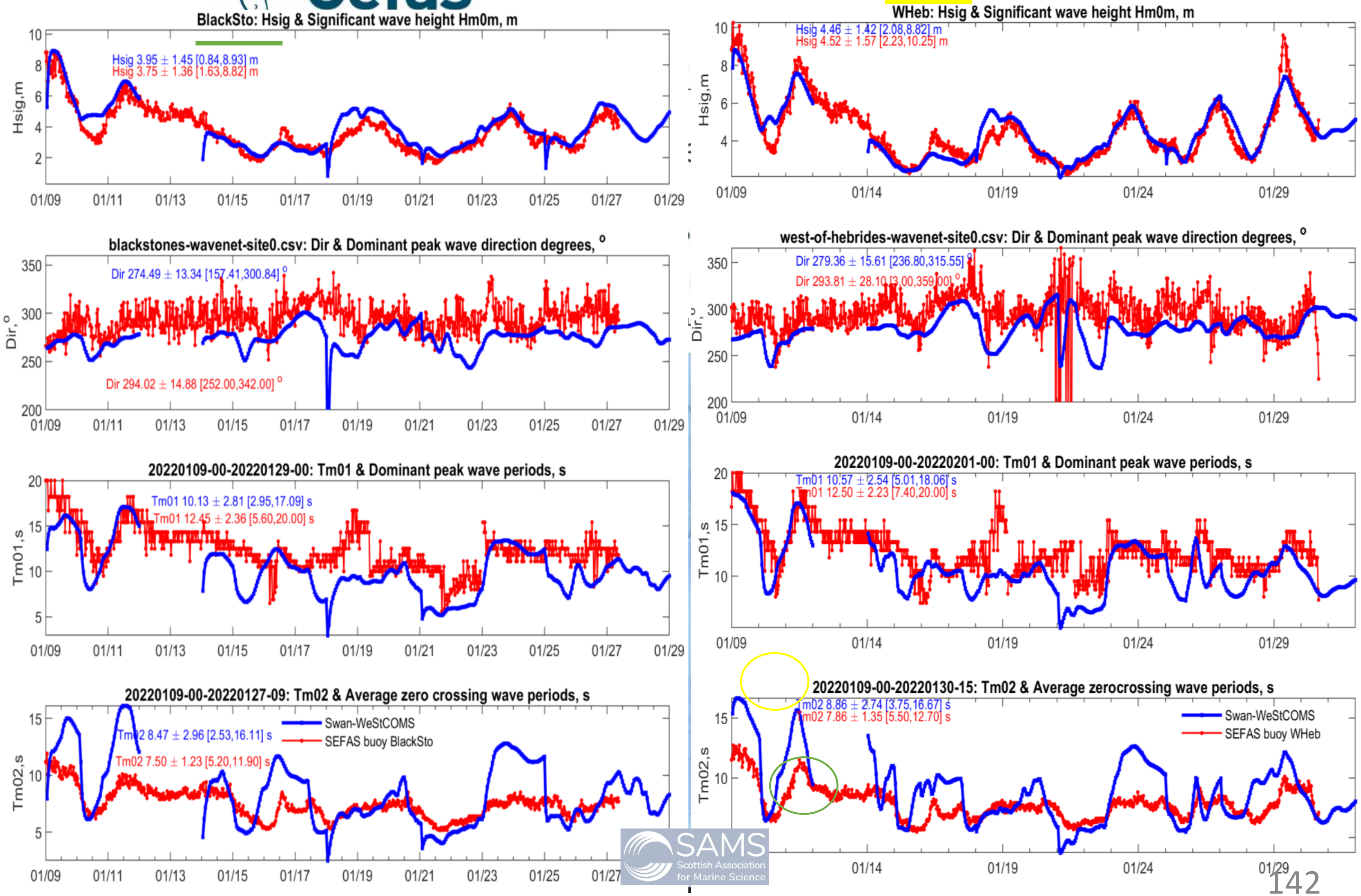
Subsurface Dispersal in upper layers due to improved fresh-water discharge



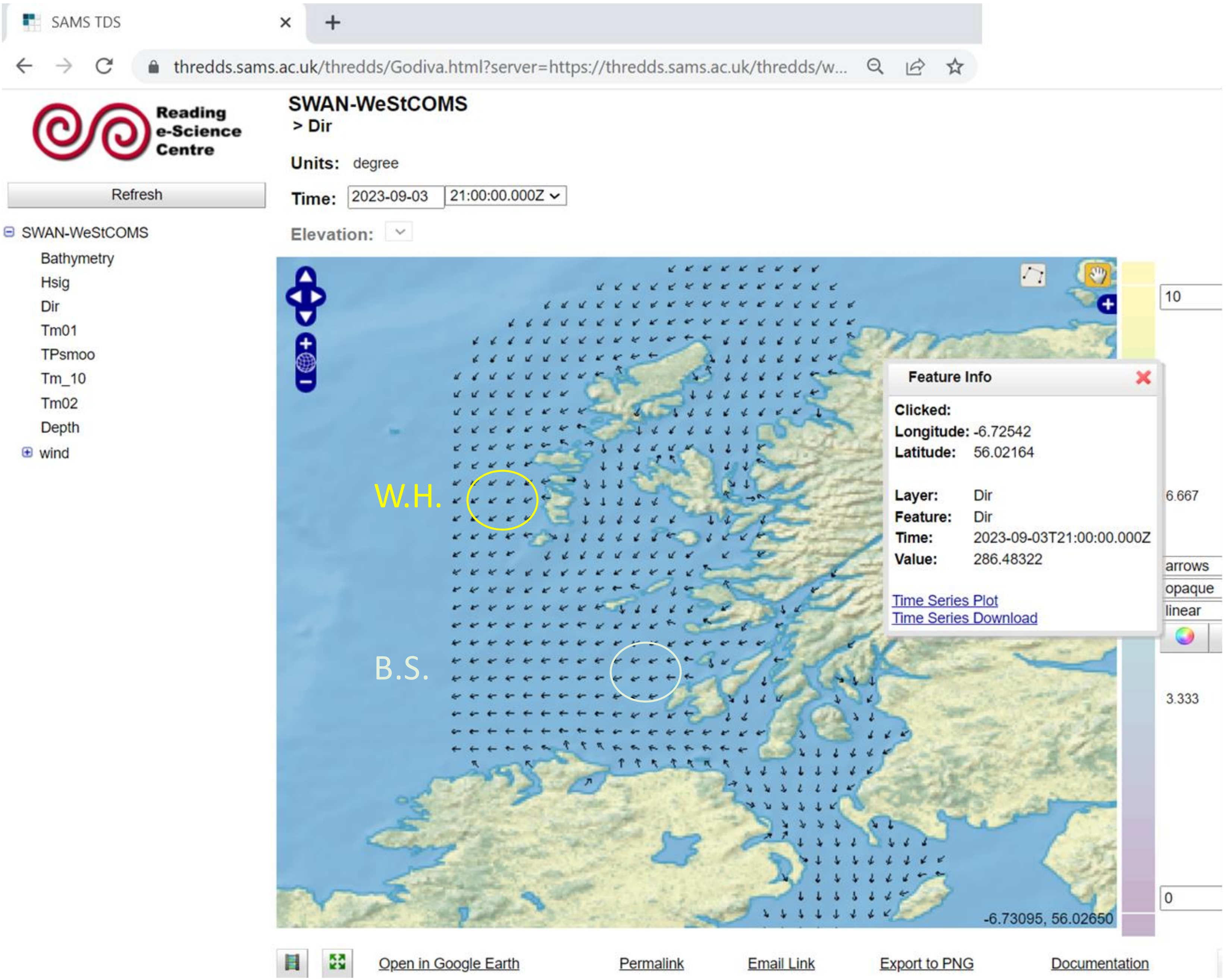
Typical model sea-surface salinity distribution on High and Low tidal phases with **easterlies** and **westerlies** prevailing winds (magenta arrows, m·s^{-1}) in Firth of Lorn

WeStCOMS-SWAN

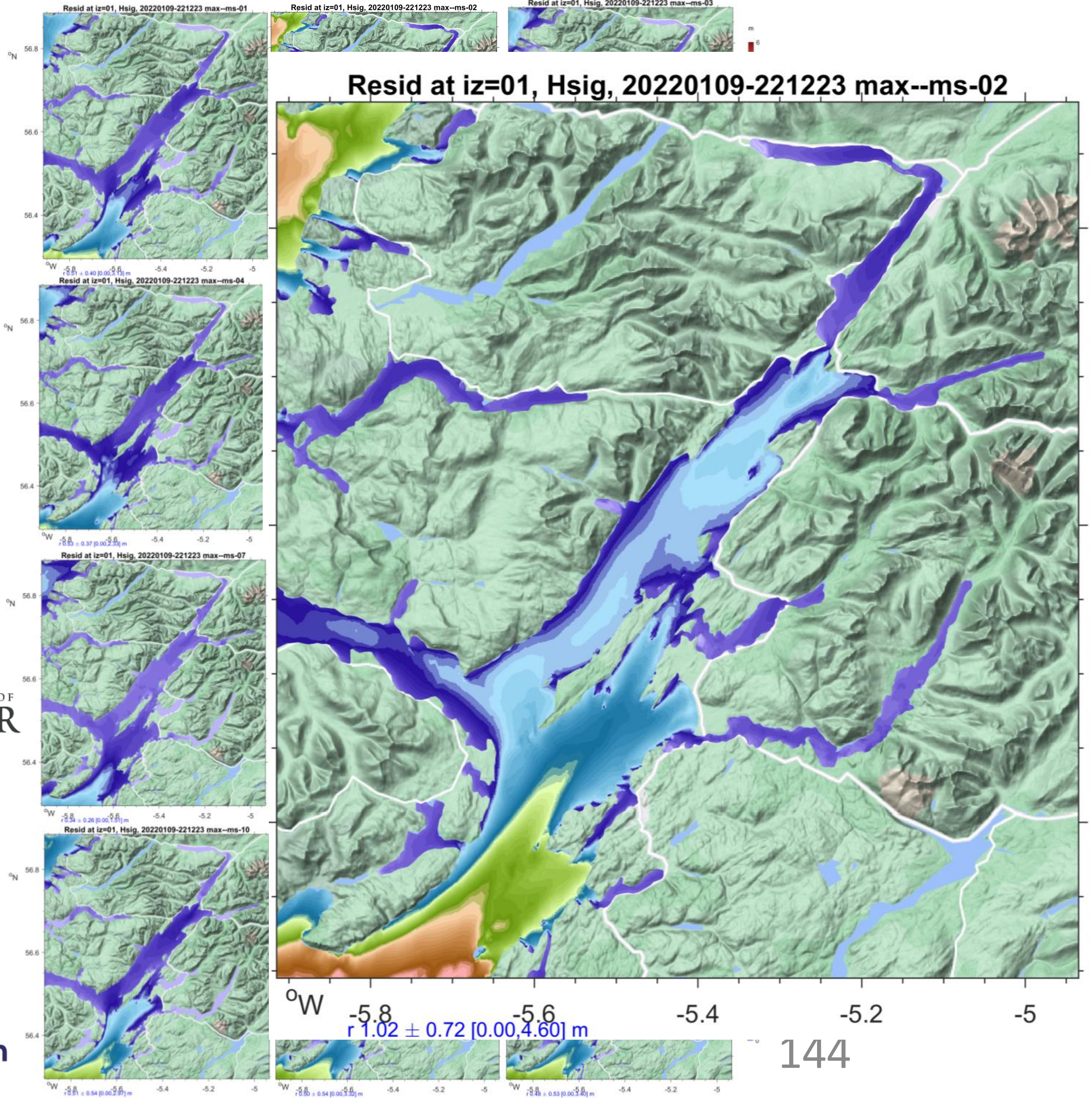
-- wavenet.cefas.co.uk



SWAN WAVES Forecast at THREDDS server



Significant Wave Height (H_{sig}, m) maximum Monthly/seasonal spatial distribution in 2022



OFF AQUA

UNIVERSITY OF EXETER

GCRF Global Challenges Research Fund

gcrf global seaweed

UKRI UK Research and Innovation

Flushing Larvae

WLLSshuna

RiCOM 3D modified WLLS mesh 10 σ-layers, horizontal spacing varies (25 m to 6 km). At the open boundary (OBC) it is forced by 8 *tidal* constituents (O1, K1, Q1, P1, M2, S2, N2, K2) obtained from the full Scottish Shelf Model (SSM). *River* flows were taken from the Grid2Grid climatological set, and *Wind stress* from ECMWF ERA5

WeStCOMS

WeStCOMS v2 (FVCOM v4.4.1) mesh 10 tanh σ-layers; horizontal spacing varies (80 m to 2.5 km). At the OBC it is driven by SSH elevation predicted with 11 *tidal* constituents (M2, S2, N2, K2, K1, O1, P1, Q1, M4, MS4, MN4) using OSU inverse solver (TMD2, ES2008). *River* catchment outflow and *wind* stress were derived from operational hindcast runs of the localized atmospheric model WeStCOMS-WRF (v4.2, **2 km**) at HPC in SAMS.

WLLS 2021 *hindcast*

The Wider Loch Linnhe System (WLLS) FVCOM mesh with 2+(6)+2 fixed+(equally) spaced σ-layers, horizontal spacing varies (15 m to 5 km). At OBC it is forced by 8 *tidal* constituents (O1, K1, Q1, P1, M2, S2, N2, K2) obtained from the SSM. *River* flow represents averaged *climatology* Grid2Grid. *Wind* stress for the 2021 *hindcast* run was derived from ECMWF ERA5 (**31 km**)

WLLS *Climatology*

The Wider Loch Linnhe System (WLLS) FVCOM mesh with 2+(6)+2 fixed+(equally) spaced σ-layers, horizontal spacing varies (15 m to 5 km). At OBC it is forced by 8 *tidal* constituents (O1, K1, Q1, P1, M2, S2, N2, K2) obtained from the SSM. *River* flow represents averaged *climatology* Grid2Grid. *Wind* stress represents *annual climatology* averaged over 1994-2014 derived from ECMWF ERA5.

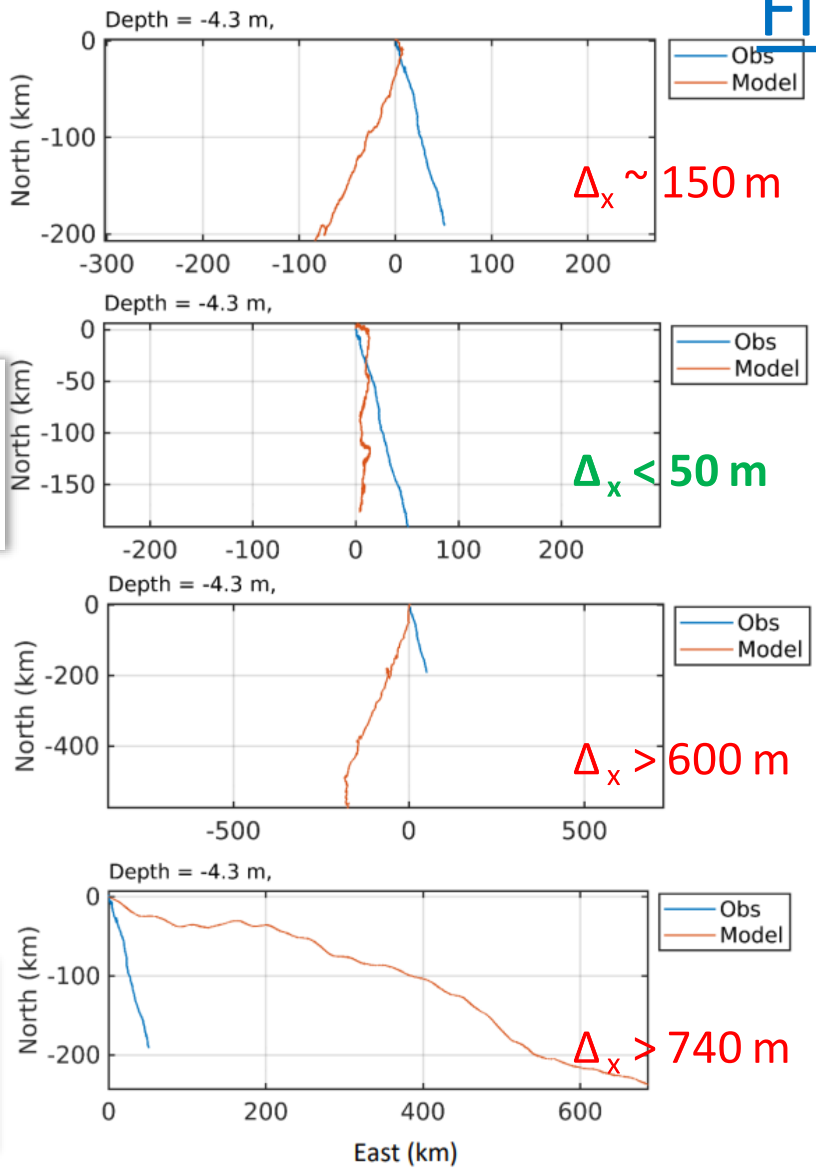


Figure 2.2. Cumulative vector plots of observed and modelled velocity in the near-surface layer from four hydrodynamic models: WLLSshuna (top); WeStCOMS (upper middle); WLLS 2021 (lower middle); WLLS Climatology (bottom). The observations are from the topmost valid ADCP cell; the modelled velocities have been interpolated in the vertical to the same depth.

Cumulative vector plots of **modelled** and **observed** **velocity** in the near-surface layer.

The *observations* are from the topmost valid **ADCP** cell, *15 days*

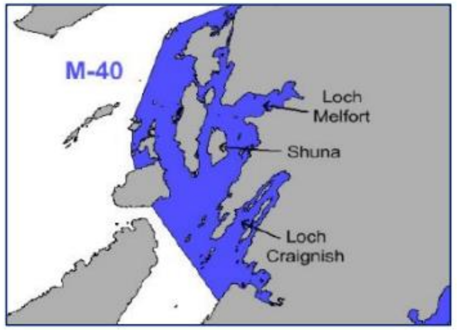


Figure 1.1: Study area at the Sound of Shuna, on the west c

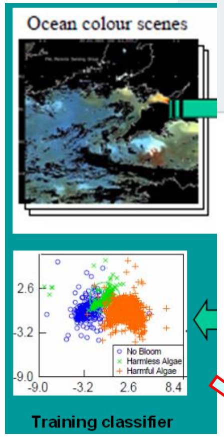
Courtesy: P. G.

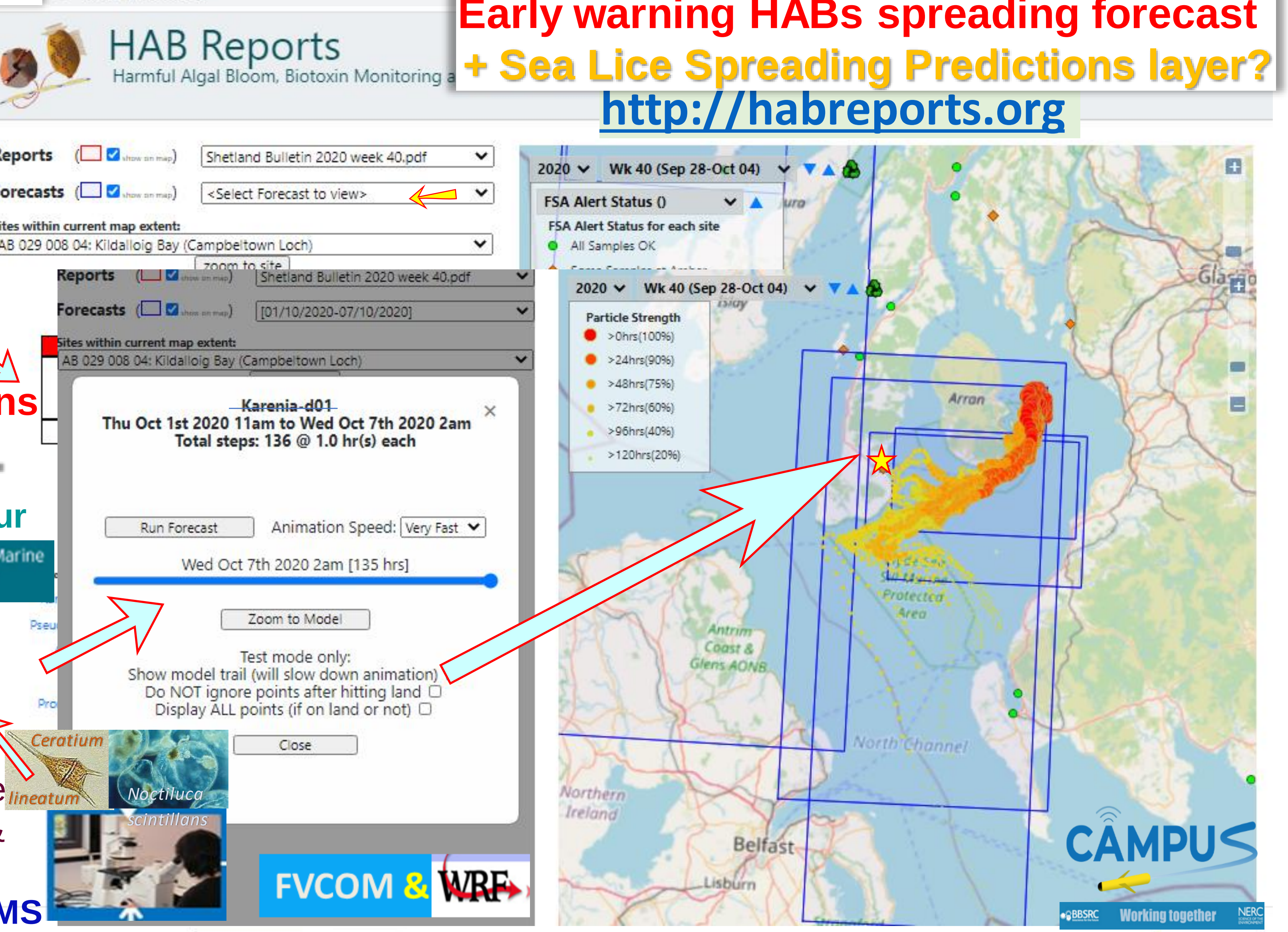
Platform for Applications:

Early warning HABs spreading forecast

+ Sea Lice Spreading Predictions layer?

http://habreports.org





Notifications

- 1&2 -

Ocean-colour

PML Plymouth Marine Laboratory

& Food Standard Agency -

Scottish Aquaculture Sampling & Monitoring Program@**SAMS**

COMPASS Collaborative Oceanography and Monitoring for Protected Areas and Species

Interreg Northern Ireland - Ireland - Scotland

The COMPASS Project is supported by the European Union's INTERREG Programme managed by the Special EU Programmes Body (SEUPB)

Food Standards Scotland

European Union

The Scottish Government

Cefas

BBSRC bioscience for the future

NERC Science of the Environment

marine scotland science

Toxin concentrations provided courtesy of the Centre for Environment, Fisheries and Aquaculture Science

S U M M A R Y

1. Operational WeStCOMS Run Schedule

- Hindcast weekly (Thu)
- Two forecasts a week (Tue, Fri)

2. Easy to add Sea Lice spreading forecasts to the existing system

To address the uncertainty/skills assessment with different approaches, i.e.

- Lice counts acquisition
- Various trigger algorithms to initiate prediction runs
- Multiple model ensemble runs
- Alternative parameterisations

3. End-User – friendly interface

To benefit key Stakeholders: Industry, Regulator bodies, NGOs and Academia via:

- SAMS *visualisation* platform http://habreports.org
- Professional modelling *data sharing* at https://thredds.sams.ac.uk/thredds/catalog/SCOATS.html

SAMS SAMS

Harmful Algae 53 (2016) 102–117
Contents lists available at ScienceDirect
Harmful Algae
journal homepage: www.elsevier.com/locate/hal

A high resolution hydrodynamic model system suitable for novel harmful algal bloom modelling in areas of complex coastline and topography DOI:10.1016/j.hal.2015.11.012

Dmitry Aleynik[1,*], Andrew C. Dale[1], Marie Porter[1], Keith Davidson[1]

Applied Ecology and Environmental Management
GLOBAL BLUE ECONOMY
Analysis, Developments, and Challenges
Edited by
Md. Nazrul Islam
Steven M. Bartell
CRC Press

3 Optimizing the Connectivity of Salmon Farms

Role of Exposure to Wind, Tides, and Isolation

Dmitry Aleynik,[1]* Thomas Adams,[1,2] and Keith Davidson[1]

Pp.61-86 in: Global Blue Economy: Analysis, Developments, and Challenges (1st ed.). Eds.: Islam, M.N., Bartell, S.M. CRC Press, P.488. https://doi.org/10.1201/9781003184287-3

frontiers in Marine Science
ORIGINAL RESEARCH
published: 09 April 2021
doi: 10.3389/fmars.2021.631732
DOI:10.3389/fmars.2021.631732

HABreports: Online Early Warning of Harmful Algal and Biotoxin Risk for the Scottish Shellfish and Finfish Aquaculture Industries

Keith Davidson[1]*, Callum Whyte[1], Dmitry Aleynik[1], Andrew Dale[1], Steven Gontarek[1], Andrey A. Kurekin[2], Sharon McNeill[1], Peter I. Miller[2], Marie Porter[1], Rachel Saxon[1] and Sarah Swan[1]
[1] Scottish Association for Marine Science, Oban, United Kingdom, [2] Plymouth Marine Laboratory, Plymouth, United Kingdom

Environmental Management of Marine Ecosystems
Edited by
Md. Nazrul Islam
Sven Erik Jørgensen
CRC Press

www.nature.com/scientificreports
(2022) 12:16613 | DOI:10.1038/s41598-022-20254-z
scientific reports

OPEN Benthic animal-borne sensors and citizen science combine to validate ocean modelling

Edward Lavender[1,2], Dmitry Aleynik[3], Jane Dodd[4], Janine Illian[5], Mark James[2], Sophie Smout[1,2,7] & James Thorburn[2,6,7]

TYPE Original Research
PUBLISHED 12 September 2022
DOI 10.3389/fmars.2022.985748
DOI:10.3389/fmars.2022.985748
frontiers | Frontiers in Marine Science

Predictive biophysical models of bivalve larvae dispersal in Scotland

Ana Corrochano-Fraile[1], Thomas P. Adams[2,3], Dmitry Aleynik[3], Michaël Bekaert[1*] and Stefano Carboni[1,4]
[1] Institute of Aquaculture, University of Stirling, Stirling, United Kingdom, [2] Scottish Sea Farms Limited, Barcaldine Hatchery, Argyll, United Kingdom, [3] Scottish Association for Marine Science, Oban, United Kingdom, [4] Fondazione IMC, Torre Grande, Italy

thredds.sams.ac.uk/thredds/catalog/scoats-westcoms2/Archive_forecast/netcdf_2022F/R2022050...

SAMS TDS 2013 - 2022 SAMS Scottish Association for Marine Science

return to catalog

Dataset: westcoms2_20220506_R20220503_0004.nc
Catalog: https://thredds.sams.ac.uk/thredds/catalog/scoats-westcoms2/Archive_forecast/netcdf_2022F/R20220503/catalog.html

dataSize	1129258522
id	model-westcoms2/Archive_forecast/netcdf_2022F/R20220503/westcoms2_20220506_R20220503_0004.nc

Access Preview

Access:

Service	Type	Description
OpenDAP	Data Access	Access dataset through OPeNDAP using the DAP2 protcol.
DAP4	Data Access	Access dataset through OPeNDAP using the DAP4 protocol.
HTTPServer	Data Access	HTTP file download.
NCML	Metadata	Provide NCML representation of a dataset.

TYPE Original Research
PUBLISHED 03 October 2022
DOI 10.3389/fenvs.2022.940892
DOI:10.3389/fenvs.2022.940892
frontiers | Frontiers in Environmental Science

Simulating the distribution of beached litter on the northwest coast of Scotland

Nicole L. Allison[1]*, Andrew Dale[1], William R. Turrell[2], Dmitry Aleynik[1] and Bhavani E. Narayanaswamy[1]
[1] Scottish Association for Marine Science, Scottish Marine Institute, Oban, United Kingdom, [2] Marine Scotland Science, Aberdeen, United Kingdom