Numerical modelling of the dispersion of wastes, medication and salmon lice (*Lepeophtheirus salmonis* Kroyer) from the proposed MHI Shot Head site, in Bantry Bay.

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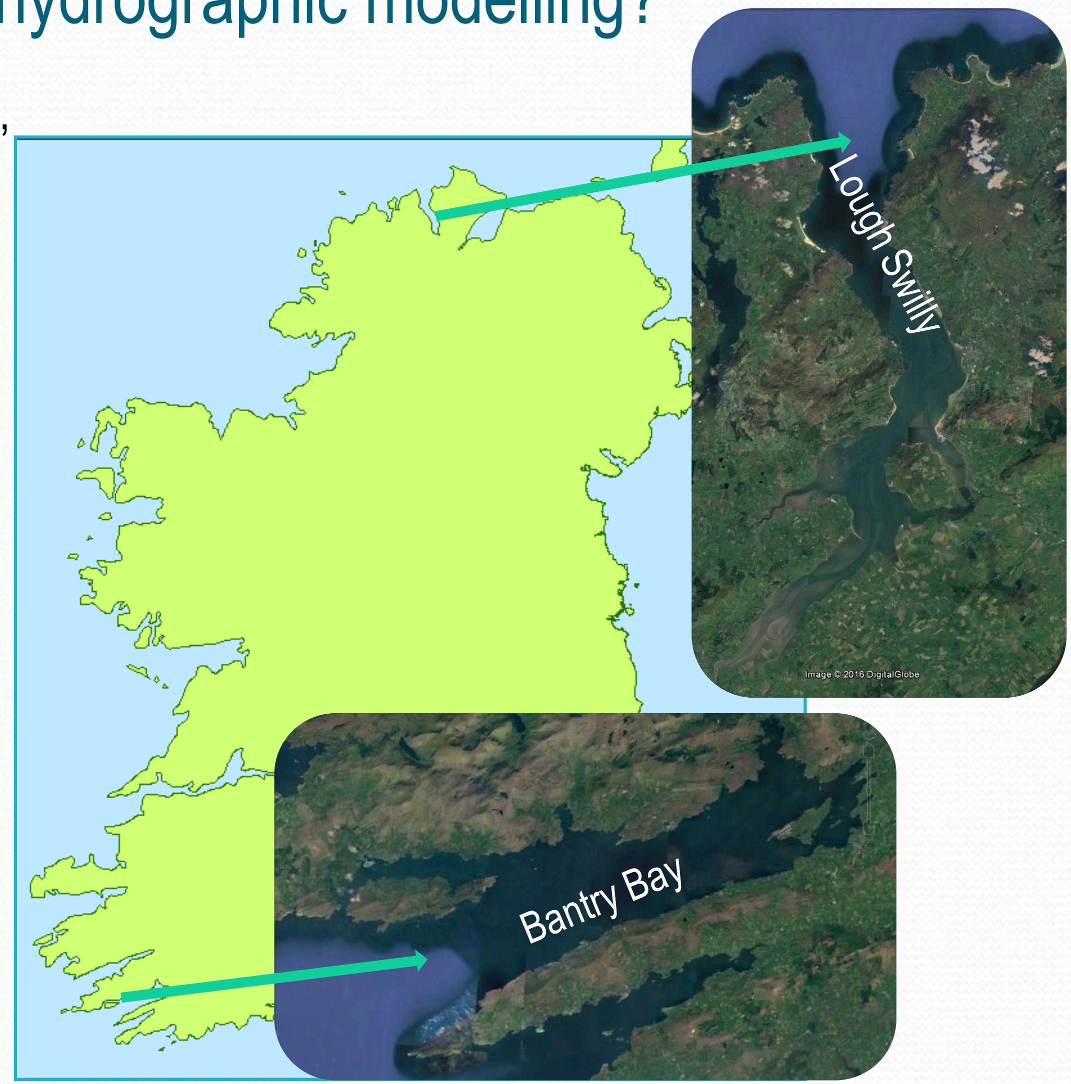
Why did MHI commission Watermark and RPS to investigate hydrographic modelling?

- To provide objective, numerical projections, of farm conditions and the fate of fish farm wastes and discharges, in response to increasing Irish and EU regulation.
- To inform Environmental Impact Statements (EIS).
- To help select sites for new licence applications.
- To inform salmon farm structural specifications, for certification.
- Modelling is conducted on hydrography (tides and currents), wave climate, dispersal and impacts of soluble and solid metabolic wastes, solids settlement, medication and salmon lice.
- So far two embayments have been fully investigated; two more are in process.

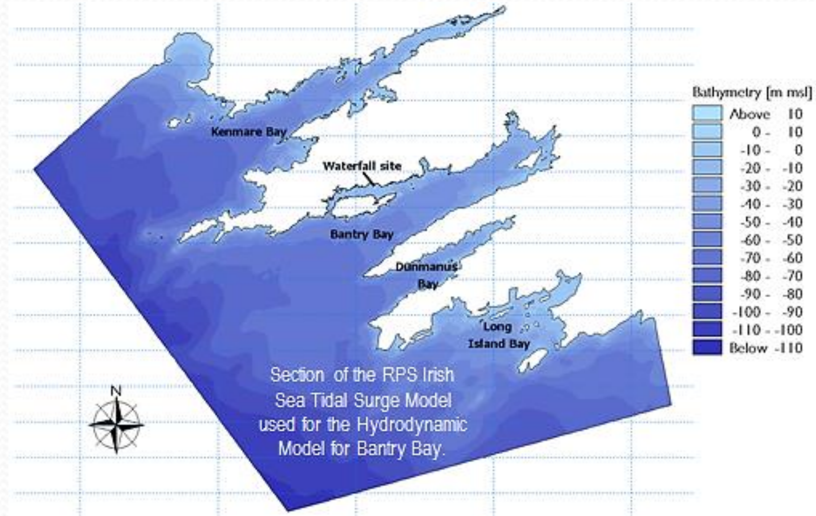


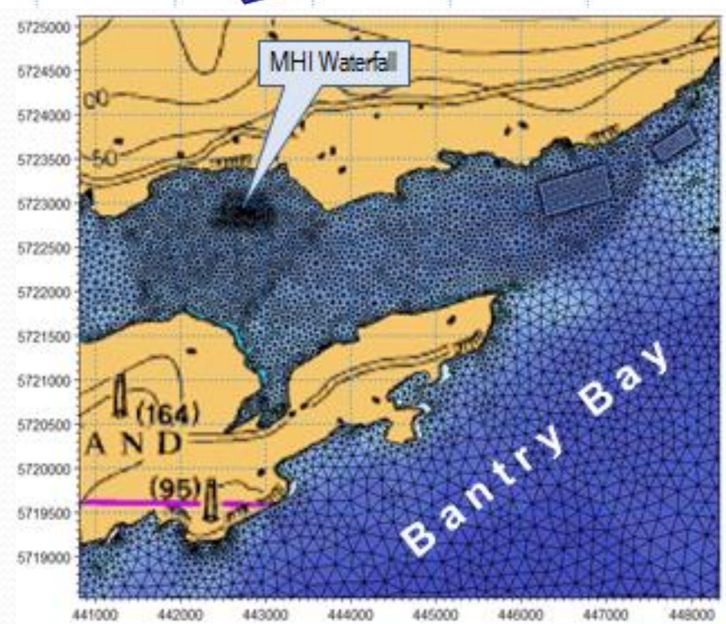
How do models work and what can they do?

- Modelling systems for coastal and estuarine environments are complex mathematical models that have been developed and tested over many years to reflect natural conditions as accurately as possible.
- For MHI modelling, RPS uses the MIKE suite of hydrodynamic modules, developed by the Danish Hydrographic Institute (DHI). MIKE is a global standard, used internationally for many environmental, planning, engineering and predictive applications.
- The latest version of MIKE, MIKE 21/3 Coupled Model FM, was used for MHI's models.
- This has many separate, coupleable modules, including the Hydrodynamic, Transport, Particle Tracking and Spectral Wave modules.
- MIKE's basic computational component is the Hydrodynamic Module, which predicts the behaviour of tides and currents. Each model is calibrated against actual data and can be "dynamically coupled" to any other module/s as required to "drive" their functions. For example, with the Spectral Wave Module, it is used to model the interaction between currents and waves to predict wave climate and with the Particle Tracking Module, it is used to model the dispersal of discharges from salmon farm sites.

The RPS Hydrodynamic model of Bantry Bay #1.

- The DHI MIKE 21/3 Coupled Model FM software was used to generate the hydrodynamic model for Bantry Bay:-
  - The model was taken from a section of the new RPS Irish Sea Tidal Surge Model, which uses flexible mesh technology.
  - This gives much higher resolution than earlier fixed-mesh models, because the mesh size can be changed to give greater modelling accuracy where required, for example around fish farm sites.
- Model calibration
  - The base model was calibrated against many global and local tidal, bathymetric and hydrographic datasets High resolution local bathymetric data, collected for MHI at the Shot Head and Waterfall sites, was also included.
  - The Bantry Bay hydrodynamic model was calibrated against 15 sets of multiple-depth current data collected around the bay.
- Application
  - The hydrodynamic models generated were then used to drive a range of dispersional models.





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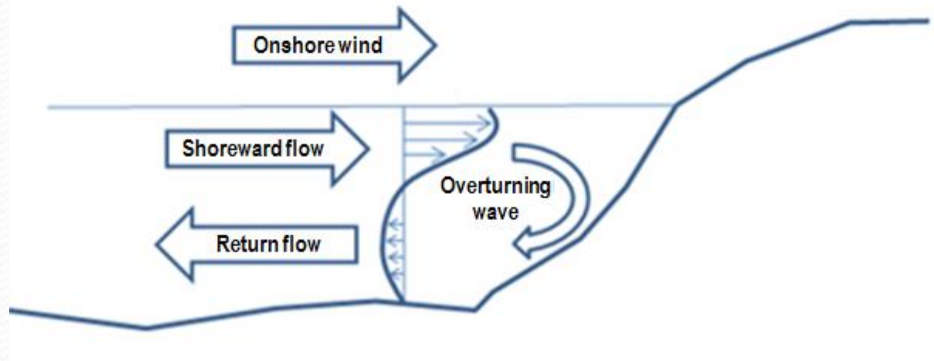
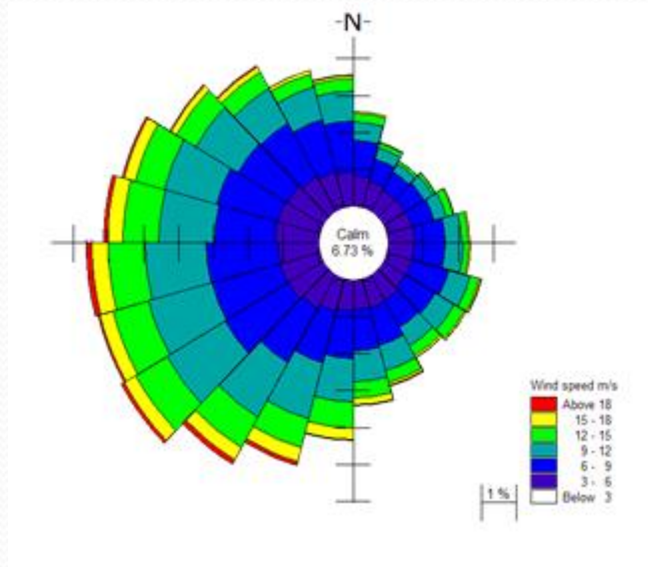
The RPS Hydrodynamic flow model of Bantry Bay #2. Forcing factors.

- Forcing factors drive hydrodynamic flow and therefore influence dispersion. Here are a selection:-

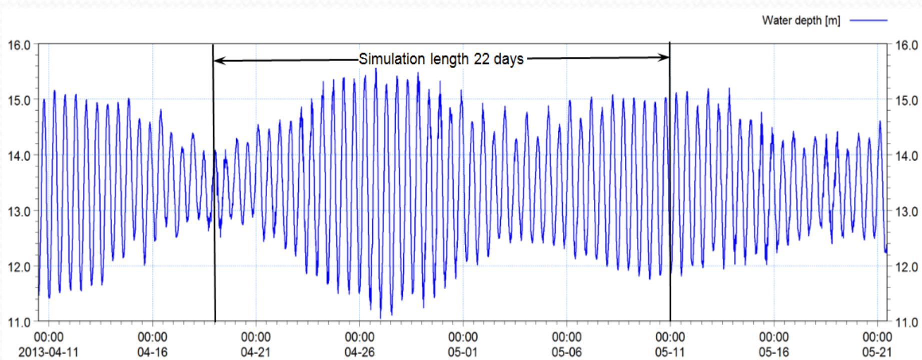
1. **Tides**; Tidal amplitude is high in Bantry Bay (max 4.5m from high water to low water) but the outer bay is deep. This and other conditions limit tidally-driven currents in the bay to <10cm/sec.
2. **Wind interaction**; a big factor in Bantry Bay, which is open to prevailing wind direction. Worst case wind force and direction considered in the wind / wave model. Both increase dispersion including inshore, as a result of the onshore overturning wave current profile.
3. **Freshwater**; not an issue in Bantry Bay since seawater flux >>> freshwater inputs, giving oceanic conditions.
4. **Stratification**; does not apply in Bantry Bay which is fully mixed, with additional mixing in sustained high winds.
5. **NB** : specific to each embayment



Wind-induced onshore current profile.



Offshore wind climate at the mouth of Bantry Bay.



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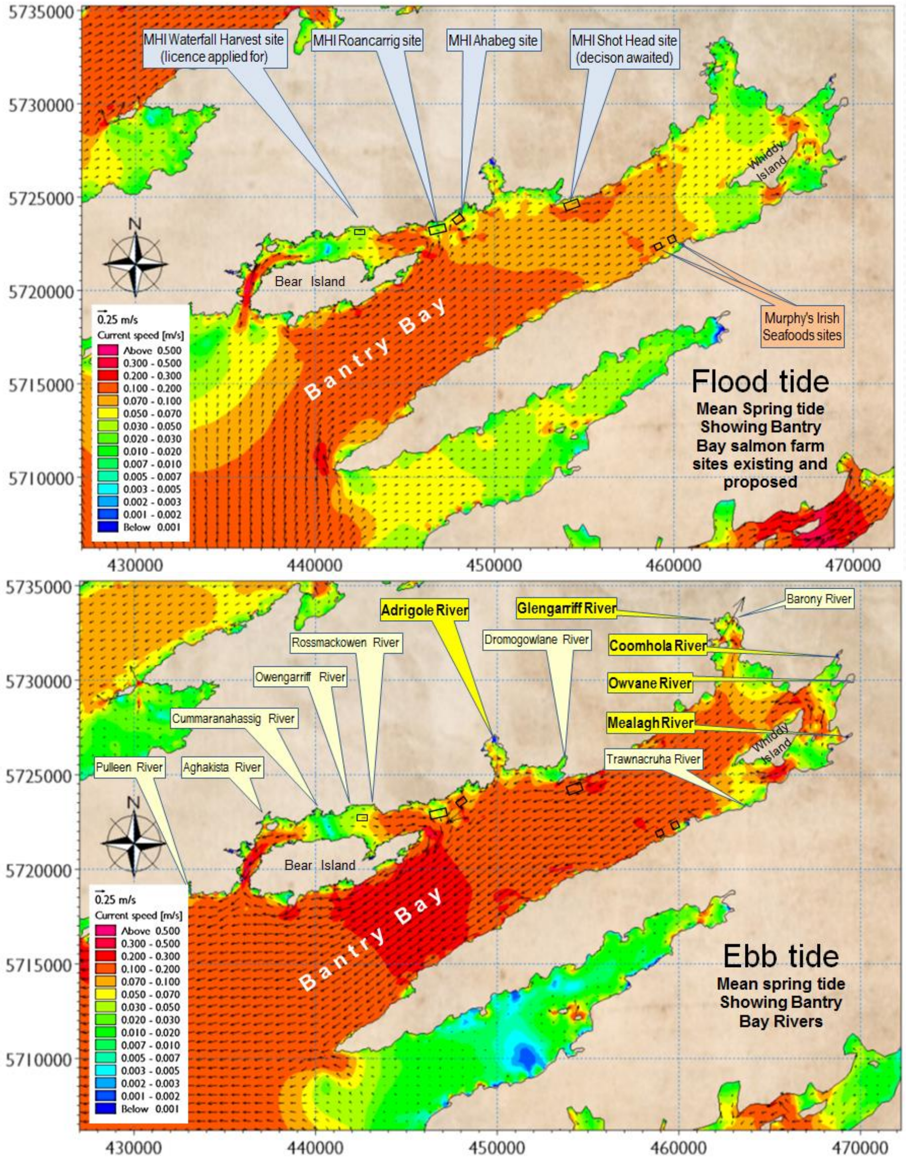
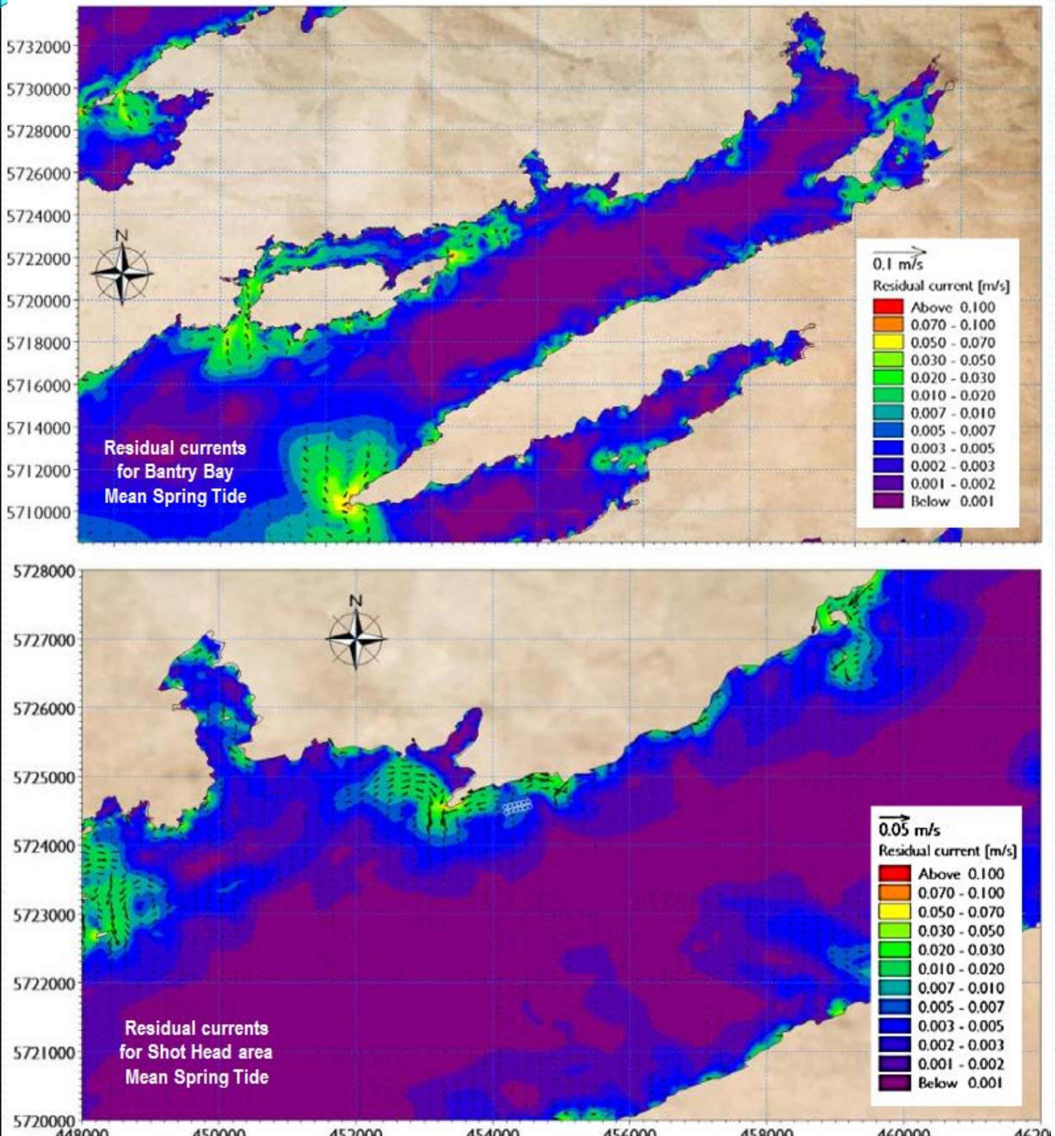
The RPS Hydrodynamic flow model of Bantry Bay #3. Tidal currents.



- The hydrodynamic model simulates the tidal flow at every mesh grid point, every 10 seconds, over 22 days, in order to include both neap and spring tidal current conditions. Each 22-day model generated for Bantry Bay has >8.5 billion datapoints.
- The figures here also show all existing and proposed salmon farm sites and the rivers around the bay. National Salmon Rivers are highlighted in yellow. Note that all of these except the River Adrigole are fully open for angling. The Adrigole is currently open for catch and release angling only.
- Tidal flow is complicated by the presence of Bear and Whiddy Islands, where the tide floods and ebbs from both ends of their inshore channels, leaving neutral current zones in their lee.
- The plots confirm the long-known complexity of tidal flow in Bantry Bay. A tidal convergence just outside the bay is a factor in limiting the bay's tidal currents to less than 10cm sec^{-1}.

The RPS Hydrodynamic flow model of Bantry Bay #4. Residual currents and flushing.



- Residual currents result from the differences in the vectoral components of flood and ebb currents over the tidal cycle.
- The figures show that residual currents are relatively low in the main body of Bantry Bay but they increase around islands and promontories where salmon farms happen to be situated.
- Residual currents reduce solids accumulation and encourage the carriage of both solid and soluble wastes away from these areas.
- Water flushes in and out of Bantry Bay at a mean rate of some 27 billion tonnes pm, resulting in a tidal flushing time of between 8 days on spring tides and 18 days on neap tides.
- Even on a neap tide, this is roughly equivalent in weight (320M tonnes) to the world's population walking in and out of the bay on every tide.
- Taken overall, flushing carries dispersing wastes out of the bay and into the Atlantic in a slow, counter-clockwise circulation.

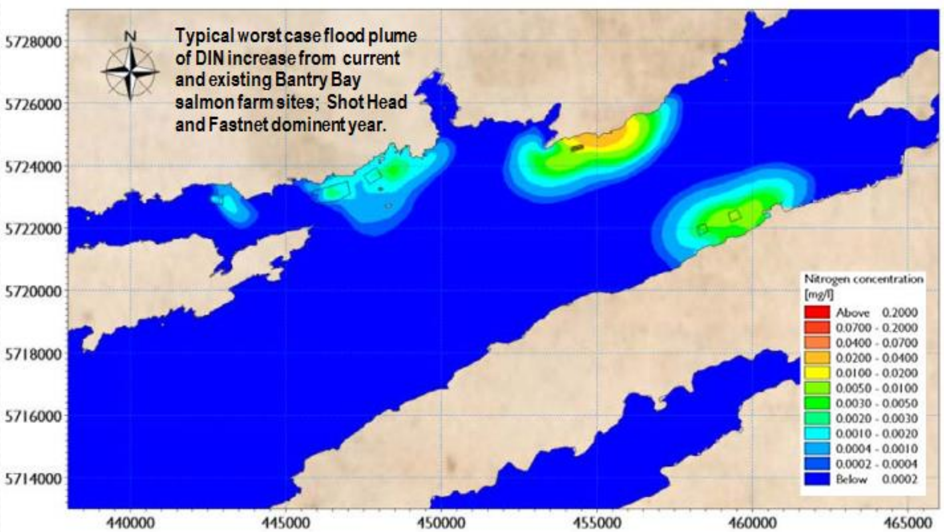
The RPS Hydrodynamic flow model of Bantry Bay #5. Conclusions

1. Modelling systems for marine, coastal and estuarine environments are complex mathematical models that have been developed and tested over many years to reflect natural conditions as accurately as possible.
2. The multinational engineering consultancy RPS Group and Watermark aqua-environmental were commissioned by Marine Harvest Ireland to investigate the hydrography of Bantry Bay, using the latest version of DHI's MIKE software, MIKE 21/3 Coupled Model FM, a global standard.
3. MIKE's Hydrodynamic (HD) Module predicts the behaviour of tides and currents. This was used to generate the MHI Bantry Bay HD model, which is calibrated against a wide range of global and local empirical data.
4. Hydrodynamic flow is driven by a range of forcing factors which are built into the model. In the case of Bantry Bay, the main forcing factors are tides and wind interaction.
5. Tidal flow in Bantry Bay is complicated by the presence of Bear and Whiddy Islands. This and the convergence of tides just outside the bay tends to limit tidal currents within the bay to less than 0.1m sec^{-1}.
6. Residual currents are highest around islands and promontories, some near fish farm sites These reduce solids accumulation and encourage the carriage of both solid and soluble wastes away from these sites.
7. Bantry Bay is flushed by roughly 27 billion tonnes of water per month. This huge volume of water dilutes and flushes wastes out of the bay and into the Atlantic in a slow, counter-clockwise circulation and maintains bay conditions well within its carrying capacity.
8. The RPS HD Model was used to drive dispersional models, to project the impacts of wastes from all existing and proposed Bantry Bay salmon farm sites on water and sediment quality
9. The model was also used to investigate the complex interrelationships involved in wild- and farm-origin lice dispersal in the bay.

Water quality modelling for Bantry Bay #1.
Soluble Nutrients and BOD modelling; methods.

- Dispersional models, driven by the RPS Hydrodynamic Model, were used to show the impacts of wastes from all existing and proposed Bantry Bay salmon farm sites on water quality .
- Standard pollution indicators for soluble and settleable solids wastes, including Dissolved Inorganic Nitrogen and Phosphorus (DIN and DIP) and Biological Oxygen Demand (BOD), which all arise from the metabolism of salmon feed, as well as discharge and dispersal of medications (where used) and lice, were all modelled.

Month	Nitrogen discharge N Tonnes / month											
	Shot Head			Fastnet			Roancarrig			Waterfall		
	Total	Settleable	Soluble	Total	Settleable	Soluble	Total	Settleable	Soluble	Total	Settleable	Soluble
Sep	Fallow site			Fallow site			9.65	0.89	8.76	0.13	0.01	0.11
Oct							11.58	1.07	10.51	0.13	0.01	0.11
Nov	0.72	0.09	0.64	0.18	0.02	0.16	12.69	1.17	11.52	0.13	0.01	0.11
Dec	1.14	0.14	1	0.29	0.03	0.25	14.15	1.31	12.84	0.13	0.01	0.11
Jan	1.66	0.22	1.45	0.42	0.05	0.36	15.26	1.41	13.85	0.13	0.01	0.11
Feb	2.68	0.35	2.32	0.67	0.09	0.58	13.84	1.28	12.56	0.13	0.01	0.11
Mar	4	0.53	3.48	1	0.13	0.87	13.42	1.24	12.18	0.13	0.01	0.11
Apr	5.18	0.68	4.49	1.29	0.17	1.12	9.15	0.85	8.31	0.13	0.01	0.11
May	6.15	0.86	5.29	1.54	0.22	1.32	4.85	0.45	4.4	Fallow site		
Jun	7.91	1.11	6.8	1.98	0.28	1.7	1.98	0.18	1.79			
Jul	9.37	1.32	8.06	2.34	0.33	2.01	1.25	0.12	1.13	0.13	0.01	0.11
Aug	8.48	0.78	7.69	2.12	0.2	1.92	0.18	0.02	0.16	0.13	0.01	0.11
Sep	9.65	0.89	8.76	2.41	0.22	2.19	Fallow site			0.13	0.01	0.11
Oct	11.58	1.07	10.51	2.89	0.27	2.63				0.13	0.01	0.11
Nov	12.69	1.17	11.52	3.17	0.29	2.88	0.72	0.09	0.64	0.13	0.01	0.11
Dec	14.15	1.31	12.84	3.54	0.33	3.21	1.14	0.14	1	0.13	0.01	0.11
Jan	15.26	1.41	13.85	3.82	0.35	3.46	1.66	0.22	1.45	0.13	0.01	0.11
Feb	13.84	1.28	12.56	3.46	0.32	3.14	2.68	0.35	2.32	0.13	0.01	0.11
Mar	13.42	1.24	12.18	3.36	0.31	3.05	4	0.53	3.48	0.13	0.01	0.11
Apr	9.15	0.85	8.31	2.29	0.21	2.08	5.18	0.68	4.49	0.13	0.01	0.11
May	4.85	0.45	4.4	1.21	0.11	1.1	6.15	0.86	5.29	Fallow site		
Jun	1.98	0.18	1.79	0.49	0.05	0.45	7.91	1.11	6.8			
Jul	1.25	0.12	1.13	0.31	0.03	0.28	9.37	1.32	8.06	0.13	0.01	0.11
Aug	0.18	0.02	0.16	0.04	0	0.04	8.48	0.78	7.69	0.13	0.01	0.11
Sep	Fallow site			Fallow site			9.65	0.89	8.76	0.13	0.01	0.11
Oct							11.58	1.07	10.51	0.13	0.01	0.11
Nov	0.72	0.09	0.64	0.18	0.02	0.16	12.69	1.17	11.52	0.13	0.01	0.11



- For metabolic wastes, base discharge data for modelling was calculated by standard means from salmon growth and feed data. Always, only worst case discharge conditions are modelled; see the example above for DIN.
- Discharges are graphed as contoured plumes of the increase over ambient concentration for each indicator.
- Where available, Environmental Quality Standards (EQS) are used as the best means to assess model outcomes.

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Water quality modelling for Bantry Bay #2.
Soluble Nutrients and BOD modelling; results.

- Results on basis of worst-case inputs only:-
  1. Only worst case monthly discharges are considered (the monthly average is < 35% of this value).
  2. In the case of nutrients, total discharge (i.e. soluble + settleable values) is modelled as soluble discharge.
  3. All wastes are discharged from point sources at each pen centre, not from actual diffuse sources within site.
  4. No decay or assimilation, which occurs naturally all the time, is built into metabolic waste dispersion models.
  5. Discharges are double-accounted for in the models for existing sites (e.g. Roancarrig), which are already contributing to ambient conditions.

- Plume graphs show the elevation to the ambient concentration that would be caused by each discharge. To check for an EQS breach, the worst case ambient concentration for each parameter is added to the dispersal result. As an example, control site Ambient DIN data and the EQS for winter DIN concentration of 168µgN/l are used. Taking a peak winter ambient DIN of say 100µgN/l and a discharge range of 0.2µgN/l (open waters) to 40.0µgN/l (peak at site centre), clearly the EQS is not breached even at site centre (very worst case). The same applies to other EQS's.

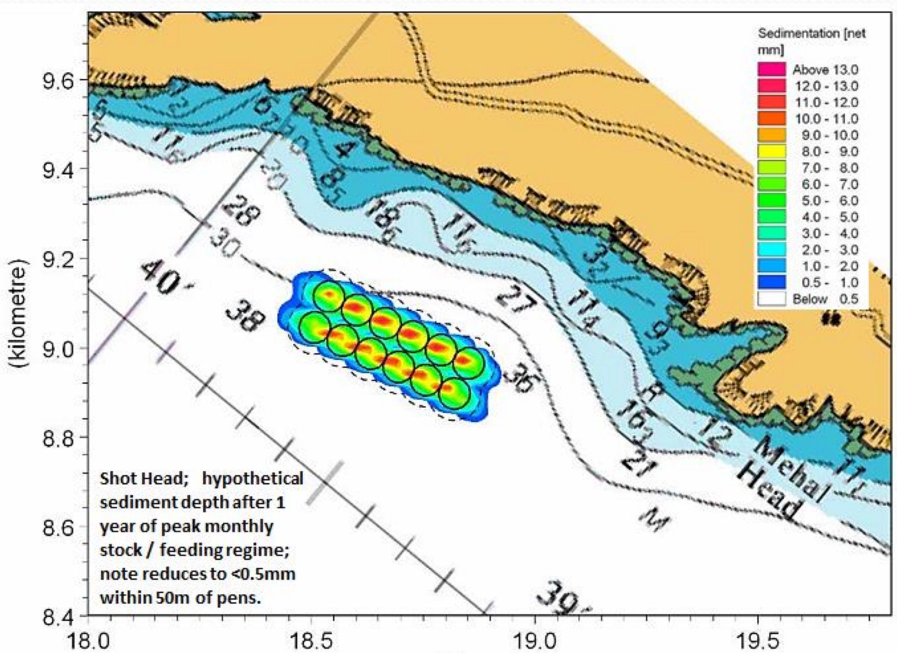
Month	Inorganic N Monthly Mean Ambient Concentration	
	Lambs Head control site	Boatyard control site
	N µg/l	N µg/l
Jan	88.0	125.11
Feb	63.0	114.87
Mar	96.0	84.08
Apr	40.5	53.95
May	10.3	6.49
Jun	4.7	3.22
Jul	16.6	1.59
Aug	3.8	2.43
Sep	23.1	19.83
Oct	37.7	38.13
Nov	72.9	76.14
Dec	80.0	93.29

- Conclusions re solute dispersal:-
  1. No value, for DIN, DIP or DO depletion by BOD breaches an EQS or standard, even at the worst case modelled. There is still more than adequate "headroom" available in the bay before there could be environmental consequences from such discharges.
  2. In all cases, wastes disperse and dilute rapidly with distance from the sites and there is no cumulative interaction between discharges from different sites
  3. Even in the worst cases modelled, there is no indication of elevation in concentrations towards the head of the bay, or into Trafrask Bay, where water nutrient levels can be expected to remain within their existing seasonal ambient concentration ranges.

Water quality modelling for Bantry Bay #3.
Solids settlement and dispersal.

- As for solutes, models run on worst-case basis only:-
  1. Only cycle peak monthly values for feed and faecal solids wastes are considered
  2. All wastes are discharged from point sources at each pen centre, not from actual diffuse sources within site.
  3. No decay, grazing or bioturbation by seabed organisms (which happens naturally all the time) is accounted for.
  4. Wave-dominated resuspension, which occurs for 40% of the time in Bantry Bay is not accounted for in the models.
- Even after a hypothetical one year of worst-case deposition every month, sediment depth will still only be <13mm under pens and <0.5mm within 50m of pens.

Month	Settleable Solids Tonnes / month							
	Shot Head		Fastnet		Roancarrig		Waterfall	
	Feed waste	Faecal waste	Feed waste	Faecal waste	Feed waste	Faecal waste	Feed waste	Faecal waste
Sep	Fallow site		Fallow site		7.93	41.52	0.1	0.54
Oct					9.52	49.8	0.1	0.54
Nov	0.53	2.86	0.13	0.72	10.43	54.57	0.1	0.54
Dec	0.84	4.5	0.21	1.13	11.63	60.86	0.1	0.54
Jan	1.27	7.04	0.32	1.76	12.55	65.65	0.1	0.54
Feb	1.89	10.49	0.47	2.62	11.38	59.52	0.1	0.54
Mar	2.66	14.77	0.66	3.69	11.03	57.73	0.1	0.54
Apr	3.44	19.09	0.86	4.77	7.52	39.37	0.1	0.54
May	4.35	24.77	1.09	6.19	3.99	20.86	Fallow site	
Jun	5.52	31.43	1.38	7.86	1.62	8.5		
Jul	6.48	36.86	1.62	9.22	1.02	5.36	0.1	0.54
Aug	6.97	36.45	1.74	9.11	0.14	0.75	0.1	0.54
Sep	7.93	41.52	1.98	10.38	Fallow site		0.1	0.54
Oct	9.52	49.8	2.38	12.45			0.1	0.54
Nov	10.43	54.57	2.61	13.64	0.53	2.86	0.1	0.54
Dec	11.63	60.86	2.91	15.21	0.84	4.5	0.1	0.54
Jan	12.55	65.65	3.14	16.41	1.27	7.04	0.1	0.54
Feb	11.38	59.52	2.84	14.88	1.89	10.49	0.1	0.54
Mar	11.03	57.73	2.76	14.43	2.66	14.77	0.1	0.54
Apr	7.52	39.37	1.88	9.84	3.44	19.09	0.1	0.54
May	3.99	20.86	1	5.22	4.35	24.77	Fallow site	
Jun	1.62	8.5	0.41	2.12	5.52	31.43		
Jul	1.02	5.36	0.26	1.34	6.48	36.86	0.1	0.54
Aug	0.14	0.75	0.04	0.19	6.97	36.45	0.1	0.54
Sep	Fallow site		Fallow site		7.93	41.52	0.1	0.54
Oct					9.52	49.8	0.1	0.54



- Conclusions re solids settlement:-
  1. Solids discharge rates per unit area are low due to low stocking densities and high feed digestibility.
  2. No settled solids accumulate beyond the immediate vicinity of any BB site due to low currents and shelter.
  3. Also passes Scottish EQS standard (SEPA) using ITI and AZE (worst case), since benthic communities remain “unchanged” at 100m from pens and “altered” but not degraded within 25m of pens.
  4. Even in the worst cases modelled, there is no indication of elevation in sediments from any site towards the head of the bay or into Trafrask Bay, where benthic sediments and fauna will remain within their existing seasonal range.

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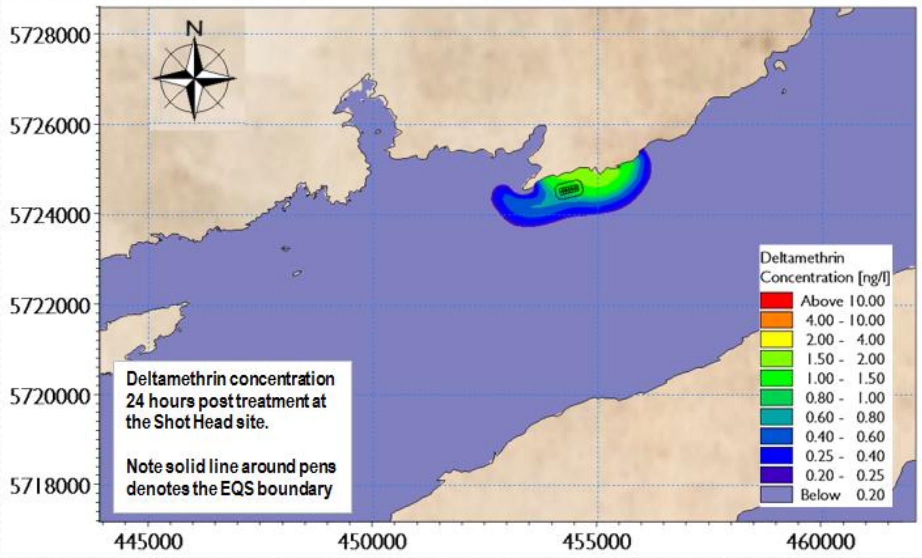
Water quality modelling for Bantry Bay #4. Medication dispersal (see Shot Head IPM).

- Background to medication dispersal modelling.
  1. Use of medication is limited by organic status.
  2. All medication is supplied on veterinary prescription.
  3. Salmon smolt are vaccinated before transfer to sea to protect against common diseases transmitted from wild fish stocks. Also, low stocking densities reduce stress-induced disease. Thus antibiotics are very rarely used on the organic MHI Bantry Bay sites. The dispersals arising from so few antibiotic treatments have no environmental consequences.
  4. Medications and other interventions are required to combat lice; Slice® (active ingredient EmBZ), AlphaMax® (active ingredient Deltamethrin), Hydrogen Peroxide (H_2O_2), cleaner fish (see Shot Head IPM).
  5. Only interventions requiring dispersional modelling, against EQS standards, are EmBZ (EQS 0.22ηg/l, 100m from treatment site, 24hrs post-treatment) and Deltamethrin (EQS 2 ηg/l, ditto).
  6. For these, as for other discharges, results are projected on worst-case basis only.
- Slice® oral lice treatment; active ingredient EmBZ.
  1. MHI only uses EmBZ until 1,000 degree days pre-harvest to avoid flesh residues; checked by testing.
  2. Modelling showed that peak permissible treatment biomass to meet the EmBZ EQS was 440T; adequate to allow strategic treatment to protect fish through first "susceptible spring period", during wild smolt migration.
- Alphamax® bath lice treatment; active ingredient Deltamethrin.
  1. Applied by bath treatment in well boat. Does not bioaccumulate in fish (thus no residue issue).
  2. Figure shows that the Deltamethrin EQS is not breached.



- Conclusions re medication and lice treatment:-
  1. Some limits on EmBZ use but adequate alternative treatment strategies are available.
  2. Other interventions now include cleaner fish.
  3. Lice infestation is naturally and consistently low in Bantry bay and medication is rarely required.

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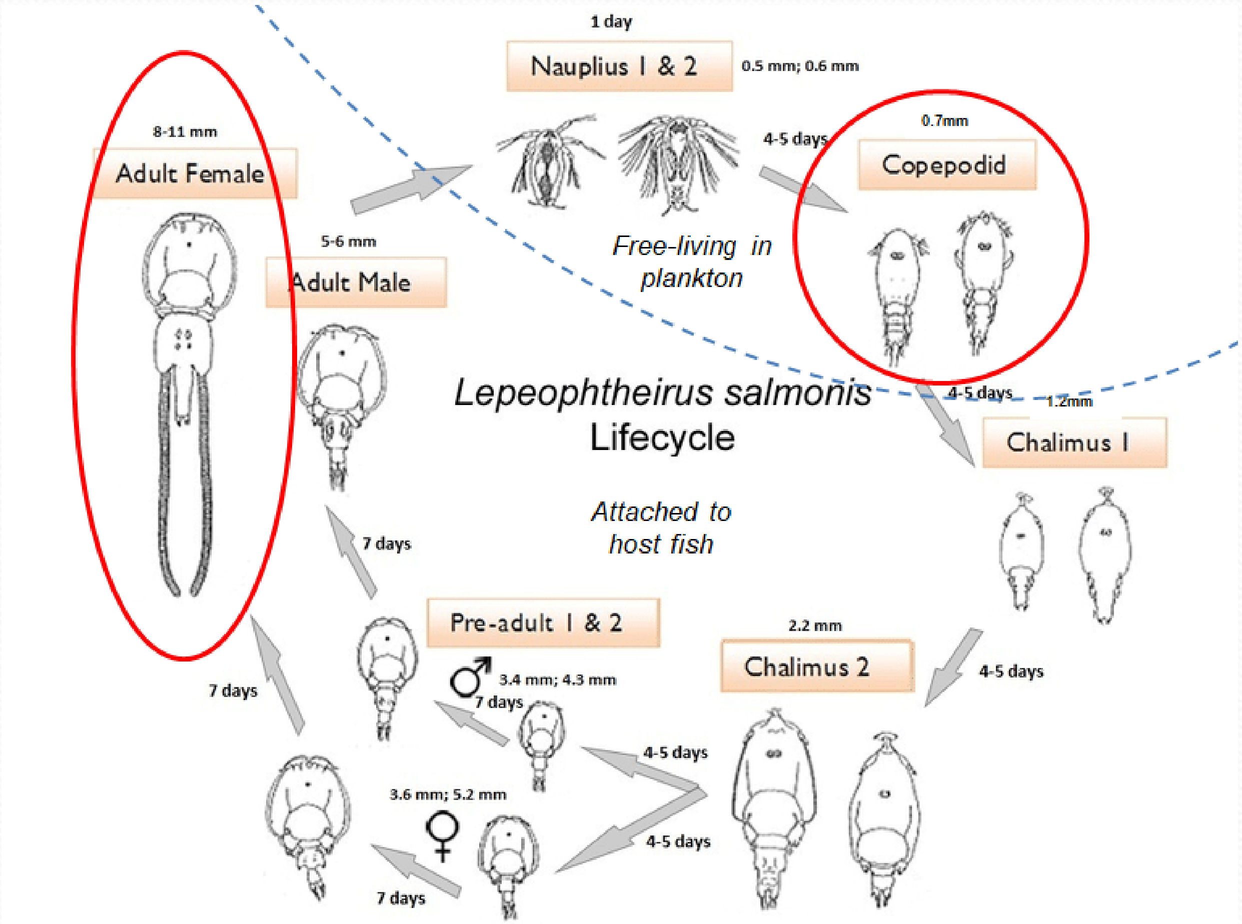
Water quality modelling for Bantry Bay #5.
Conclusions.

1. Dispersional models, driven by the RPS HD Model, were used to show the impacts of wastes from all existing and proposed Bantry Bay salmon farm sites on water and sediment quality.
2. All models reflect multiple worst case scenarios, by using peak discharges, point source dispersal, conservative parameters etc.
3. Where possible, Environmental Quality Standards (EQS) are used as the best means to assess model outcomes.
4. Re solute dispersal (DIN, DIP, DBOD), no EQS is breached.
5. Levels of solids settlement are low and within set EQS's due to low stocking densities, high feed digestibility and local hydrography.
6. Even in the hypothetical case of one year's deposition at the peak monthly rate, maximum projected sediment depth under the pens would be less than 13mm and less than 0.5mm within 50m of the pens.
7. Medication dispersal modelling shows that the lice medication Slice® can be used to treat up to 440T of fish per 7-day treatment period, without breaching the EQS for its active ingredient EmBZ.
8. The Maximum Allowable Biomass (MAB) of 2,800T of stock applied for can be treated with AlphaMax® without breaching the EQS of its active ingredient Deltamethrin.
9. The models showed that residual currents are highest around islands and promontories, some near fish farm sites, reducing solids accumulation and encouraging the carriage of both solid and soluble wastes away from the sites.
10. It is also noted that Bantry Bay is flushed by roughly 27 billion tonnes of water per month. This huge volume of water dilutes and flushes wastes out of the bay and into the Atlantic in a slow, counter-clockwise circulation and maintains bay conditions well within its carrying capacity.
11. Solid and soluble inputs (from both natural and anthropogenic sources) do not and cannot accumulate towards the head of the bay.

Salmon farms and lice in Bantry Bay #1.

The life cycle of *Lepeophtheirus salmonis*.



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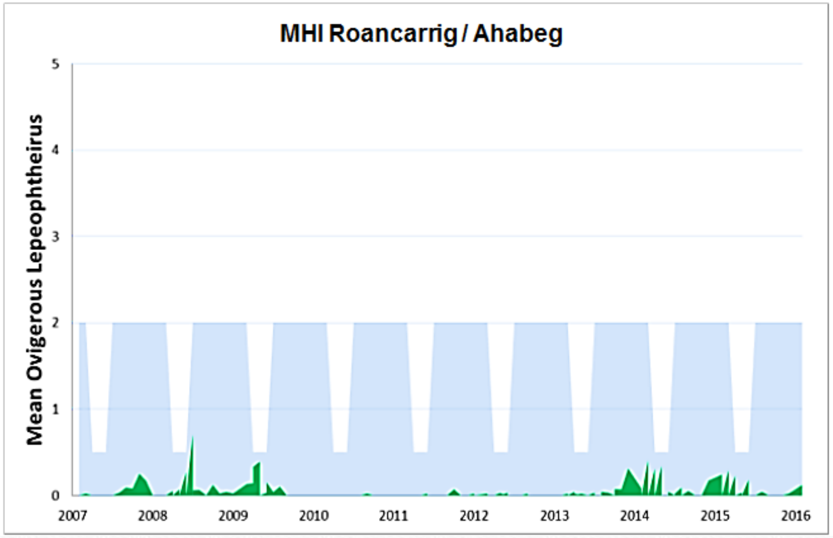
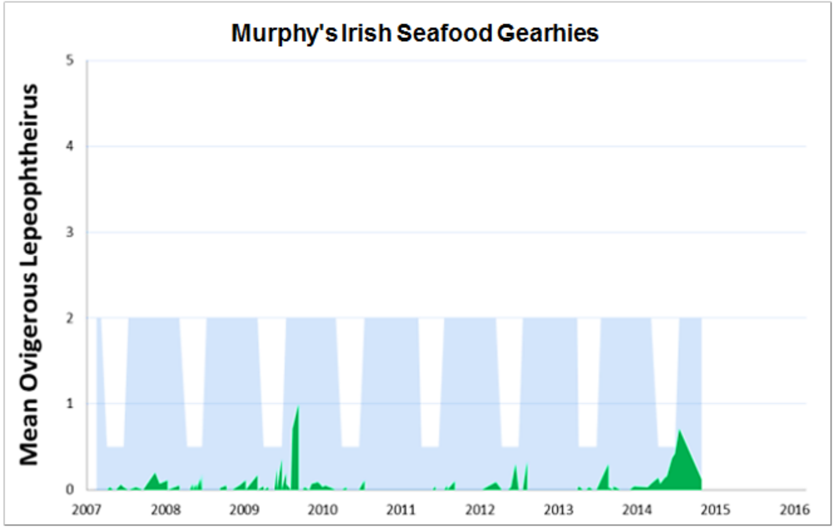
Salmon farms and lice in Bantry Bay #2.

- Salmon farms can become infested with the salmon louse, *Lepeophtheirus salmonis (Lep)*, by transmission from wild salmonid stock or from other farm sites. A lesser problem is the sea louse *Caligus elongatus*, transmitted between many marine fish species.
- On-farm lice infestation must be treated to prevent damage to farm stocks and, in the case of *Lep*, to prevent risks of infestation of wild salmonid stocks.
- The statutory National Lice Monitoring Program checks lice numbers 14 times per annum on all farm sites. All farm lice data has been in the public domain for many years. Two trigger levels are used to prompt (statutory) treatment, at 0.5 ovigerous lice / fish from March to May each year and 2 / fish at other times.
- MHI took over the Roancarrig / Ahabeg sites in 2008. Since then, trigger levels have never been breached at the sites and lice levels have always remained low and well below the national average. Much the same applies to the Murphy sites at Gearhies.
- During this period, very few lice treatments have been required at the MHI and Ahabeg sites.
- Lice levels remain naturally low in Bantry Bay due to poor transmission rates in the slow current regime and timely treatment, when required.





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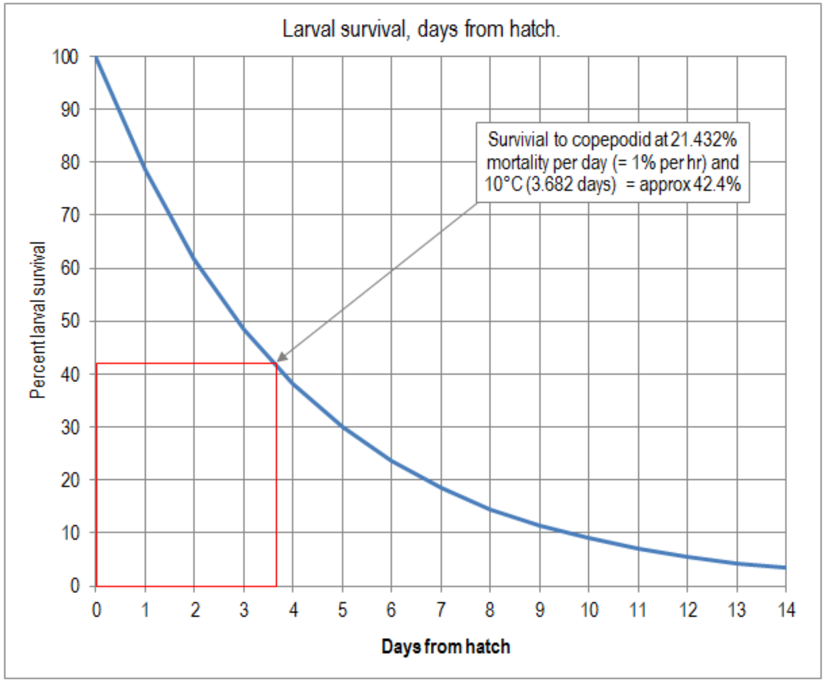
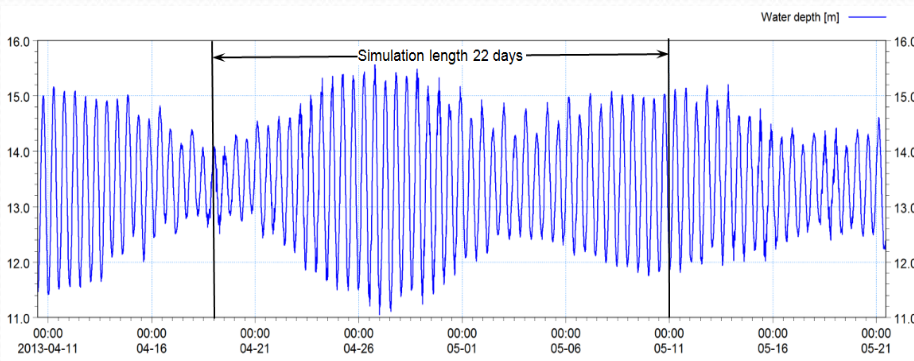
Salmon farms and lice in Bantry Bay #3.
Modelling sea lice dispersion.

- Key parameters and assumptions used for MHI lice dispersion modelling.
  1. As for all dispersion models, lice dispersion is driven by the RPS Bantry Bay Hydrodynamic Model.
  2. Worst case only modelled (e.g. maximum fish numbers, larval lice released over the flood tide only and natural predation not factored in).
  3. Larval dispersion rates from sites are based on a mean population of 1 ovigerous louse per fish (higher than historical data) and 250 larvae per egg clutch.
  4. The model disperses 270M *Lepeophtheirus* Nauplius larvae / month from all Bantry Bay sites.
  5. As per Armundrud and Murray 2009:-
     - Development time from hatch to copepodid 3.628 days (Stien et al 2005).
     - Mortality rate from hatch 1% per hour.
     - Gives attrition rate to extinction (due to feed source expiry) at 14 days post-hatch for model.
     - Larvae inanimate and neutrally buoyant in open waters (i.e. drifting in the plankton).
     - Nauplii removed from dispersion at 4 days, to simulate metamorphosis, leaving only infestive Copepodids to disperse.
  6. Simulations run for every model grid point, every 10 seconds for 22 days = >8.5x10^9 data points per simulation for Bantry Bay.





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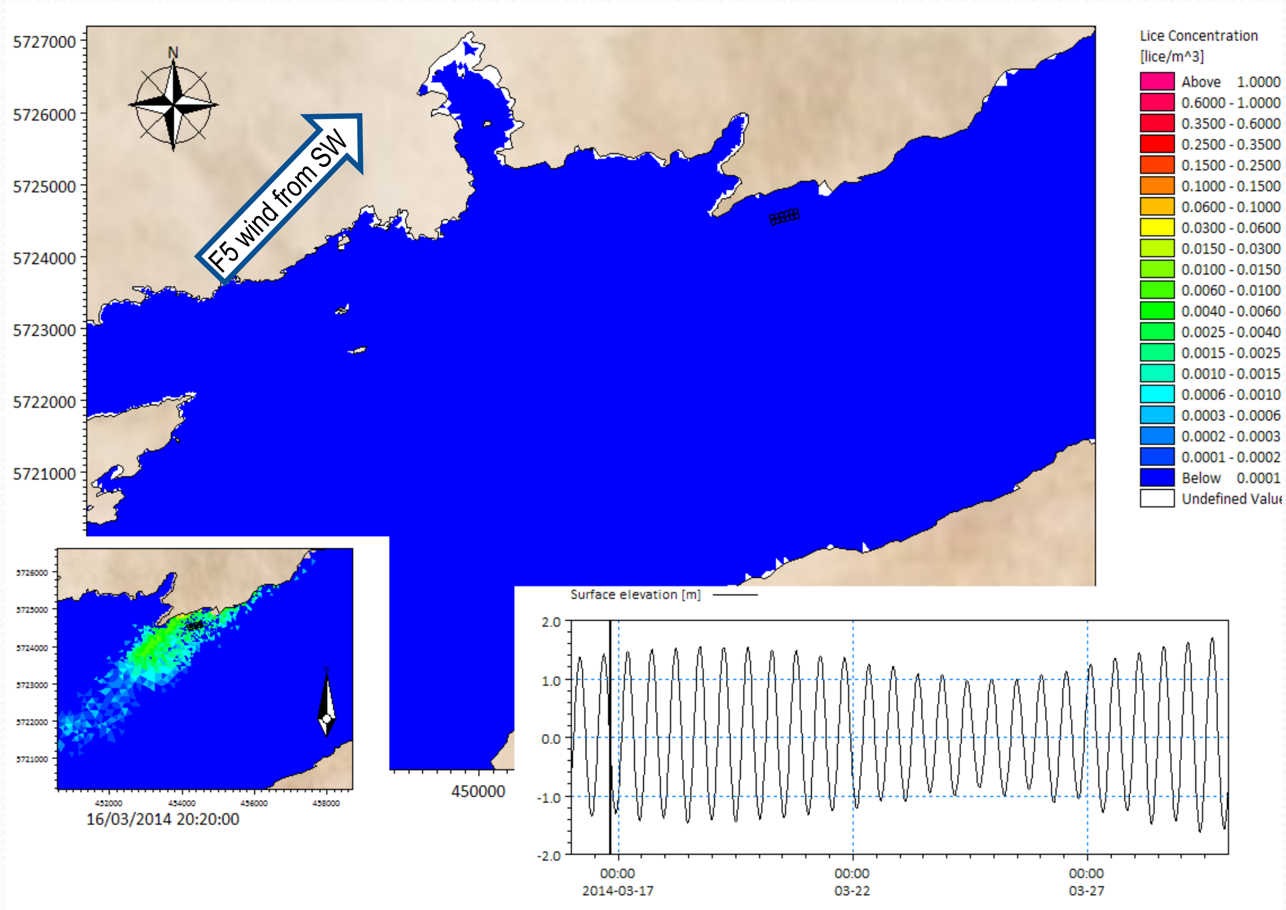
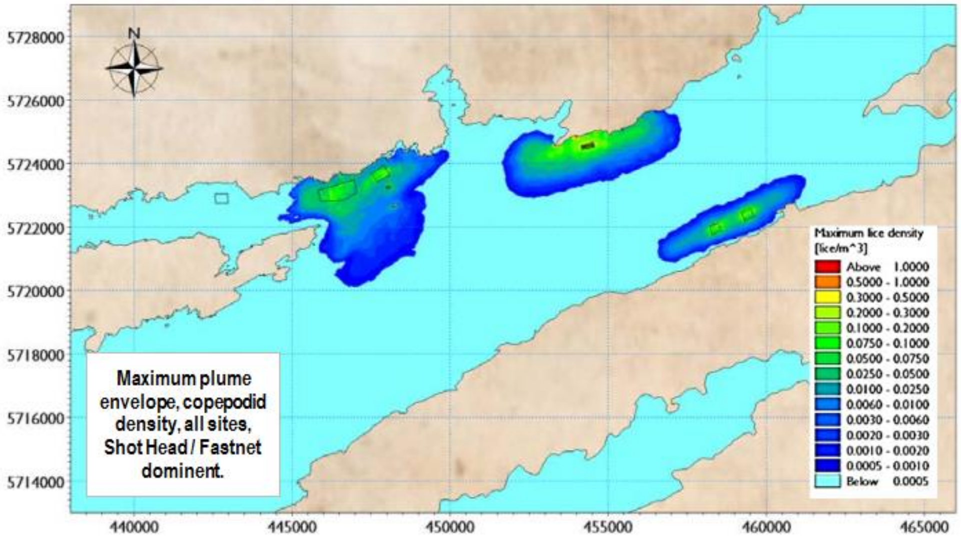
Salmon farms and lice in Bantry Bay #4.

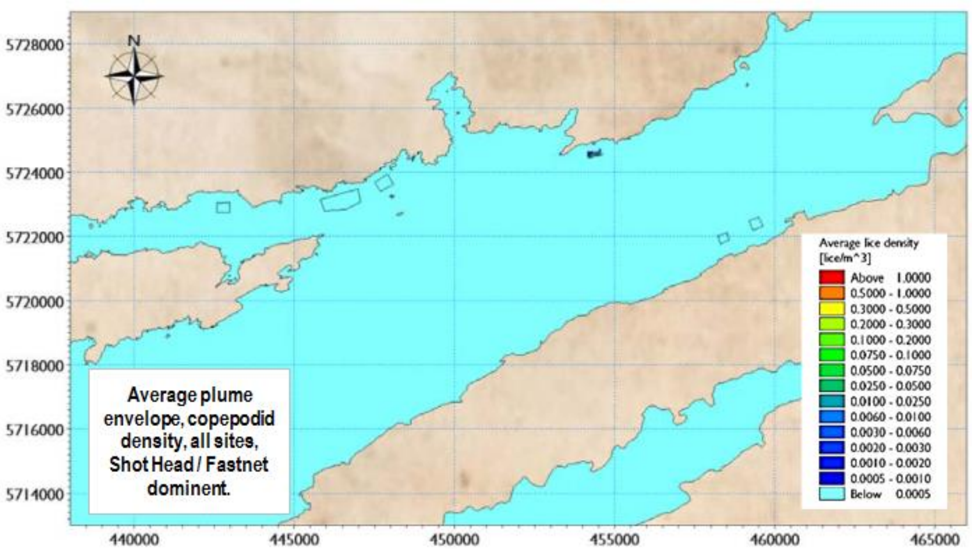
Lice dispersion modelling results; movie simulation.



1. The main movie shows infestive copepodids only.
2. The inset movie includes Nauplius stages (from hatch to 4 days post-hatch).
3. Hatch from maximum fish stock.
4. 1 ovigerous louse per farm fish.
5. 250 larvae / ovigerous louse / hatch.
6. Shows a worst case with wind forcing; F5 from SW, sustained for 22 days (simulation length).
7. Note wind-forced plume shape relative to still-weather plume.
8. Nominal peak copepodid concentration <1km from site = <0.01 /m^3 .
9. Nominal mean copepodid concentration >1km from site = <0.0001 /m^3 .
10. Note Log concentration scale.

Salmon farms and lice in Bantry Bay #5.
Lice dispersion modelling results; plume plots.





What the RPS models tell us about lice dispersion and transmission

1. Once hatched, Nauplius larvae disperse, drifting in the plankton, for 4 days before they metamorphose to the only infestive stage, the Copepodid larva.
2. This aids dilution to a maximum density of < 0.01 copepodids / m^3 (= 1 copepodid / $100m^3$) within about 1km of site.
3. Comparison of Maximum and Average Plume Envelope plots shows us that Copepodid densities of greater than 0.0001 Copepodids / m^3 water (= <u>one 0.7mm Copepodid / $10,000m^3$</u>) are extremely short-lived beyond the site boundary.
4. Average density falls rapidly to < 0.0001 copepodids / m^3 > 1km of site.
5. Wind forcing has little impact on these outcomes but may <u>increase</u> dispersal depending on wind strength, direction and duration.

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Salmon farms and lice in Bantry Bay #6.
Lice dispersion modelling results; analysis of infestation risk

- Research has shown that, if stimulated by vibration or possibly chemicals from a passing salmonid, a *Lep* Copepodid can dart up to10cm towards its host fish in order to achieve attachment.
- If this is so, then the theoretical maximum "attack range" of *Lep* Copepodids can be represented by a sphere of 10cm radius.
- 125 (5 x 5 x 5) such spheres can be close-packed into a one-metre cube (1m^3).
- Therefore, infestation of one or more wild salmonids passing through such a cube by at least one Copepodid is only 100% certain when Copepodid density is a minimum of 125 Copepodids per m^3.
- Thus, at a nominal density of 0.01 Copepodid per m^3, the confidence level for infestation by at least one Copepodid is only 0.008%, or one chance in 12,500. At 0.0001 Copepodids per m^3, the chance is 0.000008% or one chance in 1.25 million.
- This means that, at an average density of 0.01 Copepodids / m^3, there will only be a 100% chance of an average attachment of one Copepodid per fish after a the fish has swum through 12,500 one-metre cubes, which equals a journey length of 12.5km.
- At 0.0001 Copepodids per m^3, the journey length will be 1,250km (Dublin to Oslo!)!
- <u>Thus dispersed Copepodids in Bantry Bay will always be in insufficient numbers to augment natural infestation pressure inshore or, for that matter, in open waters.</u>
- <u>These models only apply to Bantry Bay. Each embayment with salmon farm sites must be individually investigated</u>.

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Salmon farms and lice in Bantry Bay #7.

The potential for wild-to-wild infestation by *Lepeophtheirus*.

1. Wild-origin *Lepeophtheirus* has evolved strategies to infest wild salmonid smolts as they migrate from rivers.
2. Wild, egg-bearing (ovigerous) female lice are able to target these natural infestation zones in river mouths, because they are carried there on their wild salmonid hosts, returning to their natal rivers to spawn.
3. Lice fertilisation occurs at sea, when both male and female adult lice are attached to host fish. Female lice have paired receptaculum seminis organs. Sperm can be stored in these so that eggs can be fertilised for a considerable period after the original fertilisation of the adult female louse by the male.
4. Such serial fertilisations may occur whilst female lice are still attached to host fish. Viable egg strings and infestive louse larvae may also be produced once females have dropped from their host fish, in the inshore zone.
5. Lice fecundity and larval hatching peaks in spring (at say 10^{o}C), when new hatches occur every nine days.
6. As a result, newly-metamorphosed wild copepodid larvae reach their highest concentrations in spring, in the inshore and estuarine margins, where and when potential hosts also reach their most concentrated, before migrating. Thus evolution has maximised *Lep's* infestation efficiency, in both time and space.
7. Marine survival of salmon is currently about 5% of escapement. Thus, for every 1,000-smolt escapement, only about 50 fish return to their natal river and breed. Assuming that each returning fish carries up to 5 wild ovigerous female lice, these could hatch enough Nauplii to generate at least 50,000 Copepodids (50 x 5 x 500 x 42%), to await the next 1,000 smolt escapement. That is enough for a mean infestation of 50 lice per smolt. If free-living ovigerous lice can fertilise further egg clutches every 9 days via their receptaculum seminis organs, natural infestation pressure could radically increase.
8. 25 years ago, marine survival of wild salmon would have been >20%, resulting in >200 Copepodids to await every migrating smolt. The first Sea Trout Working Group report was published around that time!
9. The fact is that wild lice have always had the potential to cause serious infestations of wild salmonid smolt without needing any help from salmon farms!!

Salmon farms and lice in Bantry Bay #8.
The potential for wild-to-farm / farm-to-farm infestation by Lep.

1. As we have seen, *Lepeophtheirus* has evolved specialised strategies in order to infest wild salmonids in the shallow, still, inshore zones of river estuaries, not farmed salmon held in active, open marine conditions.
2. However there is potential for wild-origin *Lep* Copepodids, which fail to locate wild hosts in their natural infestation zones, to drift into open waters and to encounter salmon farms by chance.
3. This is because salmon farms present a very large cross sectional area for copepodids (of either wild or of farm origin) to encounter as they drift with the plankton in tidal currents.
4. In the case of Bantry Bay, the cross-sectional area of two neighbouring salmon pens, facing the current (the standard configuration), is approximately 1,000m^2. Thus, at the mean tidal current of, say, 3cm/second, the water volume entering the pens per day is approximately 26M m^3. At 0.0001 copepodids/m^3 water (the nominal lice background level for Bantry Bay estimated in the RPS model), this will bring 2,600 lice into the pens each day. This is considered to be more than enough for a few to settle amongst the captive farmed fish population, from which on-farm lice populations can grow to affect the whole farm stock, if not treated.
5. Obviously, if currents are faster and / or background lice densities are higher, whether of farmed or wild origin, the number of Copepodids encountering the site (and consequent infestation potential) will rise proportionately. Mean tidal currents on Irish salmon farms range between about 3 and 25cm/sec, suggesting an 8-fold range for farm site infestation pressure. The evidence is strong that farm sites subjected to faster current regimes are more readily infested from wild sources but Bantry Bay is at the bottom of that scale due to its slow current regime.
6. Thus, stocking densities on fish farms can provide the critical host densities and fixed location required for successful infestation by very low densities of Copepodids, drifting in the plankton. However, critical host densities of wild fish only occur in river estuaries pre-migration dispersal and are not provided for in wild-to-wild infestations in open waters, where wild fish are far more dispersed and are free to move.

Salmon farms and lice in Bantry Bay #9. Conclusions.

1. *Lepeophtheirus* larvae are very small. Nauplii are only 0.5 to 0.6mm long and Copepodids only 0.7mm long.
2. The initial 4-day dispersal of non-infestive Nauplii dilutes larval density before metamorphosis to the infestive Copepodid stage to an average of < 0.01 copepodids / m^3 (= 1 copepodid / $100m^3$), within 1km of site.
3. Dispersion causes the density to fall further, to < 0.0001 Copepodids / m^3 (< 1 / $10{,}000m^3$) > 1km of site.
4. At such dilutions, from open water to river estuaries, the chances of host encounter are regarded as far too low to augment the natural infestation of wild salmonids, by farm-origin Copepodids, in Bantry Bay conditions.
5. Wind forcing has little impact on Copepodid distribution but can increase dispersal, depending on wind strength, direction and duration, both in open waters, and in particular inshore, where the overturning wave current profile become the most dispersive influence.
6. Once dispersing in open waters, Copepodids, which are planktonic and inert, can only disperse and dilute further, aided by wind forcing, if this applies.
7. These models only apply to Bantry Bay and the site locations investigated. Each embayment with salmon farm sites must be individually investigated.

Numerical modelling of the dispersion of wastes, medication and salmon lice (*Lepeophtheirus salmonis* Kroyer) from the proposed MHI Shot Head site in Bantry Bay.

Thank you!
Any questions?

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