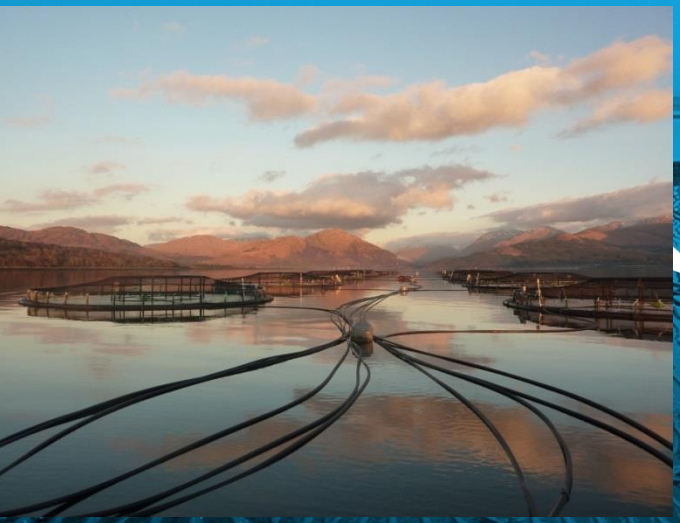
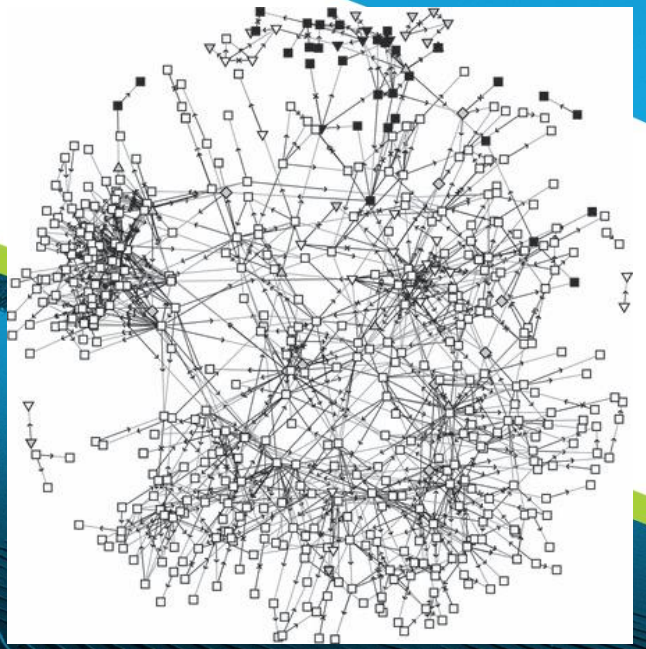
Using models to inform spatial aquatic animal health management to support production

The Scottish Government





nabeil.salama@gov.scot
OR
salaman@marlab.ac.uk

marinescotland science

marinescotland science

Increasing aquaculture production and limiting environmental impact

Increasing Production and limiting environmental impact

marinescotland science

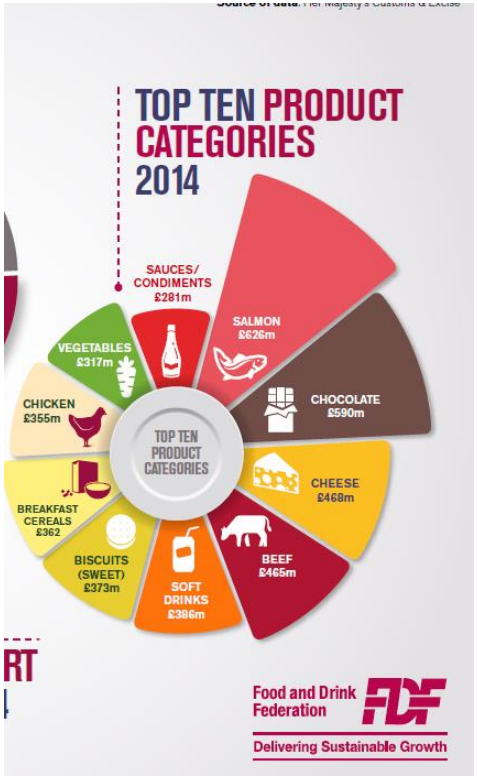
Year of smolt input	Smolt input (000s)	Number (000s)	Weight (tonnes)	Mean weight (kg)	% harvest	Number (000s)	Weight (tonnes)	Mean weight (kg)	% harvest	Number (000s)	Weight (tonnes)	Mean weight (kg)	% harvest	Total % of year class harvested	Year class weight (tonnes)	Yield per smolt (kg)
1999	41,106	1,000	2,763	2.8	2.4	23,077	89,963	3.9	56.1	9,096	40,754	4.5	22.1	80.6	133,480	3.25
2000	45,185	765	2,673	3.5	1.7	22,726	96,539	4.2	50.3	11,354	53,535	4.7	25.1	77.1	152,747	3.38
2001	48,643	557	1,227	2.2	1.1	23,528	90,230	3.8	48.4	15,619	73,255	4.7	32.1	81.6	164,712	3.39
2002	50,086	272	824	3.0	0.5	22,602	96,205	4.3	45.1	15,555	71,988	4.6	31.1	76.7	169,017	3.37
2003	43,083	82	276	3.4	0.2	19,596	85,792	4.4	45.5	13,920	61,850	4.4	32.3	78.0	147,918	3.43
2004	39,041	168	319	1.9	0.4	15,075	67,738	4.5	38.6	14,237	67,537	4.7	36.5	75.5	135,594	3.47
2005	37,168	0	-	-	0	14,036	64,099	4.6	37.8	14,999	69,000	4.6	40.3	78.1	133,099	3.58
2006	41,091	115	211	1.8	0.3	13,787	60,890	4.4	33.5	15,881	73,631	4.6	38.6	72.5	134,732	3.28
2007	37,853	23	40	1.7	0.06	13,011	54,759	4.2	34.4	14,133	66,448	4.7	37.3	71.8	121,247	3.20
2008	36,662	116	216	1.9	0.3	16,338	77,621	4.7	44.6	13,666	68,070	5.0	37.3	82.2	145,907	3.98
2009	38,548	81	178	2.2	0.2	18,266	85,826	4.7	47.4	13,772	66,606	4.8	35.7	83.3	152,610	3.96
2010	38,490	128	268	2.1	0.3	18,694	91,105	4.9	48.6	13,053	64,178	4.9	33.9	82.8	155,551	4.04
2011	42,733	109	307	2.8	0.3	21,502	97,744	4.5	50.3	11,283	57,073	5.1	26.4	77.0	155,124	3.63
2012	41,094	127	301	2.4	0.3	21,264	106,161	5.0	51.7	13,712	76,305	5.6	33.4	85.4	182,767	4.45
2013	40,936	0	-	-	0	20,316	101,997	5.0	49.6	10,910	56,984	5.2	26.7	76.3	158,981	3.88
2014	48,112	286	720	2.5	0.6	24,038	114,112	4.7	50.0	10,940	51,321	4.7	22.7	73.3	166,153	3.45
2015	45,465	223	626	2.8	0.5	24,633	111,163	4.5	54.2							
2016	42,957	114	333	2.9	0.3											

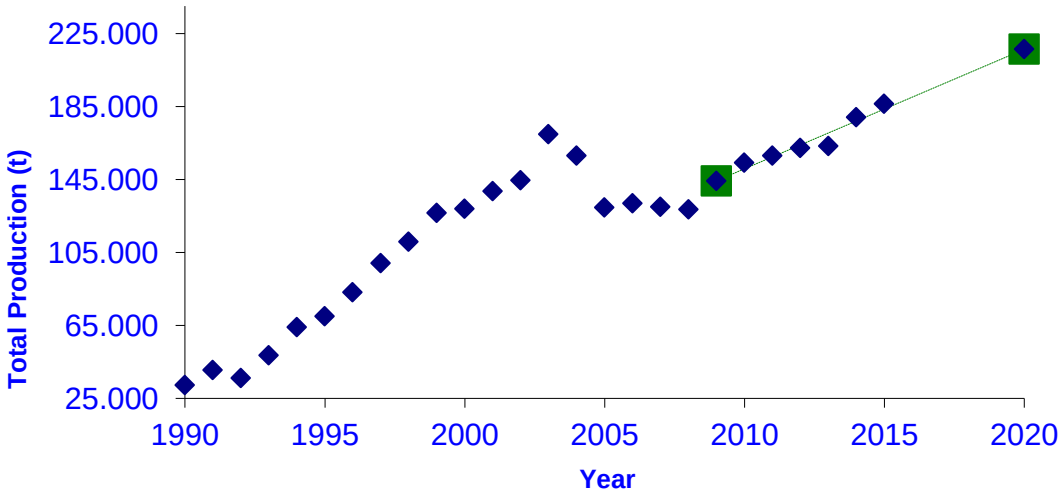
- ~22% salmon die at sea.
- 1/3 attributed to disease (Kilburn et al 2012, Soares 2011)

Kilburn et al (2012). Aquacult. 368-369, 89 – 94.
Soares et al (2011) Aquacult. 314, 7-12.

Scottish Aquaculture

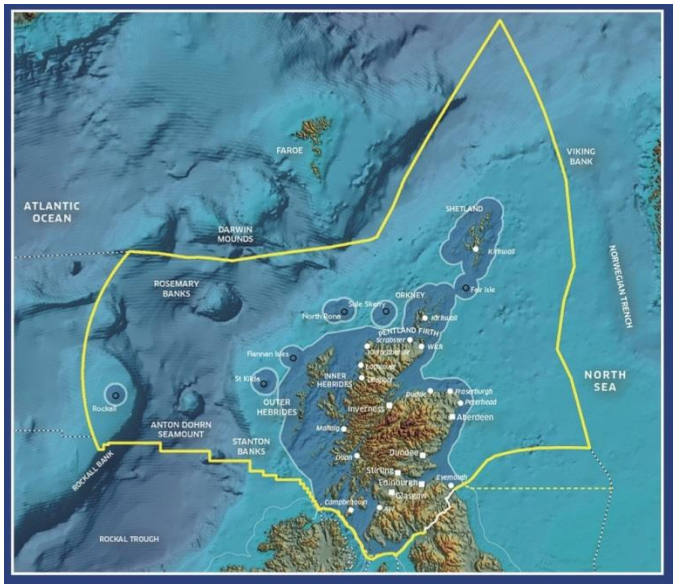
- Scotland largest single aquaculture producer by value in EU (~20%)
  - Atlantic Salmon (*Salmo salar*)
- One of the UK's most valuable food exports
- US $ 1.85 bn economy
- Employment for >6000 people
  - Remote areas





Marine Scotland

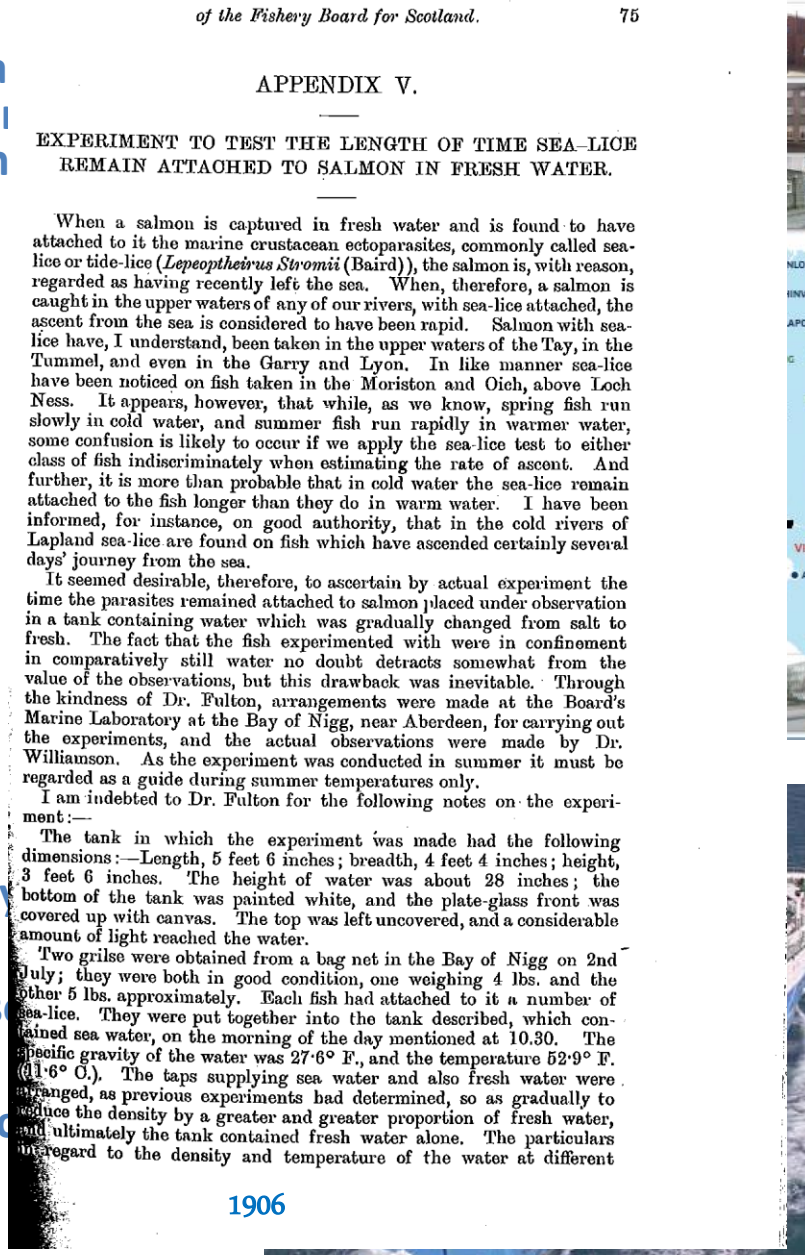
- Clean, healthy, safe, productive a
biologically diverse, managed to
the long-term needs of nature an
people.



-
-
-

1882 – Aberdeen Marine Laborator
280 scientific staff

- Environment, Monitoring and Ass
- Renewables and Energy
- Planning and Environmental Advic
- Coastal and Offshore Fisheries
- Aquaculture and Fish Health
- Freshwater Fisheries



of the Fishery Board for Scotland. 75

APPENDIX V.

EXPERIMENT TO TEST THE LENGTH OF TIME SEA-LICE REMAIN ATTACHED TO SALMON IN FRESH WATER.

When a salmon is captured in fresh water and is found to have attached to it the marine crustacean ectoparasites, commonly called sea-lice or tide-lice (*Lepeoptheirus Stromii* (Baird)), the salmon is, with reason, regarded as having recently left the sea. When, therefore, a salmon is caught in the upper waters of any of our rivers, with sea-lice attached, the ascent from the sea is considered to have been rapid. Salmon with sea-lice have, I understand, been taken in the upper waters of the Tay, in the Tummel, and even in the Garry and Lyon. In like manner sea-lice have been noticed on fish taken in the Moriston and Oich, above Loch Ness. It appears, however, that while, as we know, spring fish run slowly in cold water, and summer fish run rapidly in warmer water, some confusion is likely to occur if we apply the sea-lice test to either class of fish indiscriminately when estimating the rate of ascent. And further, it is more than probable that in cold water the sea-lice remain attached to the fish longer than they do in warm water. I have been informed, for instance, on good authority, that in the cold rivers of Lapland sea-lice are found on fish which have ascended certainly several days' journey from the sea.

It seemed desirable, therefore, to ascertain by actual experiment the time the parasites remained attached to salmon placed under observation in a tank containing water which was gradually changed from salt to fresh. The fact that the fish experimented with were in confinement in comparatively still water no doubt detracts somewhat from the value of the observations, but this drawback was inevitable. Through the kindness of Dr. Fulton, arrangements were made at the Board's Marine Laboratory at the Bay of Nigg, near Aberdeen, for carrying out the experiments, and the actual observations were made by Dr. Williamson. As the experiment was conducted in summer it must be regarded as a guide during summer temperatures only.

I am indebted to Dr. Fulton for the following notes on the experiment:—

The tank in which the experiment was made had the following dimensions:—Length, 5 feet 6 inches; breadth, 4 feet 4 inches; height, 3 feet 6 inches. The height of water was about 28 inches; the bottom of the tank was painted white, and the plate-glass front was covered up with canvas. The top was left uncovered, and a considerable amount of light reached the water.

Two grilse were obtained from a bag net in the Bay of Nigg on 2nd July; they were both in good condition, one weighing 4 lbs. and the other 5 lbs. approximately. Each fish had attached to it a number of sea-lice. They were put together into the tank described, which contained sea water, on the morning of the day mentioned at 10.30. The specific gravity of the water was 27·6° F., and the temperature 52·9° F. (11·6° C.). The taps supplying sea water and also fresh water were arranged, as previous experiments had determined, so as gradually to reduce the density by a greater and greater proportion of fresh water, and ultimately the tank contained fresh water alone. The particulars in regard to the density and temperature of the water at different

1906

marinescotland
MARINE OFFICES

Legislation

Global

- OIE

Listed diseases

Fish diseases

- Epizootic haematopoietic necrosis disease
- Infection with *Aphanomyces invadans* (epizootic ulcerative syndrome)
- Infection with *Gyrodactylus salaris*
- Infection with HPR-deleted or HPR0 infectious salmon anaemia virus
- Infection with salmonid alphavirus
- Infectious haematopoietic necrosis
- Koi herpesvirus disease
- Red sea bream iridoviral disease
- Spring viraemia of carp
- Viral haemorrhagic septicaemia

Mollusc diseases

- Infection with abalone herpesvirus
- Infection with *Bonamia exitiosa*
- Infection with *Bonamia ostreae*
- Infection with *Marteilia refringens*
- Infection with *Perkinsus marinus*
- Infection with *Perkinsus olseni*
- Infection with *Xenohaliotis californiensis*

Europe

~30 directives

- EC Directive 2006/88/EC

UN FAO

Domestic

marinescotland science

~70 statutes

Diseases of Fish Act 1937

Coast Protection Act 1949

Food and Environment Protection Act 1985

The Food Safety Act 1990

Town and Country Planning (Scotland) Act 1997.
Food Hygiene (Scotland) Regulations 2006

Town and Country Planning (Marine Fish Farming) (Scotland) Order 2007

Aquaculture and Fisheries (Scotland) Act 2007

Aquatic Animal Health (Scotland) Regulations 2009

Marine (Scotland) Act 2010

Town and Country Planning (Marine Fish Farms Permitted Development) (Scotland) Order 2011

Controlled Activities) (Scotland) Regulations 2011

marinescotland science

Aquaculture and Fisheries (Scotland) Act 2013

2013 asp 7

The Bill for this Act of the Scottish Parliament was passed by the Parliament on 15th May 2013 and received Royal Assent on 18th June 2013

An Act of the Scottish Parliament to make provision about fish farming and shellfish farming; about salmon fisheries and freshwater fisheries; about sea fisheries; about shellfish waters and fisheries for shellfish; about charging in connection with functions relating to fish farming, shellfish farming, salmon fisheries, freshwater fisheries and sea fisheries; about fixed penalty notices for offences under certain fisheries and other marine legislation; and for connected purposes.

PART 1

AQUACULTURE

CHAPTER 1

FISH FARM MANAGEMENT

1 Fish farm management agreements and statements

(1) The Aquaculture and Fisheries (Scotland) Act 2007 is amended in accordance with this section.

(2) After section 4 insert—

"Fish farm management agreements and statements

4A Fish farm management agreements and statements

(1) A person who carries on a business of fish farming at a fish farm located within a farm management area must—

(a) be party to a farm management agreement, or prepare and maintain a farm management statement, in relation to the fish farm, and

(b) ensure that the fish farm is managed and operated in accordance with the agreement or (as the case may be) statement.

(2) For the purposes of this section, a "farm management agreement" is an agreement—

(a) between two or more persons who carry on a business of fish farming at fish farms located in a farm management area, and

(b) which contains provision about the matters specified in subsection (4).

(3) For the purposes of this section, a "farm management statement" is a statement—

(a) prepared and maintained by a person who—

(i) carries on a business of fish farming at a fish farm located in a farm management area, and

(ii) is not, in relation to that fish farm, party to a farm management agreement, and

(b) which contains provision about the matters specified in subsection (4).

(4) The matters referred to in subsections (2)(b) and (3)(b) are—

(a) a description of the farm management area and the fish farm or farms to which the agreement or statement applies,

(b) arrangements for—

(i) fish health management,

(ii) management of parasites,

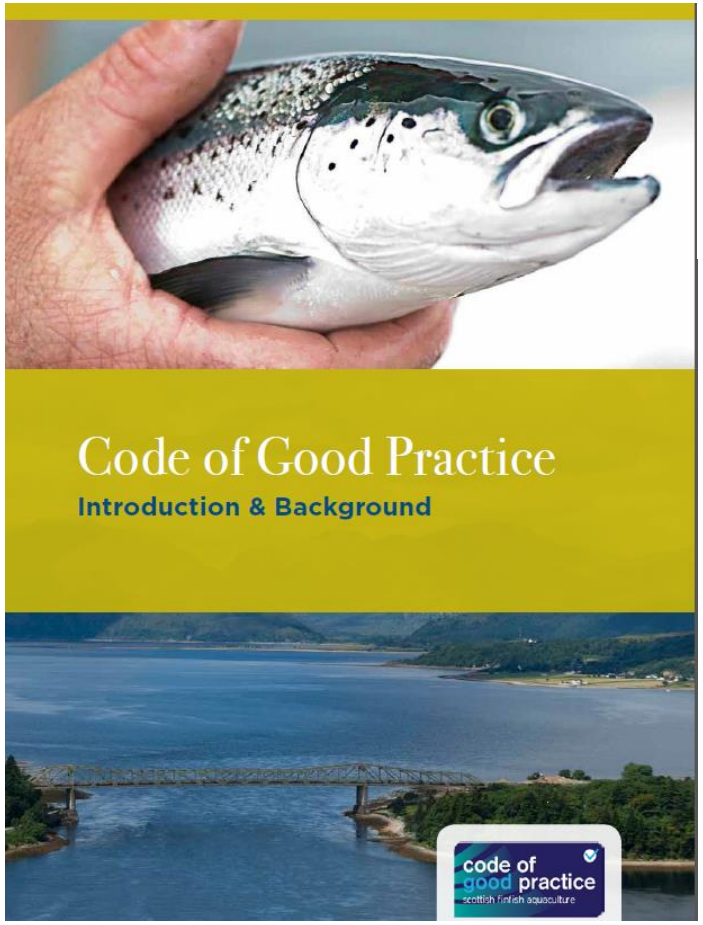
a description of the farm management area

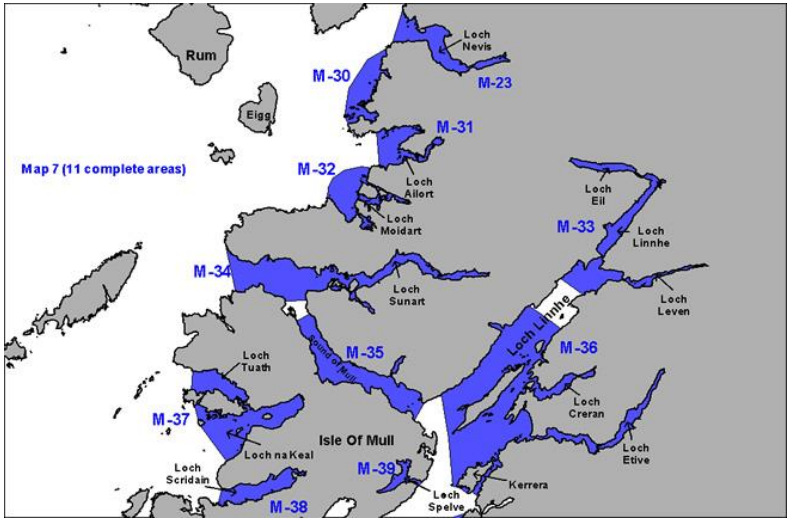
arrangements for—

(i) fish health management,

(ii) management of parasites,

- **Industry Code**
  - **>95% production**

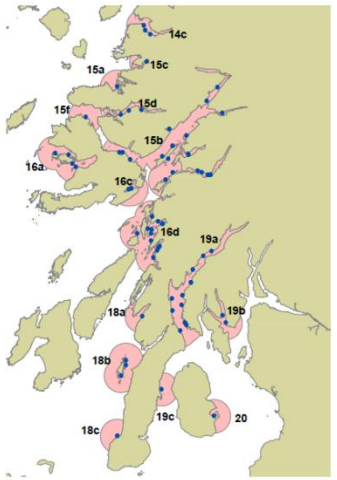




Modelling to support health management

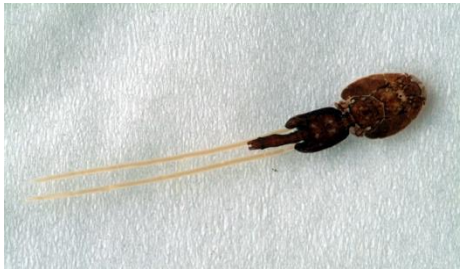
marinescotland science

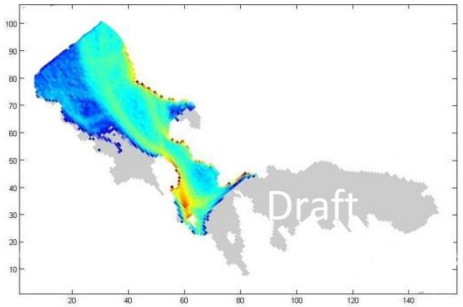
- Simple Tidal Excursion model



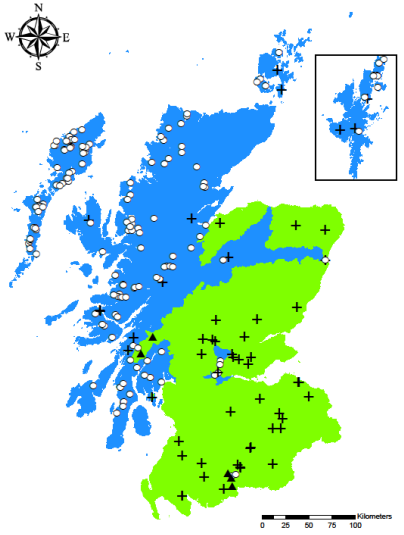
- Environmental transmission models

- Sea lice Bio-physical dispersal modelling





- Network models

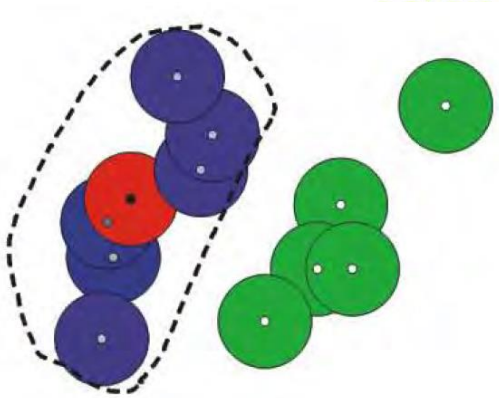


Disease Management Areas

- Based on simplified Tidal Excursion (TE) distances
- TE=

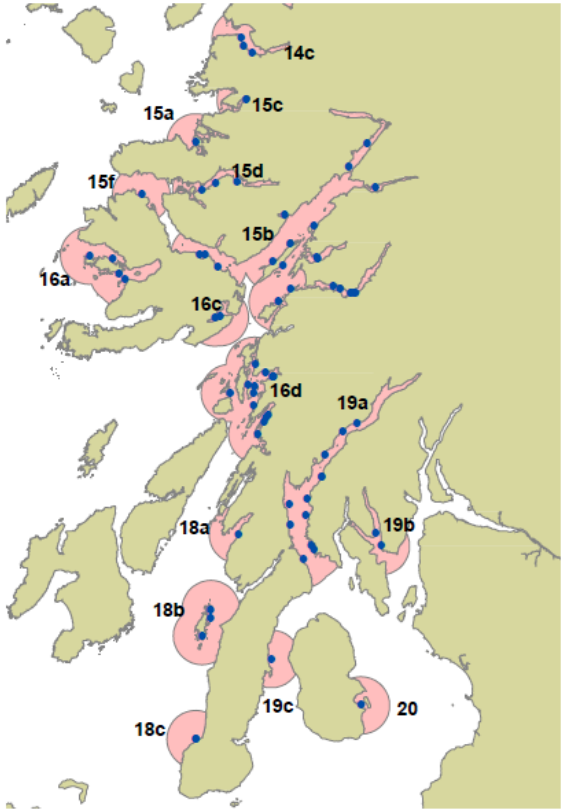
  7.258 km Mainland Scotland

  3.629 km Shetland Islands



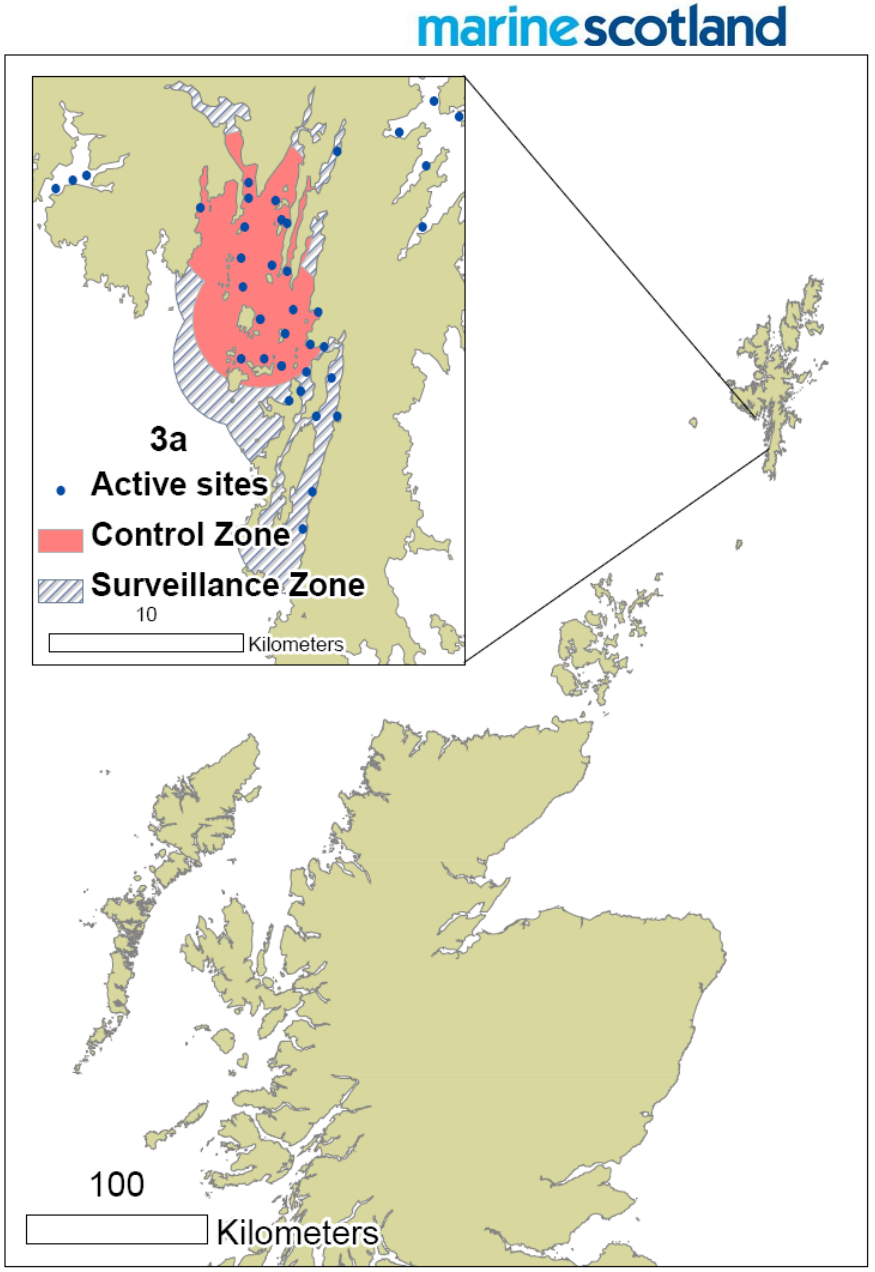
- Joint Government/Industry recommended
  - Hydrodynamically defined management areas

- After infectious salmon anaemia 1998/99
  - Not endemic to UK
  - 90% mortality
  - £20 m to eradicate



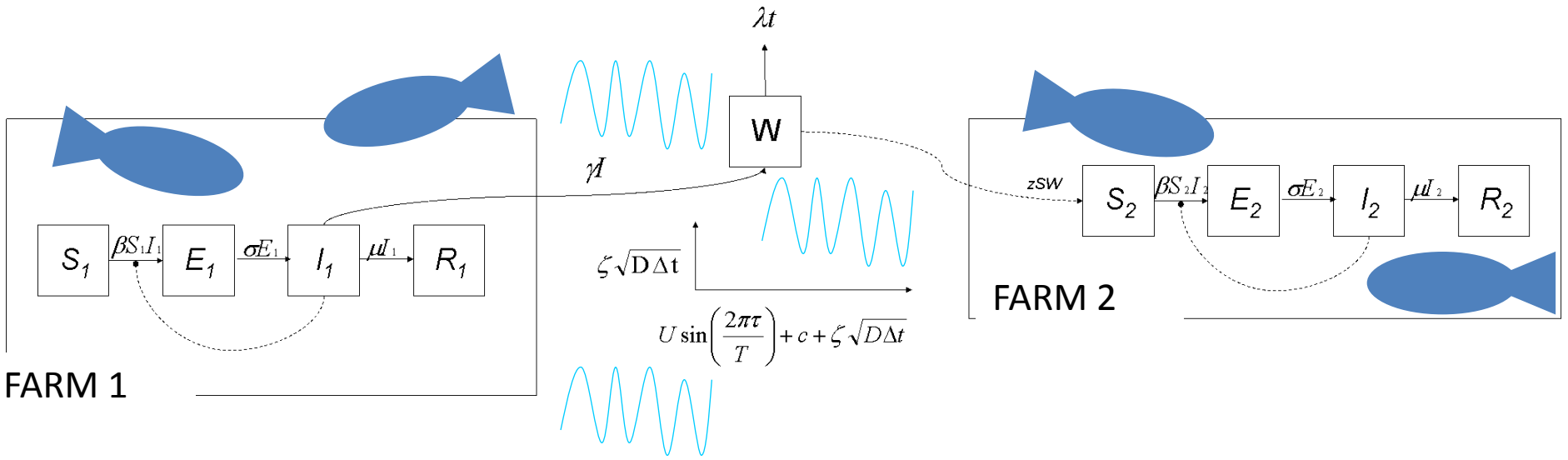
Disease Management Areas

- Establishes breaks between zones
  - 2 x TE
- Regular changes with change in farm locations
- 2008/09 ISA eradication
  - Movement restrictions
  - Depopulation
  - Sanitisation
  - Restocked ISA-free fish inspected for 2 years



Environmental Transmission

marinescotland science



Susceptible-Exposed-Infectious-Recovered (*SEIR)* model representing farms

Linked by a hydrodynamic water phase

Parameterised for IPNV, ISAV & Furunculosis agent

Salama & Murray (2011) Aquacult Environ Interact 2:61-74.

Salama & Murray (2013) Prev. Vet. Med. 108, 285-293

Size and Separation

Source farm (1000t)

Aeromonas salmonicida

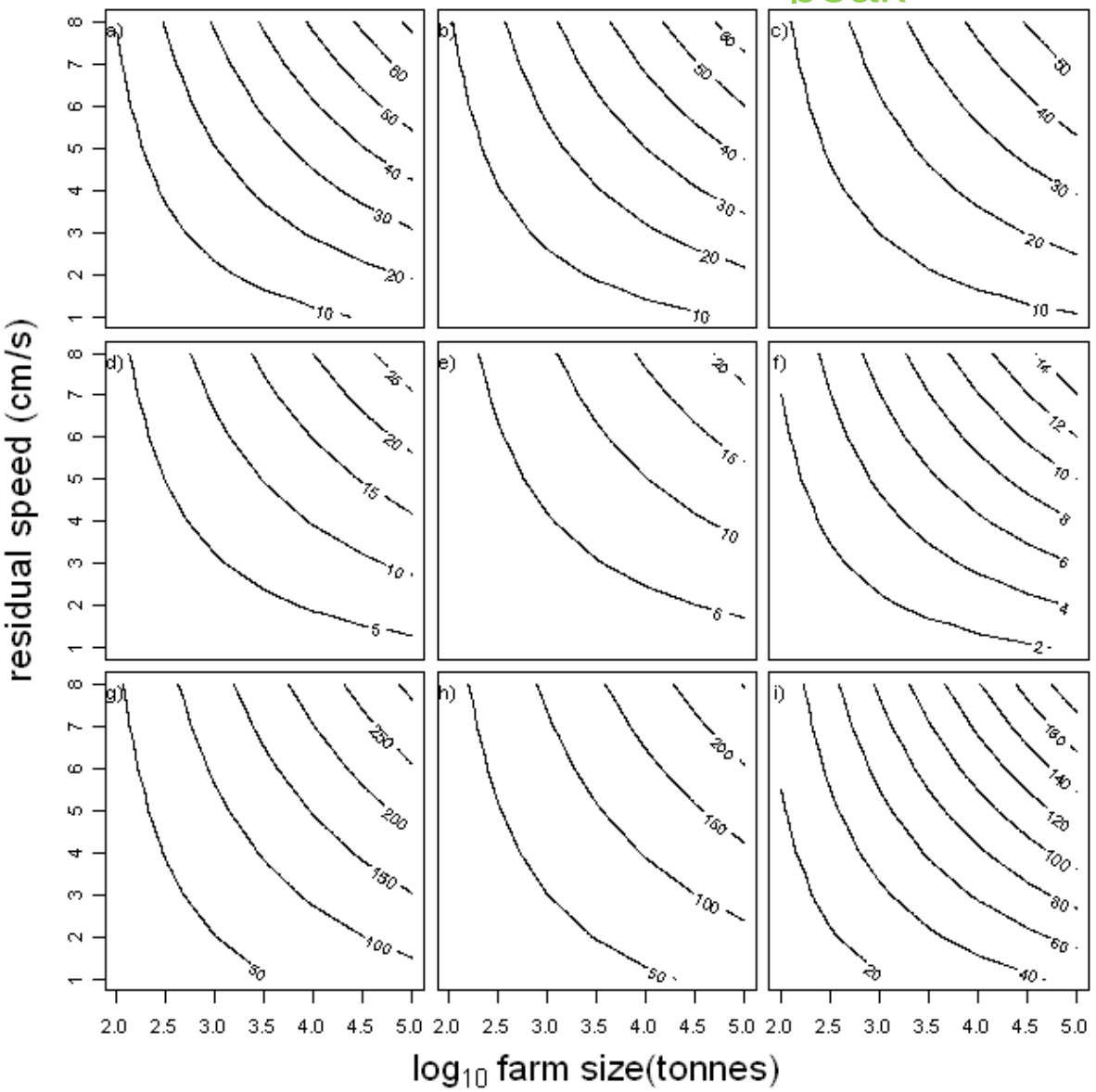
Infectious salmon anaemia virus

Infectious pancreatic necrosis virus

Dose

peak ½ peak ¼ peak

marinescotland science

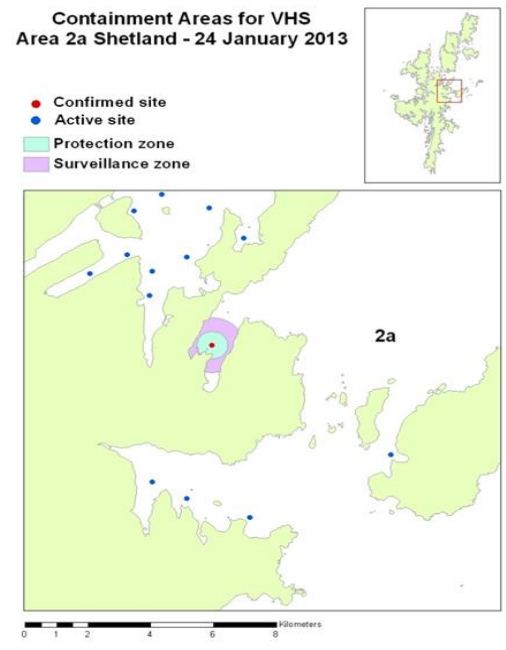


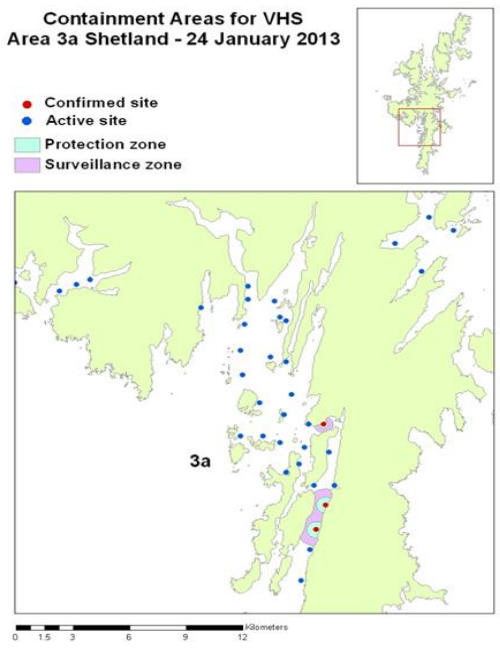
Units: km

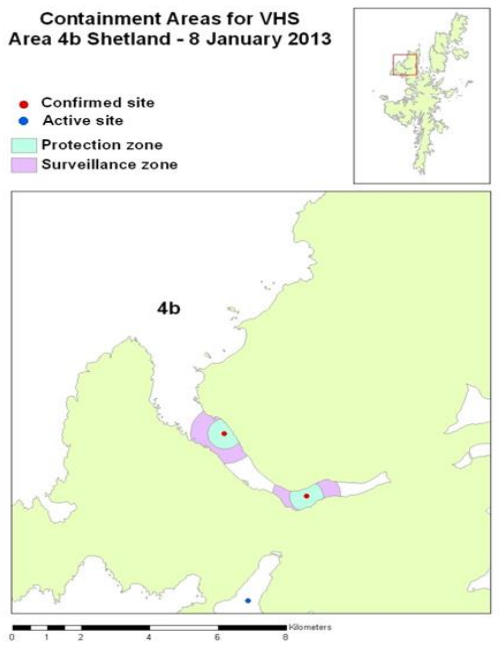
Application for VHS control

- Viral Hemorrhagic Septicemia
- In salmon cleaner fish
- Establish protection and surveillance zones

marinescotland science



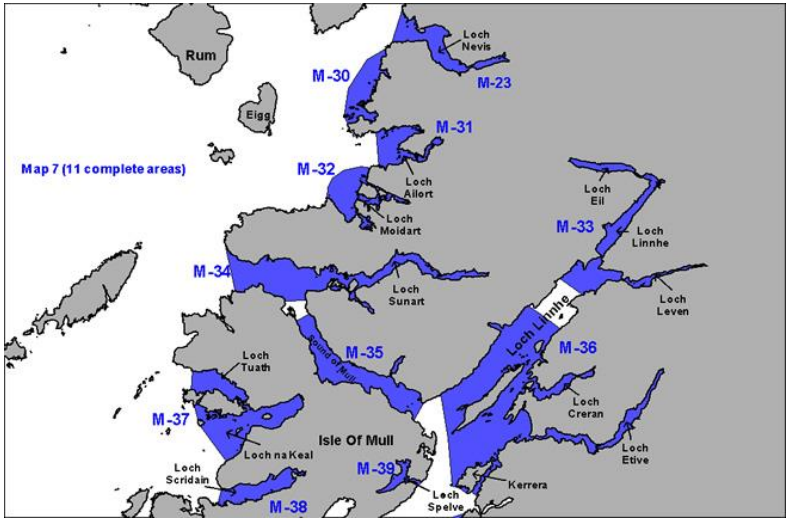




Hall et al (2014) .Scot. Mar. Fresh. Sci 4: 1-49

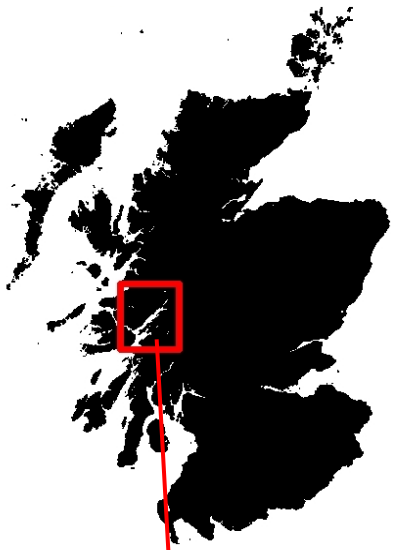
Salmon / Sea lice
Farm management Areas

- **Defined by industry**
- **No rules for**
  - **shape**
  - **Number operators**
  - **Farms**
- **Coordinated**
  - **Treatment**
  - **Fallow**
  - **Stocking**
  - **Harvesting**
- **Share information**

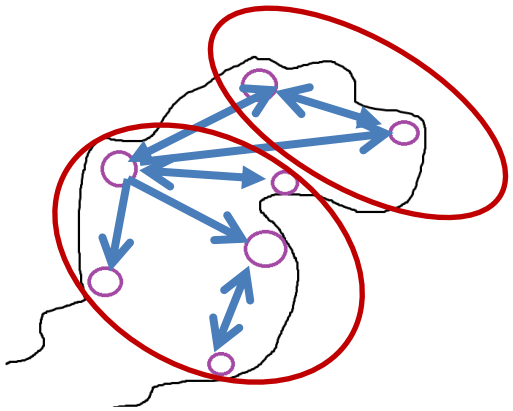


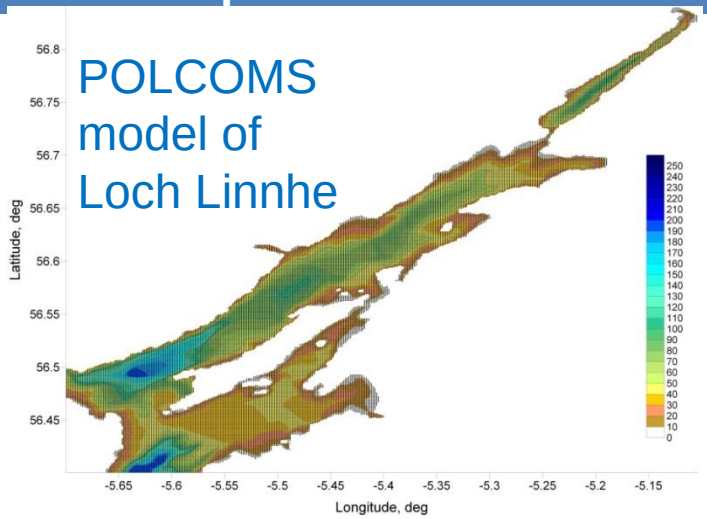
- **Primarily for sea lice**
  - 0.19€ kg^{-1} (Costello 2009) – 0.39€ kg^{-1} (Abolofia et al 2017)

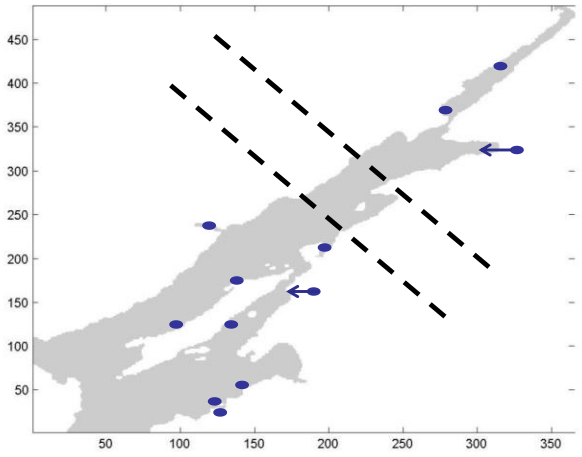
Loch Linnhe



- Large sea loch / fjord
  - ~ 60 km
- 10 “active” salmon farms
  - 2 companies in the Linnhe system
  - 6 farms in adjacent lochs
- Consented biomass approx. 17352t ≈ 10%
- 2 FMA
- Est. £50m production
- Est. £3m parasite control



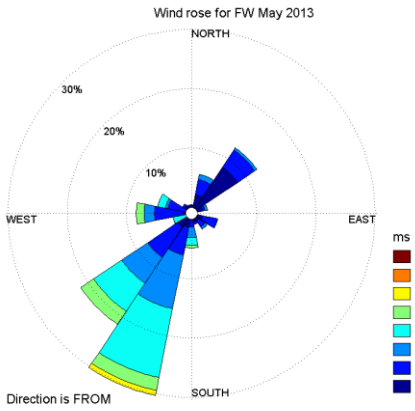


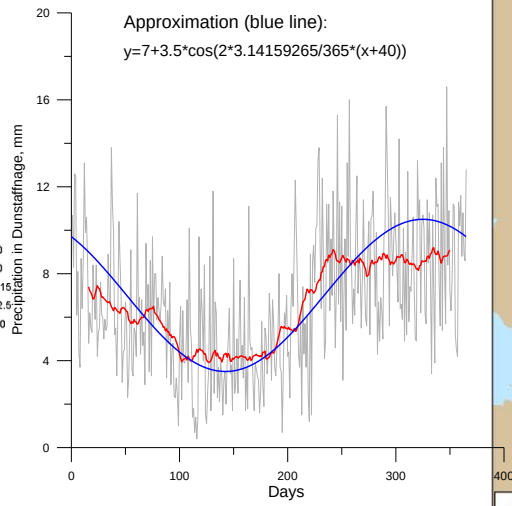


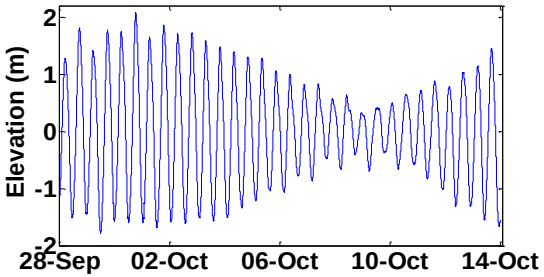
Salama et al (2013), J Fish Dis, 36: 323–337

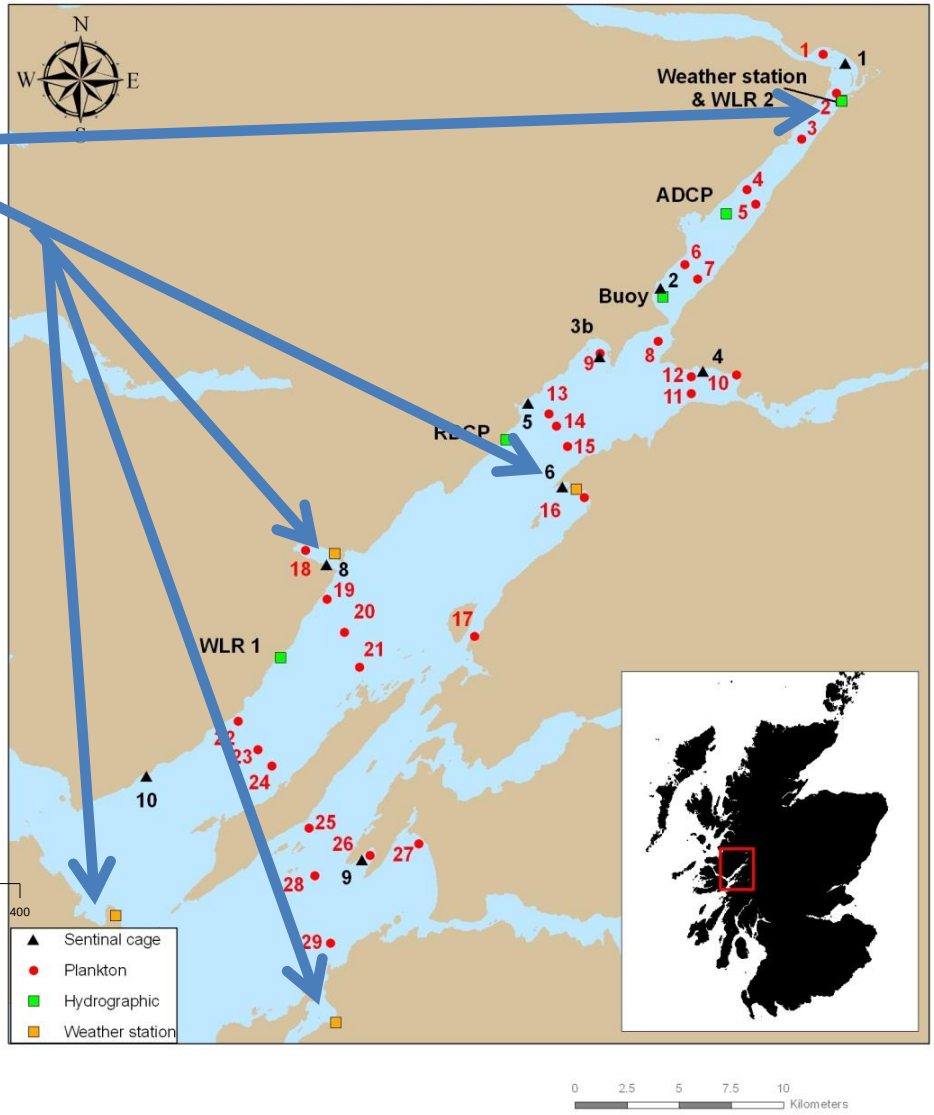
Forcing Data

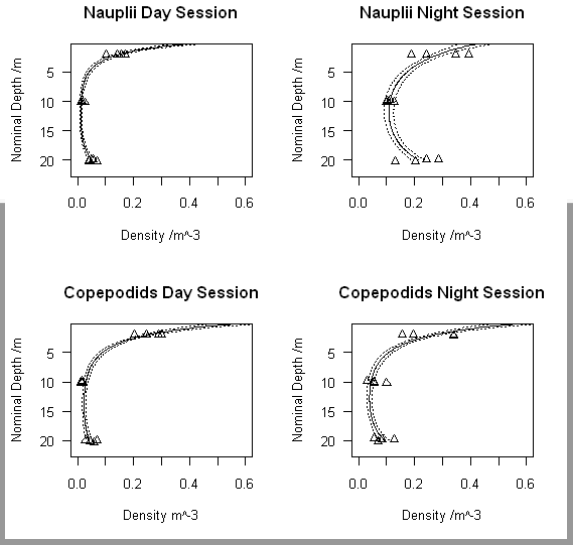
- **Physical data**
  May/Oct 2011,2012,2013
- **Collecting data**
  - Force the hydrodynamic model

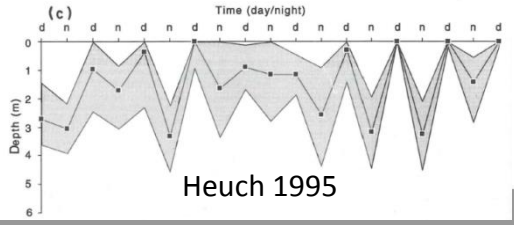












Heuch 1995

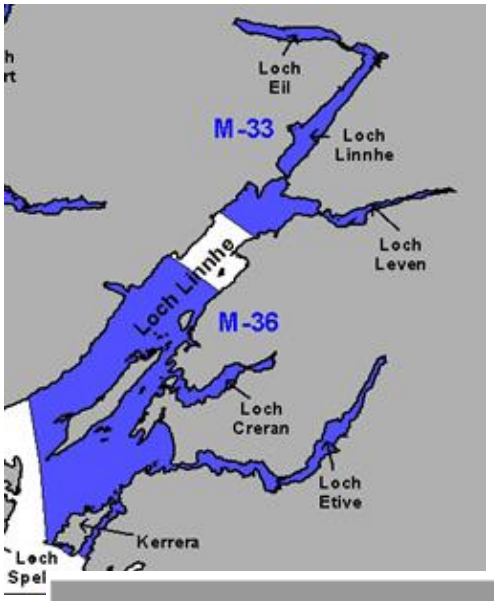
Hydrodynamic model (Ivanov et al 2011)

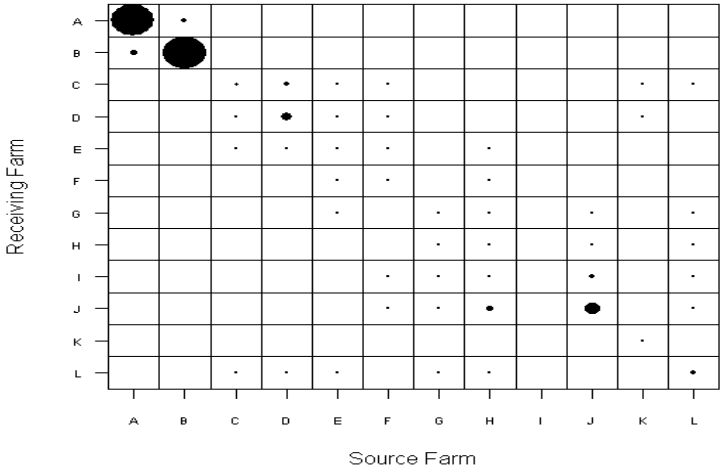
- POLCOMS 100m x 100m fixed grid
- Drivers: Freshwater, tides, wind
- 3D resolved at the surface layer
- 30 min resolution

Particle-tracking model (Amundrud & Murray 2009)

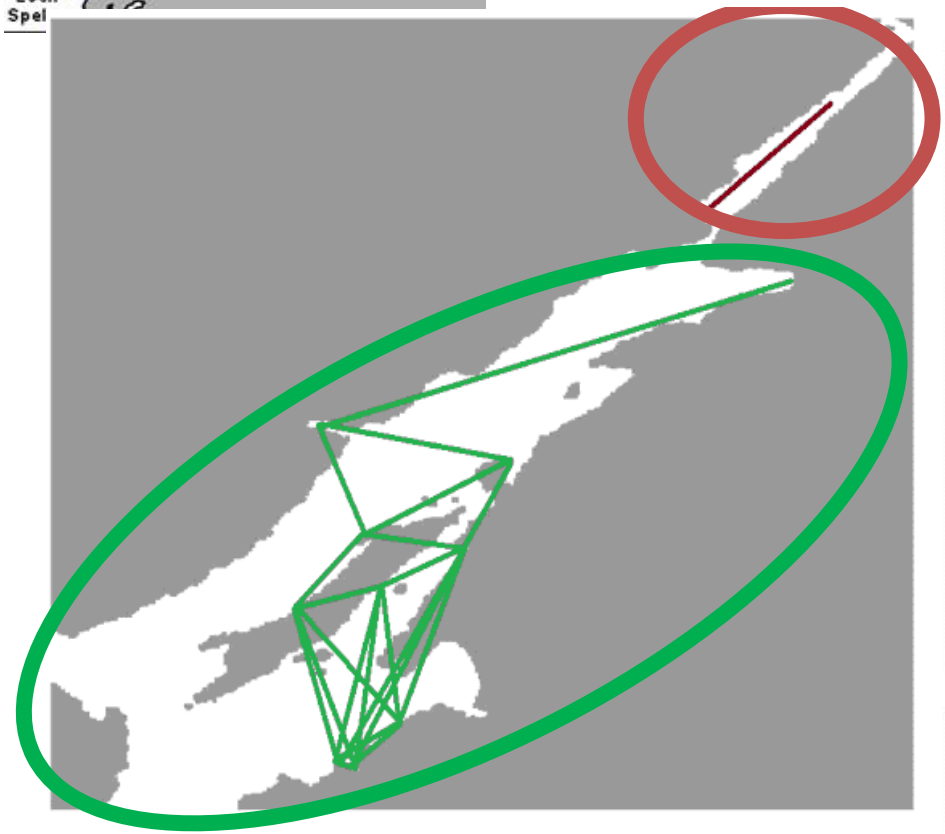
- 4th Order Runge-Kutta
- Age (10% h^{-1})
- Decay (1% h^{-1})
- Released from farms (weighted by transformed relative farm counts)
- Move in the surface layer
- Sticky land/sea boundaries
- Open sea boundaries
- 14d release + 5d

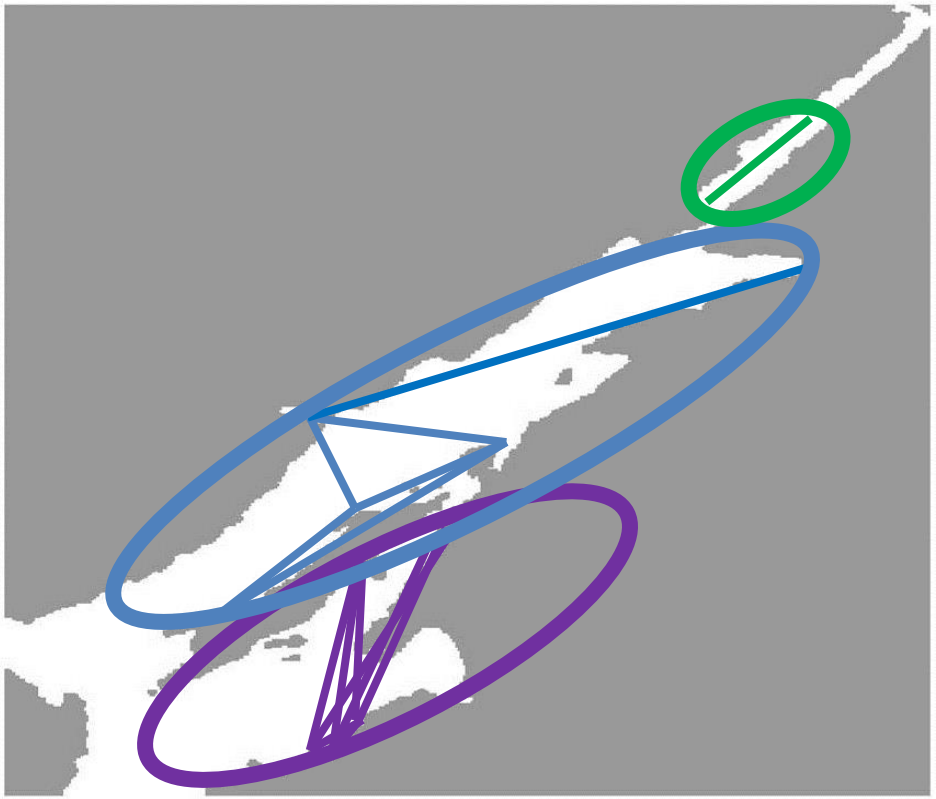
Salama NKG, et al (*in press*). *J Fish Dis*
https://doi.org/10.1111/jfd.12693



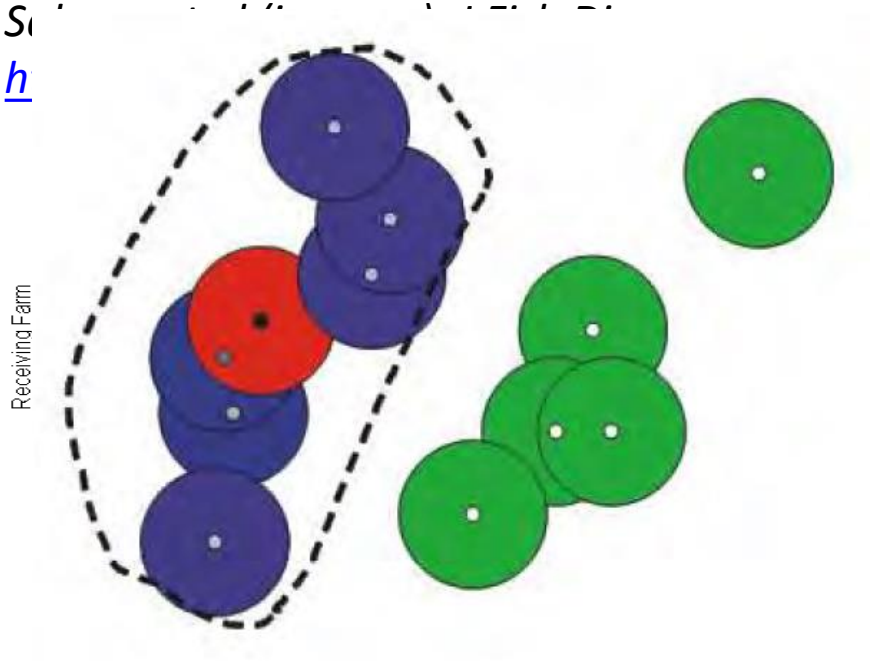


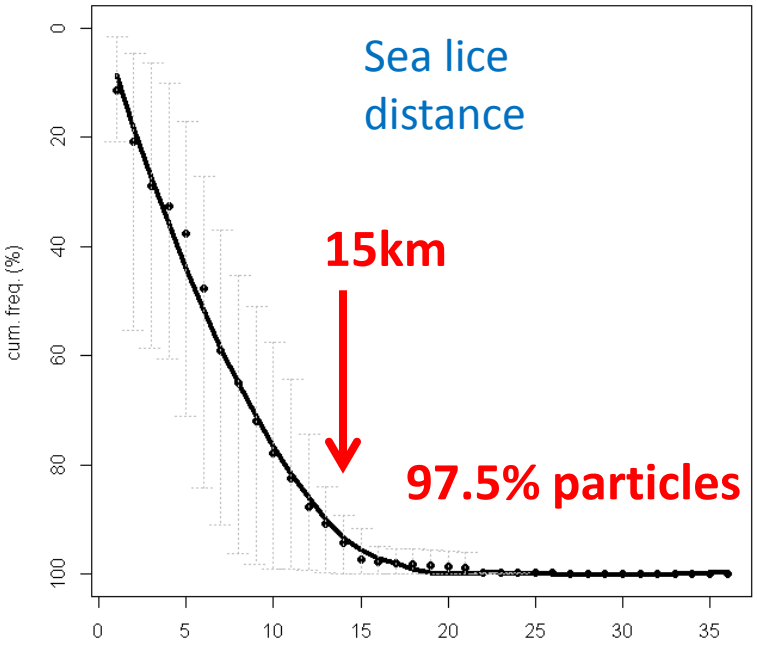
marinescotland science

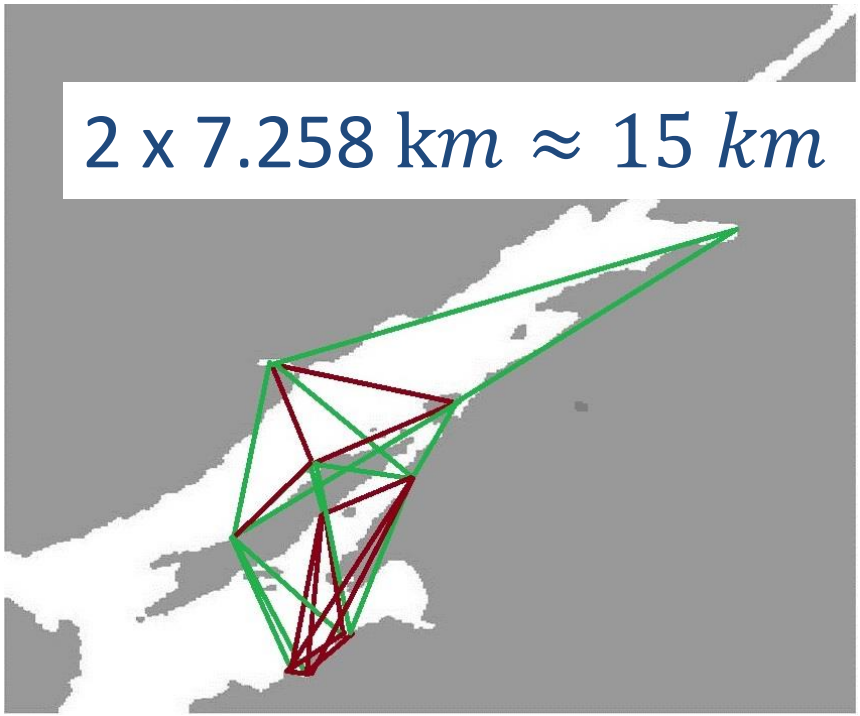


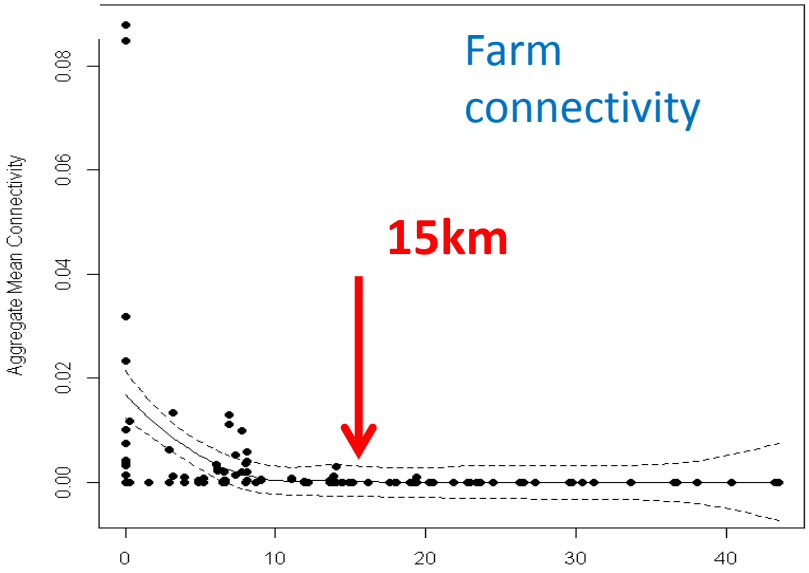


Salama et al (2016) J Fish Dis, 39: 419–428.







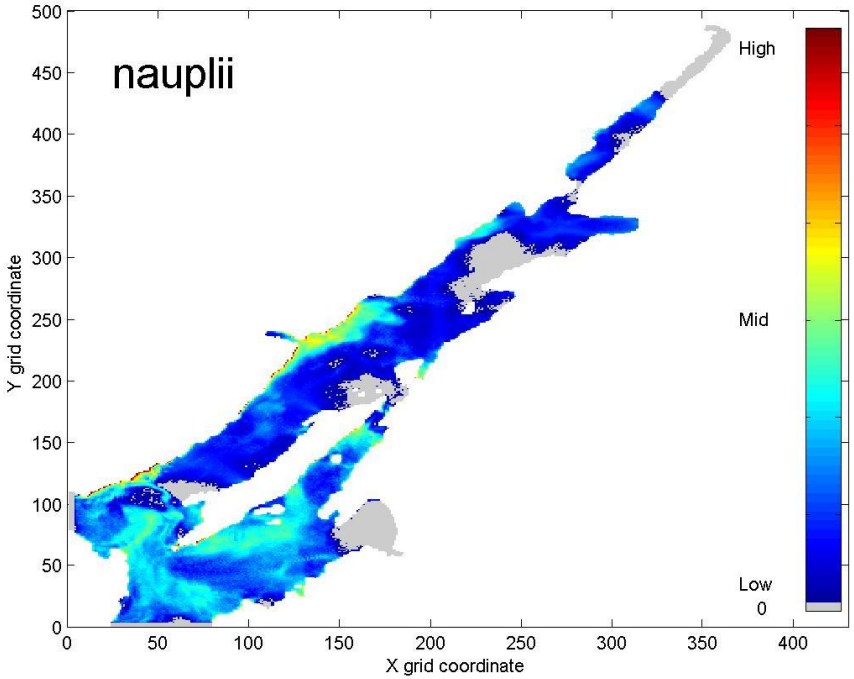


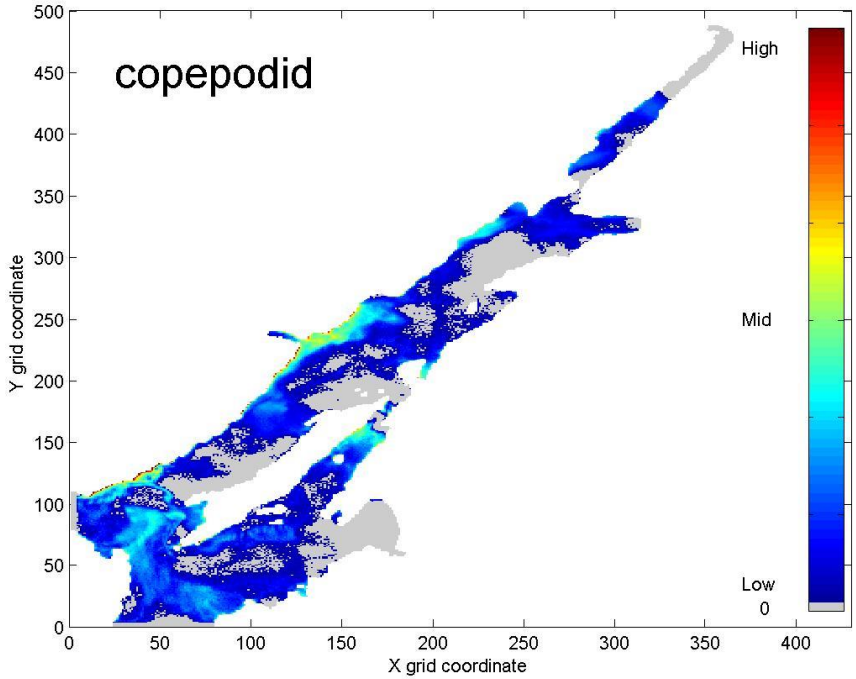
Predictions: Where lice accumulate

Relative input from transformed farm lice information

Density of relative Particle-hours

marinescotland science





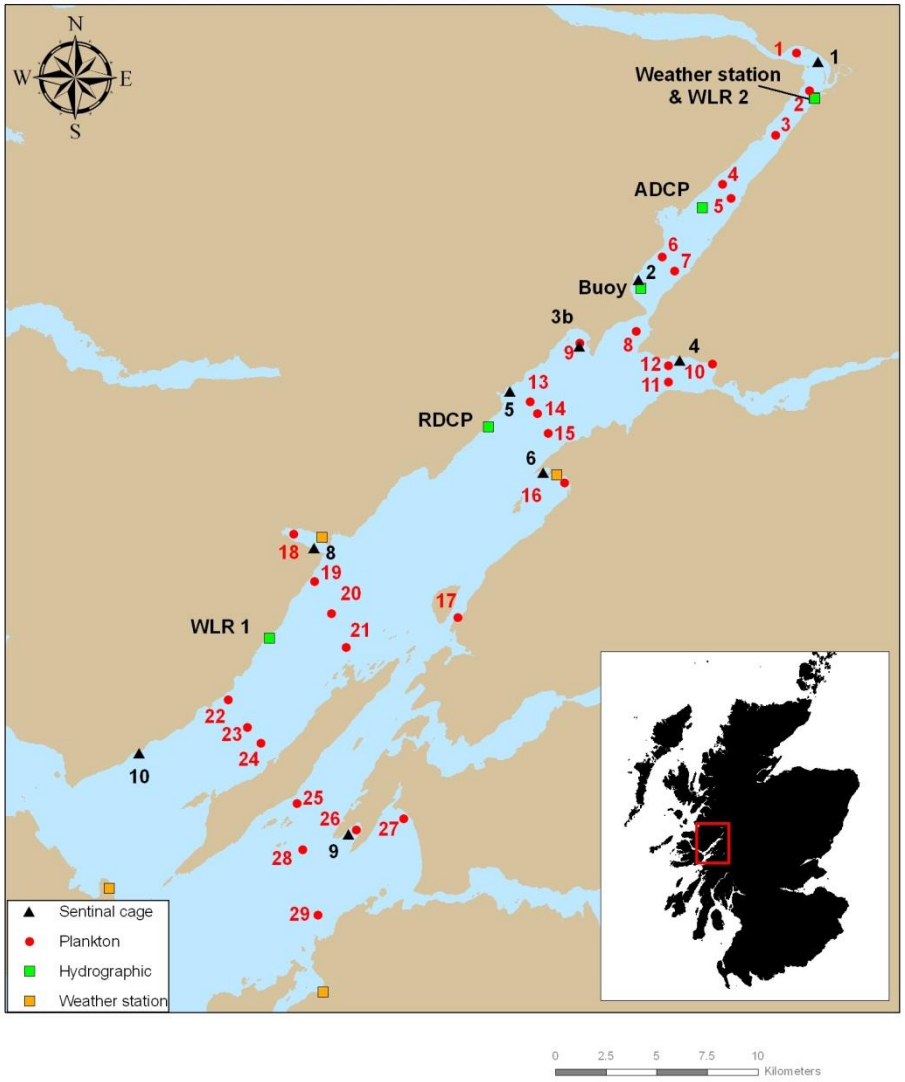
Lower relative density of particles

Higher relative density of particles

Grey: zero particles

Model Confidence

- **Biological Sampling (May/Oct 2011,2012,2013)**
  - **Undertaking plankton trawls**
    - 31 stations in duplicate each week
    - For assessing transport model predictions
  - **Deploy 10 sentinel cages**
    - 50 fish each week
    - Assess settlement stage



Model Confidence

Sentinel cages

- **Used since mid 2000's**

- **10 sites**
- **50 smolts per week**
- Euthanised
  ethyl 3-aminobenzoate methanesulfonate salt (MS222; Sigma-Aldrich) dose of 1 g l^{-1}.
- **Fish individually bagged for survey**
- **Lice**
  - **Counted**
  - **Staged**

Vol. 5: 49–59, 2014
doi: 10.3354/aei00094
AQUACULTURE ENVIRONMENT INTERACTIONS
Aquacult Environ Interact
Published online March 20

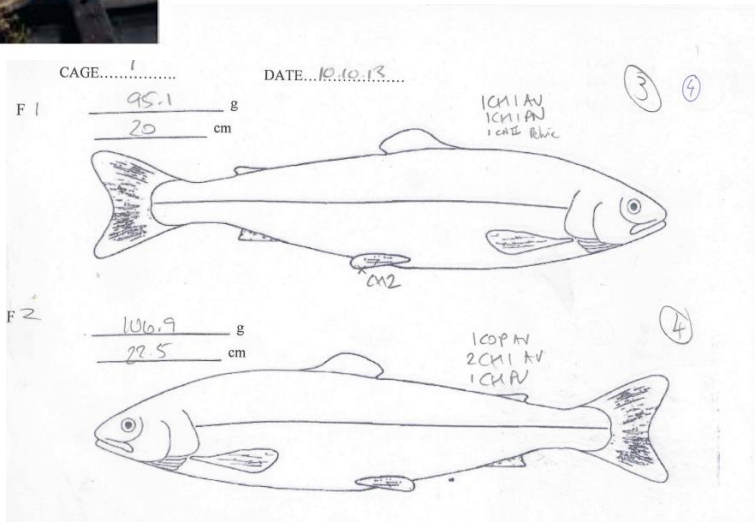
OPEN ACCESS

Using sentinel cages to estimate infestation pressure on salmonids from sea lice in Loch Shieldaig, Scotland

Campbell C. Pert[1,*], Rob J. Fryer[1], Paul Cook[1], Rachel Kilburn[1], Sonia McBeath[1], Alastair McBeath[1], Iveta Matejusova[1], Katy Urquhart[1], Sarah J. Weir[1], Una McCarthy[1], Catherine Collins[1], Trish Amundrud[1], Ian R. Bricknell[1,2]

[1]Marine Scotland Science, Marine Laboratory, PO Box 101, 375 Victoria Road, Aberdeen, Scotland AB11 9DB, UK
[2]School of Marine Sciences, University of Maine, 5735 Hitchner Hall, Orono, Maine 04469-5735, USA

marinescotland science



Model Confidence

Vol. 81: 109–117, 2008
doi: 10.3354/dao01946
DISEASES OF AQUATIC ORGANISMS
Dis Aquat Org
Published August 27

Reduced *Lepeophtheirus salmonis* larval abundance in a sea loch on the west coast of Scotland between 2002 and 2006

Michael J. Penston*, Colin P. Millar, Ian M. Davies

Fisheries Research Services Marine Laboratory, 375 Victoria Road, Aberdeen AB11 9DB, UK

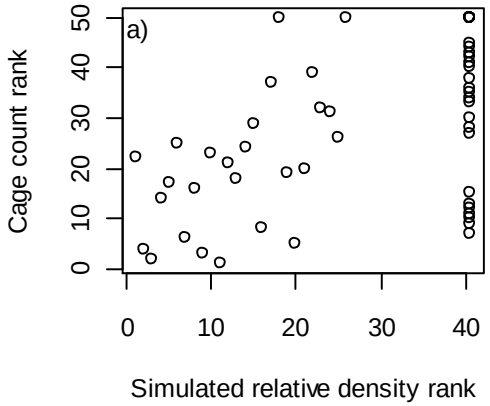
Plankton trawls

- Used since early 2000's
- 31 sites weekly
- Duplicate
- 5 min trawl
- Plankton net
  - 0.5m mouth x1.5m length
  - 150µm mesh
- Nets individual rinse
- Stored in 4% formaldehyde
- Lice
  - Counted
  - Staged
- Lice ID using standard keys and subsample by PCR

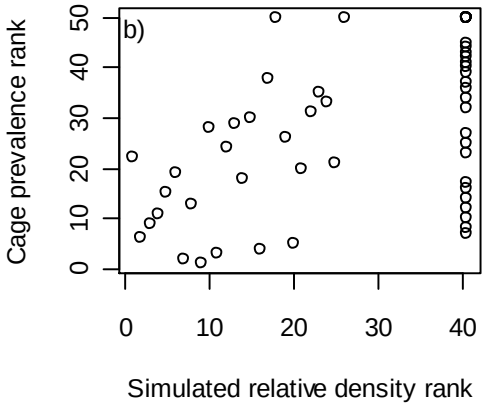
Model Confidence

marinescotland science

ρ(52)= 0.51***

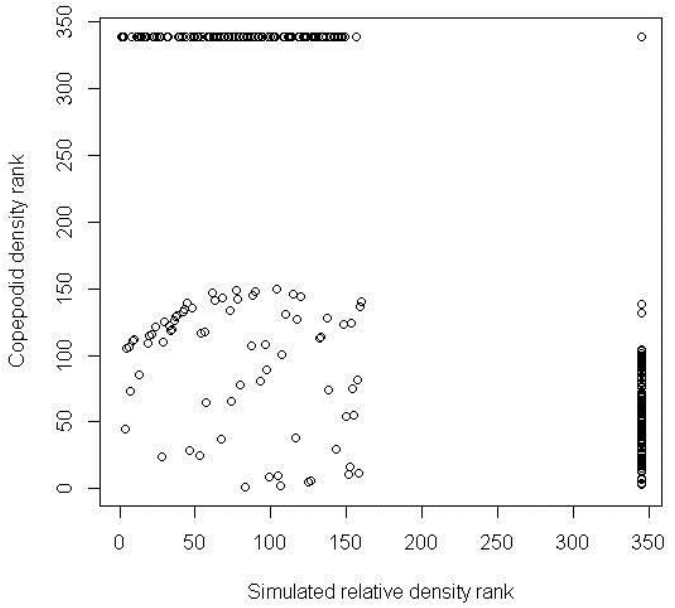


ρ(52)= 0.51***

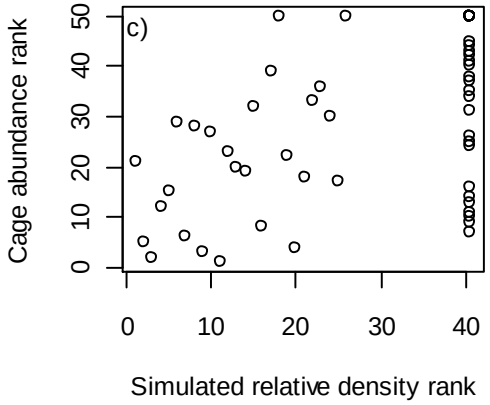


- **Model input weighted by transformed count score**
- **Reflecting a feature of the model**

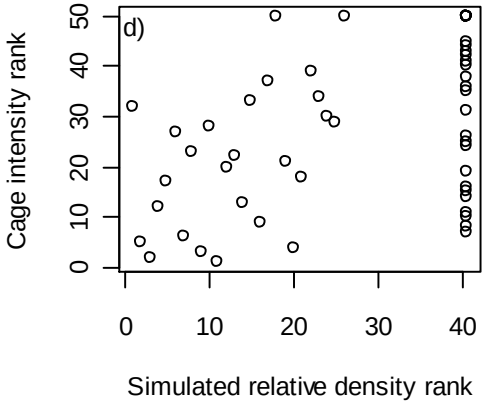
Plankton trawl ρ(526)= 0.19***



Sentinel fish



ρ(52)= 0.48***



ρ(52)= 0.45***

Which farm first?

marinescotland science

POPULATION MODEL

Temperature (*T*) mediated:

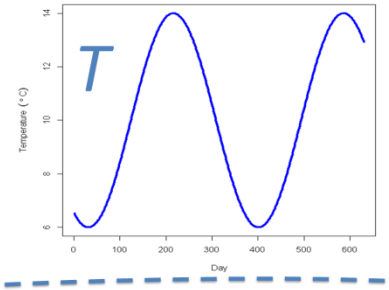
- **Maturation (*m*) settlement (*s*), egg production (*λ*)**

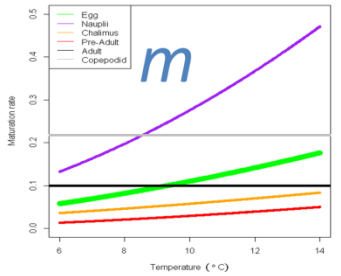
salmon lice sources:

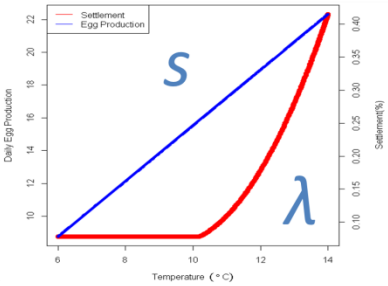
- **wild salmon, neighbours, internal**

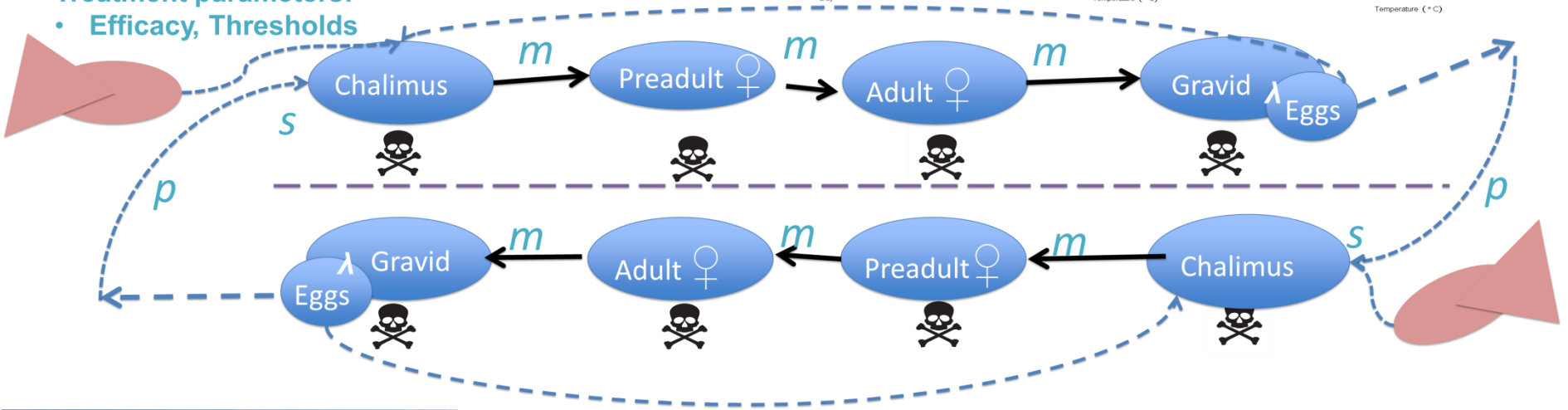
Treatment parameters:

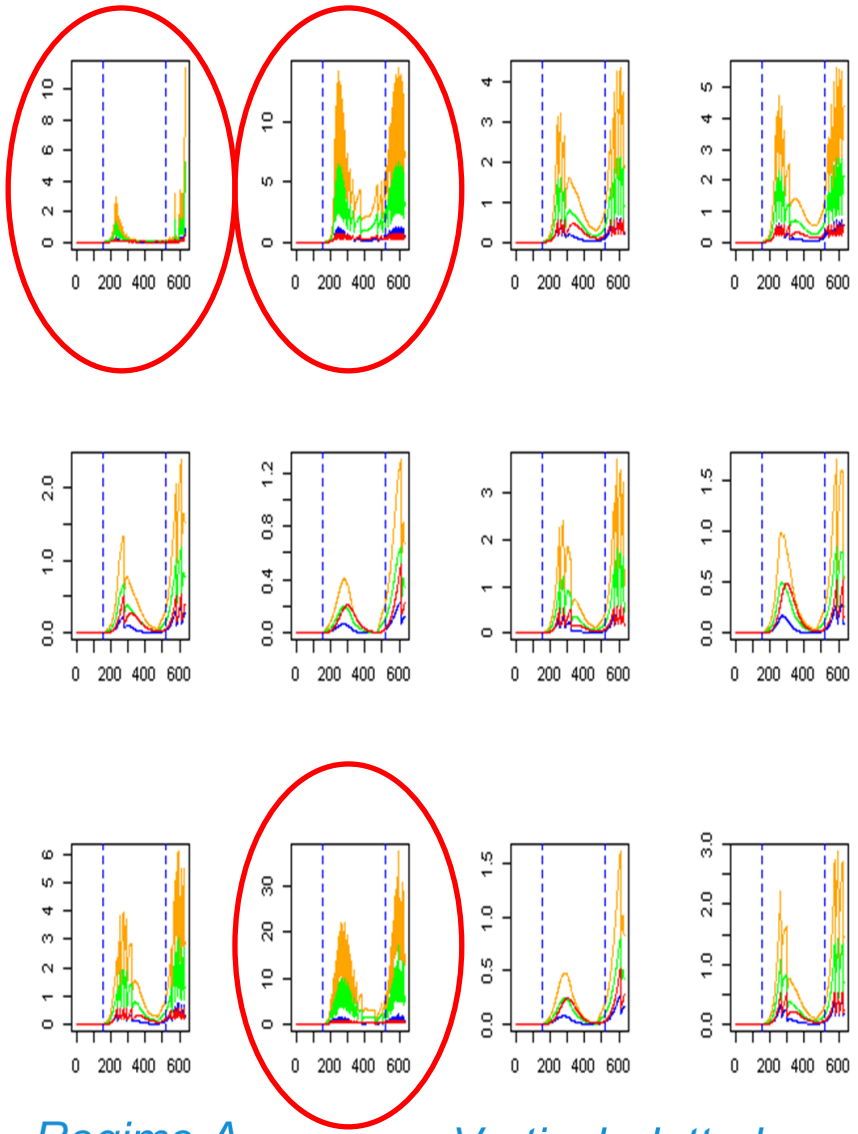
- **Efficacy, Thresholds**





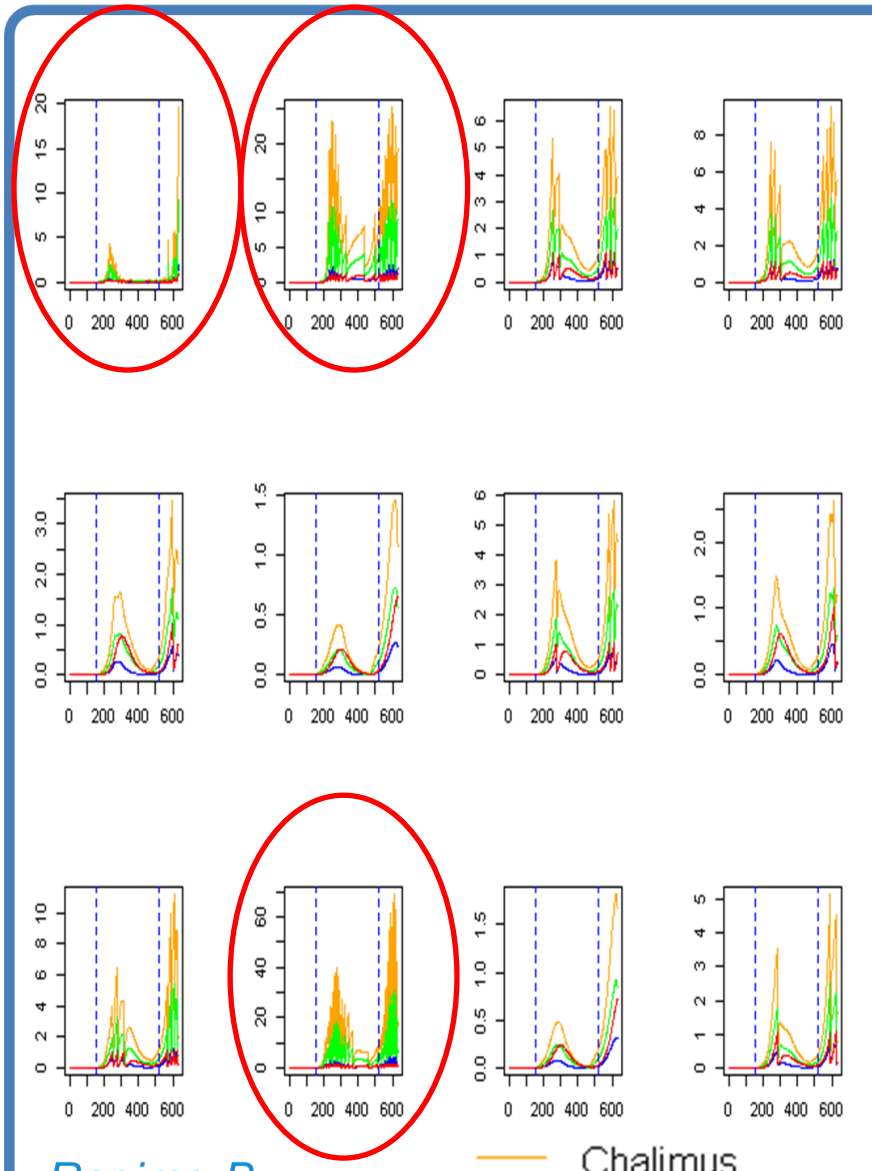






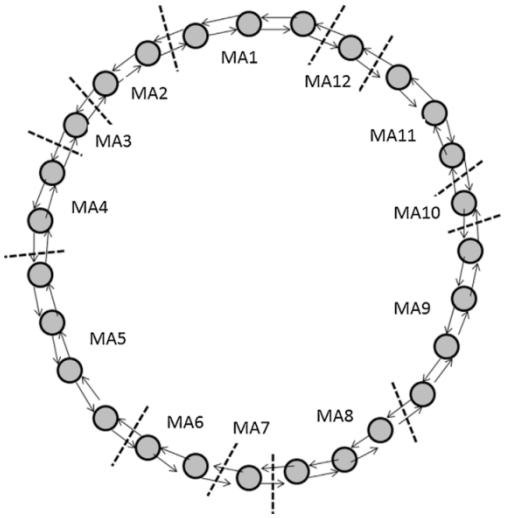
Regime A
Treatment level:
0.5 gravid
Efficacy : 0.5

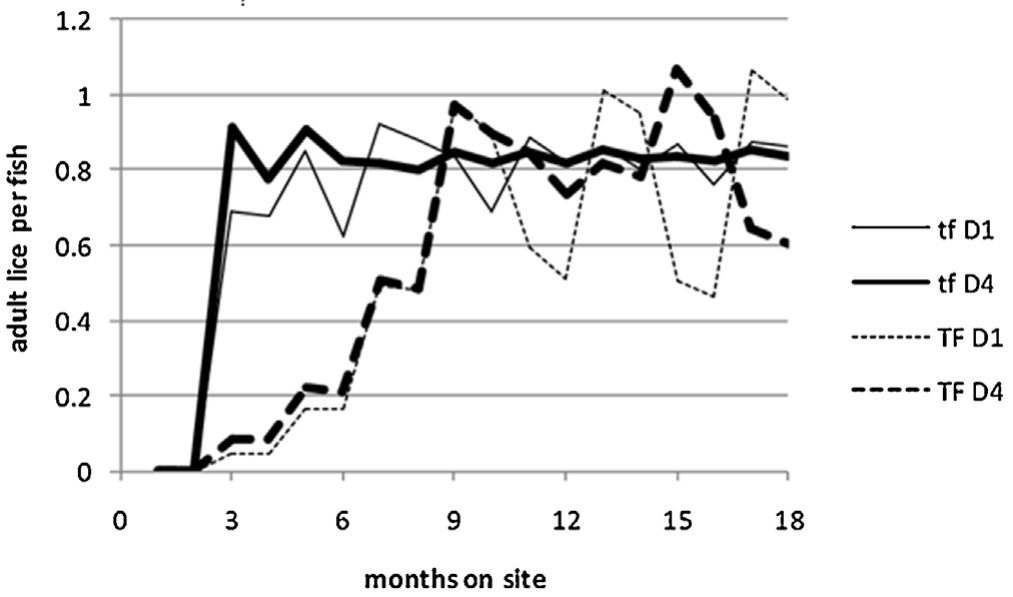
Vertical dotted lines = wild salmon returns

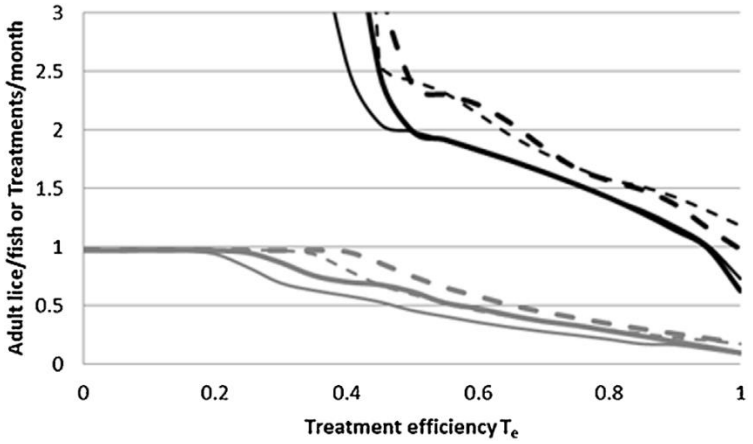


Regime B
Treatment level: :
1 gravid
Efficacy : 0.7

Do coordinated zones work?



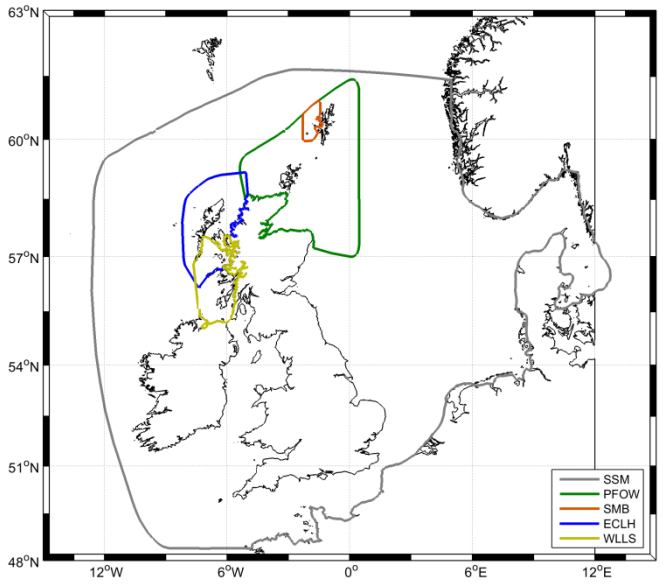


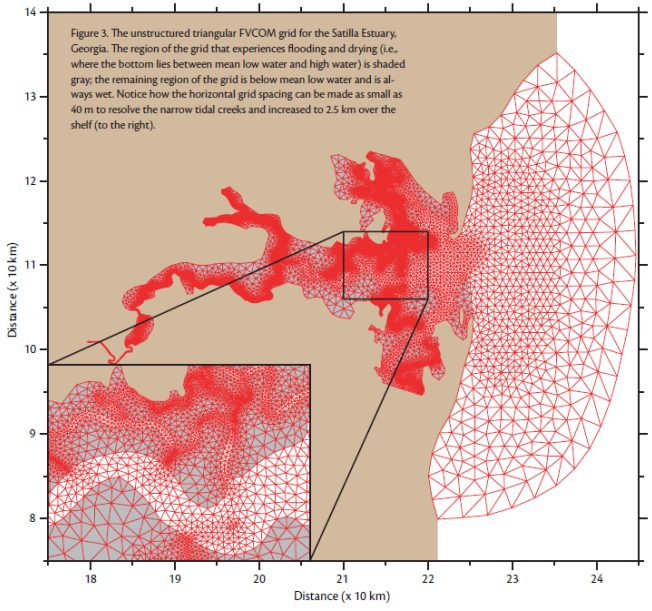


Averaged adult lice loads with time on site under two management strategies(TF synchronous (dashed) or tf asynchronous (solid)) and two dispersal scenarios(local D1 (thin), mixed D2 (thick))

Murray & Salama (2016) *Ecol. Model.* **337**:39 – 47

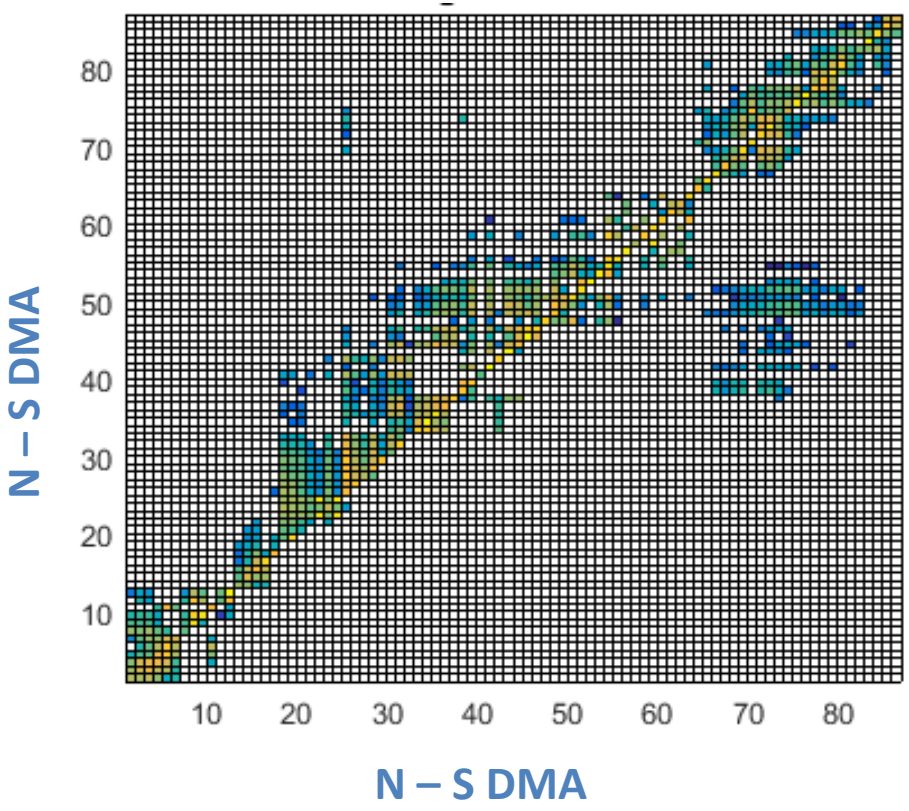
Sea lice – Scottish shelf Model





12 year averaged model

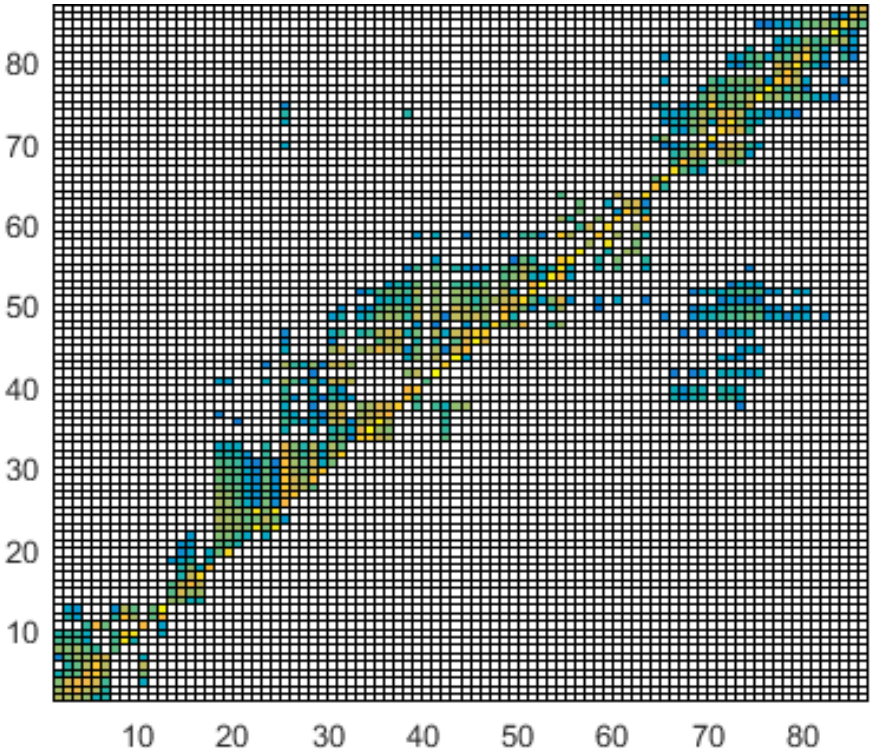
Released across management areas
Sea lice particles "lifespan"
18 days (winter)
15 days (spring and autumn)
10 days (summer)



marinescotland science

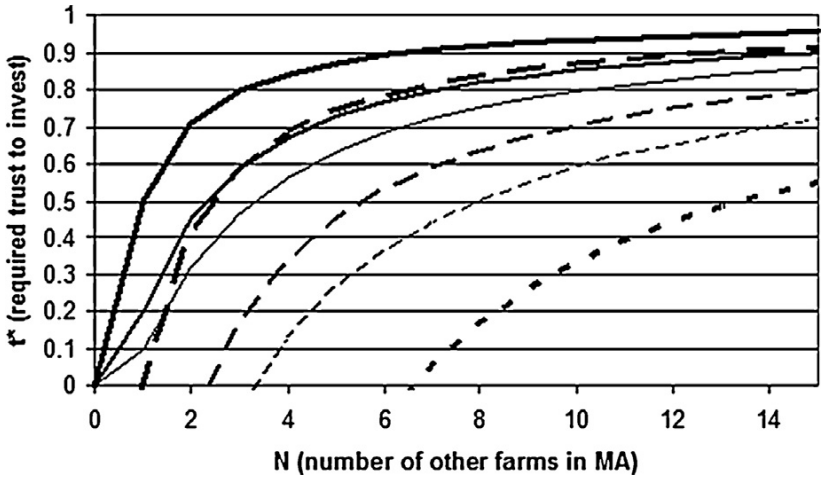
Regional retention of sea lice
Most MA self expose
Transmission to neighbour MA
Low p(transmission) between MA

Threshold: 10^{-5}



Farms/zone ?

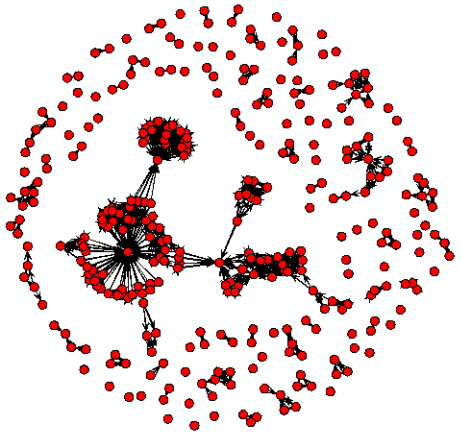
Trust



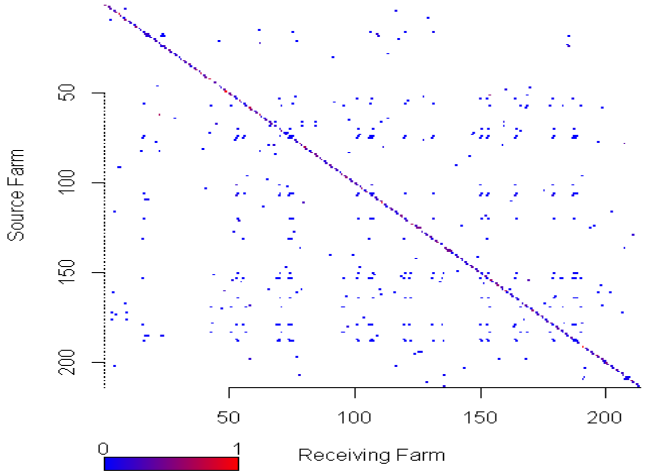
Murray (2014) Prev vet med 115: 255

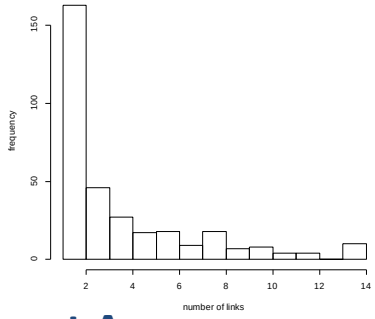
marinescotland science

Parameterised with ISAV
Simplified hydrodynamic model



1261 edges
Density: 0.009
Connectedness: 0.03
mean = 3.8 (SD:6.45)
Max= 36





Locally connected
Supports Disease Management Areas
No "ideal" number

Salama et al (under review) Aquacult.

SUMMARY

marinescotland science

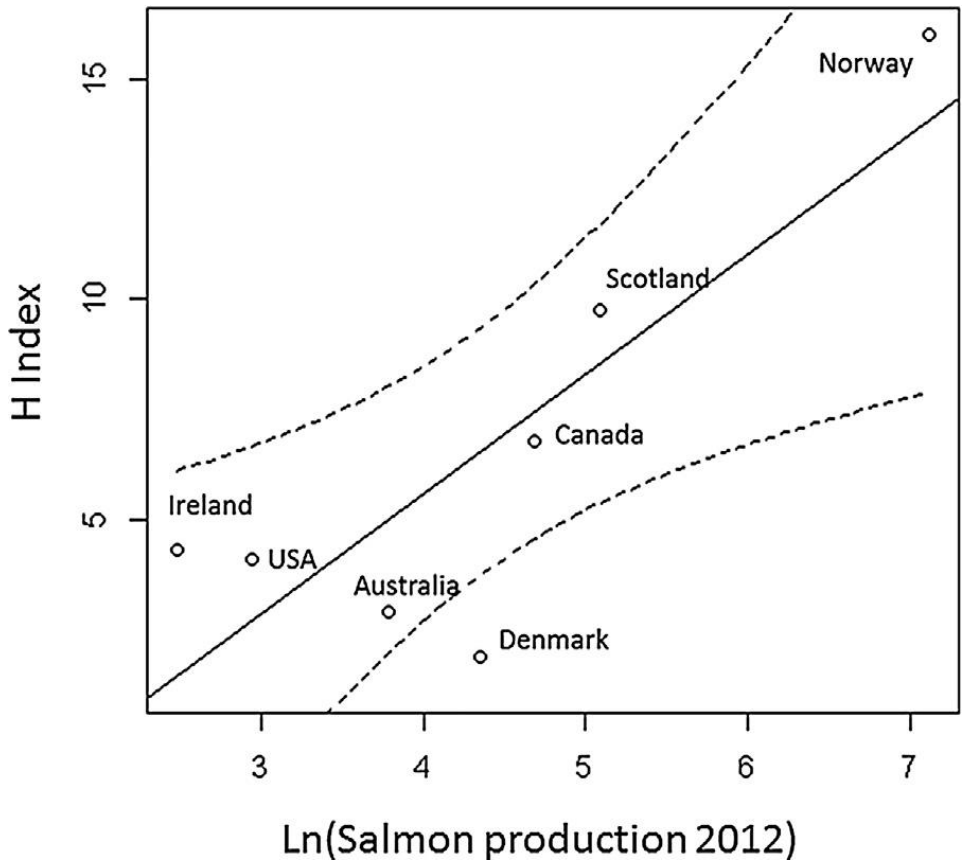
- Disease reduces production capacity
- Spatial management legislation and industry code
- Modelling help defines spaces
  - Simple expressions
  - Expressional models
  - Bio-physical models
  - Networks

Less disease = >less treatment = >less impact + $

- If production and carrying capacity is to increase……

Research and production

marinescotland science



Disease or pathogen	Synonym/short name	TI	TS
Amoebic Gill Disease	AGD	**23**	28
Bacterial Kidney Disease	BKD	**12**	29
CardioMyopathy Syndrome	CMS	**9**	13
Diplostomum spathaceum	D. spath	**0**	9
Epizootic haematopoietic necrosis	EHN	**0**	5
Enteric Redmouth	ERM	**5**	19
Epitheliocystis	Epitheliocystis	**5**	15
Furunculosis	Furunc	**32**	67
Gyrodactylus salaris	G.salaris	**22**	36
Heart and Skeletal Muscle Inflammation	HSMI	**10**	12
Infectious haematopoietic necrosis	IHN	**8**	33
Infectious Salmon Anaemia	ISA	**28**	43
Infectious Pancreatic Necrosis	IPN	**24**	35
Pancreas Disease	PD	**22**	29
Proliferative Kidney Disease	PKD	**3**	20
Red Mark Syndrome	RMS	**0**	0
Red vent	Red Vent	**3**	12
Saprolegnia	Saprolegnia	**4**	12
Sarcocystis	Sarcocystis	**0**	1
Sea lice	Sea lice	**41**	54
Salmon rickettsial syndrome	SRS	**8**	22
Vibriosis	Vibriosis	**17**	53
Viral haemorrhagic septicaemia	VHS	**2**	28

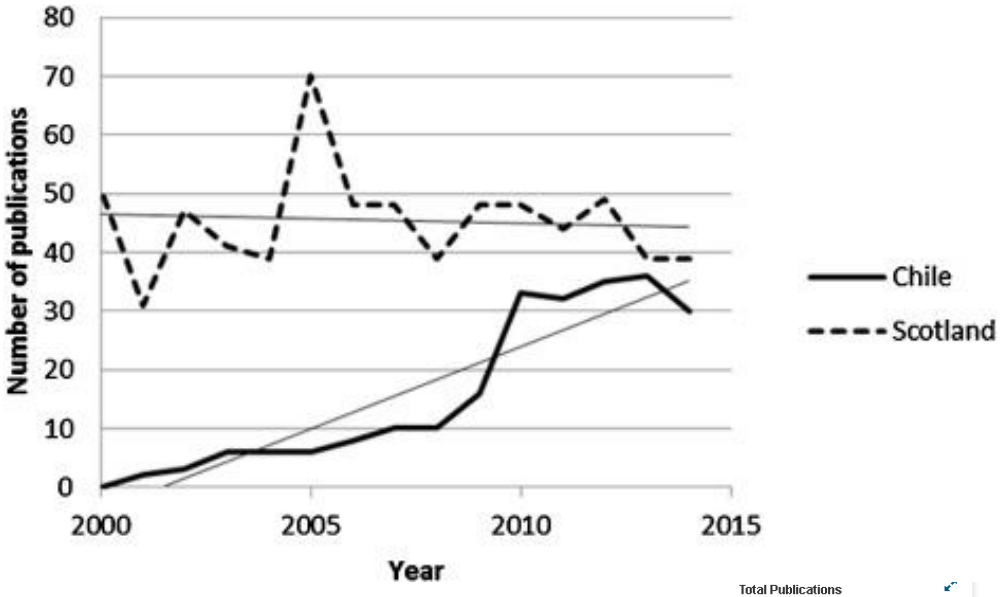
Chile SRS US $100M
Not elsewhere

Murray et al (2016) Prev Vet Med 126: 199

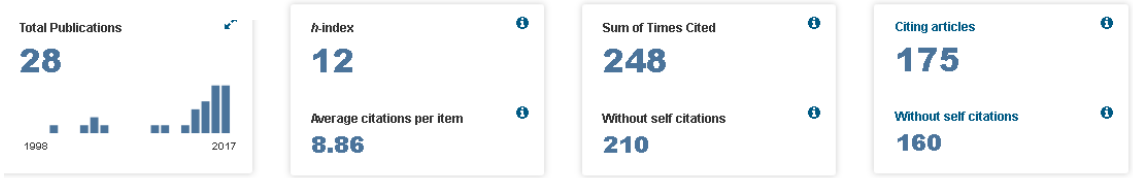
Murray & Salama (*In press*) CAB Reviews

Research and production – Good news

marinescotland science

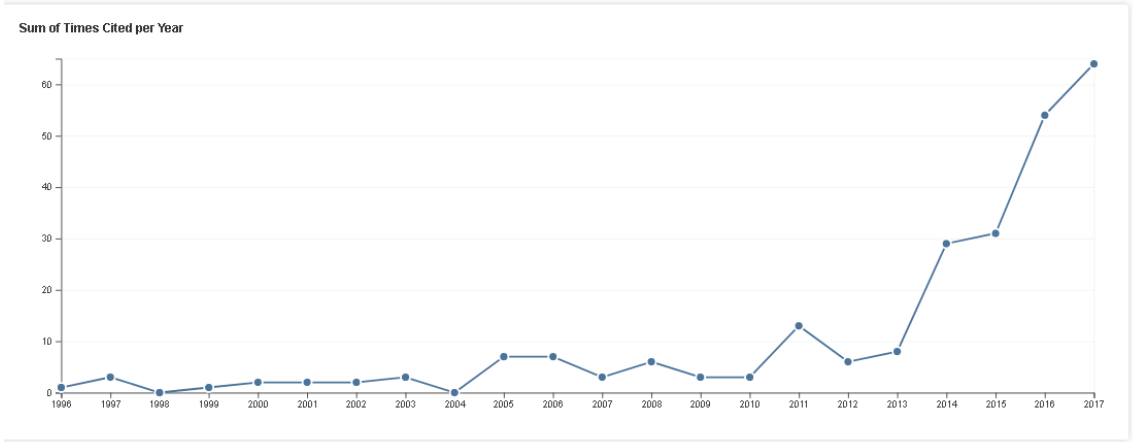


SRS US $100M



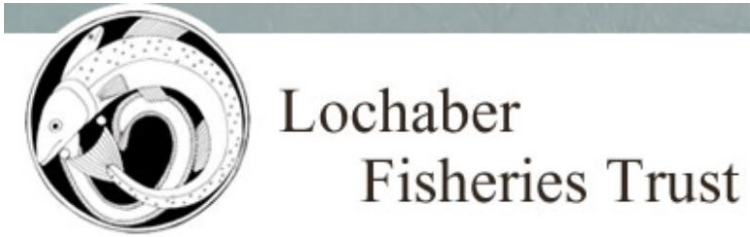
WOK MIMAS

TI=((salmon) AND (Piscirickettsiosis OR "Salmon rickettsial syndrome" OR "Piscirickettsia salmonis")) AND CU = (Chile)



Murray et al (2016) Prev Vet Med 126: 199

Murray & Salama (*In press*) CAB Reviews



Environmental transmission

Murray AG**, Salama NKG, (2017)** *CAB Reviews* **12**, No. 032

Salama NKG, et al (*in press*). *J Fish Dis* https://doi.org/10.1111/jfd.12693

Wallace IS et al (2016) *J Fish Dis* **39**: 1021

Murray AG, **Salama NKG** (2016) *Ecol Model* **337**:39

Salama NKG, et al (2016) *Aquacult* **450**: 283

Salama NKG, et al (2016). *J Fish Dis* **39**: 419

Salama NKG, et al (2013) *J Fish Dis* **36**: 323

Salama NKG, Murray AG. (2013) *Prev Vet Med* **108**: 285

Salama NKG, Rabe B. (2013) *Aquacult Env Interact* **4**: 91

Salama NKG, Murray AG. (2011). *Aquacult Env Interact* **2**: 61