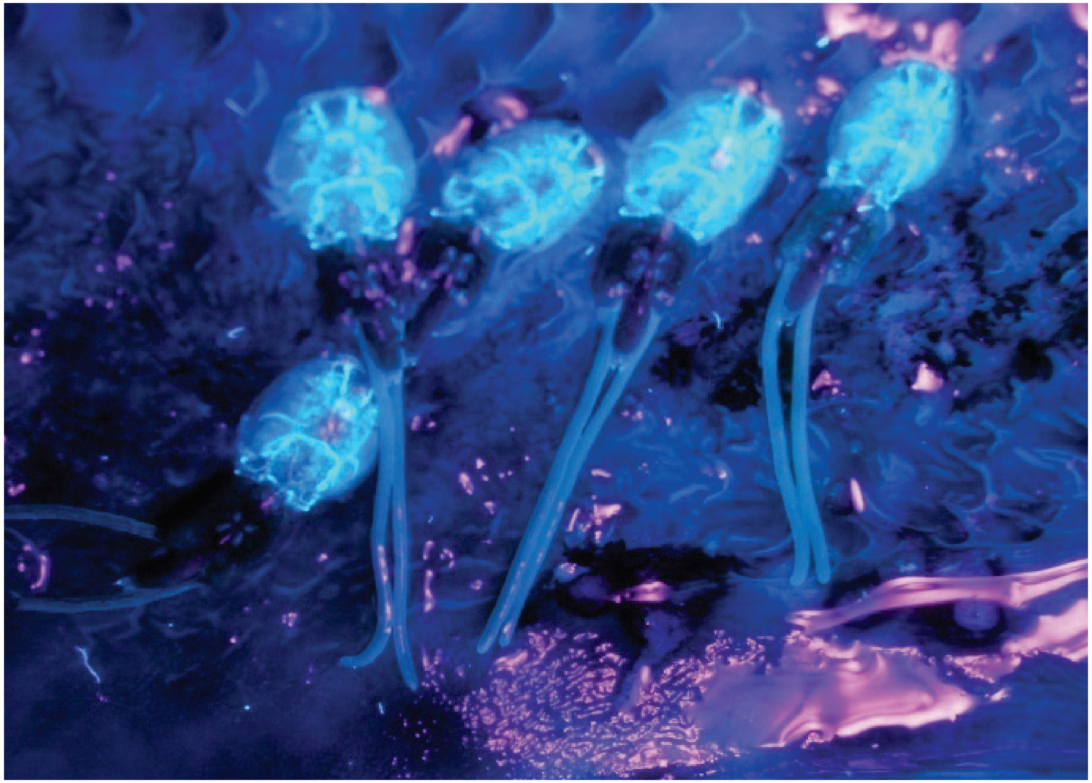
Using data-driven models to explore sea louse infestations on wild and farmed salmon



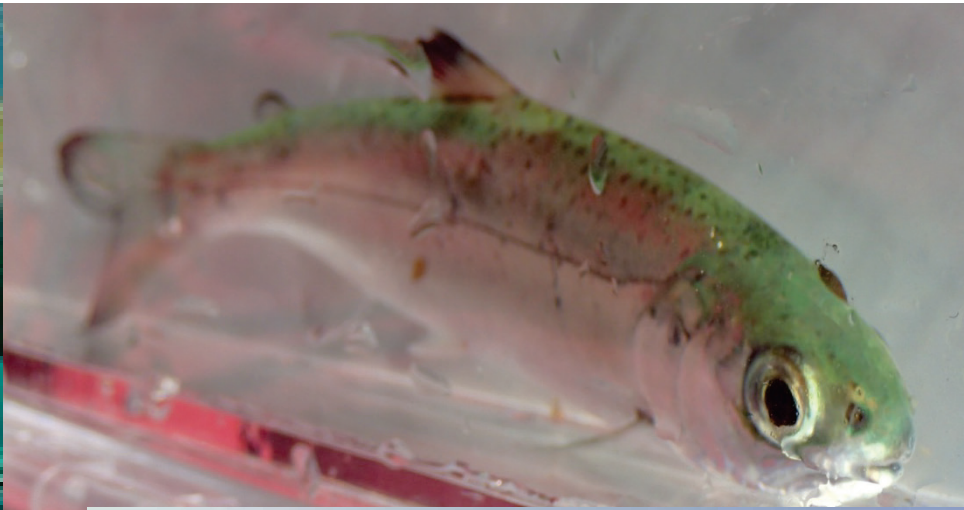
Maya Groner

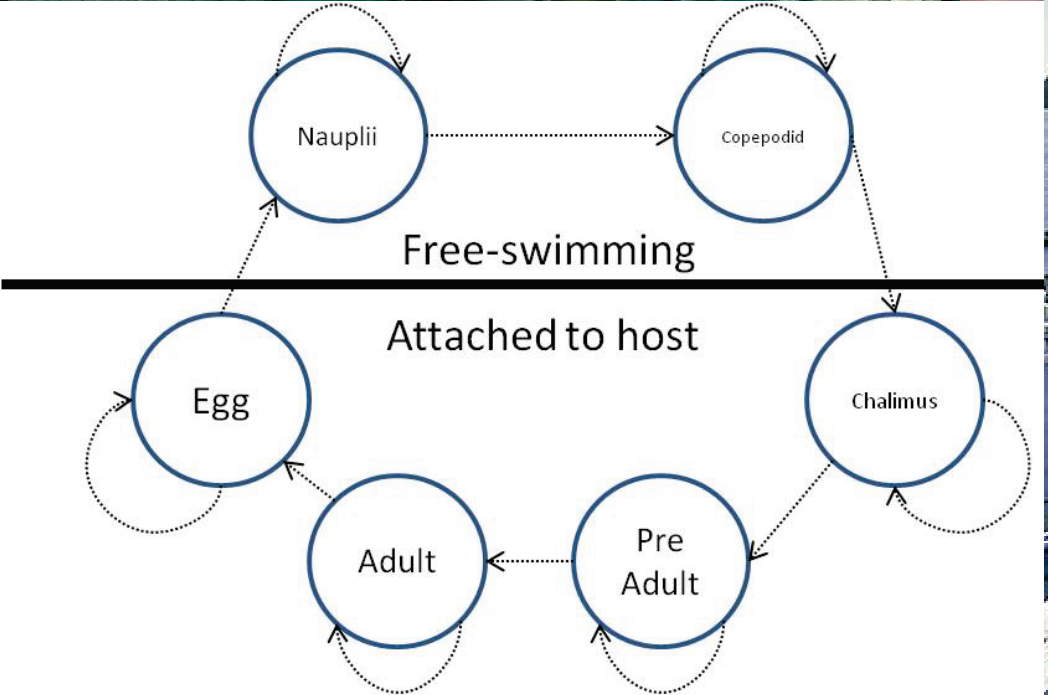
Atlantic Veterinary College
University of Prince Edward Island
Canada

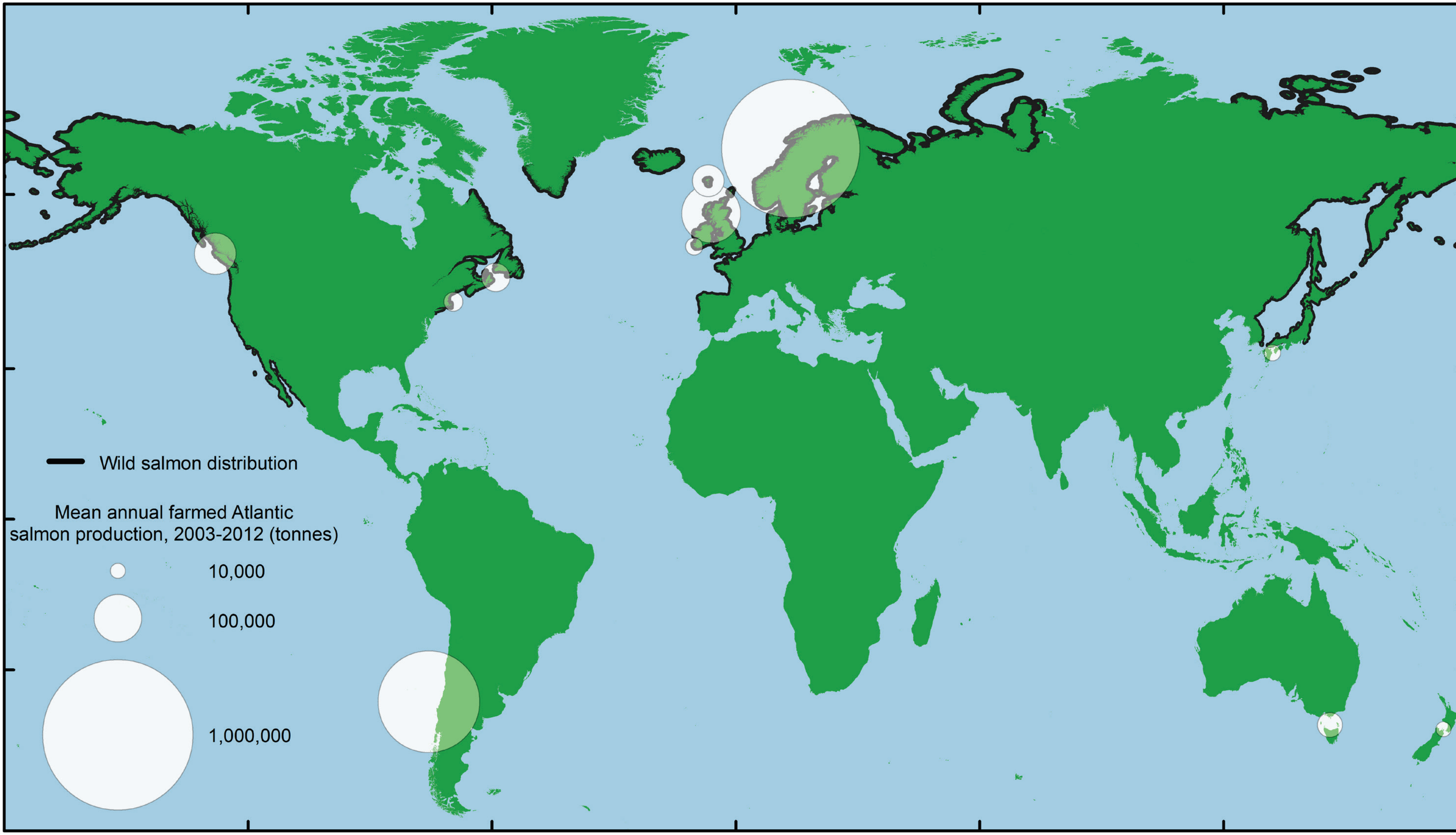
Sea louse think tank

Erin Rees
Marty Krkosek
Mark Lewis
Stephanie Peacock
Andrew Bateman
Neil Frazer
Crawford Revie
Gregor McEwan
Mark Fast
Luke Rogers
Uli Schlagel
Sophie St. Hilaire

Sea louse parasites of salmon







Groner et al. *In review*

Sea Lice – serious farm concern

undercurrentnews

seafood business news from beneath the surface

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Marine Harvest takes hit from sealice, 'extraordinary mortality' costs

Marine Harvest salmon farms in Scotland.

Share

October 22, 2014, 10:10 am

Undercurrent News

Sealice mitigation and extraordinary mortality shaved NOK 156.5 million ($23.7m) off Marine Harvest's profit in the third quarter of the year.

The world's largest salmon farmer said sealice mitigation in Norway cost it NOK 91.8 million in the quarter, taking the total costs so far this year to NOK 238.2m ($36.1m).

The group also incurred NOK 64.7m in costs from 'exceptional mortality' in Norway, Scotland, Canada and Chile.

Sea Lice - the wild angle

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Research

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http://dx.doi.org/10.1098/rspb.2012.2359

Received: 4 October 2012
Accepted: 15 October 2012

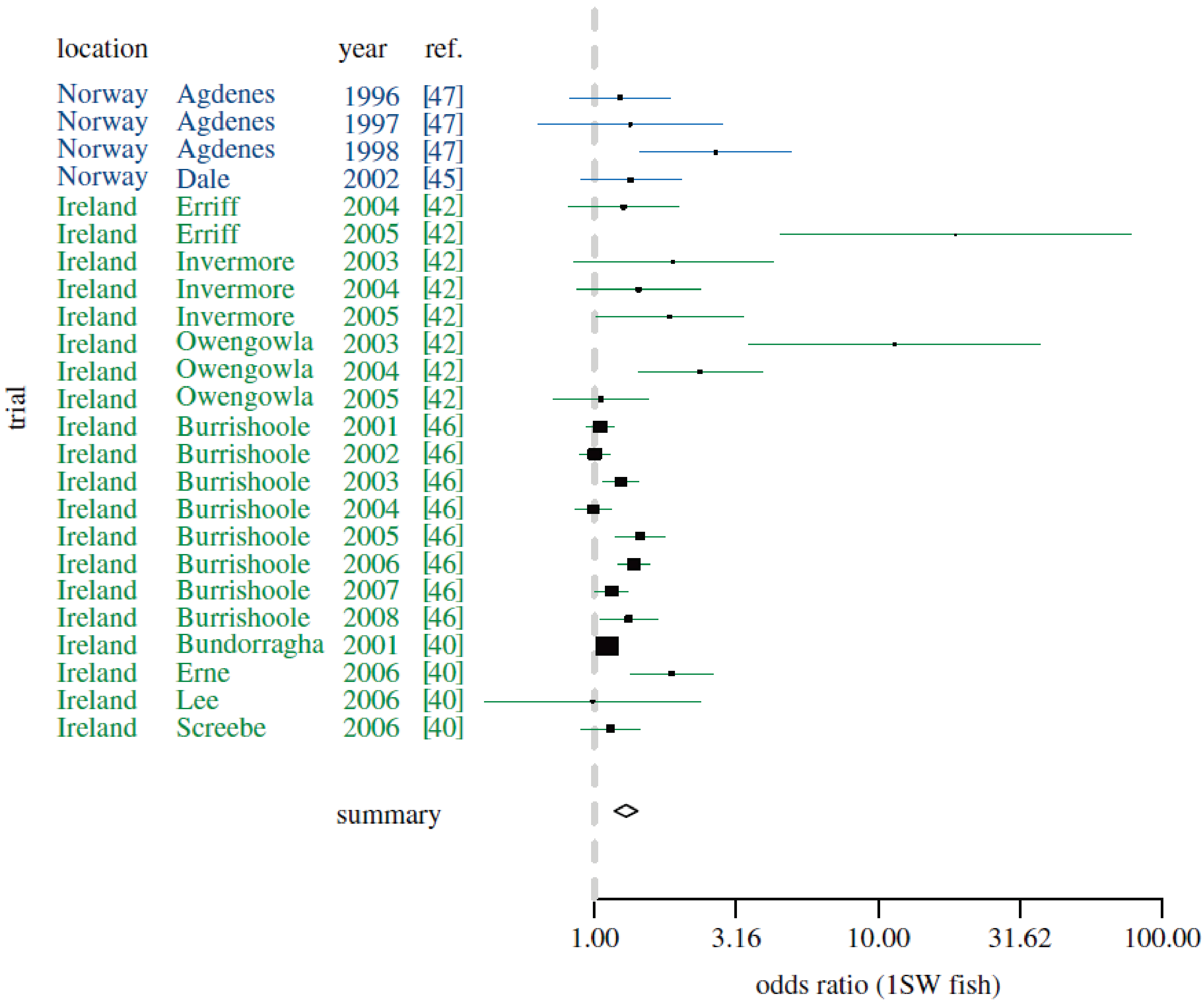
Impact of parasites on salmon recruitment in the Northeast Atlantic Ocean

Martin Krkošek[1], Crawford W. Revie[2], Patrick G. Gargan[3], Ove T. Skilbrei[4], Bengt Finstad[5] and Christopher D. Todd[6]

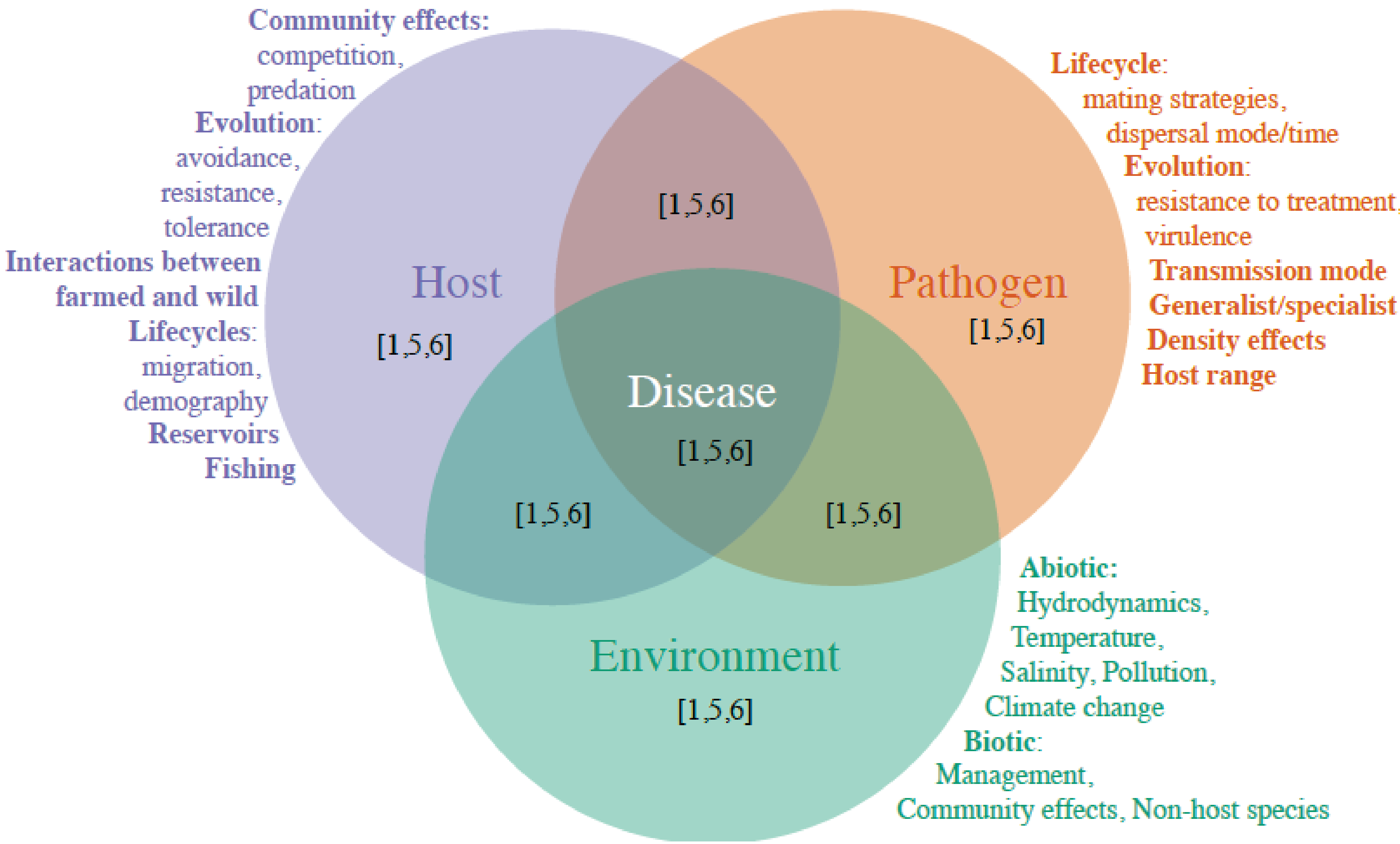
[1]Department of Zoology, University of Otago, Dunedin, New Zealand
[2]Atlantic Veterinary College, University of Prince Edward Island, Charlottetown, Canada
[3]Inland Fisheries Ireland, Dublin, Ireland
[4]Institute of Marine Research, Bergen, Norway
[5]Norwegian Institute for Nature Research, Trondheim, Norway
[6]Scottish Oceans Institute, University of St Andrews, St Andrews, UK

Parasites may have large effects on host population dynamics, marine fisheries and conservation, but a clear elucidation of their impact is limited by a lack of ecosystem-scale experimental data. We conducted a meta-analysis of replicated manipulative field experiments concerning the influence of parasitism by crustaceans on the marine survival of Atlantic salmon (*Salmo salar* L.). The data include 24 trials in which tagged smolts (totalling 283 347 fish; 1996–2008) were released as paired control and parasiticide-treated groups into 10 areas of Ireland and Norway. All experimental fish were infection-free when released into freshwater, and a proportion of each group was recovered as adult recruits returning to coastal waters 1 or more years later.

Sea Lice - the wild angle

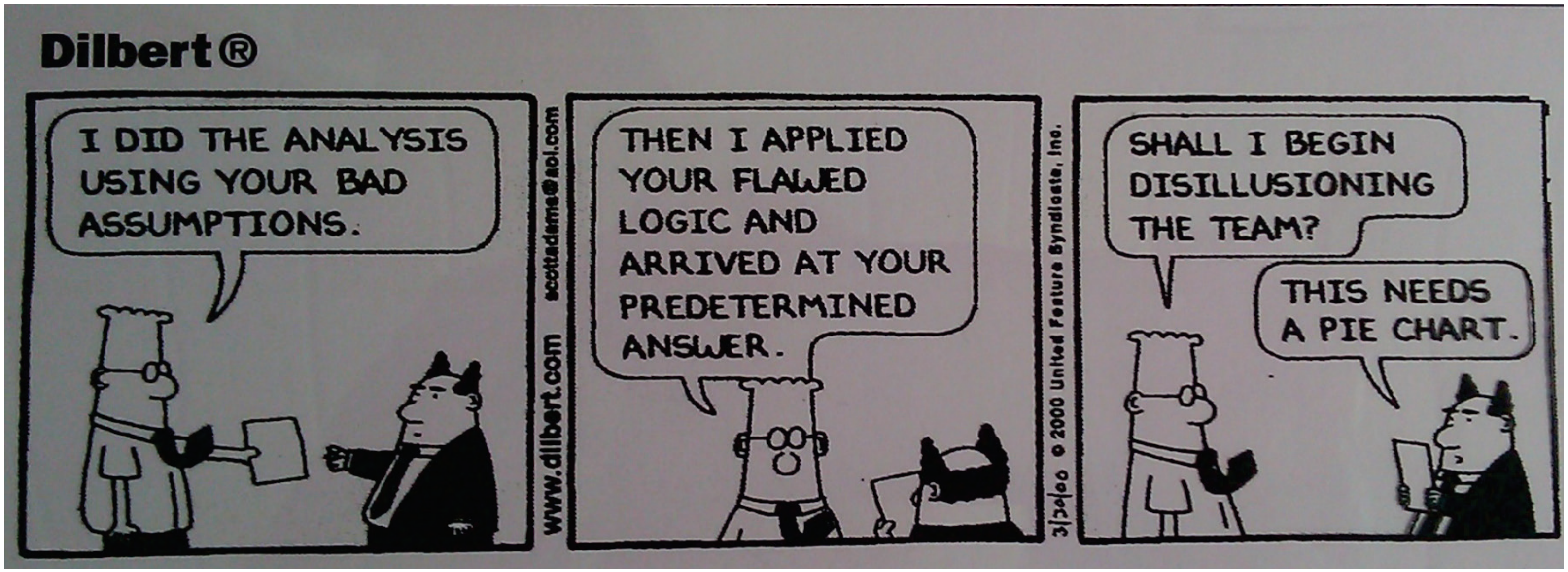


Potential factors affecting sea louse infestations



Simulations and mathematical models are useful for exploring hypothetical scenarios, intractable systems, long term projections, and testing general theory

PROVIDED YOU HAVE THE RIGHT DATA….



BAMP DATA

Broughton Archipelago Monitoring Plan (BAMP)

- tripartite: eNGOs / Producers / DFO

Data from wild field sampling (2004-2014)

- specific fish-level data (177,152 records)
- individual lice details (198,392 samples)

Complementary data from farms

BAMP.ca

Questions we may want to address with simulations

How does current and projected environmental variation influence sea louse populations?
(Temperature, salinity, hydrodynamics)

How can we manage salmon farms to reduce sea lice infections?

How does sea louse population structure impact evolutionary processes such as resistance to chemicals?

Modeling approaches

Factors to incorporate	Differential Equation	Population matrix model	Delay-differential Equation	Individual-Based Model
Sea Lice Growth and Survival				
Dynamic processes (e.g. density dependence)				
Instantaneous events (e.g., treatments)				
Behaviour and individual variation				
Stochastic processes				
Solve for equilibriums				

Modeling approaches

Factors to incorporate	Differential Equation	Population matrix model	Delay-differential Equation	Individual-Based Model
Sea Lice Growth and Survival	✓	✓	✓	✓
Dynamic processes (e.g. density dependence)	✓		✓	✓
Instantaneous events (e.g., treatments)	✓	✓		✓
Behaviour and individual variation				✓
Stochastic processes		✓		✓
Solve for equilibriums	✓	✓		

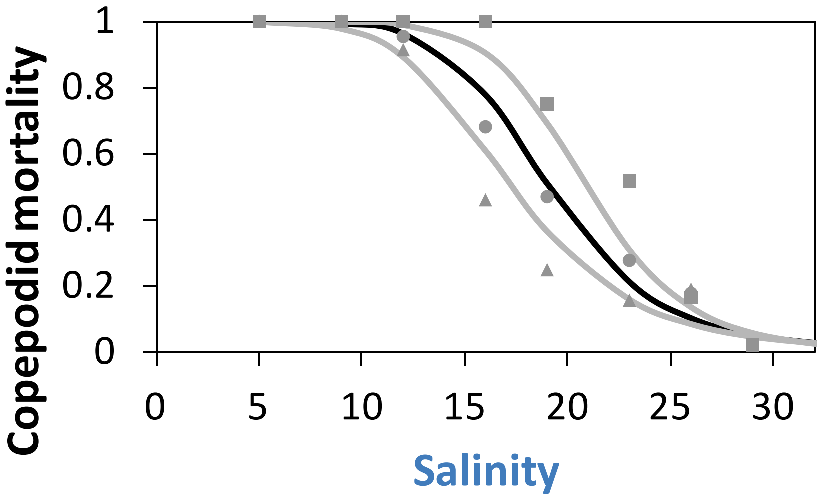
Questions we may want to address with simulations

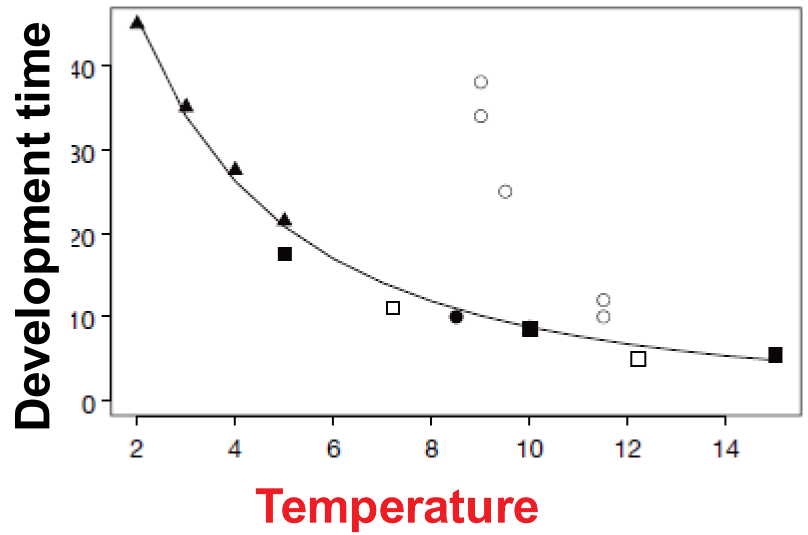
How does current and projected environmental variation influence sea louse populations?

How can we manage salmon farms to reduce sea lice infections?

How does sea louse population structure impact evolutionary processes such as resistance to chemicals?

Salinity influences sea louse survival, while temperature alters development

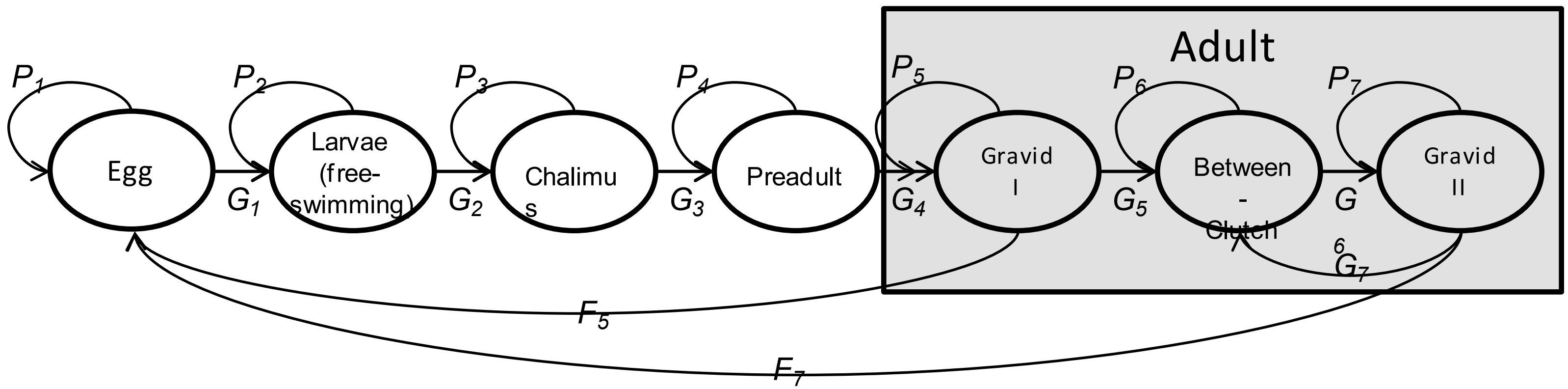




Stien et al. 2005

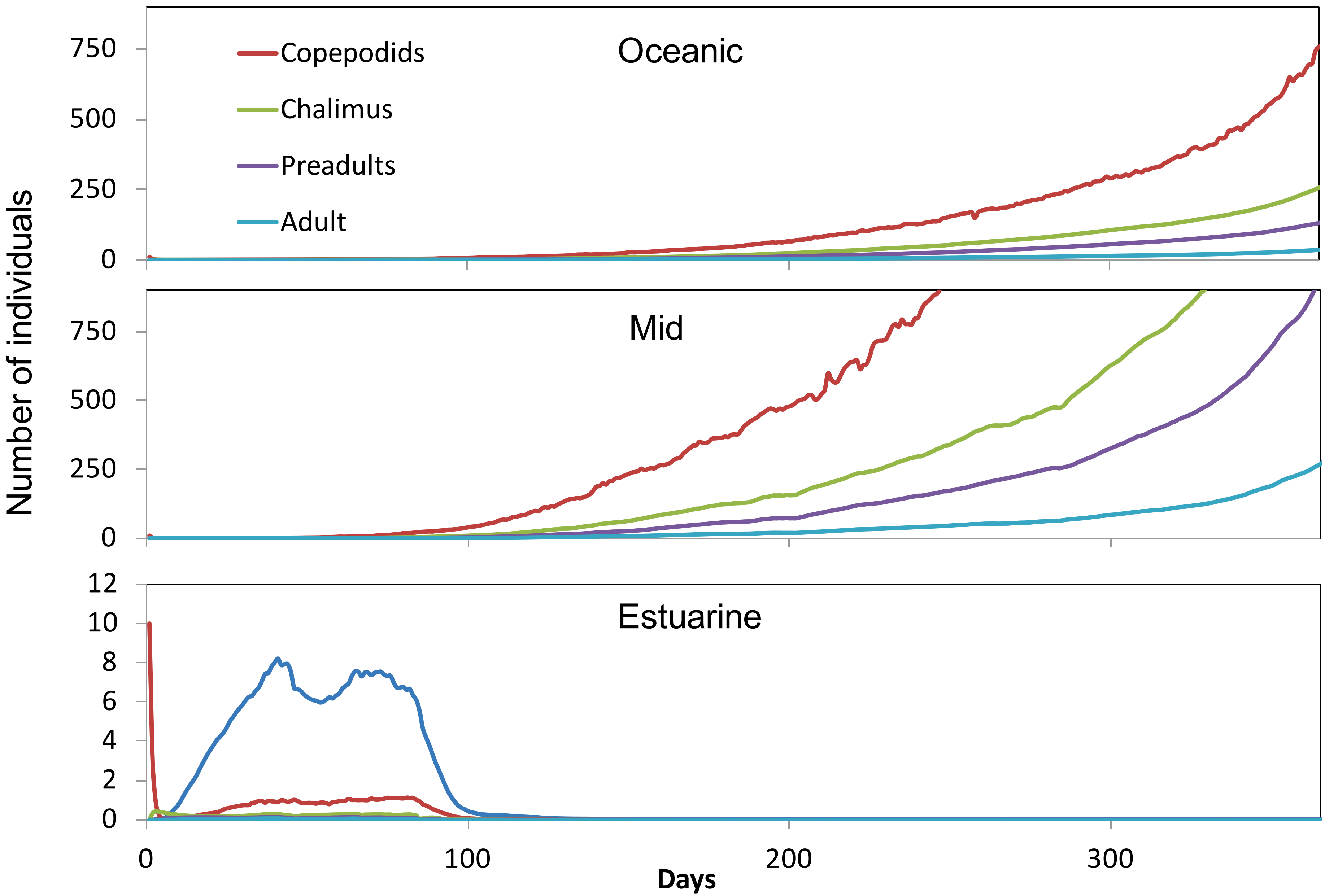
Quantifying the role of temperature and salinity on sea lice

Population matrix model

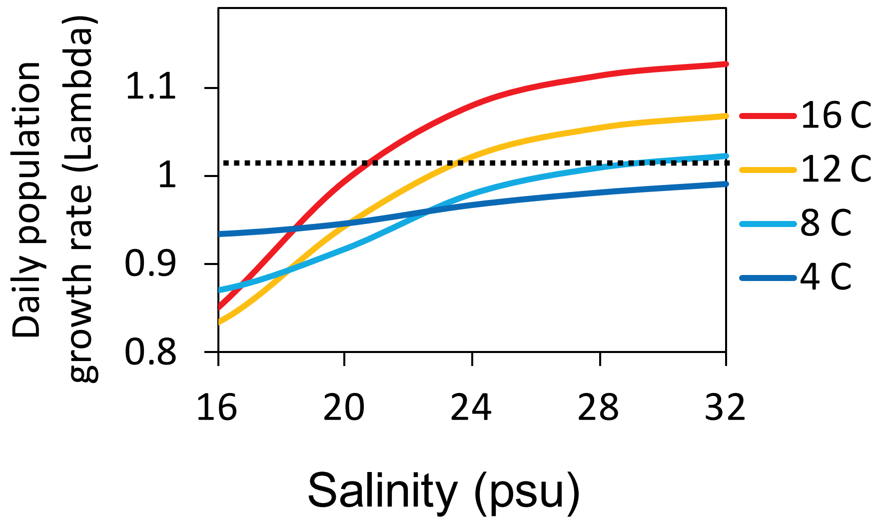


Groner et al. 2014 PLoS one, 2015 MEPS

Influence of ocean conditions on sea lice life history in the absence of migration



Solving for equilibriums using population matrix models

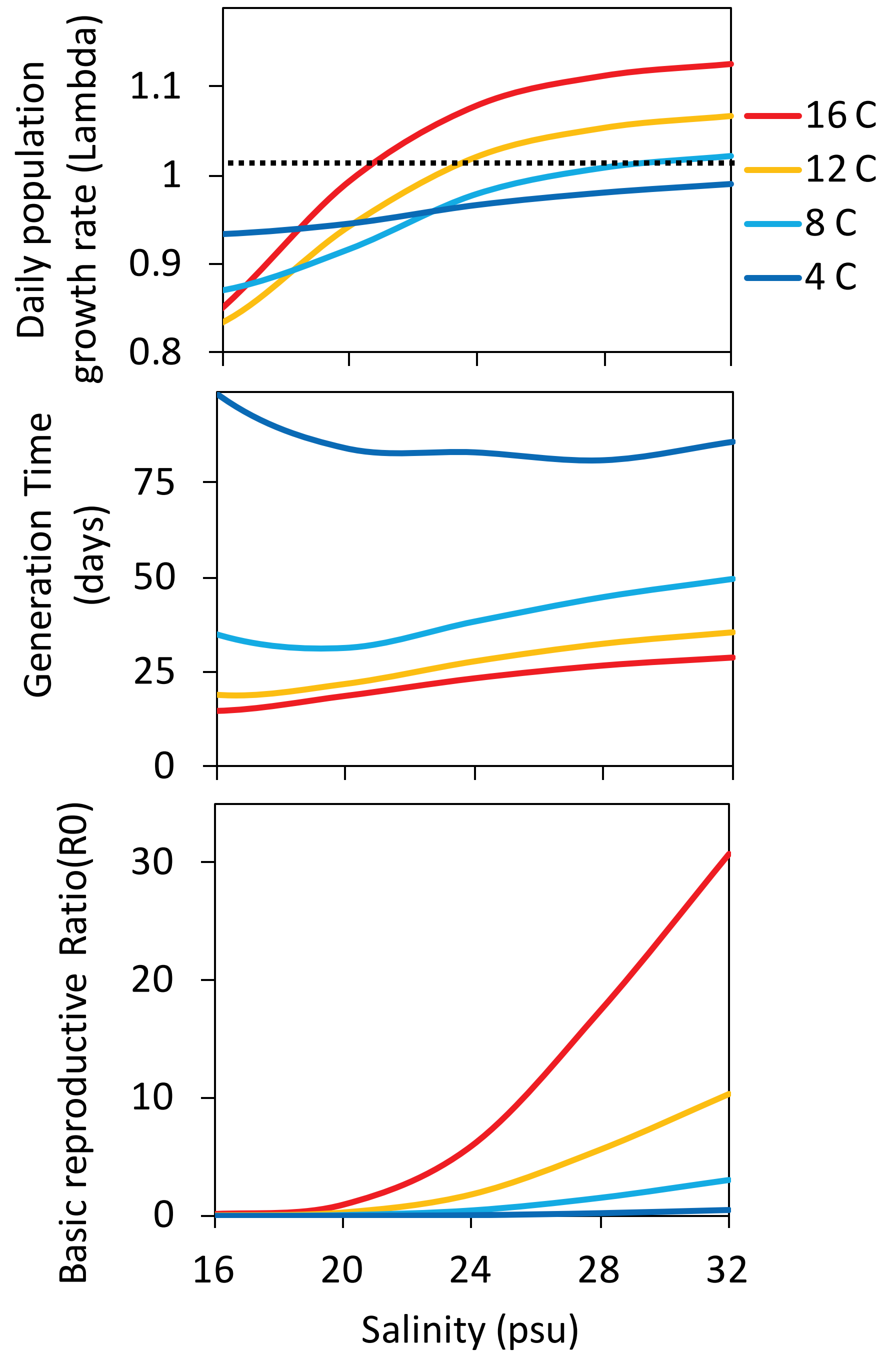


Groner et al. 2014 PLoS one, 2015 MEPS

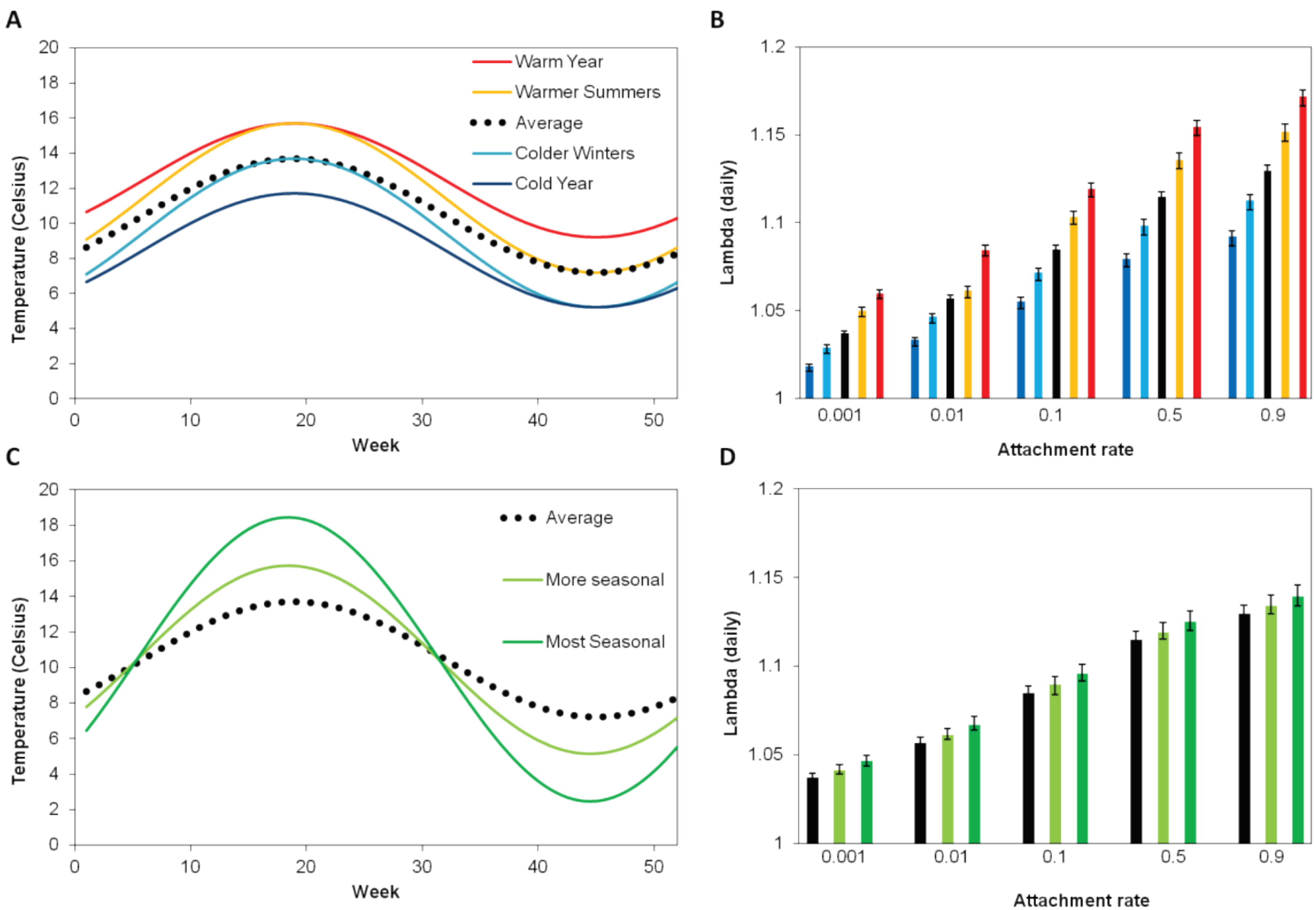
Solving for equilibriums using population matrix models

Temperature increases population growth by increasing in reproductive success and decreasing generation time.

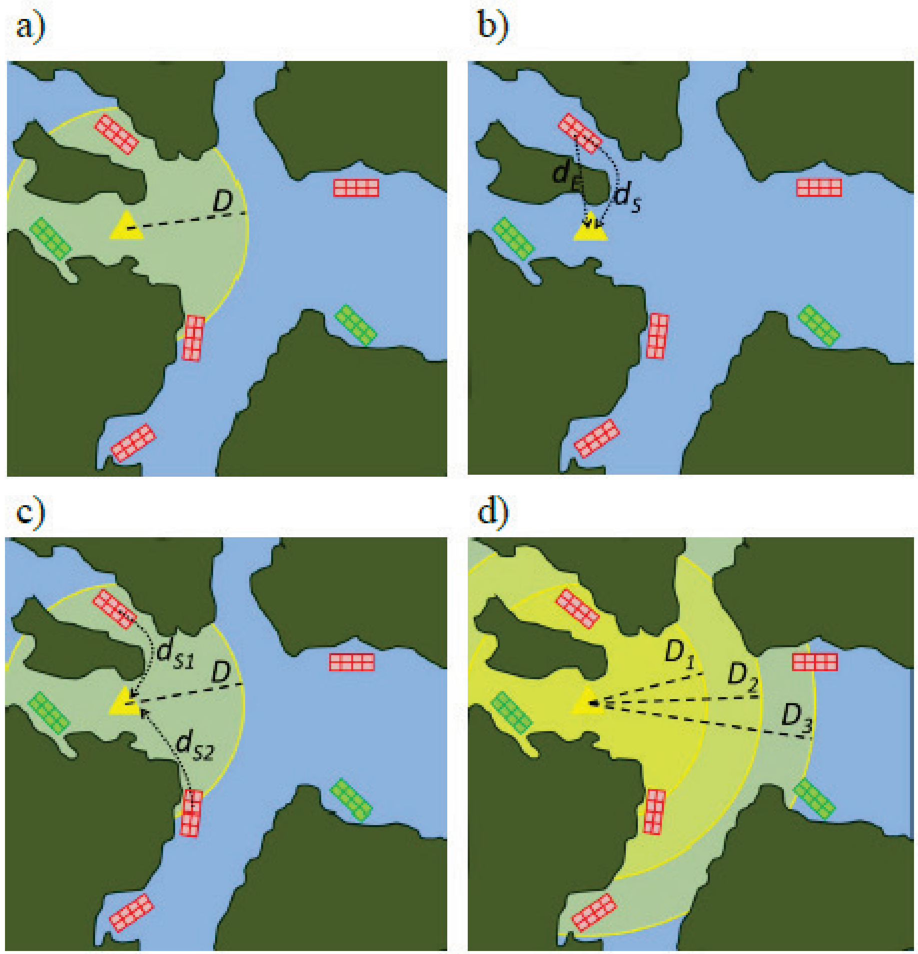
Salinity increase population growth by increasing reproductive success

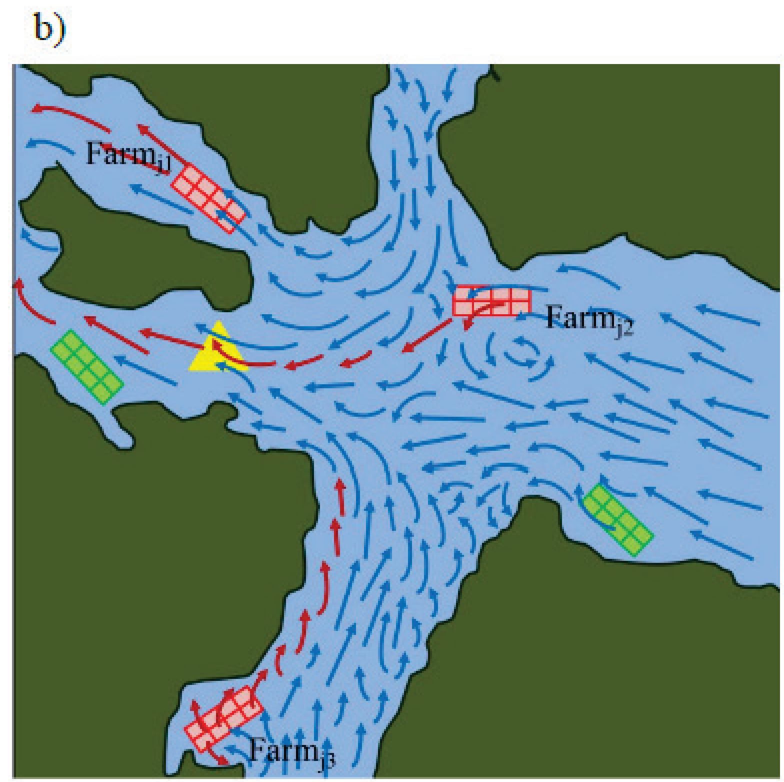


How does yearly variation impact population growth?



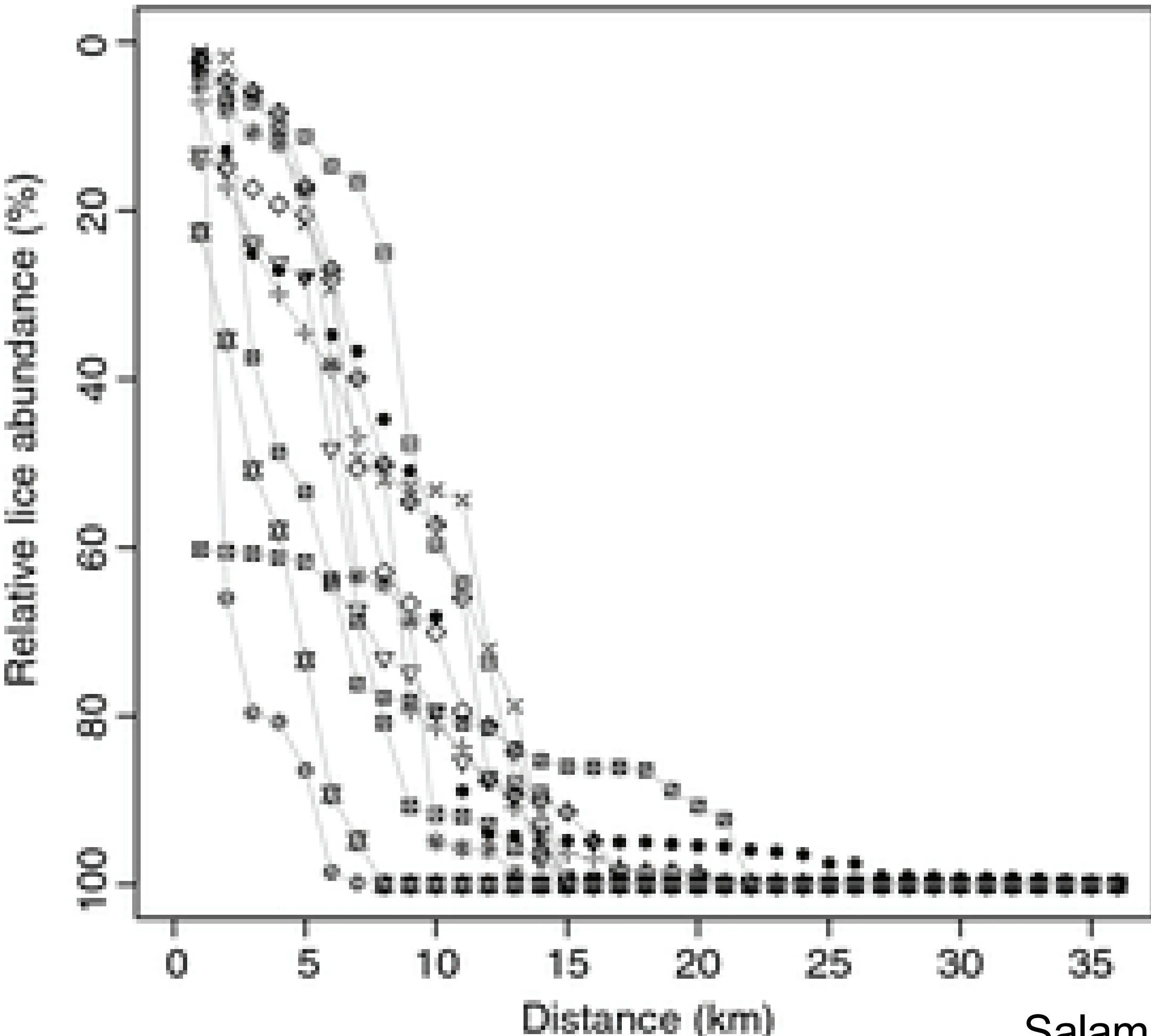
How can we evaluate transmission processes?





Finite-Volume, primitive equation Community Ocean Model (FVCOM)

Simulated environmental transport distances of *Lepeophtheirus salmonis* in Loch Linnhe, Scotland, for informing aquaculture area management structures



Salama et al. 2015, JOFD

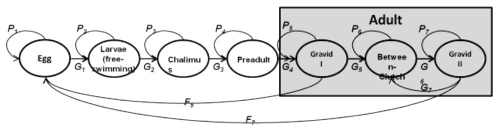
How can we evaluate transmission processes?

Table 2. Passive particle trajectory modelling estimates of the connectivity among the twenty farms shown in Figure 16. Higher (lower) connectivity is denoted by redder (bluer) colours. White cells denote zero connectivity.

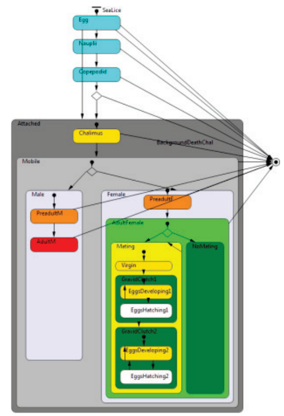
	release farm																			
capture farm	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	29867	4078	2372	135	339	25	85	28	3	14	118	1	3	13	25	1	4	-	-	-
2	282	32400	3032	4	47	82	205	5	9	96	442	-	3	3	180	11	11	2	-	-
3	236	833	22134	20	80	-	3	3	-	1	14	1	-	1	1	-	-	-	-	-
4	1241	311	363	21113	64	-	1	20	-	-	-	5	4	4	-		-	-	-	-
5	1030	369	448	620	21784	1	2	281	51	-	2	121	61	148	7	1	-	-	-	-
6	29	14	16	41	14	32400	390	294	339	463	665	158	255	322	1445	41	33	6	10	20
7	-	-	-	-	-	8	32400	-	-	517	225	-	-		265	801	1078	521	86	31
8	1887	640	528	3241	954	69	81	32400	3576	103	322	3284	2595	9972	795	4	1		1	1
9	50	9	19	85	25	111	120	429	32400	137	454	231	323	548	968	10	5			
10	-	2	2	-	-	13	585	2	4	19473	471	-	1	1	322	86	74	22	5	6
11	4	218	190	2	-	346	982	40	85	616	16899	13	34	53	877	87	98	28	9	13
12	291	64	69	416	814	3	1	943	229	1	6	15775	1383	517	38	-	-	-	-	-
13	528	147	181	808	393	5	5	2113	850	12	32	4770	15449	1437	88	1	-	-	3	7
14	1403	464	380	2337	681	39	48	12477	3068	71	227	2755	2365	32400	565	5	1	-	2	2
15	4	58	61	14	5	883	1865	156	213	2165	5917	85	127	190	32400	211	221	53	31	34
16	-	-	-	-	-	96	136	4	11	23	16	1	12	10	20	11945	10017	5482	2058	908
17	-	-	-	1	-	36	9	4	3	1	-	-	6	6	2	2014	12491	4827	658	381
18	-	-	-	-	-	17	4	1	-	-	-	-	3	7	-	1164	1641	19349	289	169
19	4	1	3	9	1	805	36	112	164	16	28	90	140	178	69	1850	1016	656	32400	10229
20	21	-	4	11	2	1125	31	160	195	19	31	150	197	236	100	1274	689	459	14866	32400

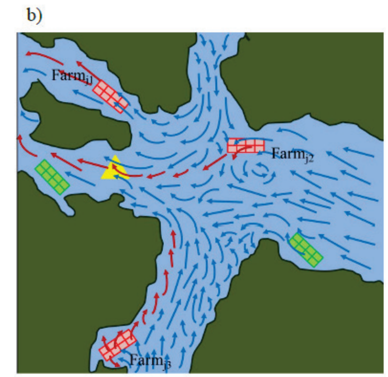
Foreman et al. 2015

Various levels of complexity



$$A = \begin{bmatrix} P_1 & 0 & 0 & 0 & F_5(\phi) & 0 & F_7(\phi) \\ G_1 & P_2(\gamma) & 0 & 0 & 0 & 0 & 0 \\ 0 & G_2(\gamma) & P_3 & 0 & 0 & 0 & 0 \\ 0 & 0 & G_3 & P_4 & 0 & 0 & 0 \\ 0 & 0 & 0 & G_4 & P_5 & 0 & 0 \\ 0 & 0 & 0 & 0 & G_5 & P_6 & G_7 \\ 0 & 0 & 0 & 0 & 0 & G_6 & P_7 \end{bmatrix}$$





ODE models w/ demographic stochasticity

Agent Based Models w/ demographic stochasticity

Hydrodynamic transmission model- coupled with ODE model of farm transmission processes

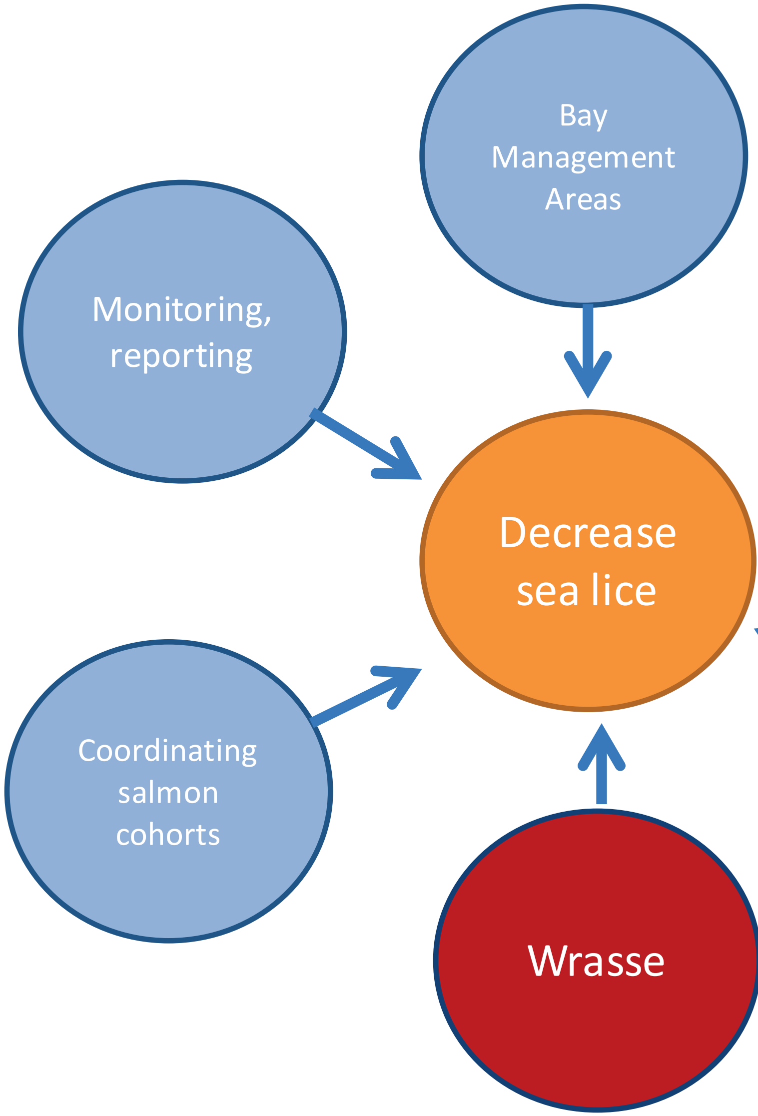
Questions we may want to address with simulations

How does current and projected environmental variation influence sea louse populations?

How can we manage salmon farms to reduce sea lice infections?

How does sea louse population structure impact evolutionary processes such as resistance to chemicals?

Numerous methods are used to control these parasites



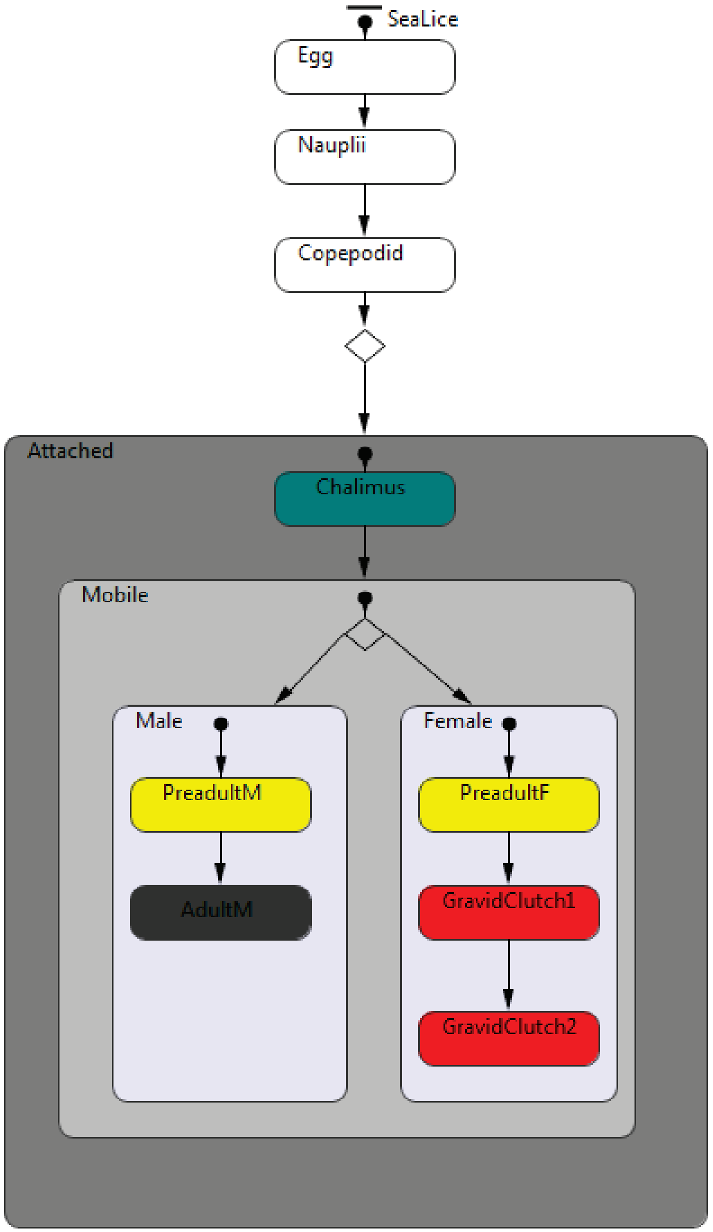
Still very dependent on chemicals for control

What are the alternatives to chemicals?

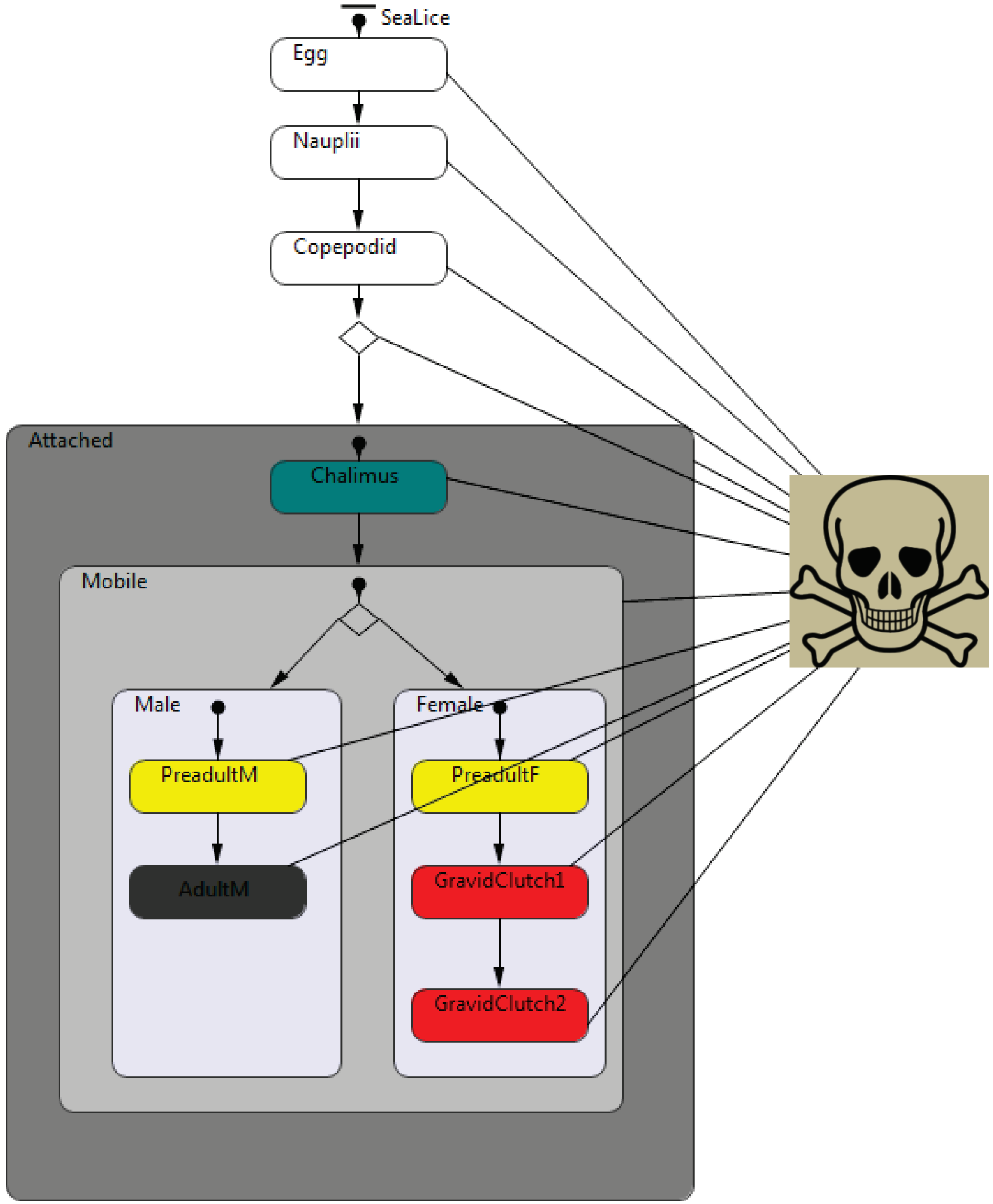
Can we use modeling techniques to quantify optimal stocking levels for wrasse?

To what extent does using wrasse reduce the need for chemical treatments?

Individual-based model of sea lice

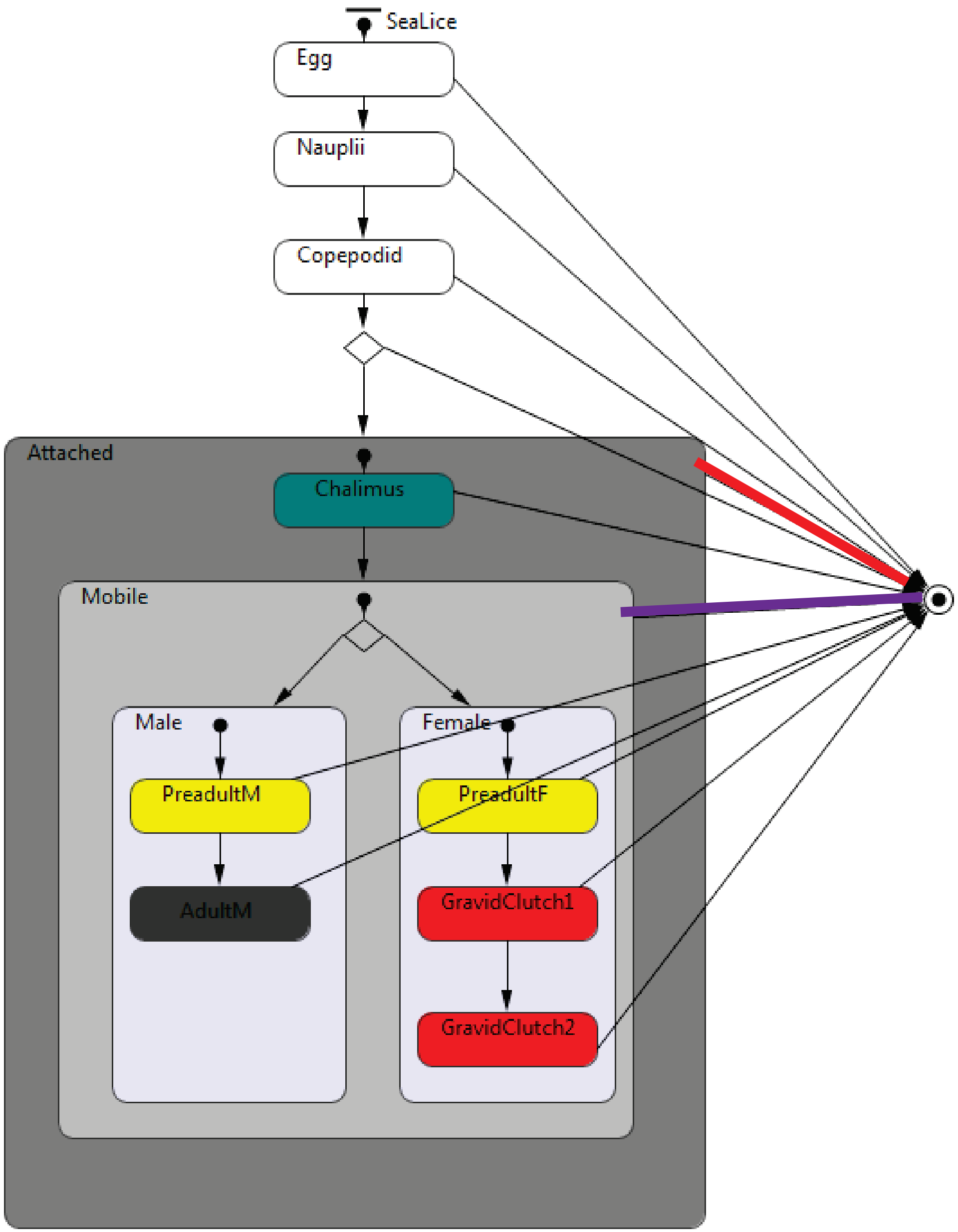


Individual-based model of sea lice



anylogic® 7

Additional causes of mortality



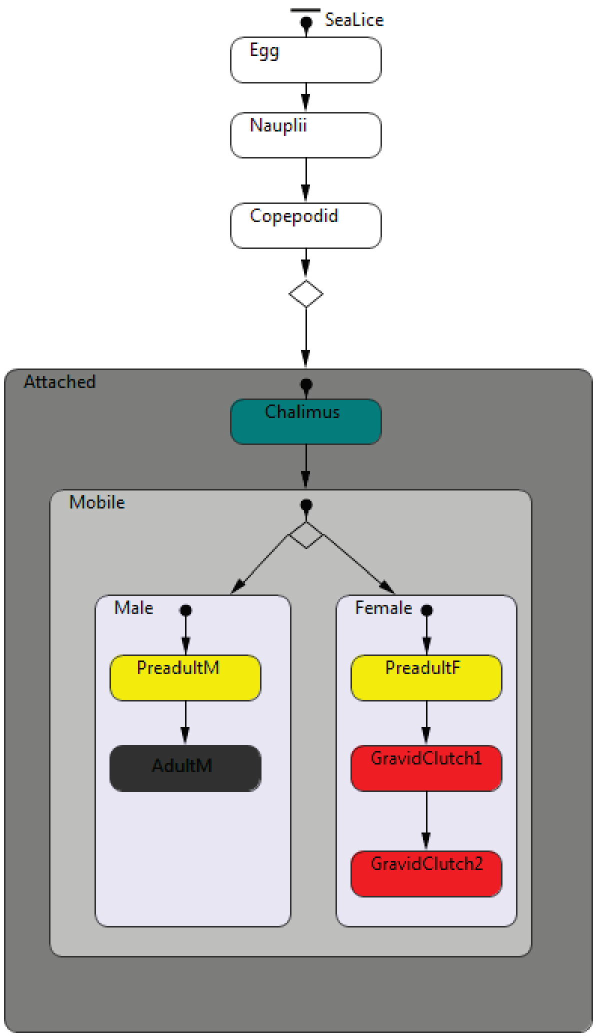
Treatments

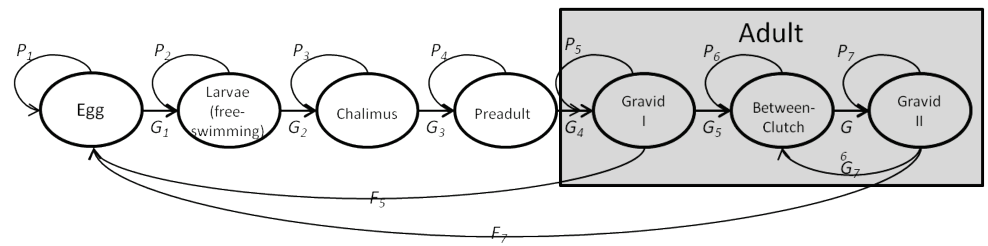
Wrasse Predation

Feed at a constant rate

Wrasse: salmon ratios
0, 1:200, 1:100, 1:50, 1:25, 1:10

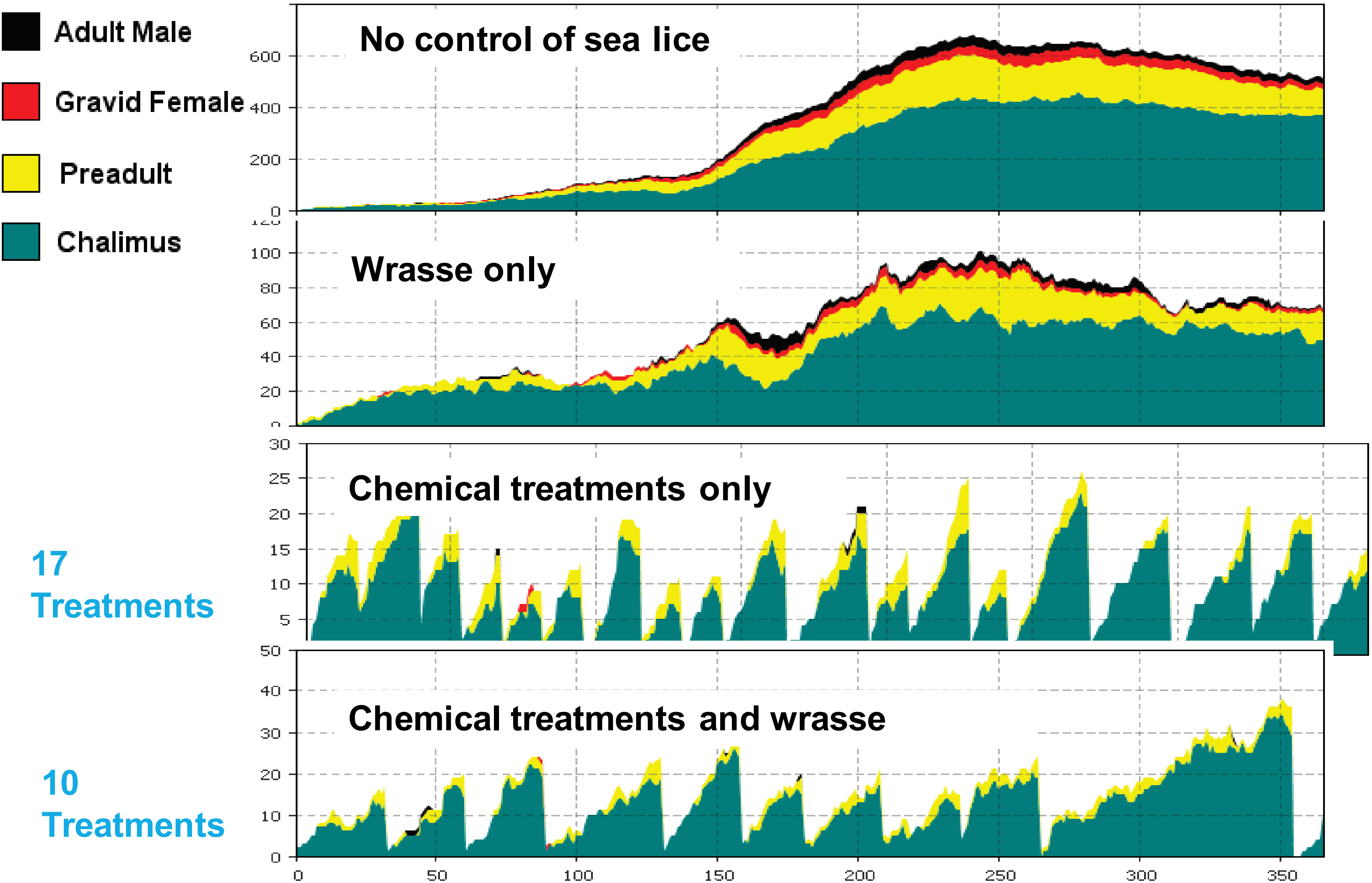
So….are these really different?





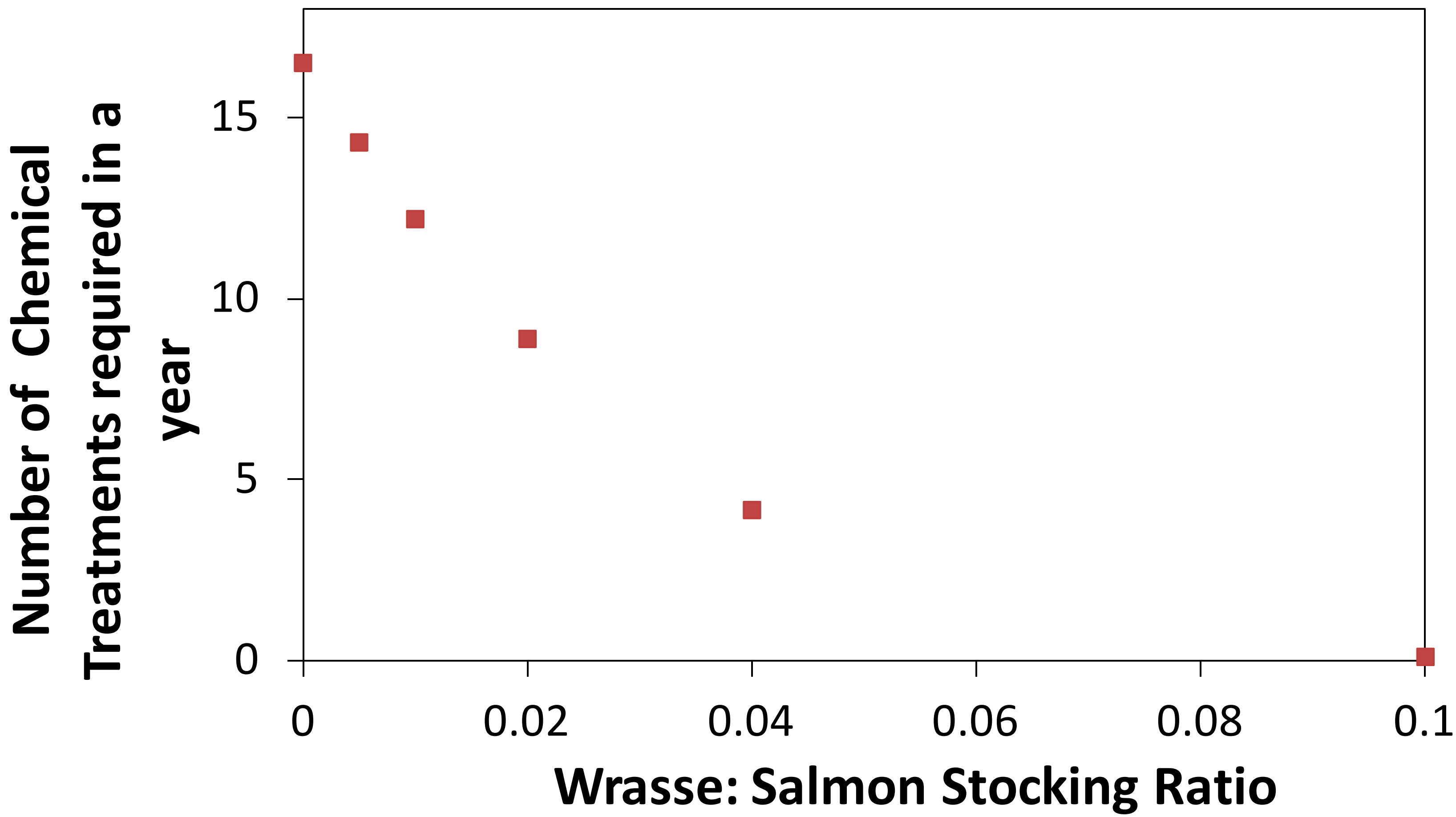
$$A = \begin{bmatrix} P_1 & 0 & 0 & 0 & F_5(\phi) & 0 & F_7(\phi) \\ G_1 & P_2\,(\gamma) & 0 & 0 & 0 & 0 & 0 \\ 0 & G_2(\gamma) & P_3 & 0 & 0 & 0 & 0 \\ 0 & 0 & G_3 & P_4 & 0 & 0 & 0 \\ 0 & 0 & 0 & G_4 & P_5 & 0 & 0 \\ 0 & 0 & 0 & 0 & G_5 & P_6 & G_7 \\ 0 & 0 & 0 & 0 & 0 & G_6 & P_7 \end{bmatrix}$$

Some results from simulations



Groner et al. 2013, JOFD **Time (days)** http://tinyurl.com/wrassemodel

Using wrasse can reduce the number of chemical treatments for all infection scenarios



http://tinyurl.com/wrassemodel

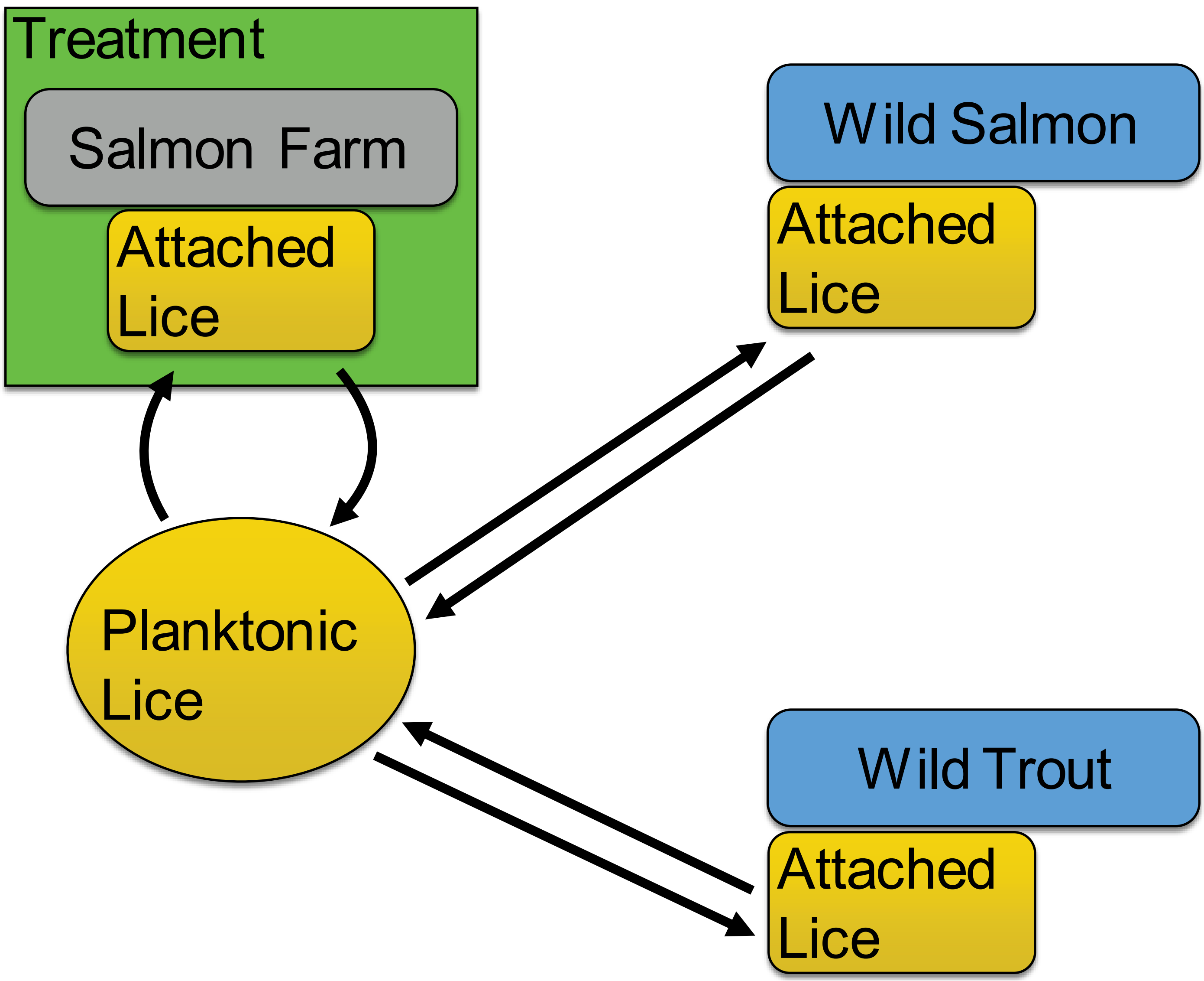
Questions we may want to address with simulations

How does current and projected environmental variation influence sea louse populations?

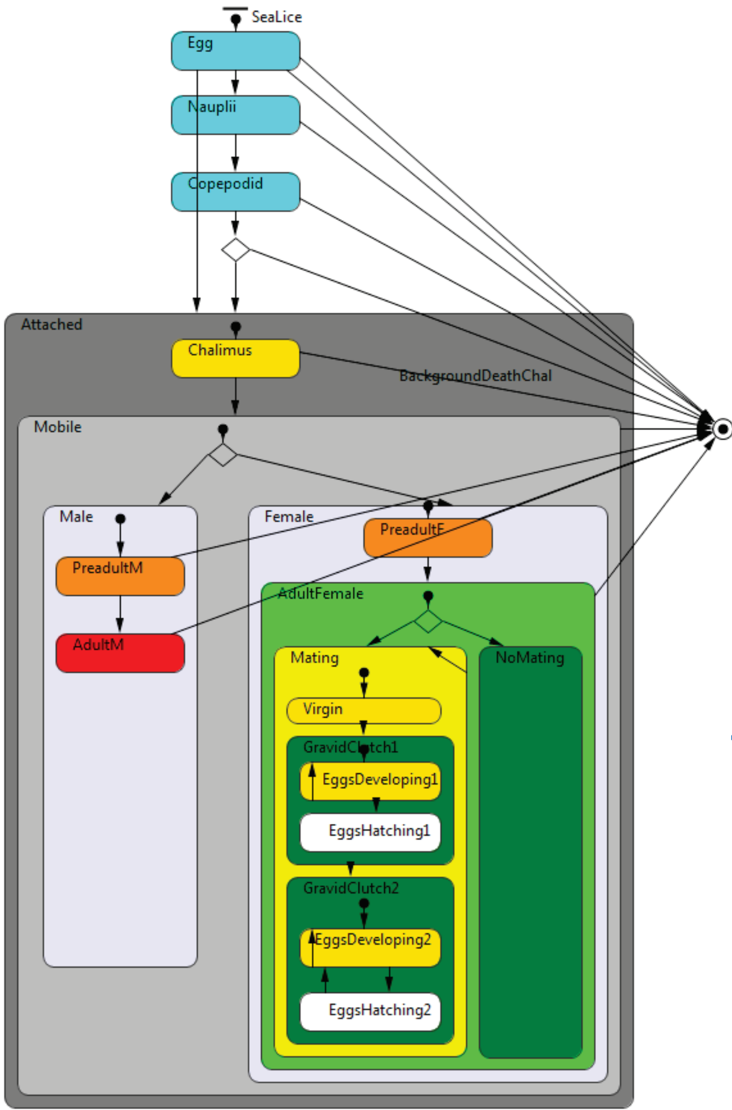
How can we manage salmon farms to reduce sea lice infections?

How does sea louse population structure impact evolutionary processes such as resistance to chemicals?

How does a refugia from chemical treatments impact the evolution of resistance?



Modified individual-based model to understand evolutionary processes



1) Model both the host and the parasite salmon from farmed and wild populations

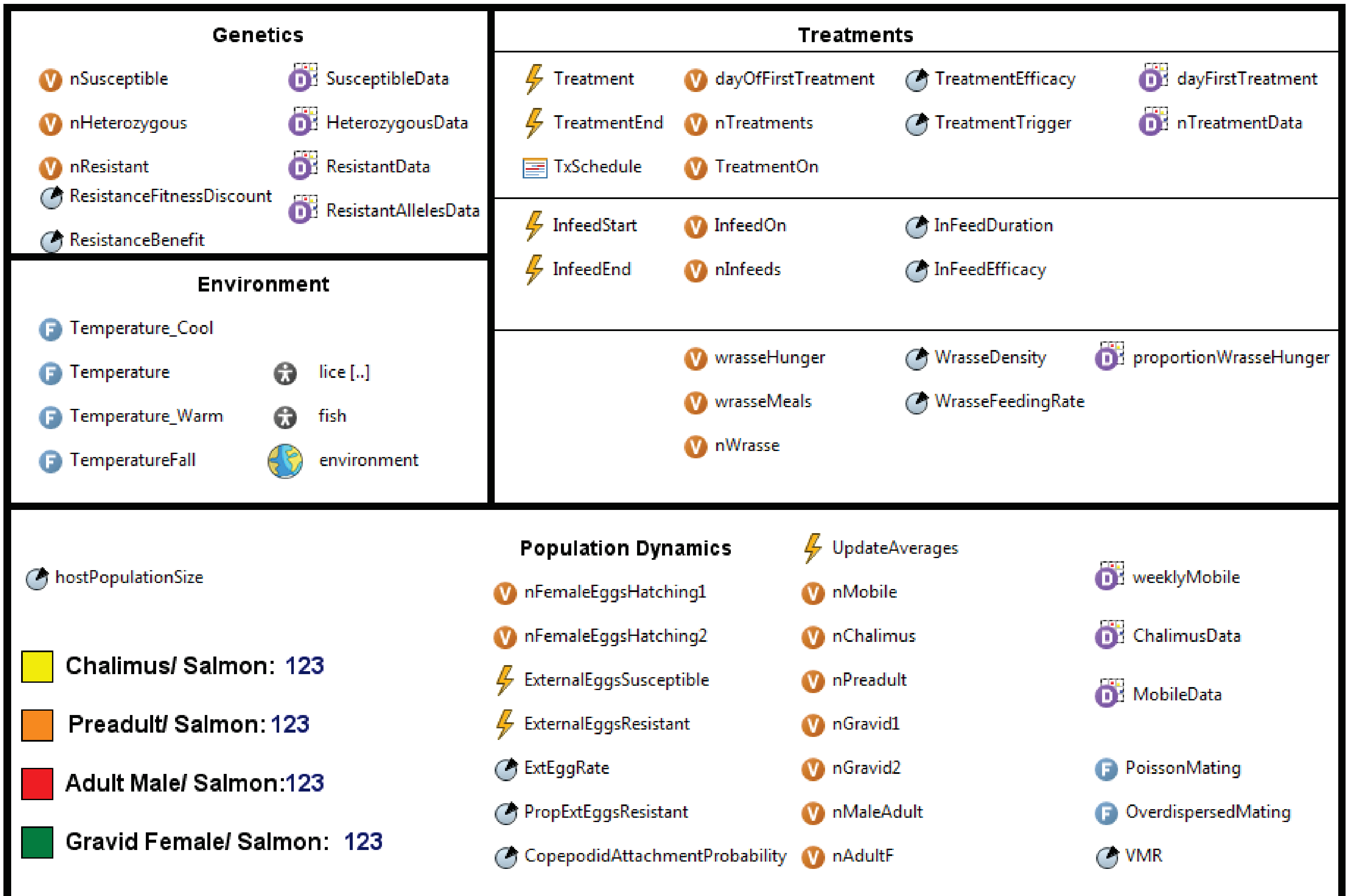
2) Resistance is conferred through a single gene with resistant and susceptible alleles

3) Genes are transferred through Mendelian genetics

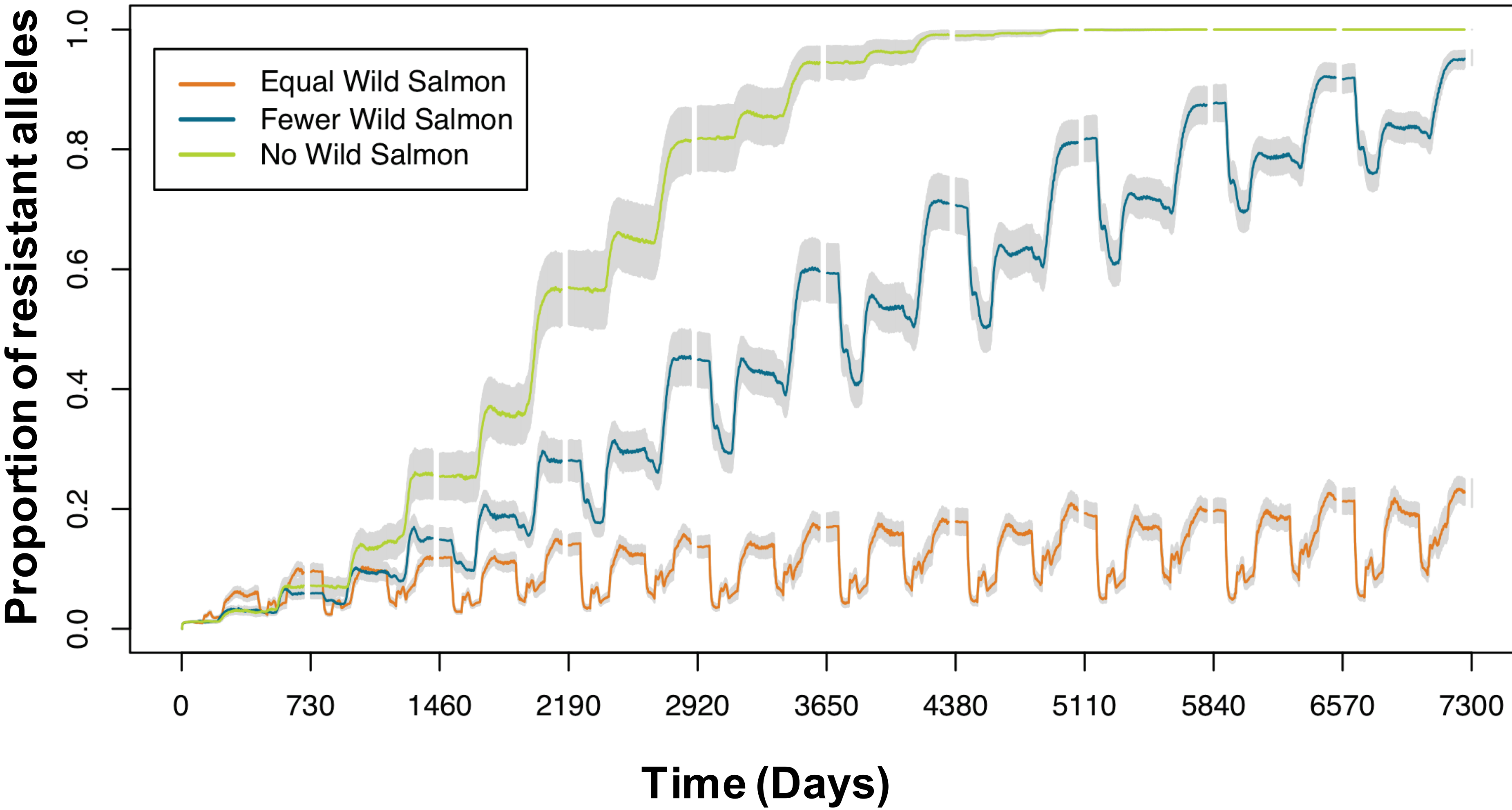
4) Emergent properties of interest
   populations size
   population-level resistance

Model Structure

Upper level variables



Wild salmon refugia reduces the evolution of resistance (*in review*)



McEwan et al. *in review*

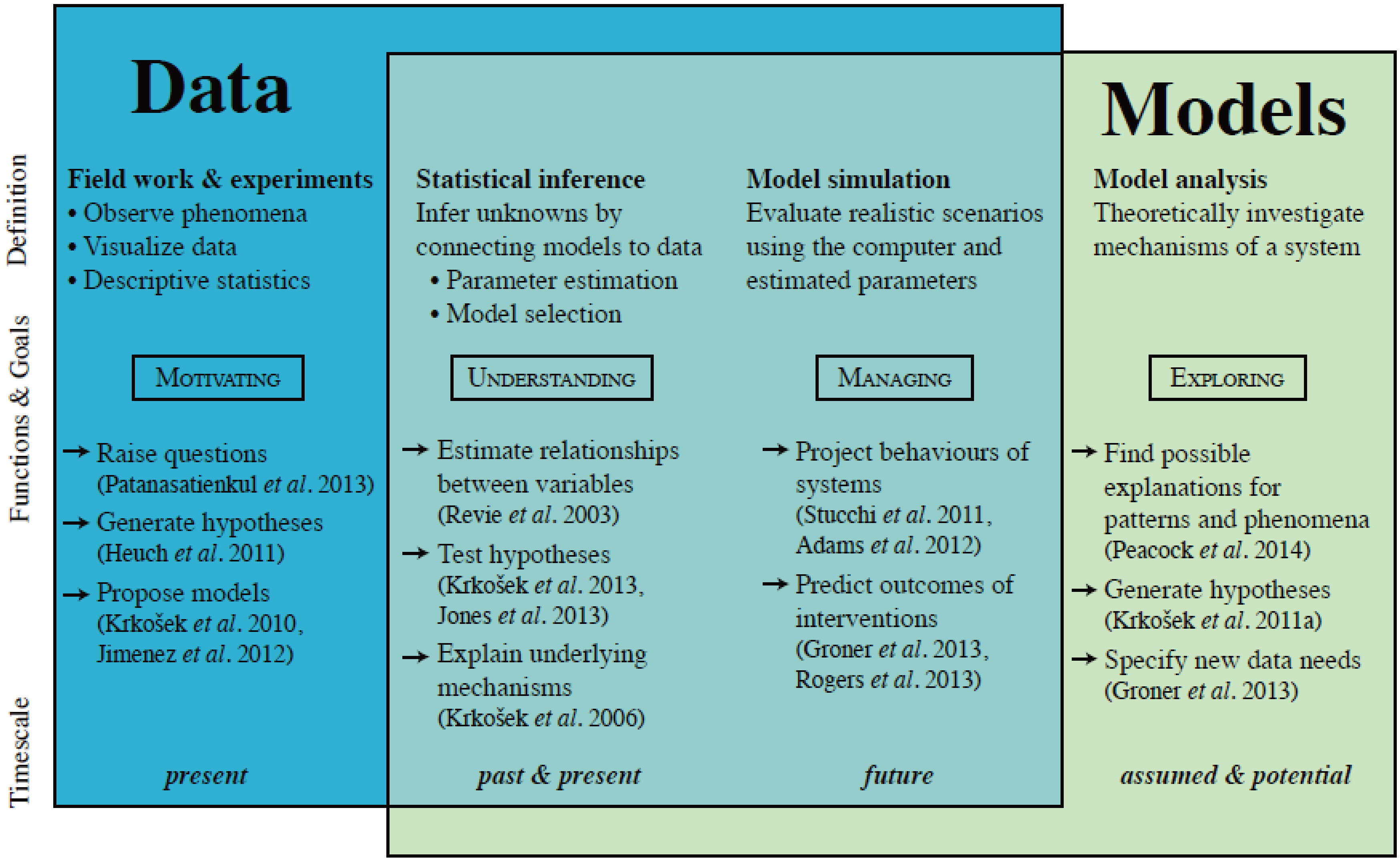
What have we learned about sea lice from simulations?

Predictions of how salinity and temperature on influence sea louse population growth

Recommendations for more sustainable management of sea lice on fish farms

Predictions for how wild refugia influence evolution of chemical resistance in sea lice

- validation required


Data
Models
Definition
Functions & Goals
Timescale
Field work & experiments
• Observe phenomena
• Visualize data
• Descriptive statistics
Statistical inference
Infer unknowns by connecting models to data
• Parameter estimation
• Model selection
Model simulation
Evaluate realistic scenarios using the computer and estimated parameters
Model analysis
Theoretically investigate mechanisms of a system
MOTIVATING
UNDERSTANDING
MANAGING
EXPLORING
→ Raise questions (Patanasatienkul et al. 2013)
→ Generate hypotheses (Heuch et al. 2011)
→ Propose models (Krkošek et al. 2010, Jimenez et al. 2012)
→ Estimate relationships between variables (Revie et al. 2003)
→ Test hypotheses (Krkošek et al. 2013, Jones et al. 2013)
→ Explain underlying mechanisms (Krkošek et al. 2006)
→ Project behaviours of systems (Stucchi et al. 2011, Adams et al. 2012)
→ Predict outcomes of interventions (Groner et al. 2013, Rogers et al. 2013)
→ Find possible explanations for patterns and phenomena (Peacock et al. 2014)
→ Generate hypotheses (Krkošek et al. 2011a)
→ Specify new data needs (Groner et al. 2013)
present
past & present
future
assumed & potential

Questions

Data and modeling

All models are wrong but some are useful

"It doesn't matter how beautiful your theory is,
it doesn't matter how smart you are.
If it doesn't agree with the experiment [data], it's wrong."
(Richard Feyman)

Modeling – ‘take home’ message?

Modeling – ‘take home’ message?