Population Approach Group in Europe
(www.page-meeting.org)
Glasgow 11-14 June 2013

Two models for the control of sea lice infections using chemical treatments and biological control on farmed salmon populations

George Gettinby

Maya Groner
Ruth Cox
Crawford Revie

Chris Robbins

Salmon production - background

- In Scotland 14 tonnes in 1971, 158000 tonnes in 2012
- Scotland's largest food export and goes to over 60 countries
- Scotland's National Marine Plan is for 210000 tonnes by 2020
- Other leading producers are Norway, Chile, Canada, USA and Ireland
- Major constraint is sea lice

Sea lice - background

- Parasitic copepods
- Heavy infestation – fish health problems
- Enormous cost to European, North and South American salmon industries
  - treatment costs
  - mortalities
  - down-grade at harvest
  - poor growth / low Feed Conversion Ratio
- Implications for wild salmon and sea trout

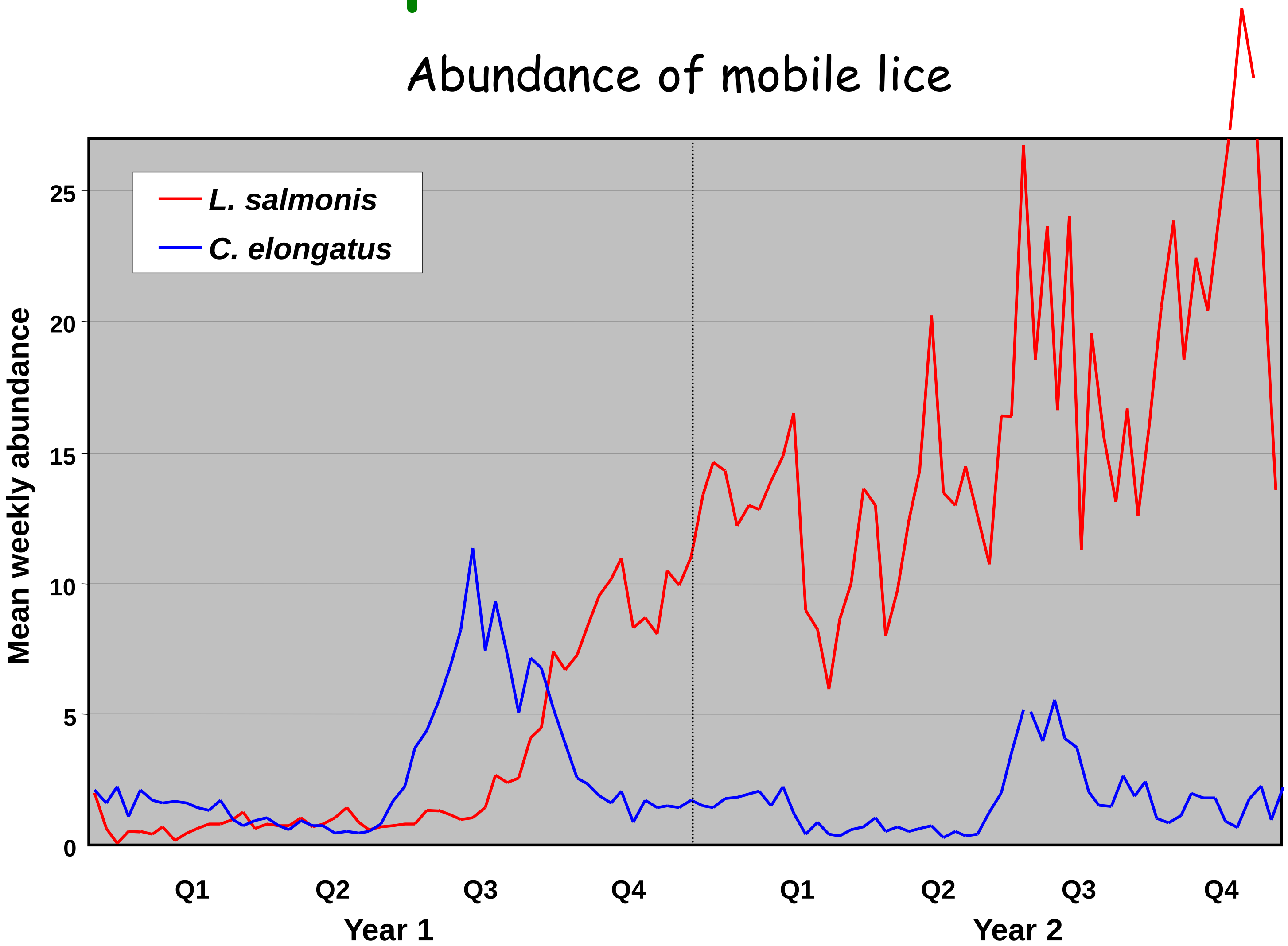
Sea lice - species

- *Lepeophtheirus salmonis (Scotland, Ireland, Norway, North America)*
- *Caligus elongatus* (multiple hosts)
- *Caligus clemensi* (BC / western Canada)
- *Caligus rogercresseyi* (Chile)

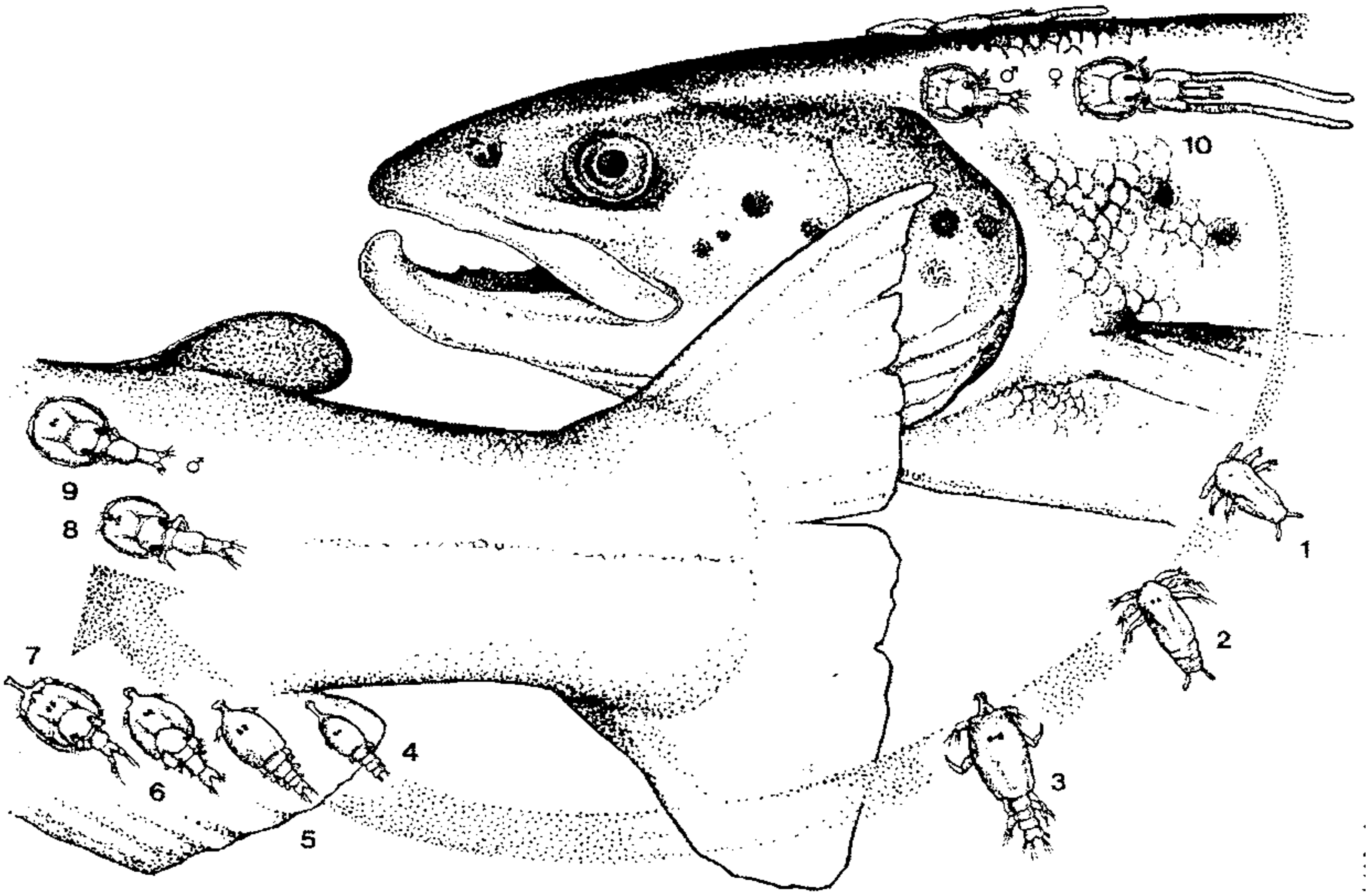
- in Scotland

	L. salmonis	*C. elongatus*
	on farm re-infestation	external pressure
	endemic	epidemic

Typical sea lice population growth on European salmon farms



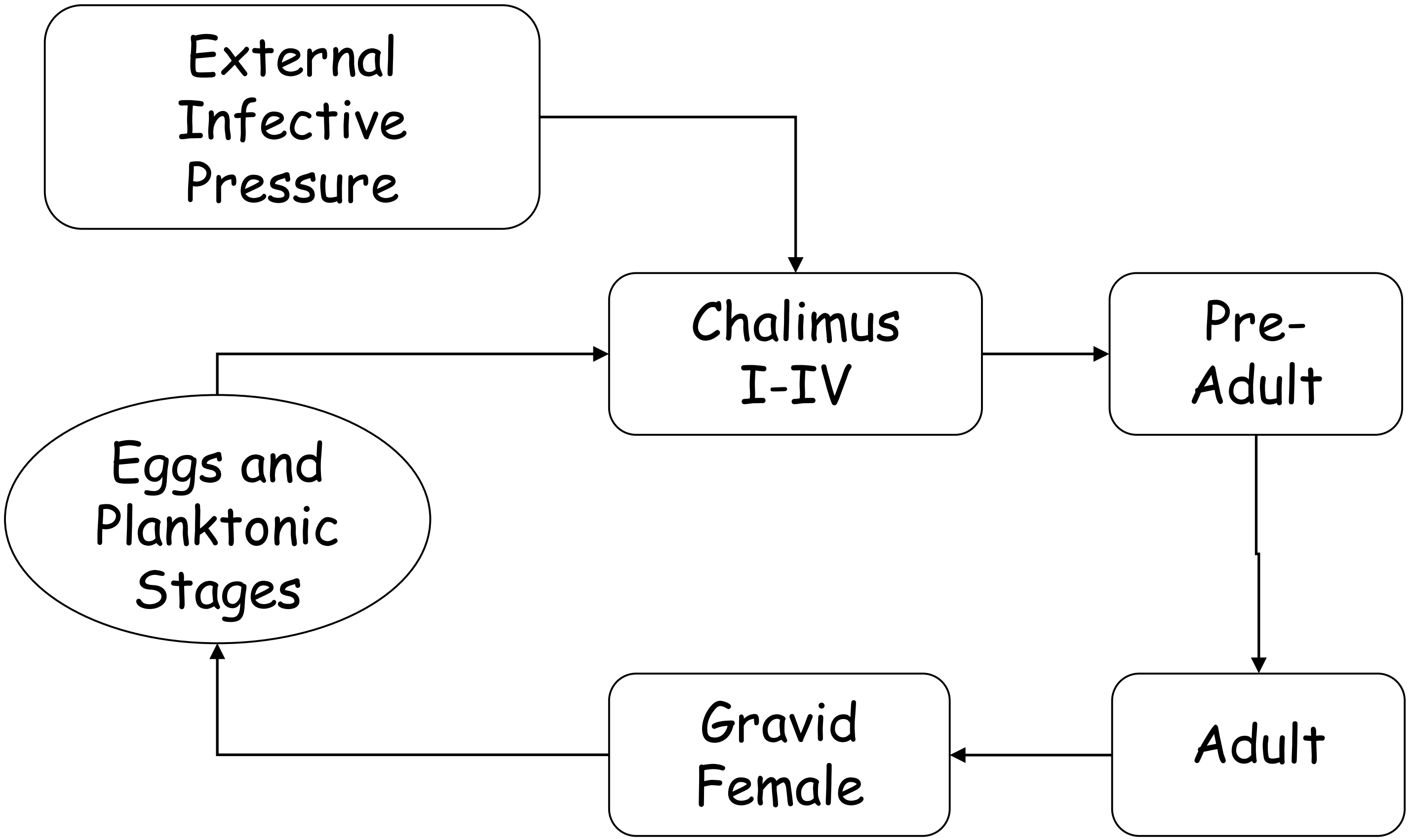
Modelling the sea lice life-cycle



First Model: Compartmental population model for *L. salmonis*

- Initially considered a ‘full’ 10-stage biological model
- Too complex, didn’t work, too many parameters to fit, too many unknowns!
- Simplified to 6 stages (chalimus, pre-adult, adult, gravid female, egg, external infection)

Population model simple structure



Population model mathematical equations

$\frac{dn_1(t)}{dt} = R_1(t) - R_1(t-\tau_1)e^{-b_1\tau_1} - b_1(t)n_1(t)$	(1)
$\frac{dn_2(t)}{dt} = \eta R_1(t-\tau_1)e^{-b_1\tau_1} - \eta R_1(t-\tau_1-\tau_2)e^{-b_1\tau_1-b_2\tau_2} - b_2(t)n_2(t)$	(2)
$\frac{dn_3(t)}{dt} = \eta R_1(t-\tau_1-\tau_2)e^{-b_1\tau_1-b_2\tau_2} - \eta R_1(t-\tau_1-\tau_2-\tau_3)e^{-b_1\tau_1-b_2\tau_2-b_3\tau_3} - b_3(t)n_3(t)$	(3)
$\frac{dn_4(t)}{dt} = \eta R_1(t-\tau_1-\tau_2-\tau_3)e^{-b_1\tau_1-b_2\tau_2-b_3\tau_3} - b_4(t)n_4(t)$	(4)

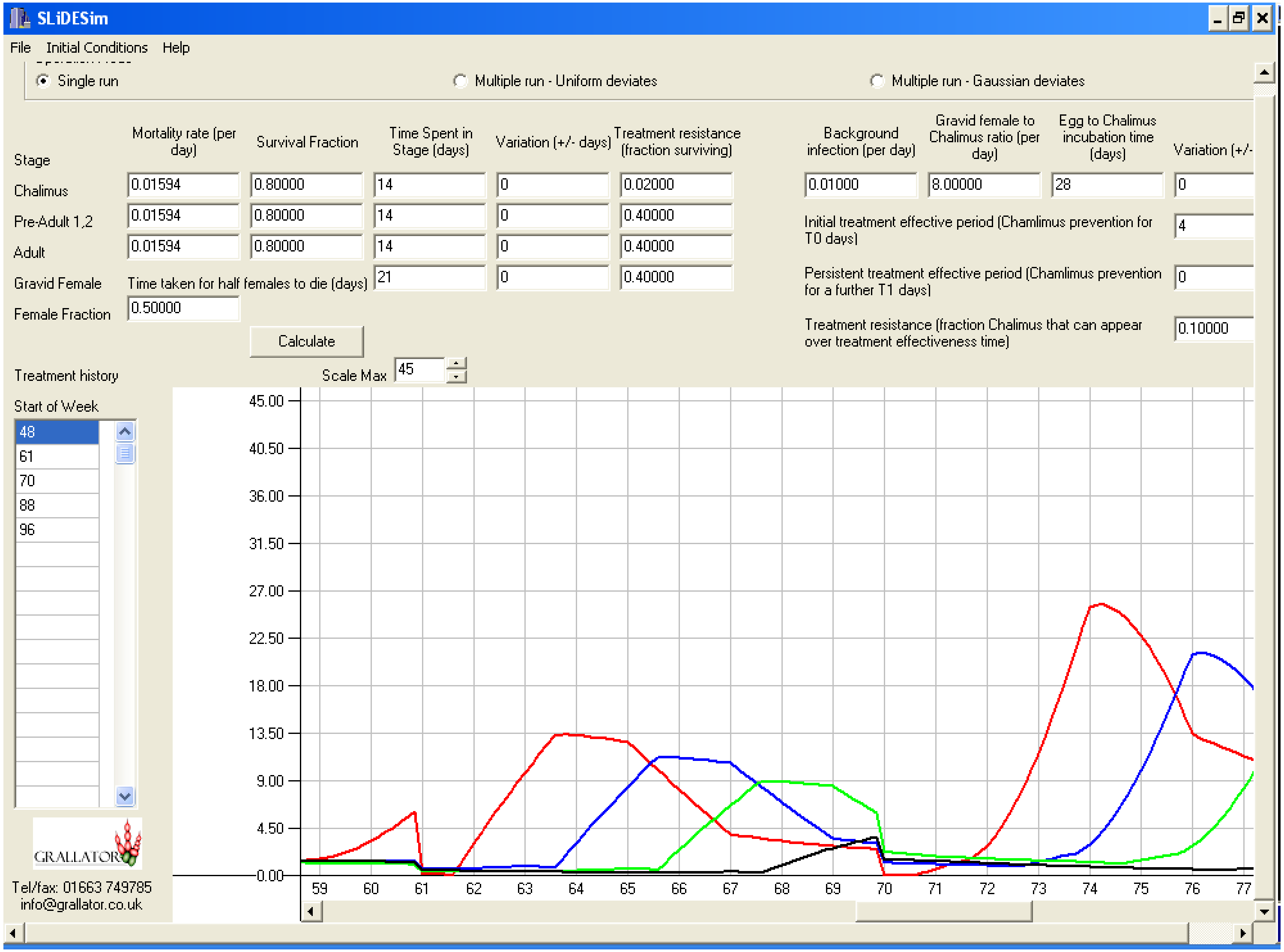
n1 is the number of chalimus per fish, n2 is the number of pre-adult female per fish, n3 is the number of adult female per fish, n4 is the number of gravid female per fish, t1 is the time spent in the chalimus stage, t2 is the time spent in the pre-adult stages, t3 is the time spent in the adult stage,	b1 is the mortality rate in the chalimus stage, b2 is the mortality rate in the pre-adult stages, b3 is the mortality rate in the adult stage, b4 is the mortality rate in the gravid female stage, R1 is the population feedback and external source term, h is the fraction of the pre-adult population that develop into females.

Implementation of population model for *L. salmonis*

SLiDESim (Sea Lice Difference Equation Simulation)

- Equations implemented in software with estimated parameters for:
  - development and mortality rates
  - background infection pressure
  - treatment timings and efficacy

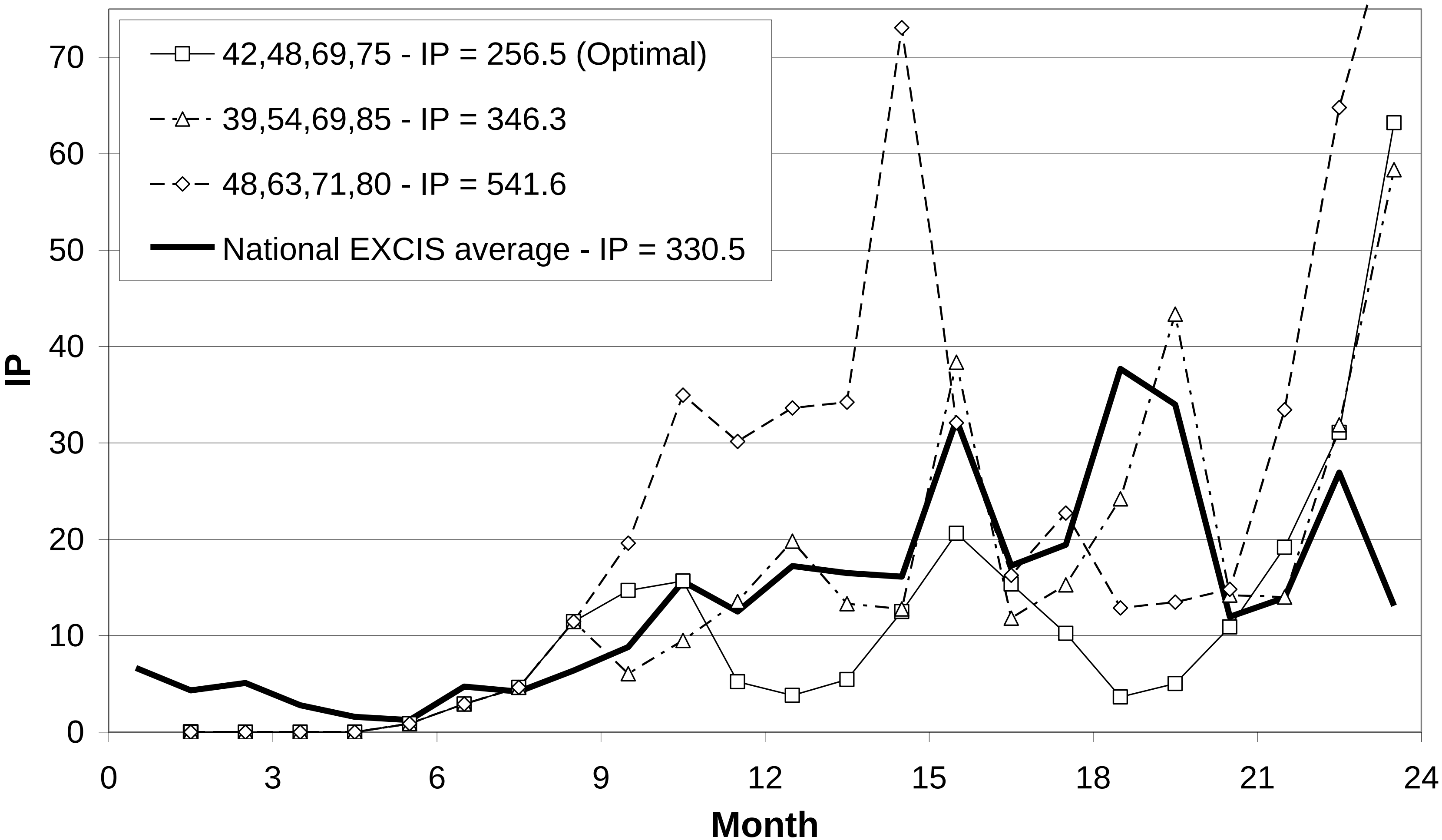
Making the SLiDESim model operational



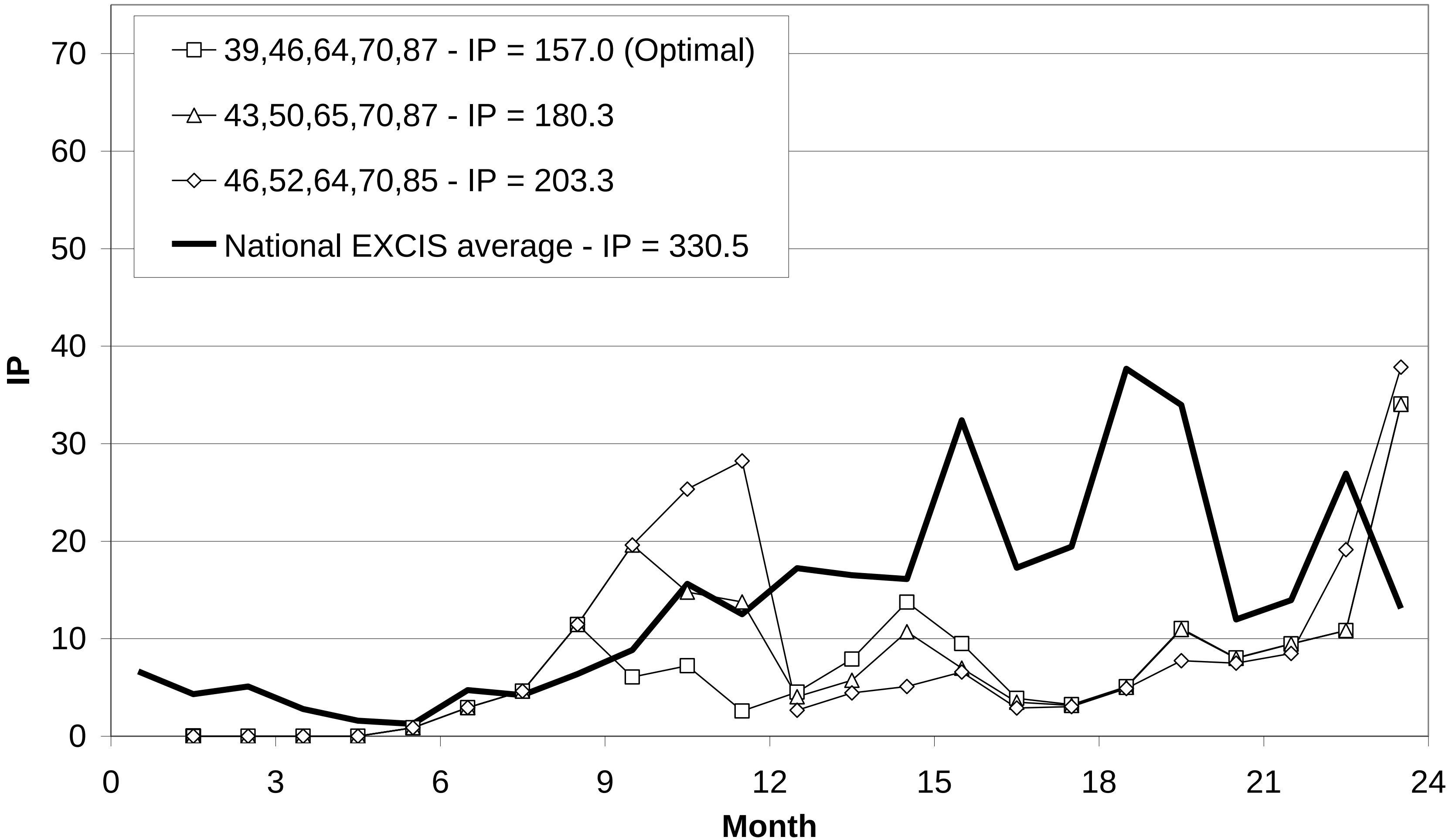
Using chemical and other treatments to control sea lice infections

- Hydrogen peroxide
- Bath treatments – *Excis* (cypermethrin)
- In-feed treatment – *Slice* (emamectin benzoate)
- Constraints: commercial and environmental
- Use of synchronised treatment within area management agreements
- When and how often to treat?
- Use Infection Pressure (IP) as measure of effectiveness

What the model predicts when using FOUR *Excis* treatments i.e. treat in weeks 42,48,69,75



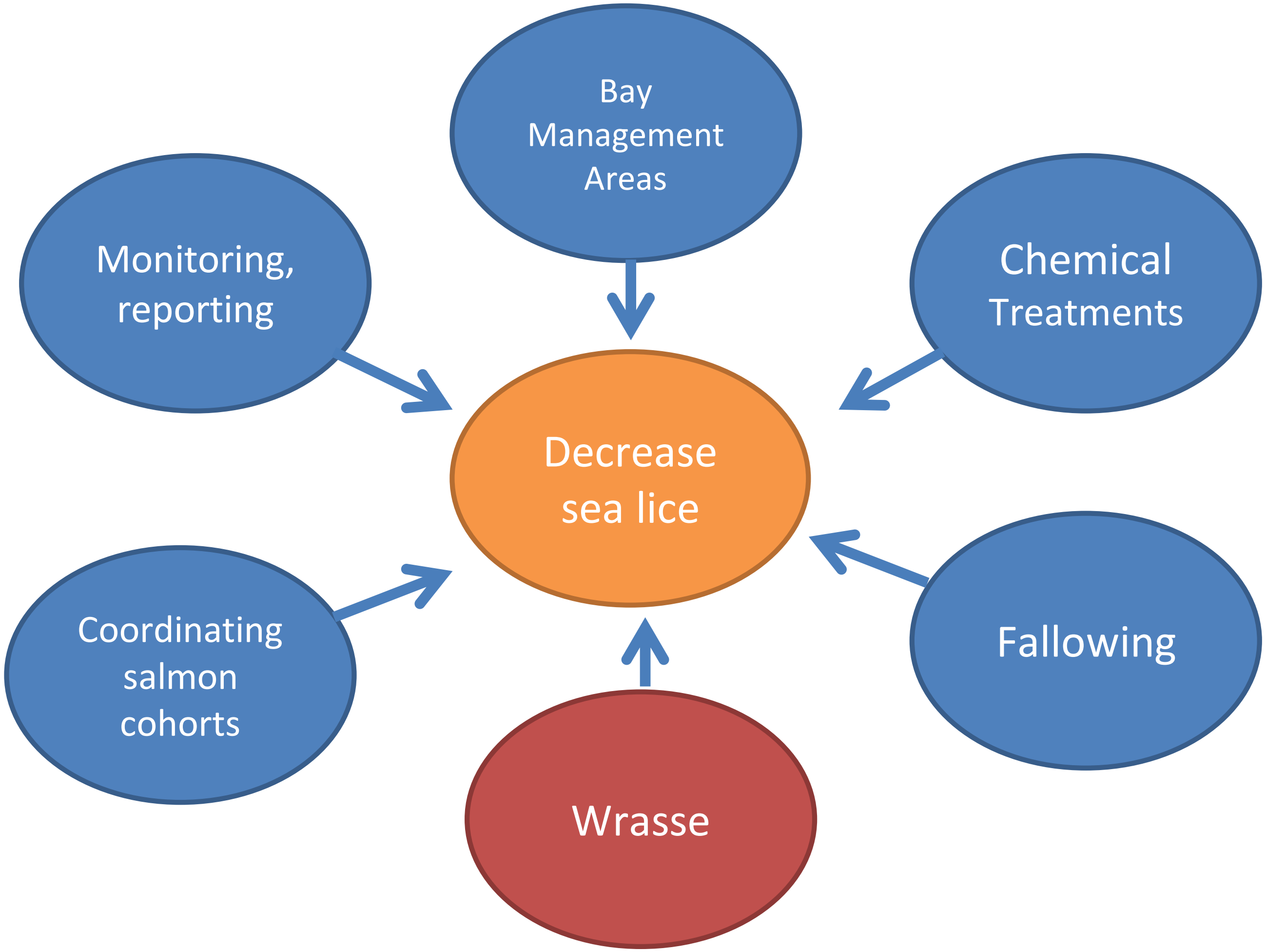
What the model predicts when using FIVE *Excis* treatments i.e. treat in weeks 39,46,64,78,87



Results from compartmental modelling

- You can find effective combinations of treatment numbers and timing for different compounds
- You can carry out multifactorial investigations
- You cannot easily include stochasticity
- You cannot easily include water temperature effects and stage development
- You cannot easily include pulses of external infections
- You cannot easily adapt to new ways of controlling sea lice

Sea lice - the use of cleaner fish

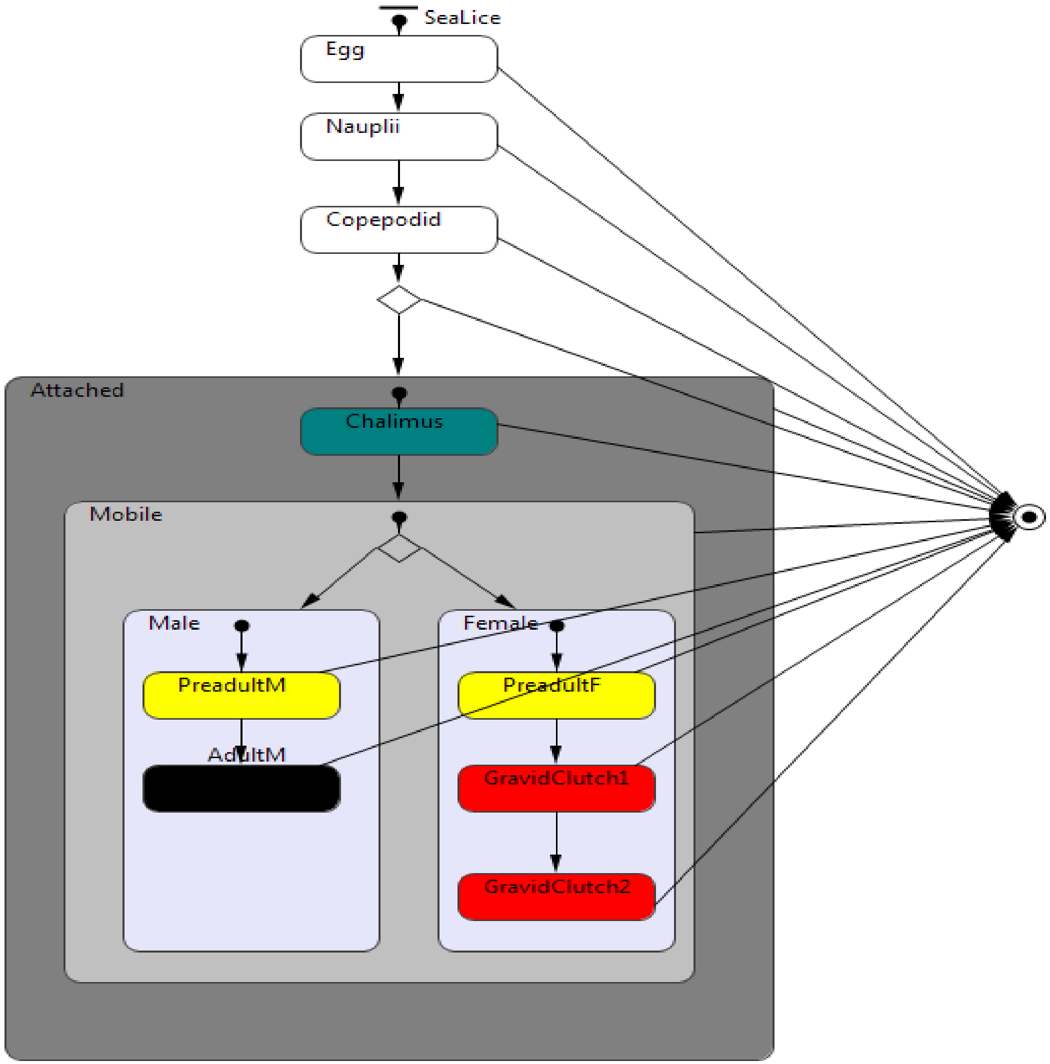


Sea lice - the use of "cleaner" fish

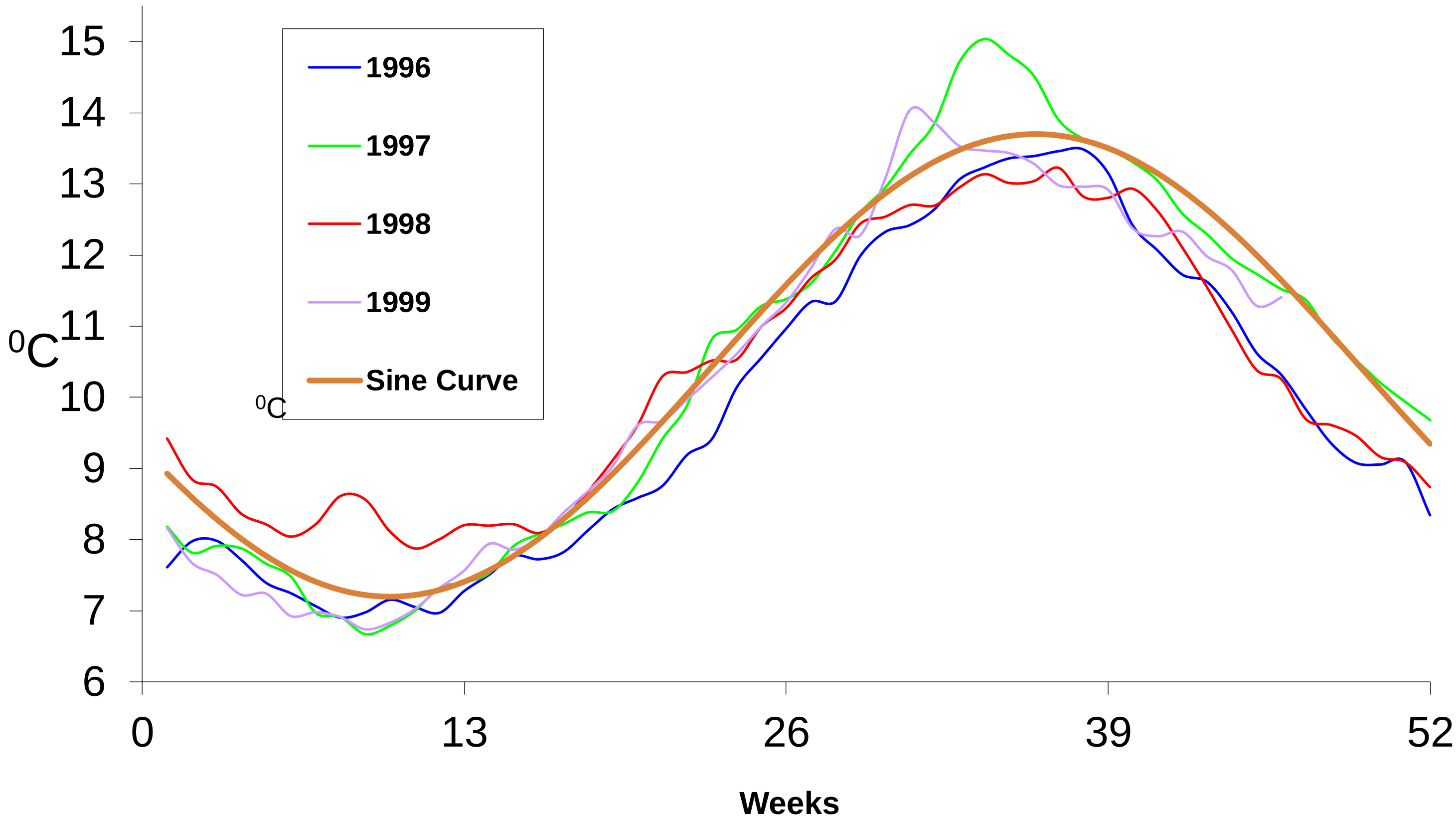
- Increasing use of wrasse
- Interest in Norway, Ireland, Scotland and Atlantic Canada
- In 1990s 1 wrasse per 50 salmon. Currently 1 wrasse pre 25 salmon. Trials undergoing on 1 wrasse per 10 salmon.
- Increasing use of wrasse on salmon production units in Norway and Ireland with development of wrasse aquaculture

Photo: Alan Dykes

Second Model: Individual-Based Model formulated in Anylogic



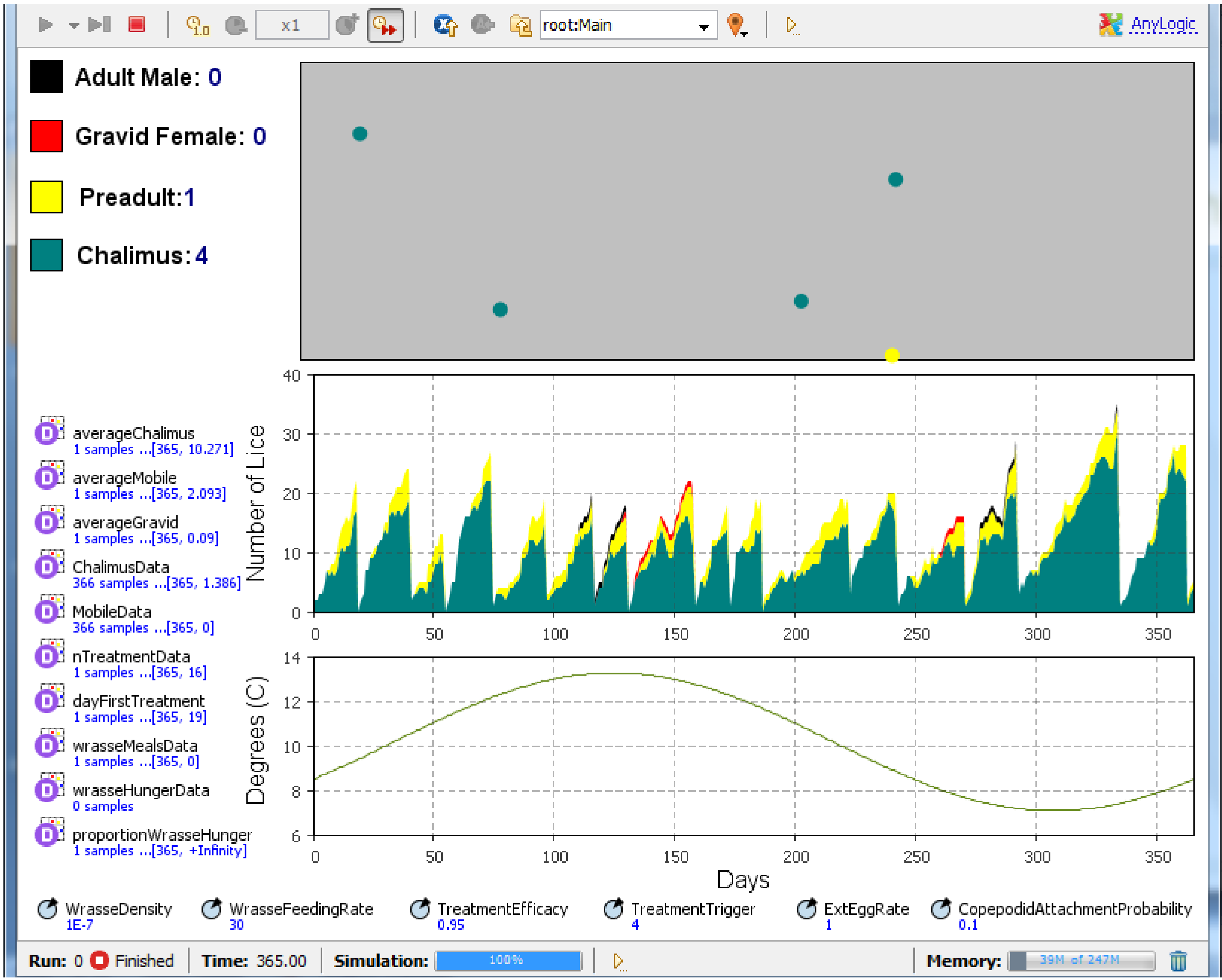
Development and survival of lice depends on water temperature



Individual-Based Model formulated in Anylogic

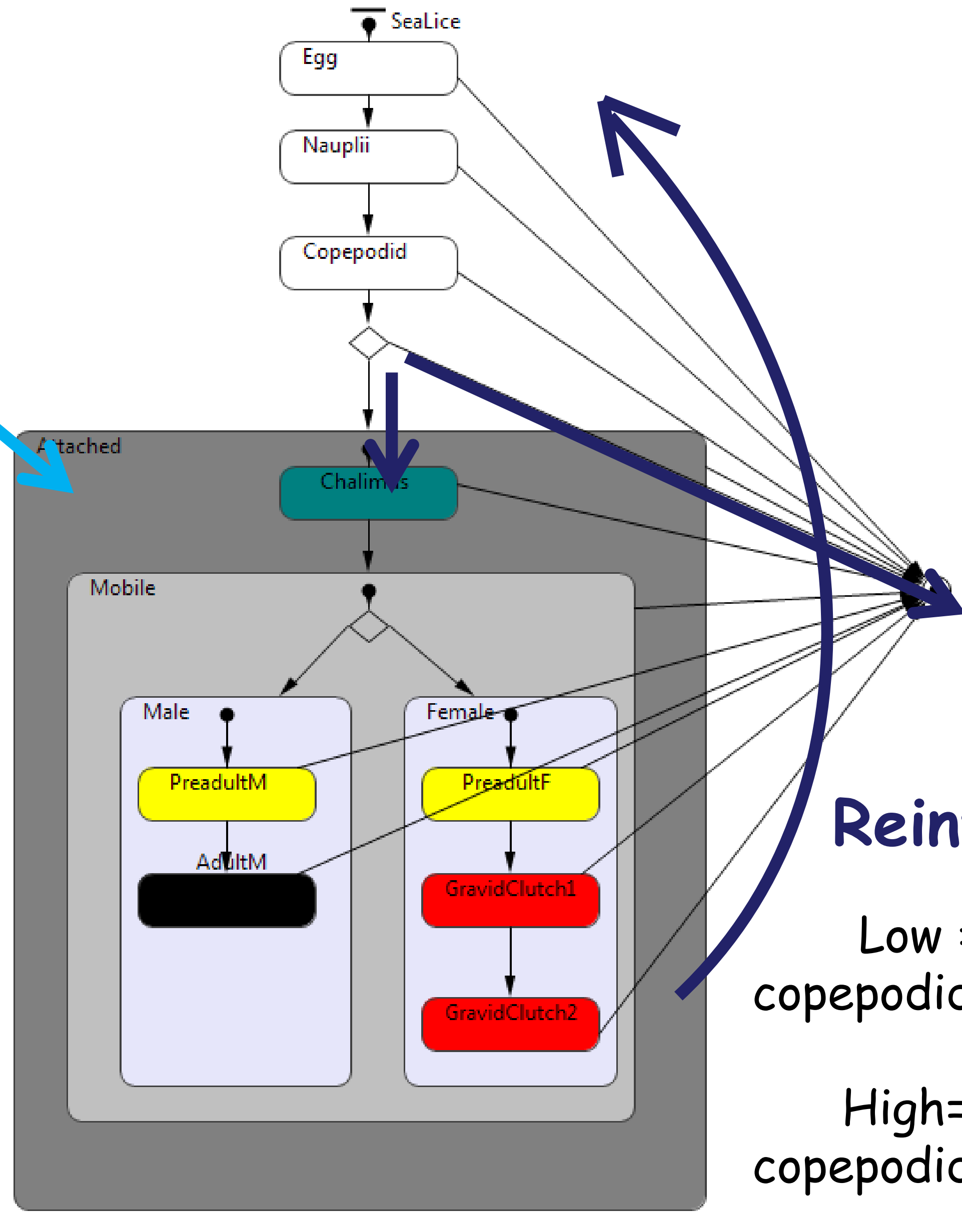
- Effect of temperature on stage development and survival based on meta-analysis by Stein et al 2005
- Fish inspected weekly and if mobiles exceed a limit e.g. 4 lice per fish then a chemical treatment applied
- Treatment effectiveness flexible e.g. 95%
- Wrasse predate at a constant rate e.g. 30 lice per day
- Ratio of wrasse to salmon flexible e.g. 1:200, 1:100, 1:50, 1:25, 1:10, 0

Results for low reinfection and high external infection



External infection

Low = 0.1 lice/ day
High = 1 lice/day

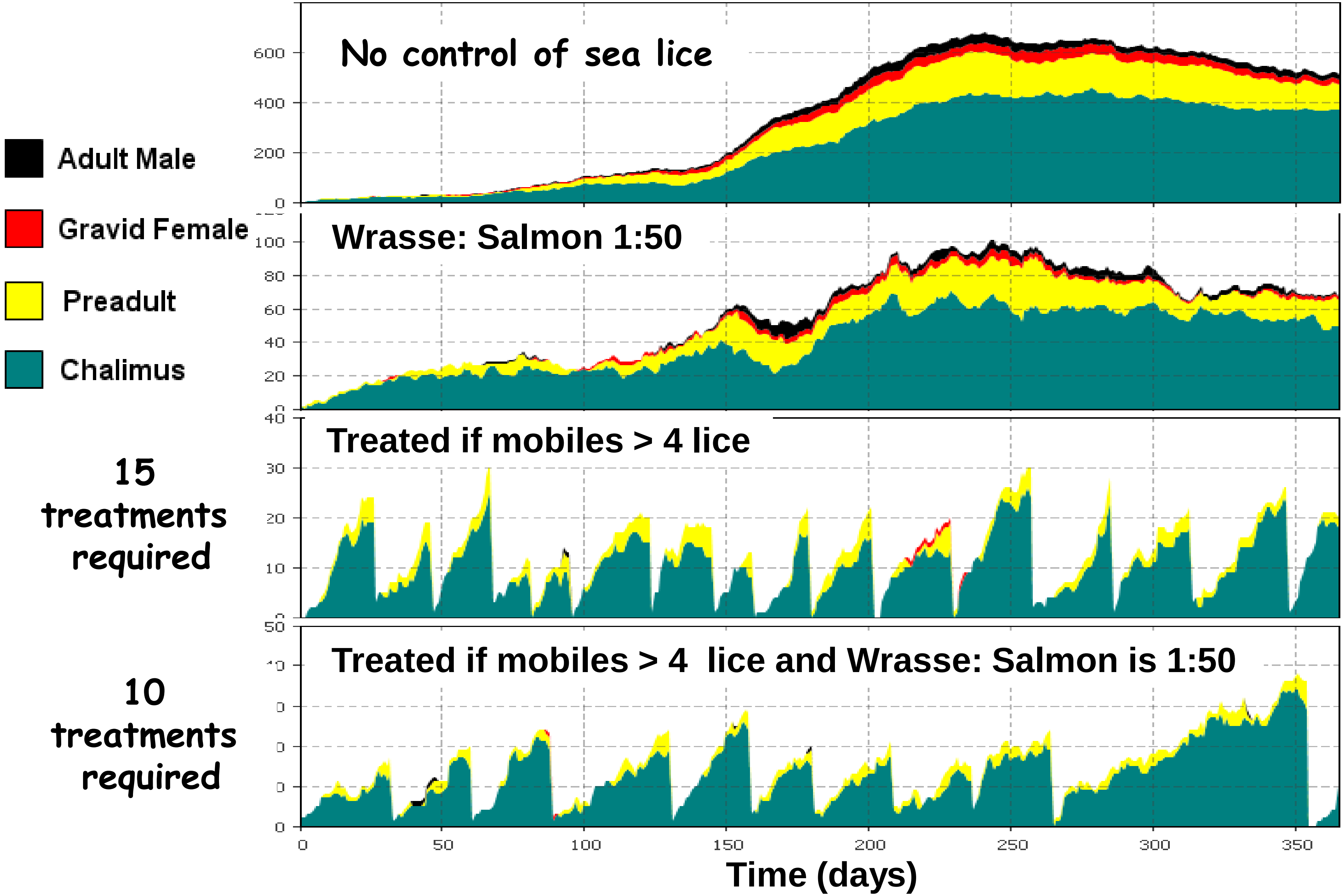


Reinfection

Low = 10% of copepodids find a host

High= 100% of copepodids find a host

Results for low reinfection and high external infection at different wrasse ratios



Individual-Based Model findings

- Individual- based models are useful for mimicking complex, stochastic processes with dynamic and pulsed effects
- Cleaner fish have the potential to reduce the average number of chemical treatments in salmon production systems
- Wrasse can be effective at controlling infestations that arise from both external and internal sources

Finally… which model is better - Compartmental Population or Individual-Based ?

"errors using inadequate data are much less than those using no data"

Charles Babbage (1792-1871)

"essentially, all models are wrong, but some are useful."

George Box (1919-2013)

"The purpose of models is not to fit the data but to sharpen the questions."

Samuel Karlin (1924-2007)

Acknowledgements

Funding:

DEFRA (Link ENV12; VM02134)

Department for Environment Food and Rural Affairs

Industrial / Research support:

Marine Harvest (Scotland) Ltd / Nutreco Aquacultu
(Chris Wallace / Gordon Ritchie)

Grallator Modelling, Simulation & Software
(Chris Robbins)

Scottish Association for Marine Science
(Jim Treasurer)

NVI, Oslo, Norway

National Veterinary Institute