Dispersion of salmon lice, connection between farms and economic cost

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RESEARCH COUNCIL FAROE ISLANDS

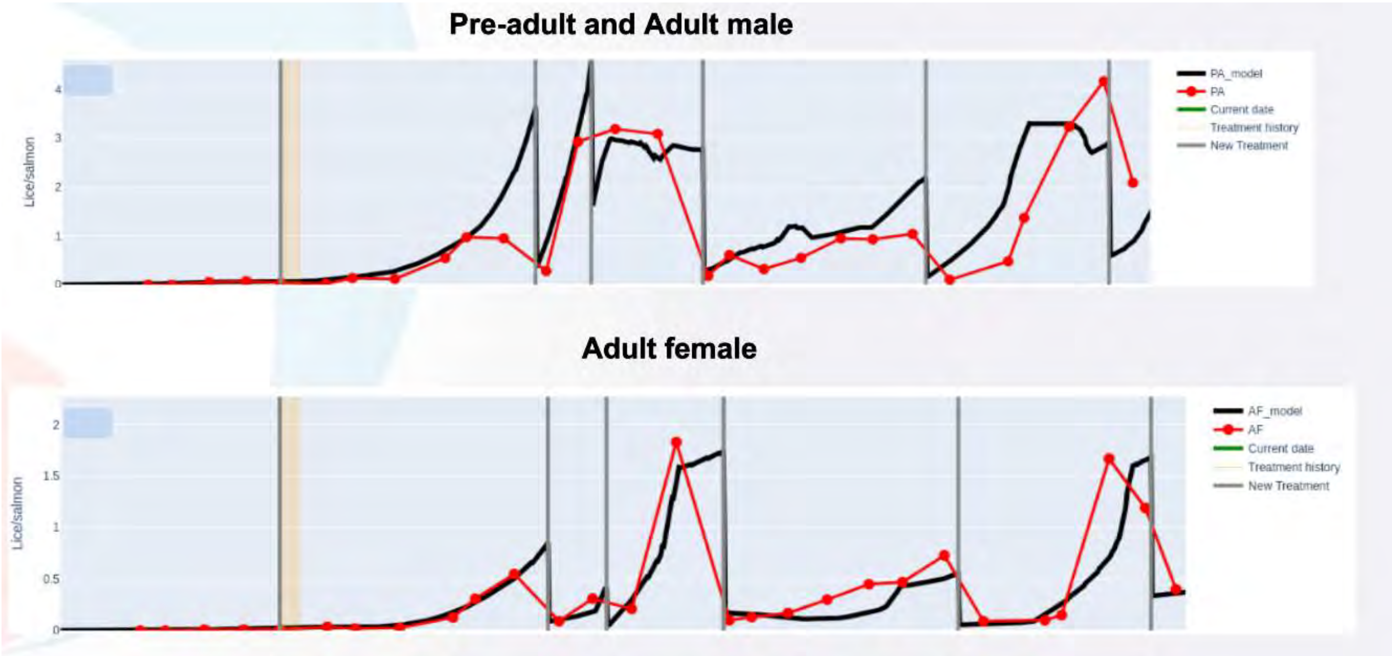
DTU Aqua
National Institute of Aquatic Resources

Fiskaaling
Aquaculture Research Station of the Faroes

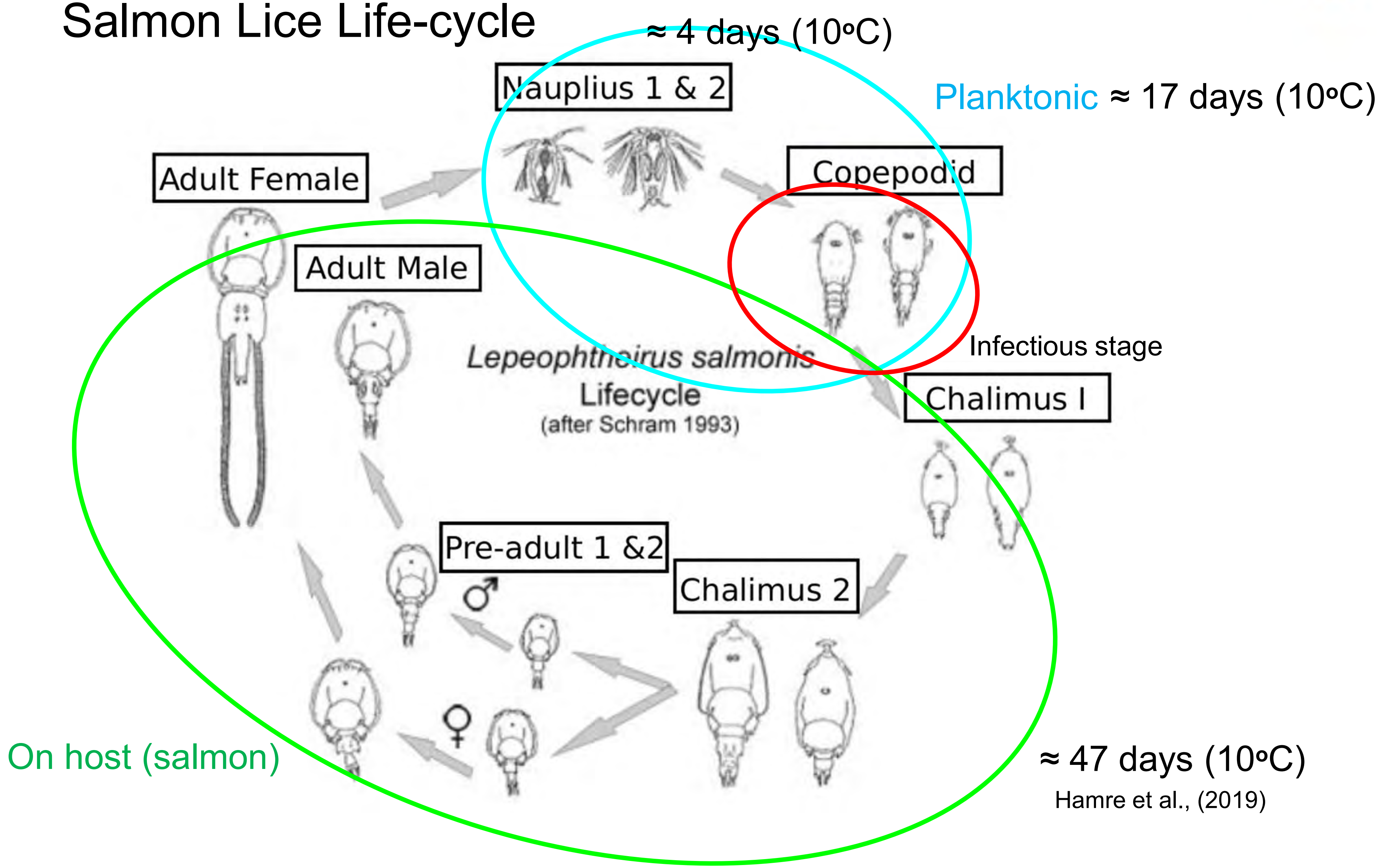
Overall aim:

Develop a tool for optimal salmon lice management:

- Lice dispersion
- Connectivity
- Salmon lice population dynamics
- Lice Economics



Salmon Lice Life-cycle



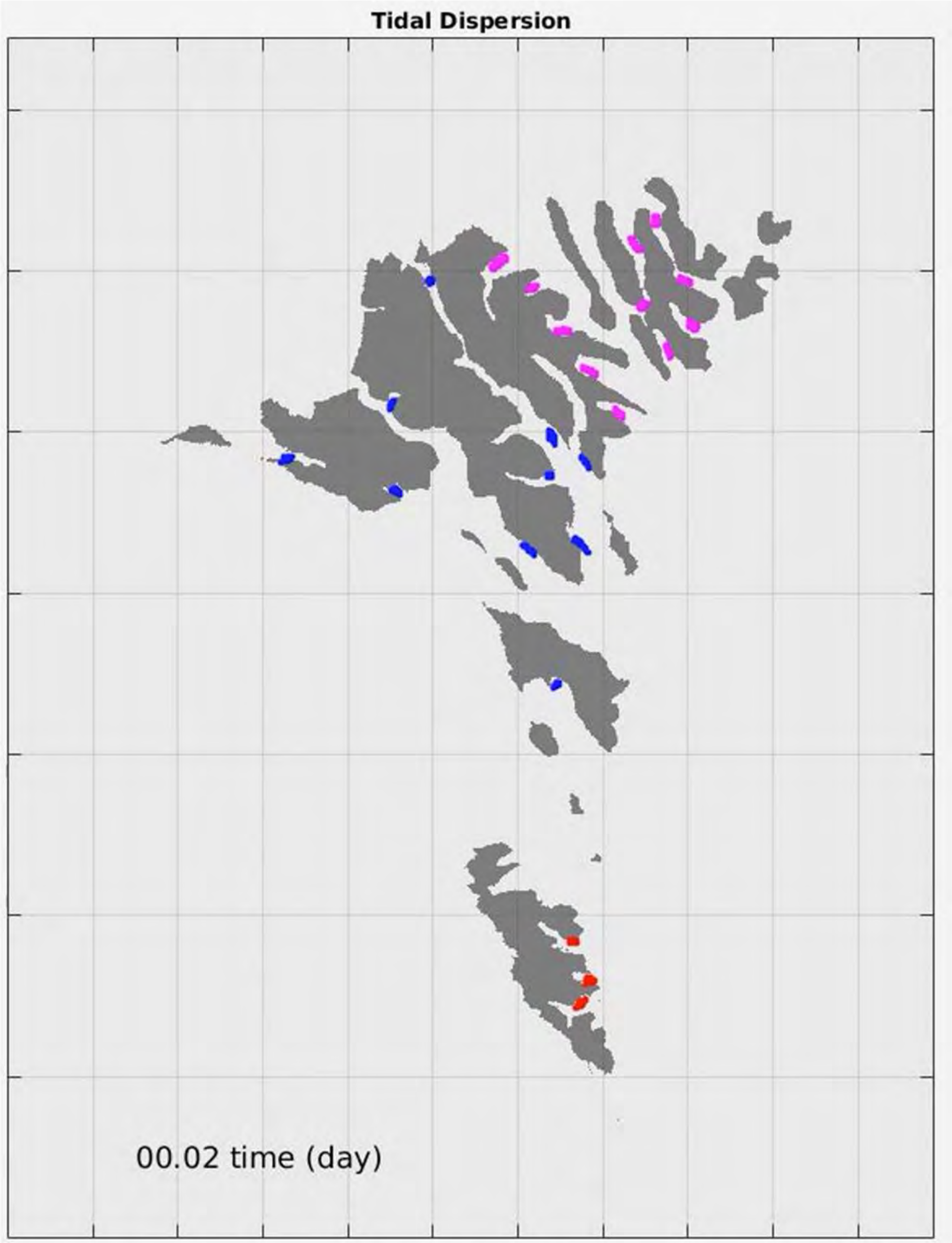
The Dispersal Model

Hydrodynamic Model
- Tidal currents
    - 6 tidal constituents
    - Residual current
    - 100 m

(Simonsen & Niclasen, 2021)

Particle Tracking Model
- Lagrangian
- Biological parameters
    - Length of planktonic phases
      (Phase 1: **3.7 d** Phase 2: **13 d)**
    - Mortality (**0.17 d^{-1}**)

(Samsing et al., 2016) (Stien, 2005)


Tidal Dispersion
00.02 time (day)

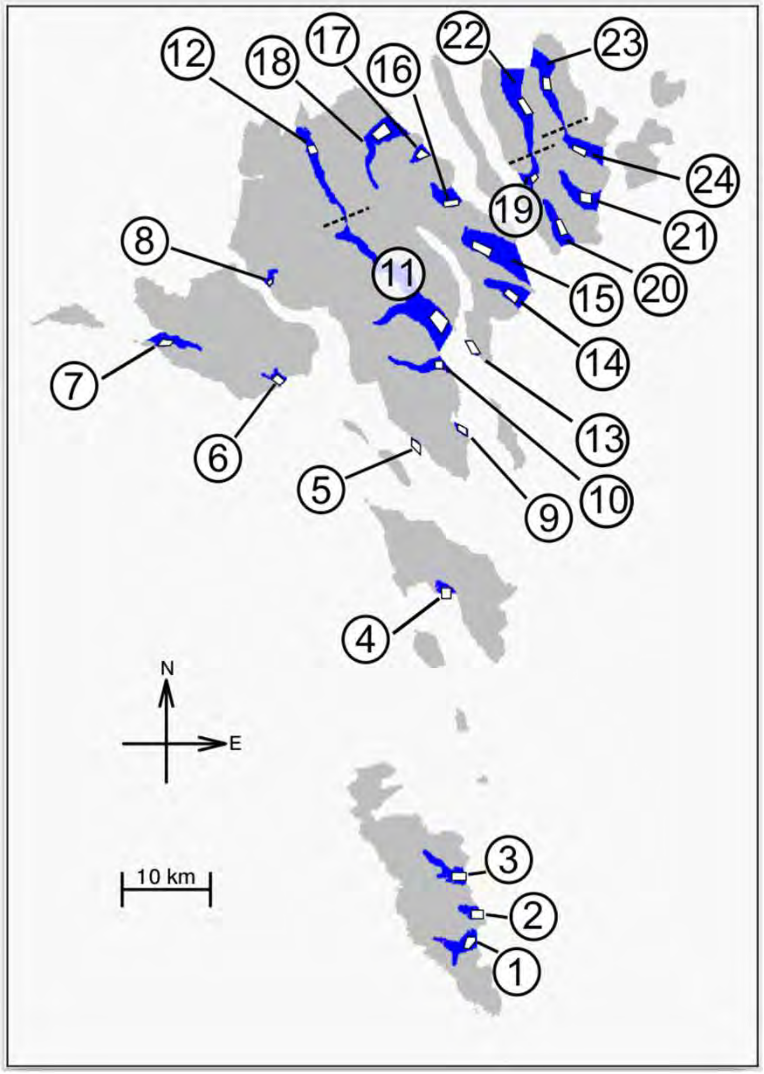
Connectivity Matrix

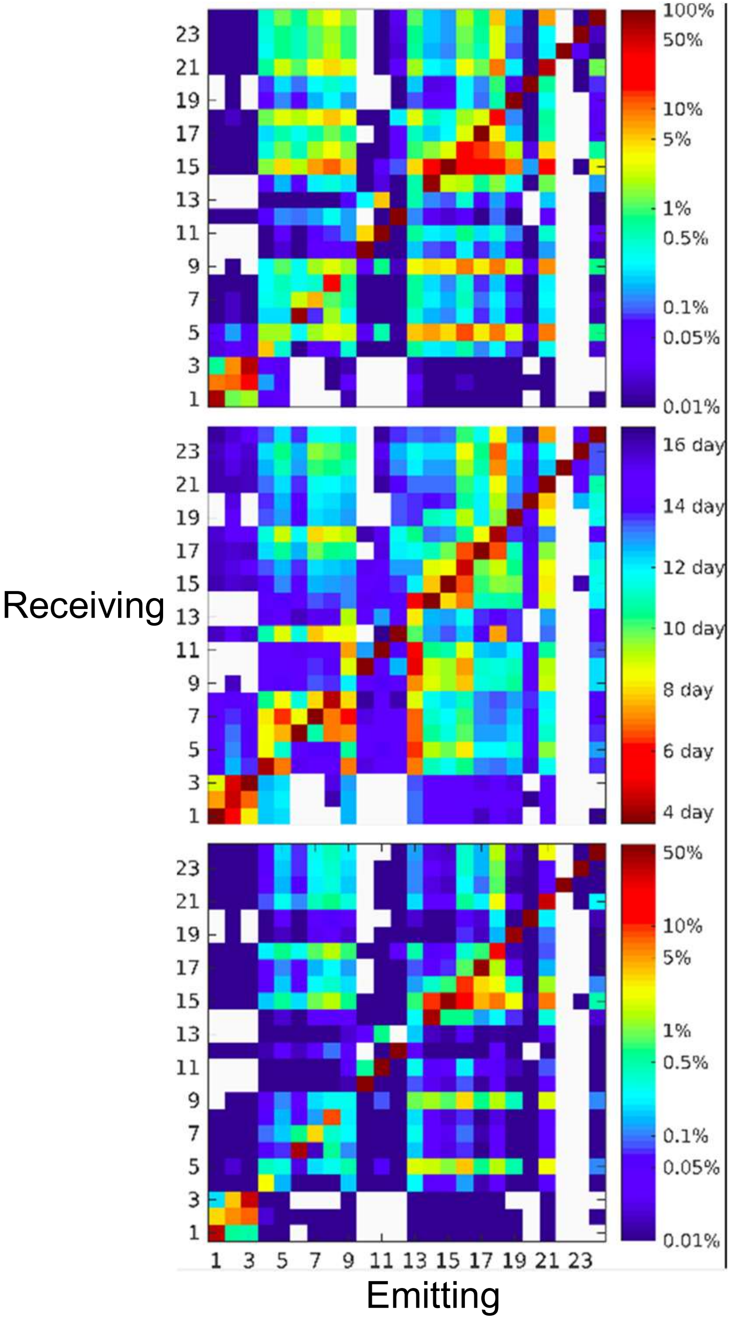
24 farm sites:

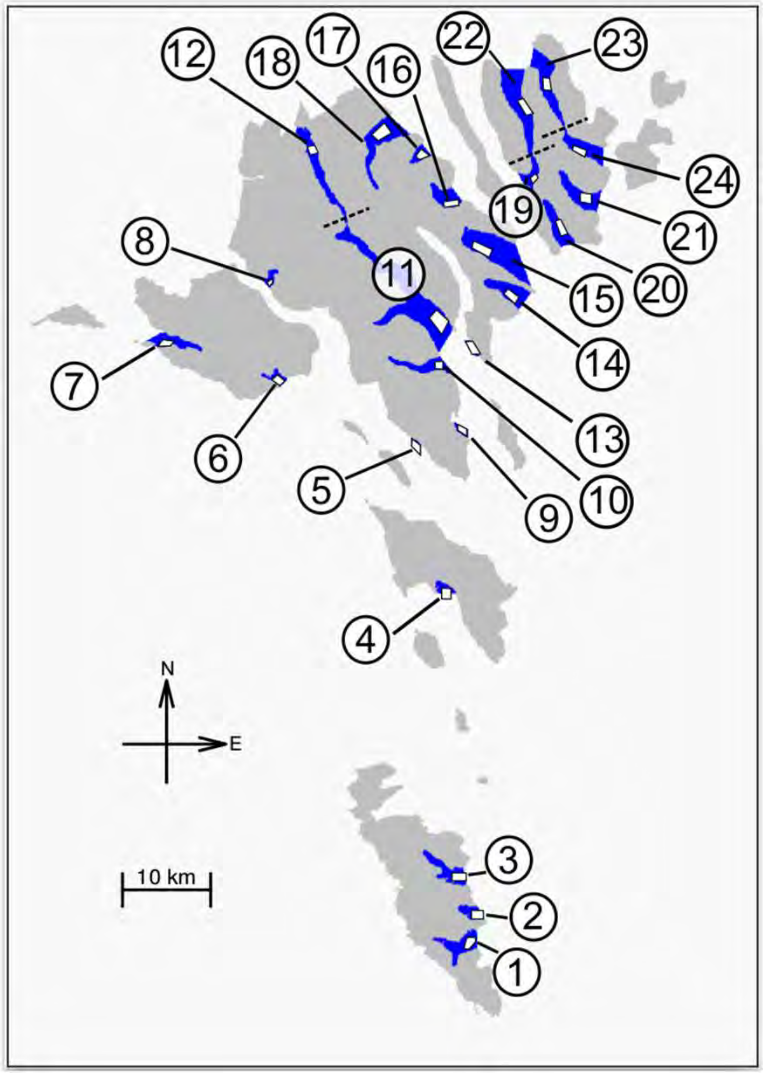
- Emitting sites (White area →)
- Receiving sites (Blue area →)

Connectivity Simulation:

- 900 particles ever hour for 83 days
- Particles were allowed to live out their planktonic life span
- Only recorded once in a farm area
- Only copepodids are recorded







Complex and highly connected farm network

Two clusters of farms

Salmon lice Management:

Salmon louse are usually managed with treatments:
Cost of salmon lice:

- €0.25 kg^{-1} (Costello, 2009)
- €0.39 kg^{-1} (Abolofia et al., 2017)

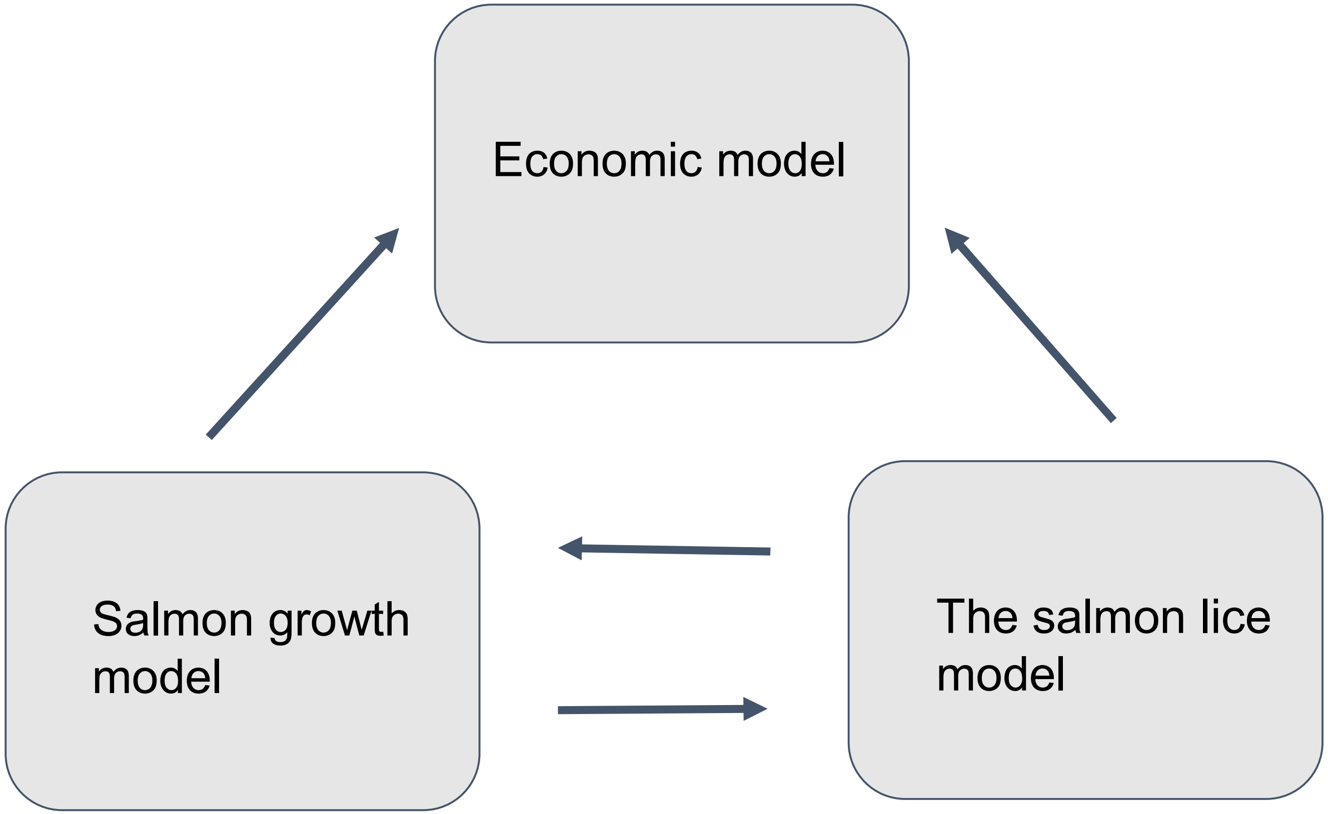
Translates to 675-1 billion € with global production of 2.7 million ton.

When treatments are required is mainly regulated with lice treatment thresholds:

- Norway has 0.5 adult female per salmon (0.2 in migration periods)
- In Scotland 0.5 adult female per salmon is recommended, while 8 adult female lice per salmon mandates intervention
- Faroe Islands has currently 1 adult female per salmon (0.5 in migration periods)

What is the optimal treatment threshold??
(Kragesteen el al., 2019)

A conceptual bioeconomic model



Method - A conceptual bioeconomic model

Profit of Harvest

Time of harvest

Cost of treatment

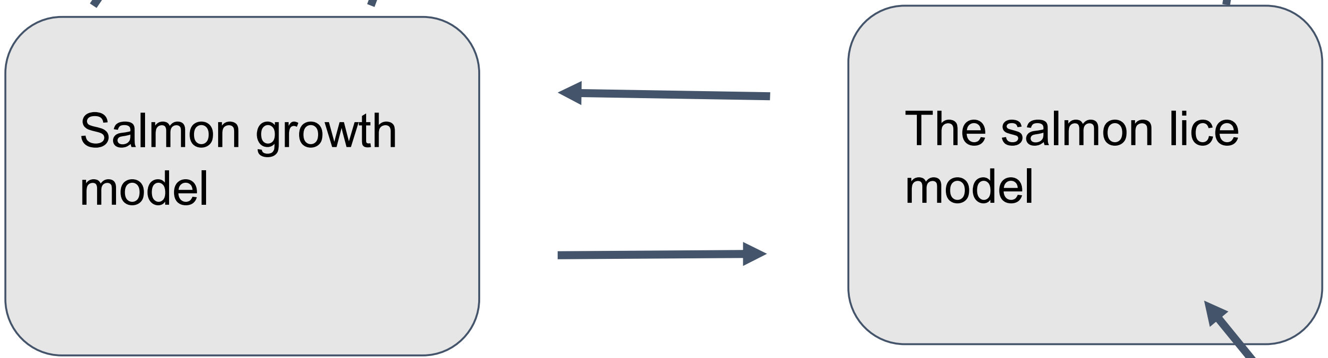
$$\Pi = \frac{1}{t_{tot}}\left(\sum_{j=1}^{n_H}(\pi - C)W(t_{H,j})P(t_{H,j}) - \sum_{j=1}^{n_H}\sum_{i=1}^{n_{treat(t_{H,j})}} C_{treat}W(t_{T,i,j})P(t_{T,i,j})\right)$$

Salmon weight

Salmon survival

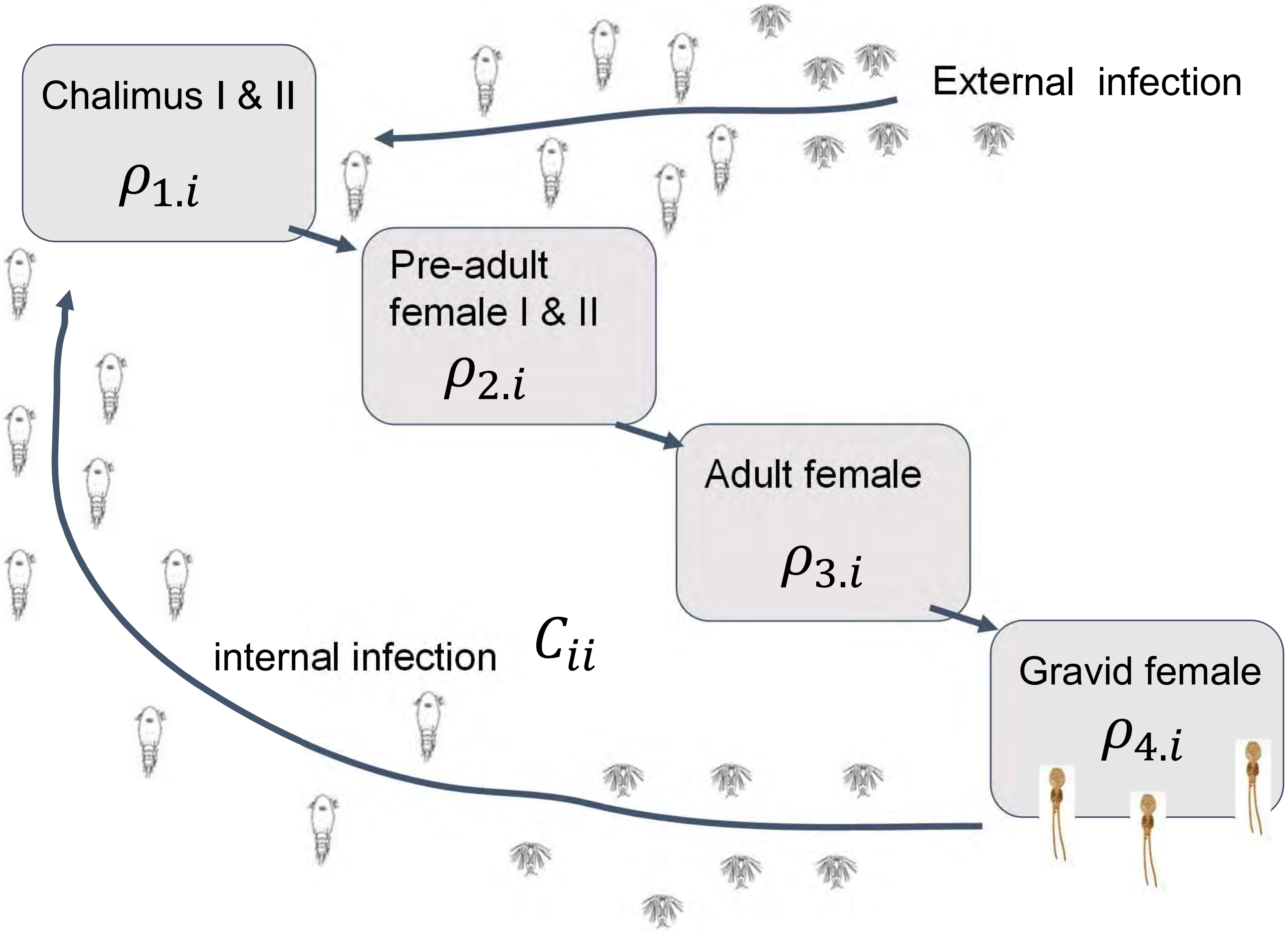
Number of treatment

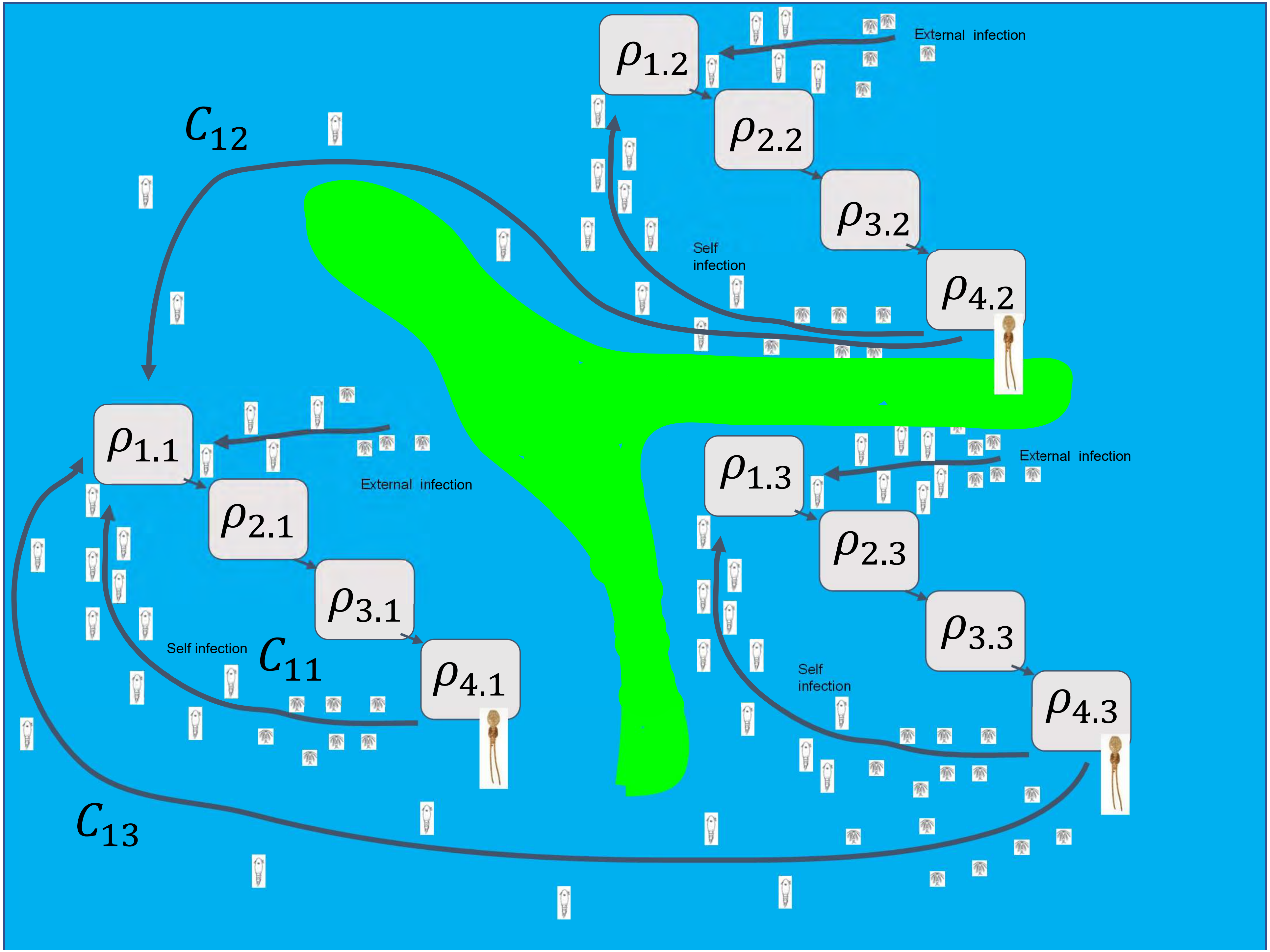
Time of treatment



Treatment threshold

The salmon lice model





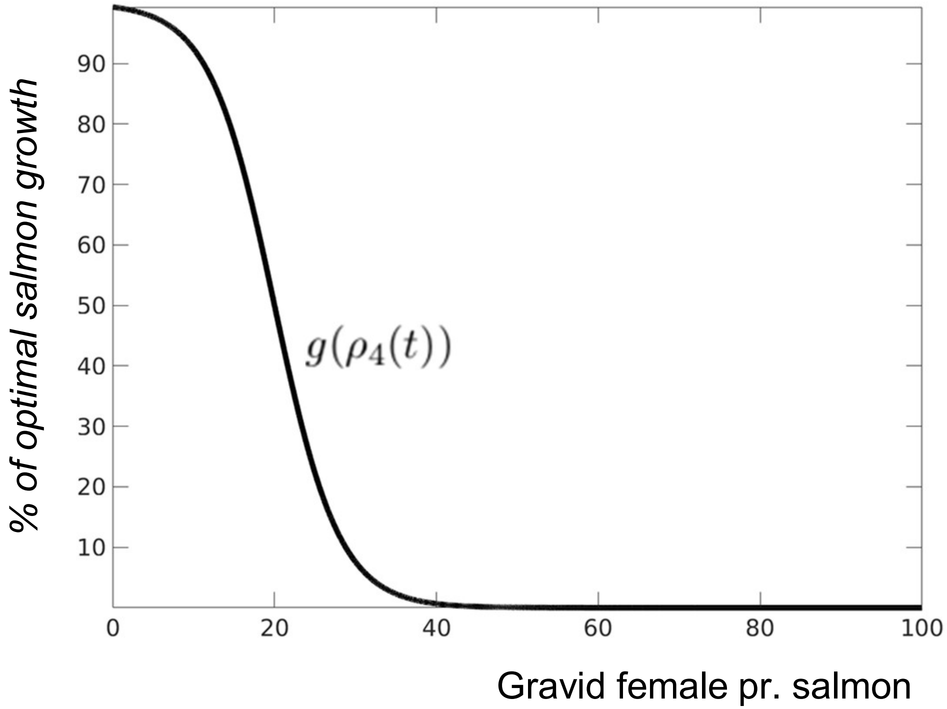
$\rho_{1.2}$
External infection
C_{12}
$\rho_{2.2}$
$\rho_{3.2}$
Self infection
$\rho_{4.2}$
$\rho_{1.1}$
External infection
$\rho_{2.1}$
$\rho_{3.1}$
Self infection
C_{11}
$\rho_{4.1}$
$\rho_{1.3}$
External infection
$\rho_{2.3}$
$\rho_{3.3}$
Self infection
$\rho_{4.3}$
C_{13}

Method - What we added

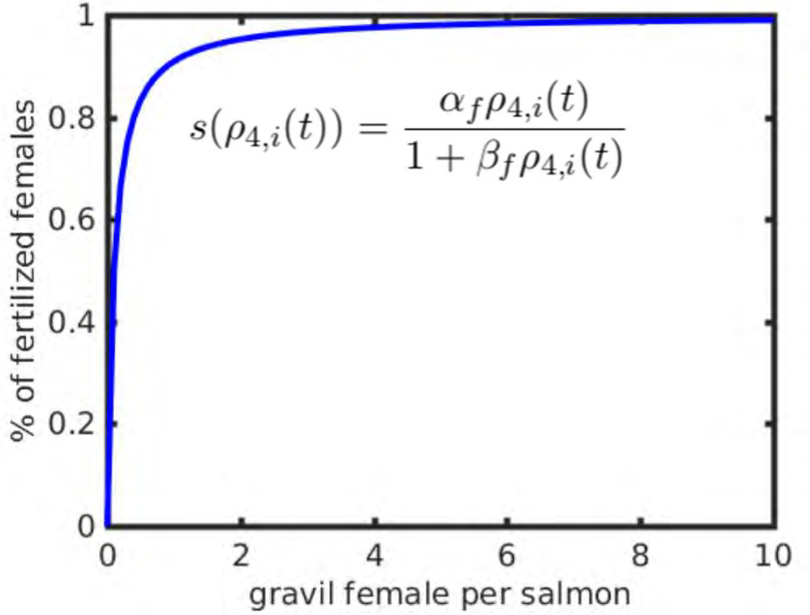
Lice cost (Stormoen, 2013)

Lice cost on Salmon growth

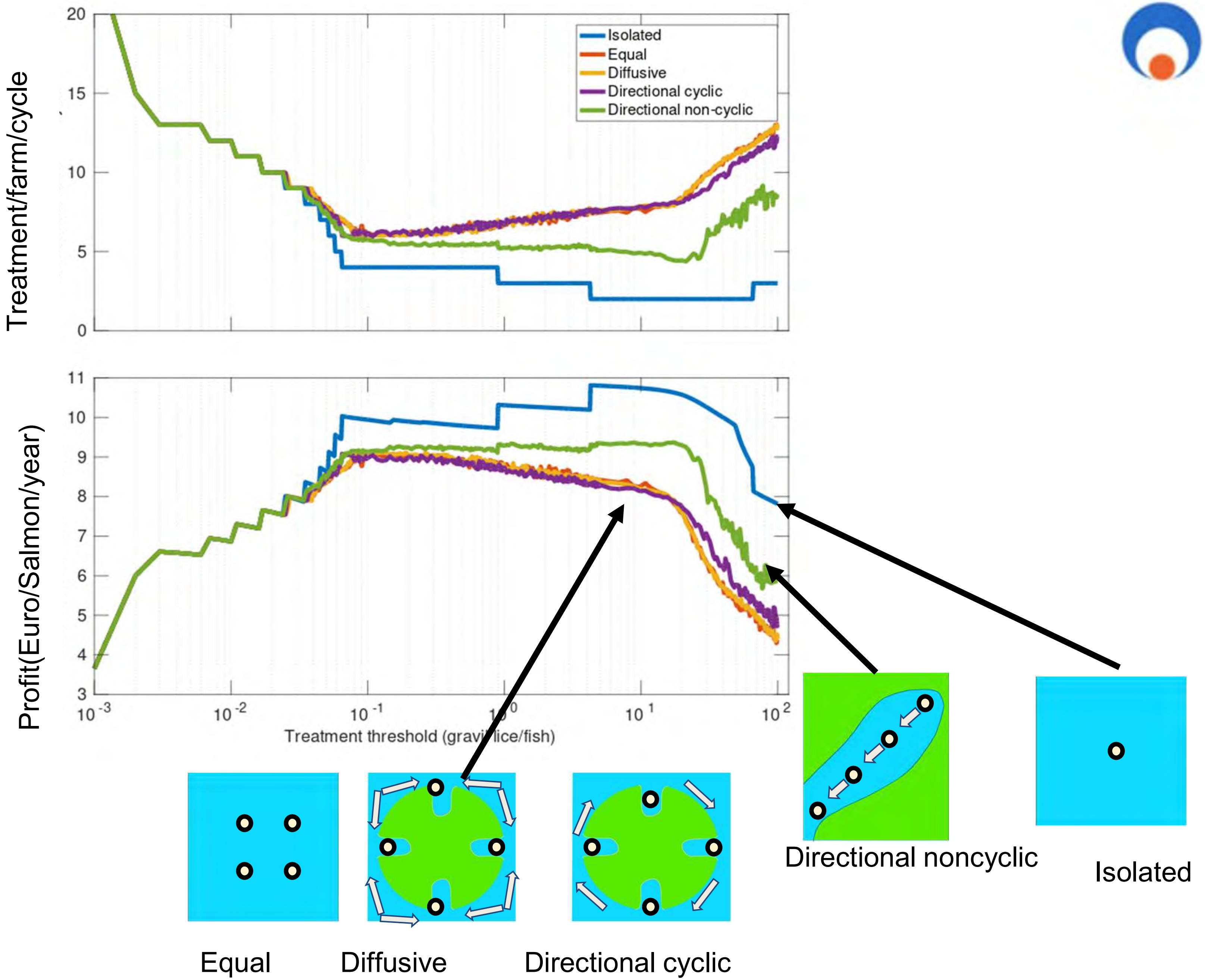
Effect on growth as function of gravid lice



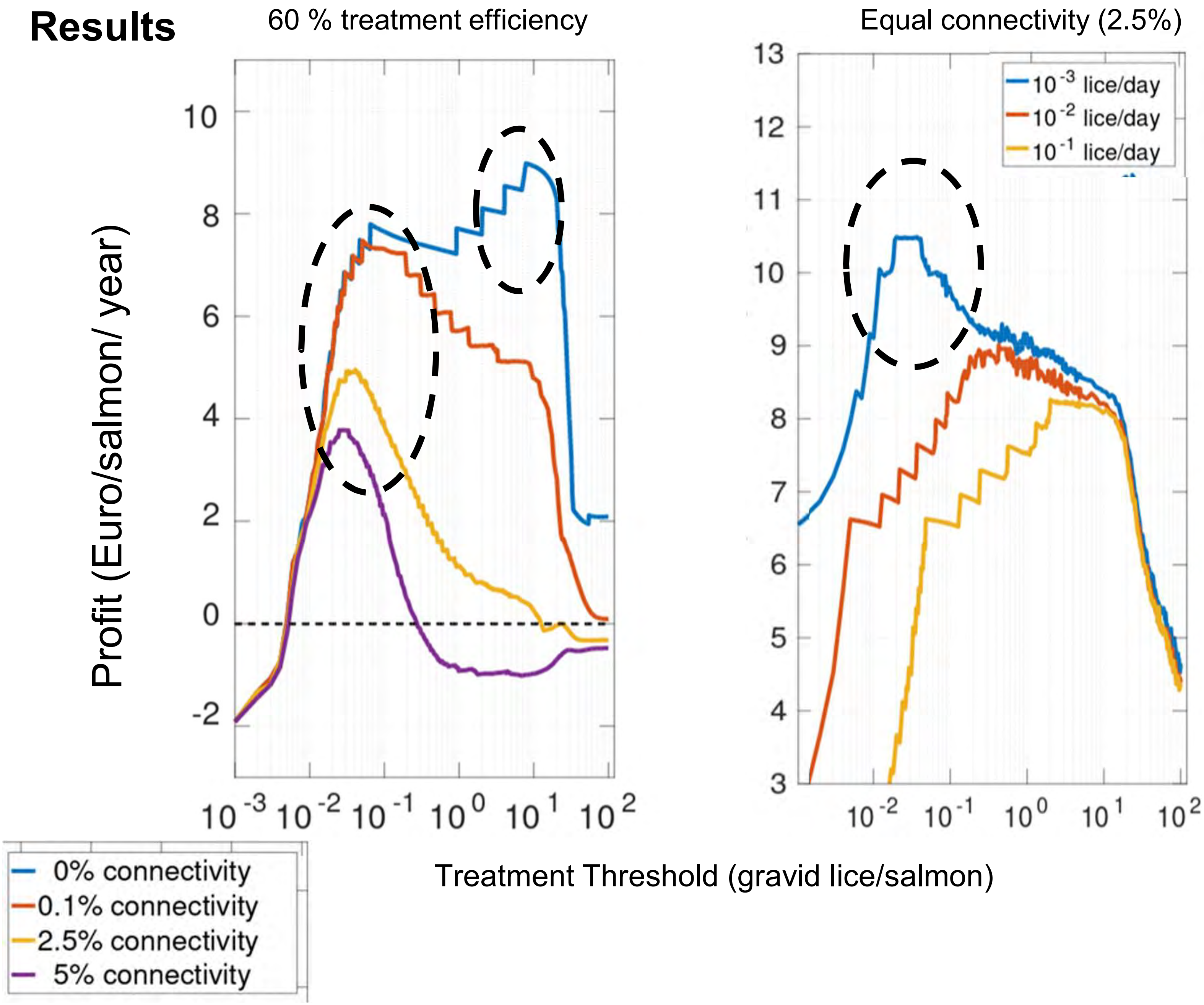
Allee effect (Stormoen, 2013, Krkosek et al., 2012)



Results

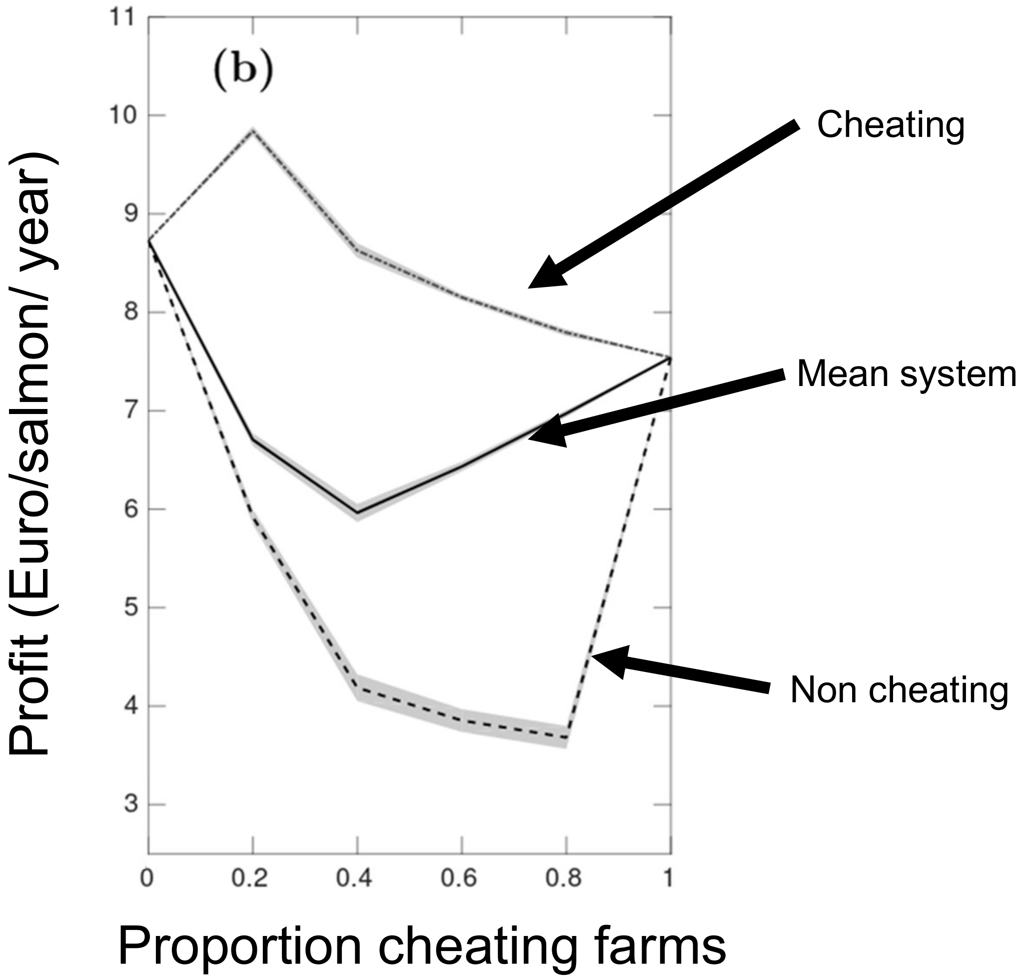

Treatment/farm/cycle
Isolated
Equal
Diffusive
Directional cyclic
Directional non-cyclic
Profit(Euro/Salmon/year)
Treatment threshold (gravid lice/fish)
Equal
Diffusive
Directional cyclic
Directional noncyclic
Isolated

Results



Treatment Threshold (gravid lice/salmon)

Results - *Tragedy of the Commons*



- 5 farm network with equal connectivity of 2.5 %.
- Non-cheating: 0.1 gravid lice/salmon treatment threshold
- Cheating farms: 10 gravid lice/salmon treatment threshold.

Conclusion

Dispersion and connectivity:

- Dispersion highway clockwise around the Faroe Island
- Southernmost island is relatively isolated
- Faroese farms form a complex and highly connected farm network
- Two Faroese farm clusters

Conclusion

Lice management:

Two optimal treatment thresholds peaks:

- Isolated farms profit most with a higher treatment threshold
- Except with really high self-infection or really low treatment efficiency

- Connected networks (overlapping production) profit most with low treatment thresholds
- Except with high external infection pressure

Tragedy of the Commons

- Is present in connected farm networks with overlapping production
- Farm network profit is lowest when about half of farms are cheating

Suggest: strict regulation is needed when managing with a low treatment threshold.

Further Perspective

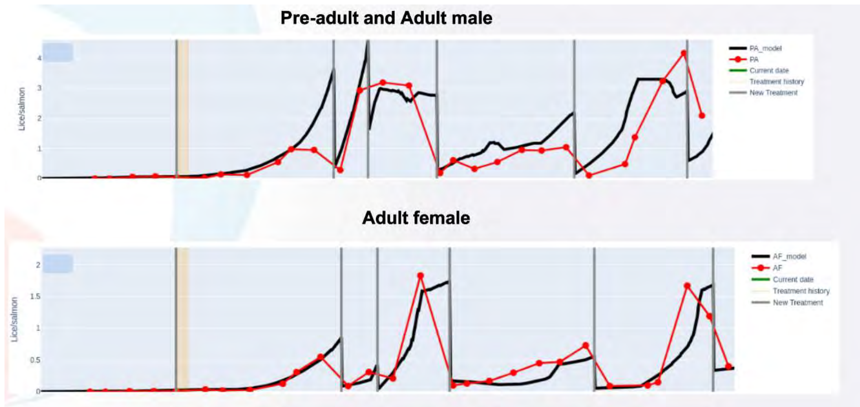
Trying to model real systems…

If we can couple all mentioned aspects, and simulate a real system as the Faroe Islands:

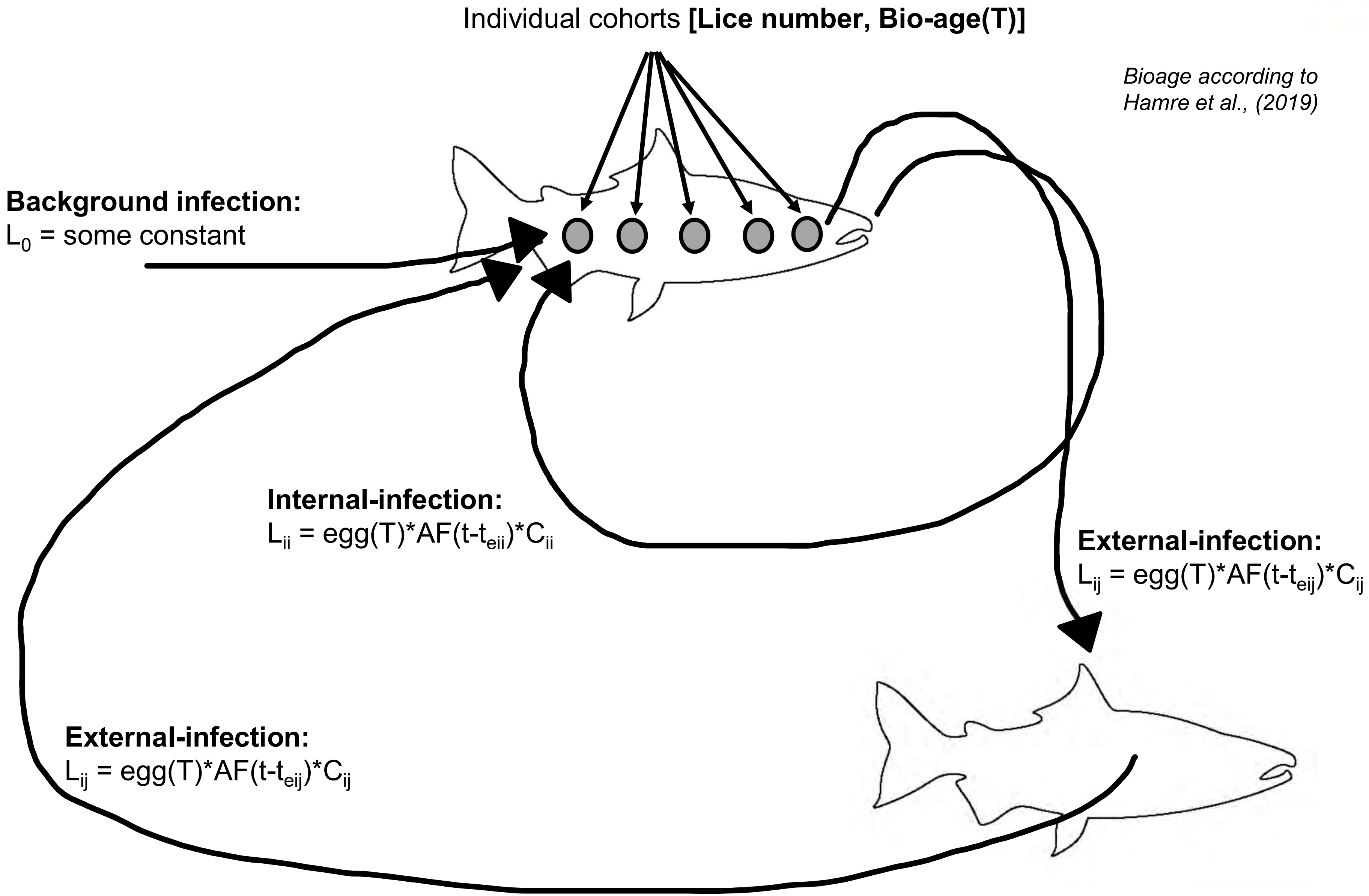
- have a powerful tool to combat or control salmon lice in aquaculture.

However, it requires further work in:

- Hydrodynamics models
- Connectivity
- Biological knowledge of salmon lice
- Salmon lice population dynamics
- Treatment efficiency



The salmon lice model:



Dispersion

How to estimate dispersion

- Particle tracking forced by hydrodynamics
    - Hydrodynamic model:
        - ROMS (Norway)
        - FVCOM (Canda, Scotland)
        - We so far use a simplified ROMS (tidal)
    - Particle tracking model:
        - Normal method:
            - 4th order Runga Kutta + diffusion (random walk)
            - Norway has probably the most advanced method using ligth and salinity sensitive particles.
            - We use euler forward + diffusion (random walk)

What are salmon lice (*Lepeophtheirus salmonis*) and why are they a problem?

Global cost of controlling sea lice:

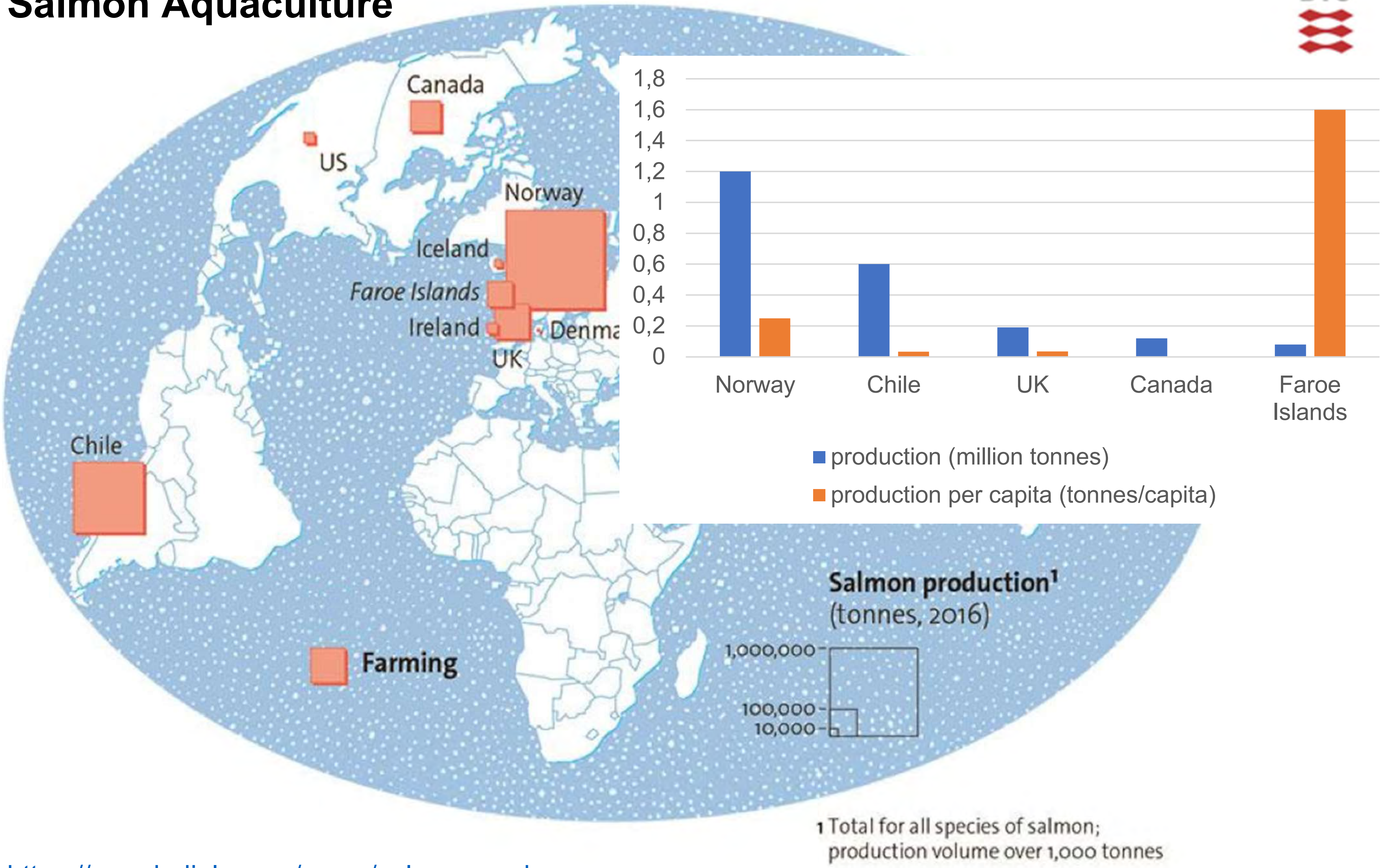
230 million to 1 billion euro/year

Research questions:

Main question:
What are the optimal lice management strategies in salmon farm networks?

Secondary question:
How can salmon lice growth be modelled in Faroe Islands?

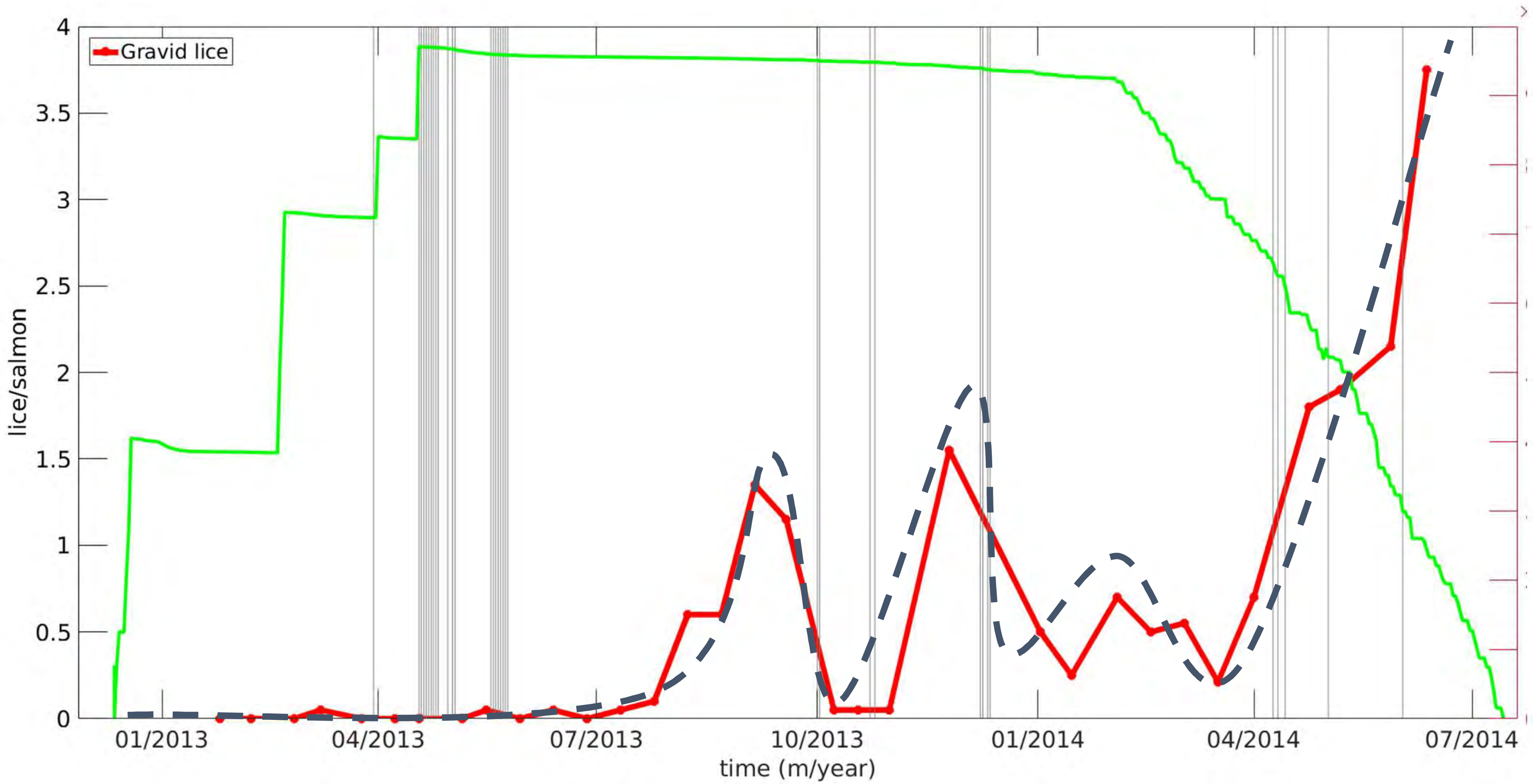
Salmon Aquaculture



https://mondediplo.com/maps/salmon-producers

FAO 2016

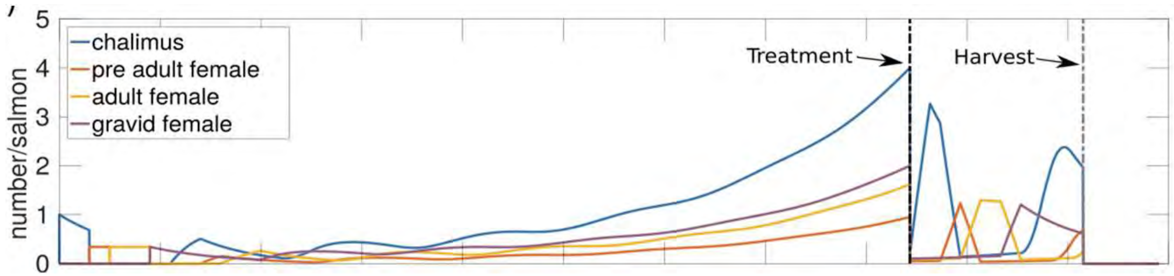
Aim



Gravid lice
lice/salmon
4
3.5
3
2.5
2
1.5
1
0.5
0
01/2013
04/2013
07/2013
10/2013
01/2014
04/2014
07/2014
time (m/year)

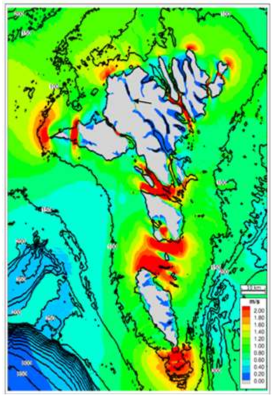
Method

Model of salmon lice growth

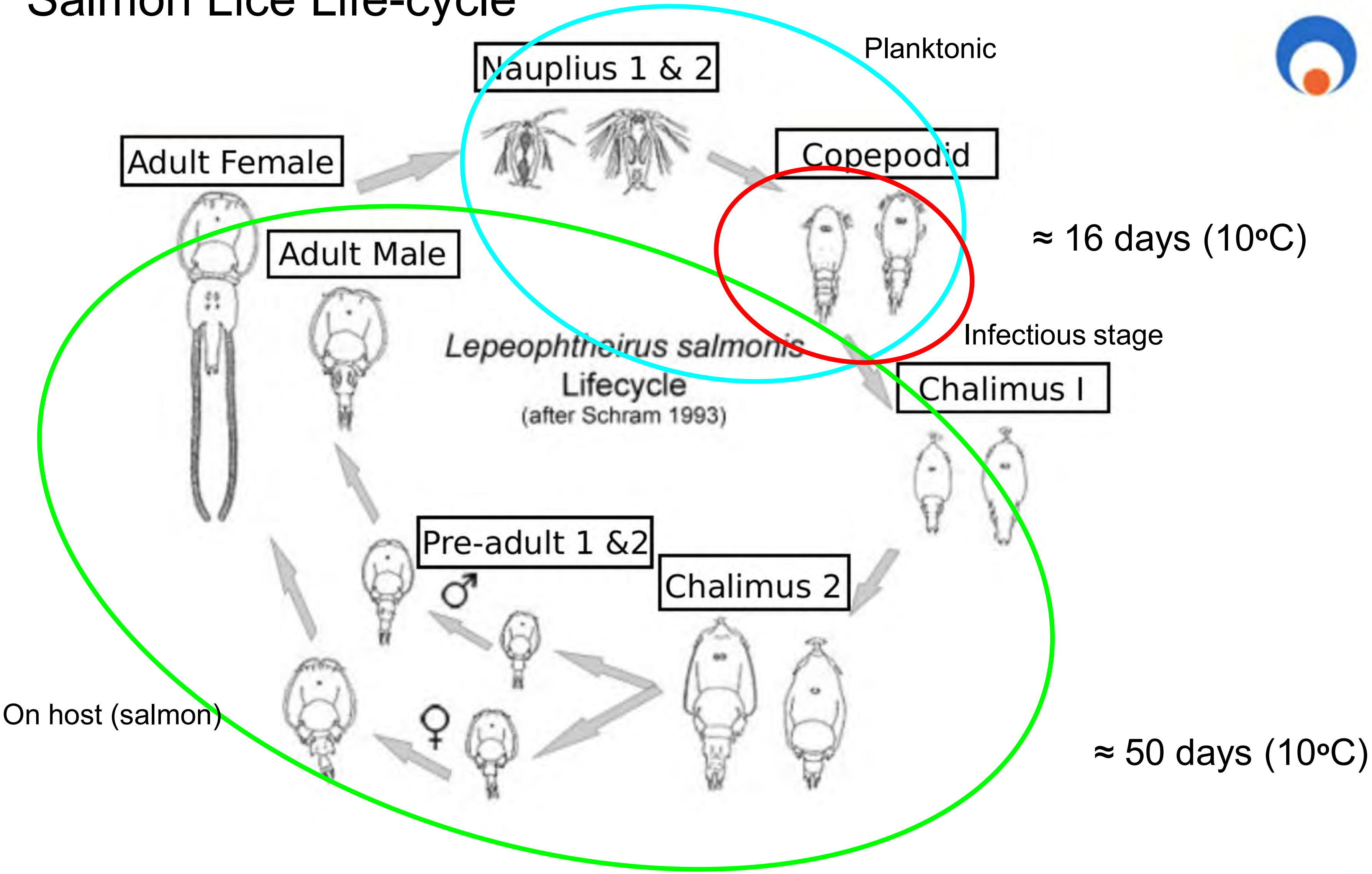


Model of physical environment to estimate lice dispersion.

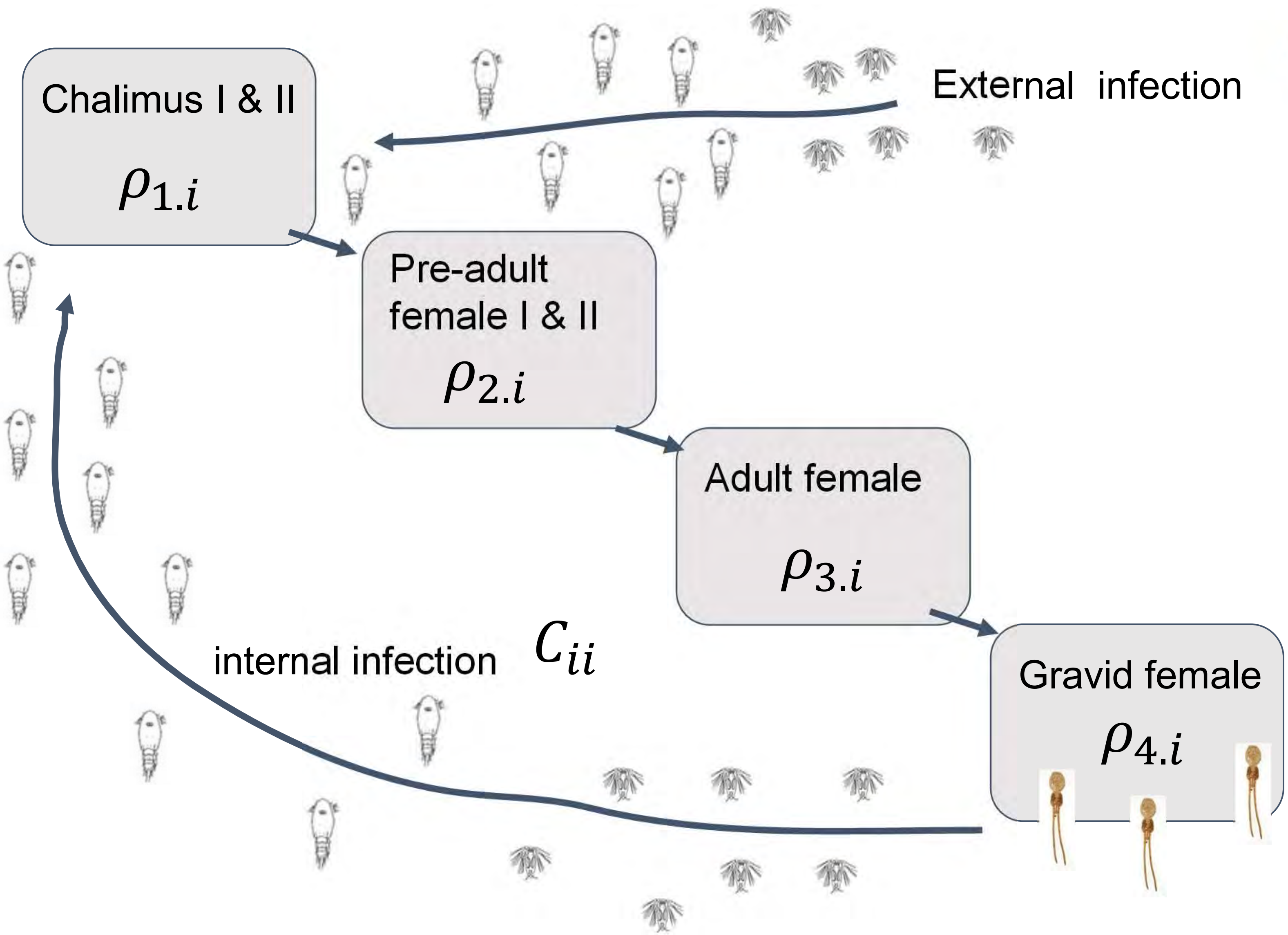
Using the Faroe Islands as case site

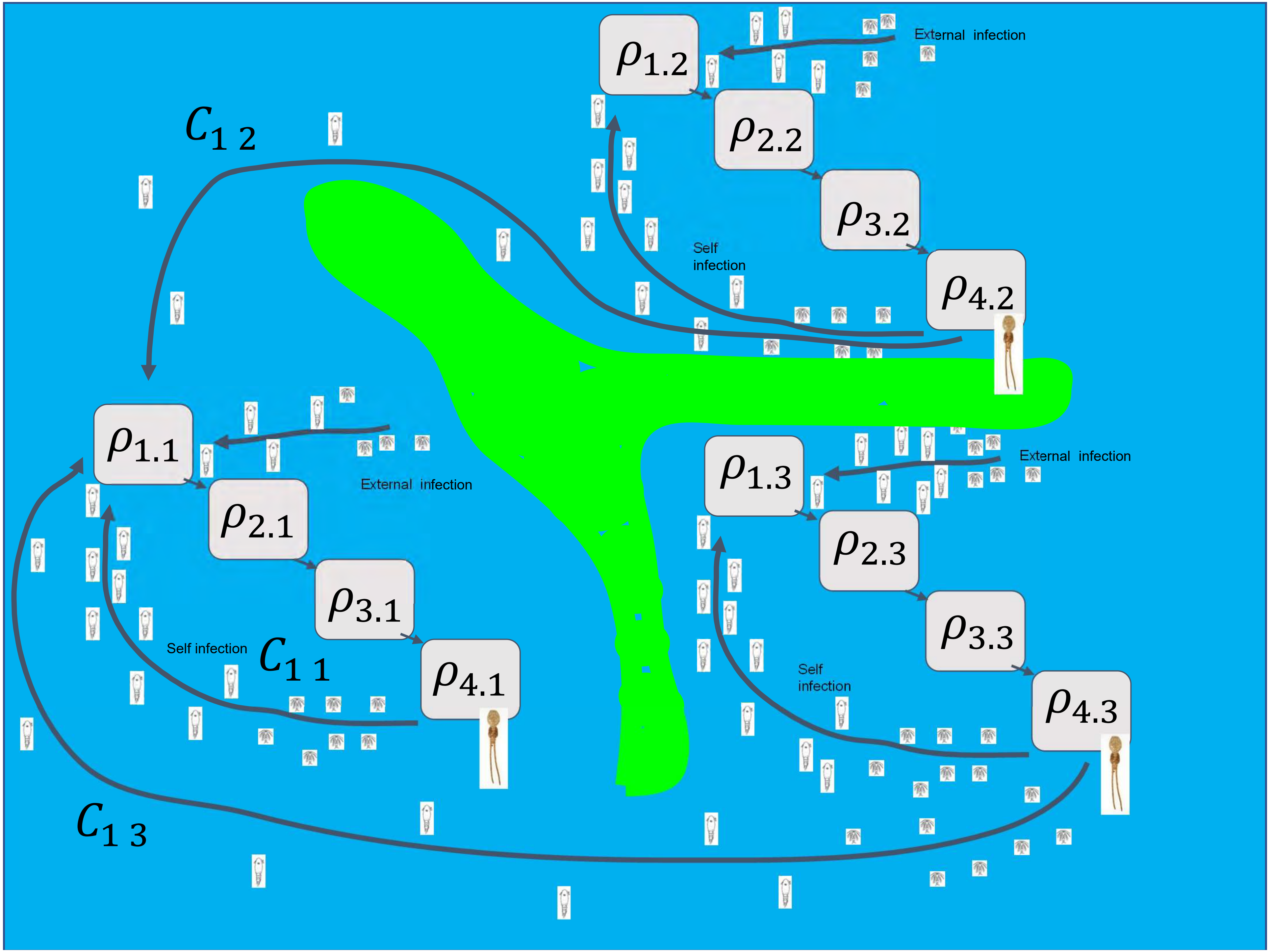


Salmon Lice Life-cycle



The salmon lice model





$\rho_{1.2}$
$\rho_{2.2}$
$\rho_{3.2}$
$\rho_{4.2}$
External infection
Self infection
$C_{1\ 2}$
$\rho_{1.1}$
$\rho_{2.1}$
$\rho_{3.1}$
$\rho_{4.1}$
External infection
Self infection
$C_{1\ 1}$
$\rho_{1.3}$
$\rho_{2.3}$
$\rho_{3.3}$
$\rho_{4.3}$
External infection
Self infection
$C_{1\ 3}$

The salmon lice model

$$\frac{\mathrm{d}\rho_{1.i}(t)}{\mathrm{d}t} = \beta_i(t) - \beta_i(t-t_1)e^{-\mu_1 t_1} - \mu_1 \rho_{1.i}(t)$$
$$\frac{\mathrm{d}\rho_{2.i}(t)}{\mathrm{d}t} = \eta\beta_i(t-t_1)e^{-\mu_1 t_1} - \eta\beta_i(t-t_1-t_2)e^{-\mu_1 t_1-\mu_2 t_2} - \mu_2 \rho_{2.i}(t)$$
$$\frac{\mathrm{d}\rho_{3.i}}{\mathrm{d}t}(t) = \eta\beta_i(t-t_1-t_2)e^{-\mu_1 t_1-\mu_2 t_2} - \eta\beta_i(t-t_1-t_2-t_3)e^{-\mu_1 t_1-\mu_2 t_2-\mu_3 t_3} - \mu_3 \rho_{3.i}(t)$$
$$\frac{\mathrm{d}\rho_{4.i}(t)}{\mathrm{d}t} = \eta\beta_i(t-t_1-t_2-t_3)e^{-\mu_1 t_1-\mu_2 t_2-\mu_3 t_3} - \mu_4 \rho_{4.i}(t).$$

(Revie, 2005)

(Adams, 2015)

$\beta_i(t) =$ internal infection + external infection + natural background infection

$$\beta_i(t) = \frac{1}{N_i(t)}\left(C_{ii}F_{ii} + \sum_{\substack{j=0\\ j\neq i}}^{n} C_{ij}F_{ij} \right) + L_0 = \frac{1}{N_i(t)}\sum_{j=1}^{n}(C_{ij}F_{ij}) + L_0$$