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Resistant salmon lice

Mechanisms, Monitoring, and Management

Introduction to resistant salmon lice

Why and how NVI and I work with resistance

Resistance testing

Resistance surveillance

Resistance modelling

Future resistance

Jannicke Wiik, NVI

Norwegian
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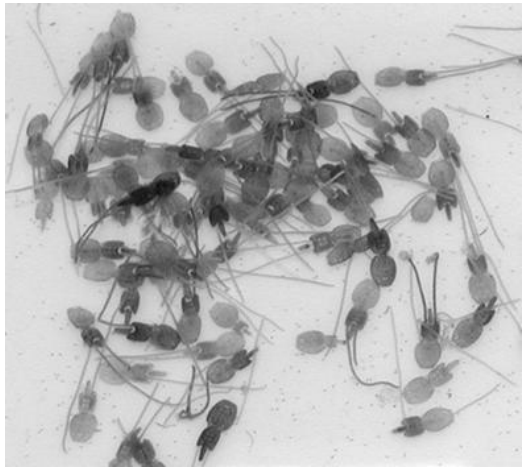
Introduction to resistant salmon lice

What is antiparasitic resistance?

- “Genetic ability of parasites to survive treatment with an antiparasitic drug that was generally effective against those parasites in the past” (U.S. Food & Drug Administration, 2024)



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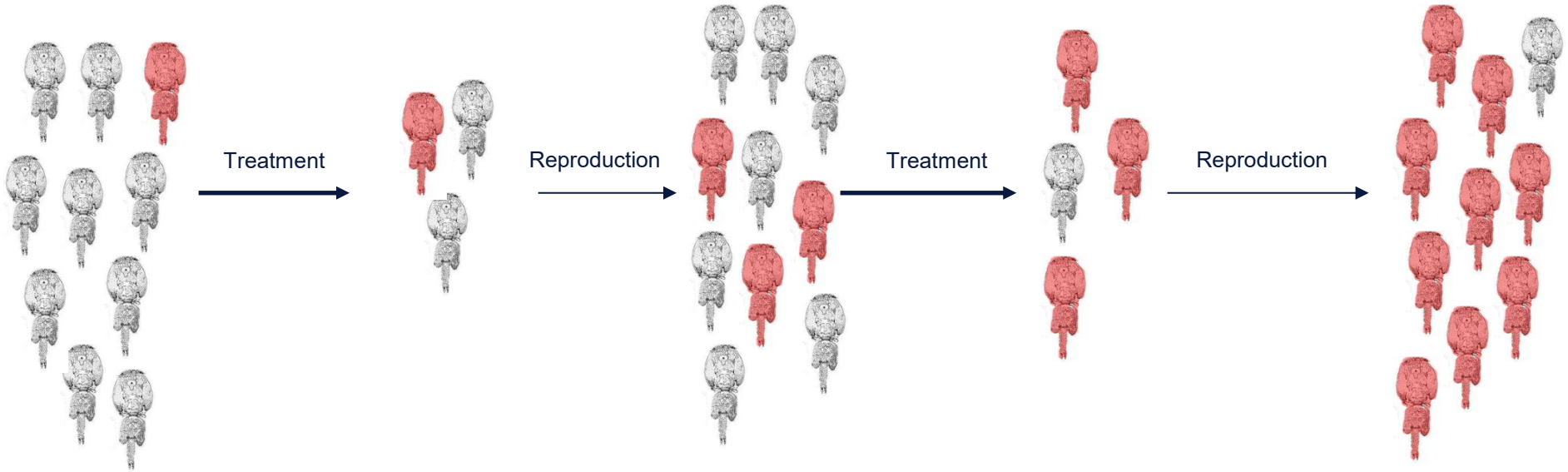
Why are lice resistant?

- Treatment history
  - Few classes of active substances: organophosphates, pyrethroids, chitin synthesis inhibitors, emamectin benzoate, hydrogen peroxide and neonicotinoids
  - Frequent treatments



Tor Einar Horsberg, NMBU

Why are lice resistant?

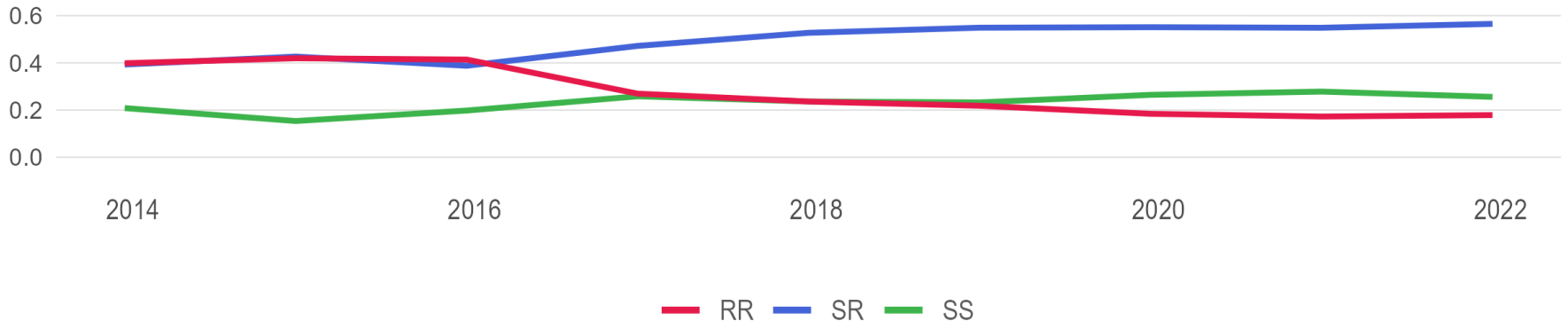
- Resistance mechanisms
  - Separate mechanism(s) per chemical class
  - Two main types of mechanisms:

    Target-site mutation

    Metabolic resistance
- Example: Organophosphate resistance
  - Target-site mutation in one of the genes for acetylcholinesterase (Kaur et al. 2015)
  - Lice can have zero (SS), one (RS) or two copies (RR)
  - RR-lice are more resistant than RS-lice
  - SS-lice are fully sensitive

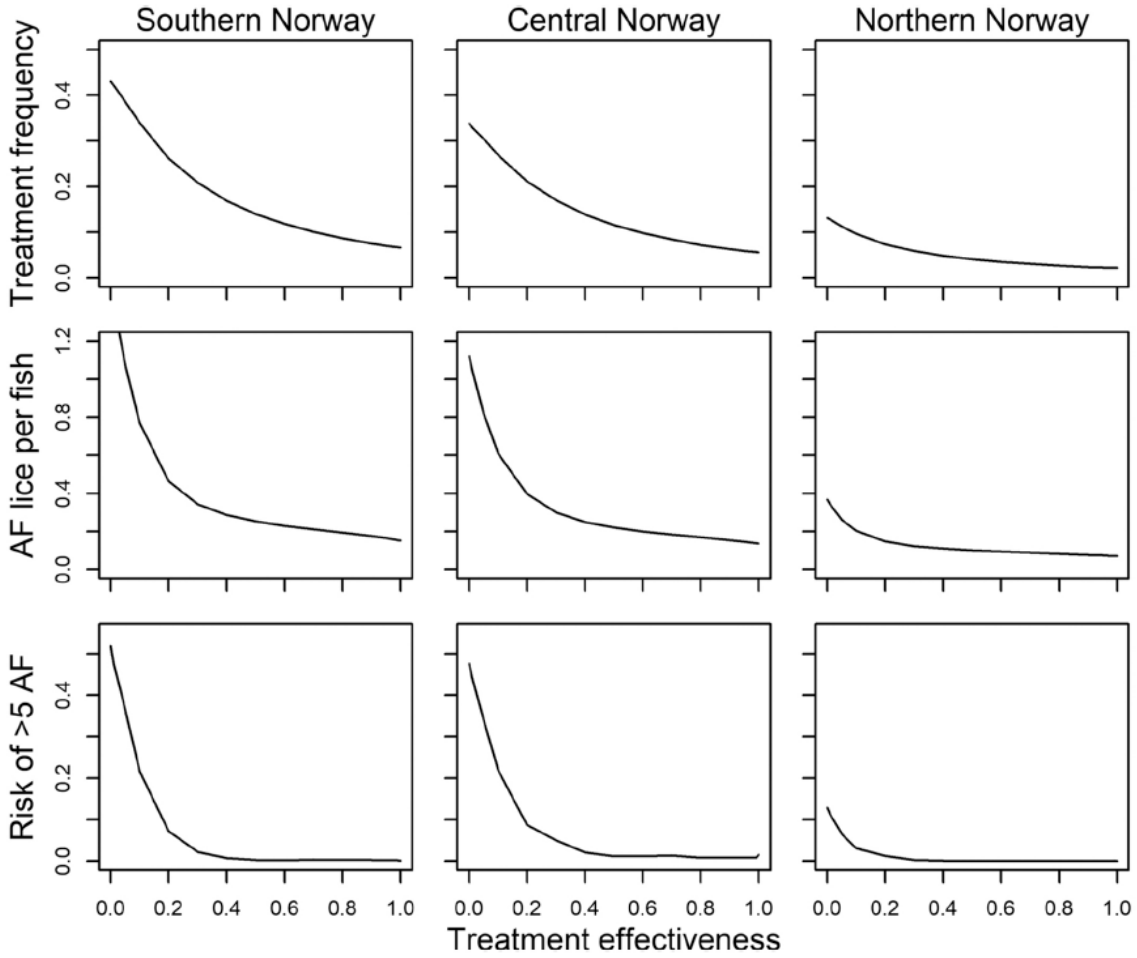
How resistant are lice

- Organophosphate resistance in Norway 2014-2022
  - Less than 30 percent fully sensitive lice



Helgesen et al., 2025

Why is resistant lice a problem?



Stige et al., 2024

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Resistance affects:

- Fish health
- Fish welfare
- Surronding environment, wild fish and other organisms
- Economy
- Food supply

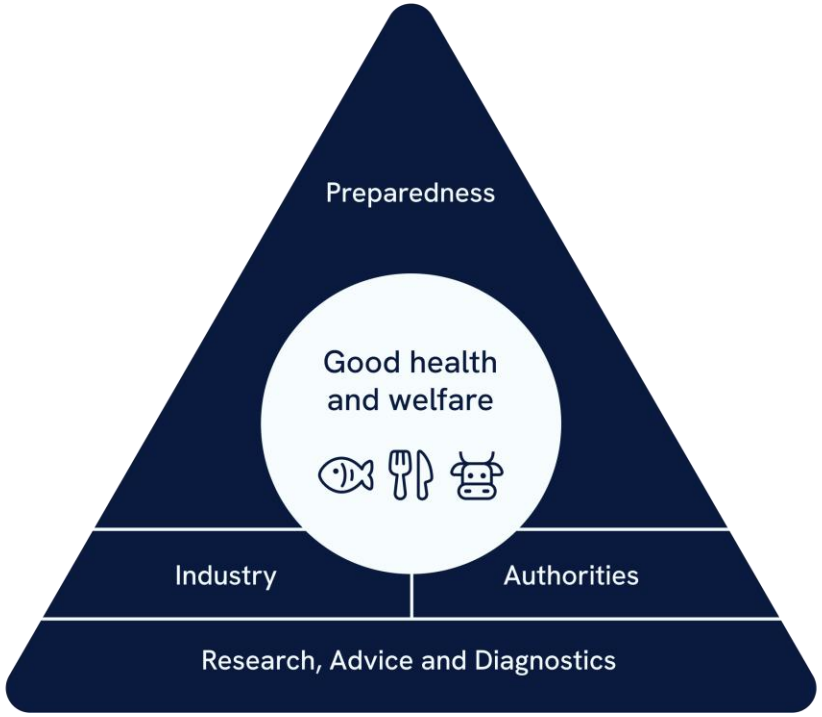
Resistance in Norwegian salmon lice regulation

- Part of the aim: To reduce and combat resistance
- Farms in an area should have routines on the exchange of resistance test results
- Medicinal treatments should follow relevant resistance test indicating good treatment efficacy
- Low treatment efficacy should be investigated, including resistance testing
- Maximum lice limits per fish: 0.5 adult female/fish
- All cages should be treated simultaneously unless proven obviously unnecessary

https://lovdata.no/dokument/SF/forskrift/2012-12-05-1140

Why and how NVI and I work with resistance

NVI community mission



NVI's work on resistance

- 2013-2023: Surveillance program for resistance in salmon lice
- Research on salmon lice resistance
- Knowledge based advise to the authorities on the topic resistance in salmon lice

My journey with resistant salmon lice

- 2011-2015: PhD in veterinary medicine
  - Thesis: «Monitoring of drug resistance and resistance development mechanisms in salmon lice (*Lepeophtheirus salmonis*)"
- 2016-2023: Project leader for the surveillance programme for resistance in salmon lice
  - Ran by NVI for the Norwegian Food Safety Authority
- 2023-2026: Project leader for "Helhetlig lusekontroll"
  - NVI + 4 partners, financed by Norwegian Seafood Research Fund
  - Aim: Otimal lice control with minimal side effect
- Resistance publications
  - 15 scientific publications
  - 14 scientific reports

Resistance testing

Trial treatments

- Require several small cages
- Animal testing?
- Not relevant for commercial farms
- Sometimes relevant for research purposes
- Why resistance testing against chitin synthesis inhibitors is difficult

Biological assays = Bioassays

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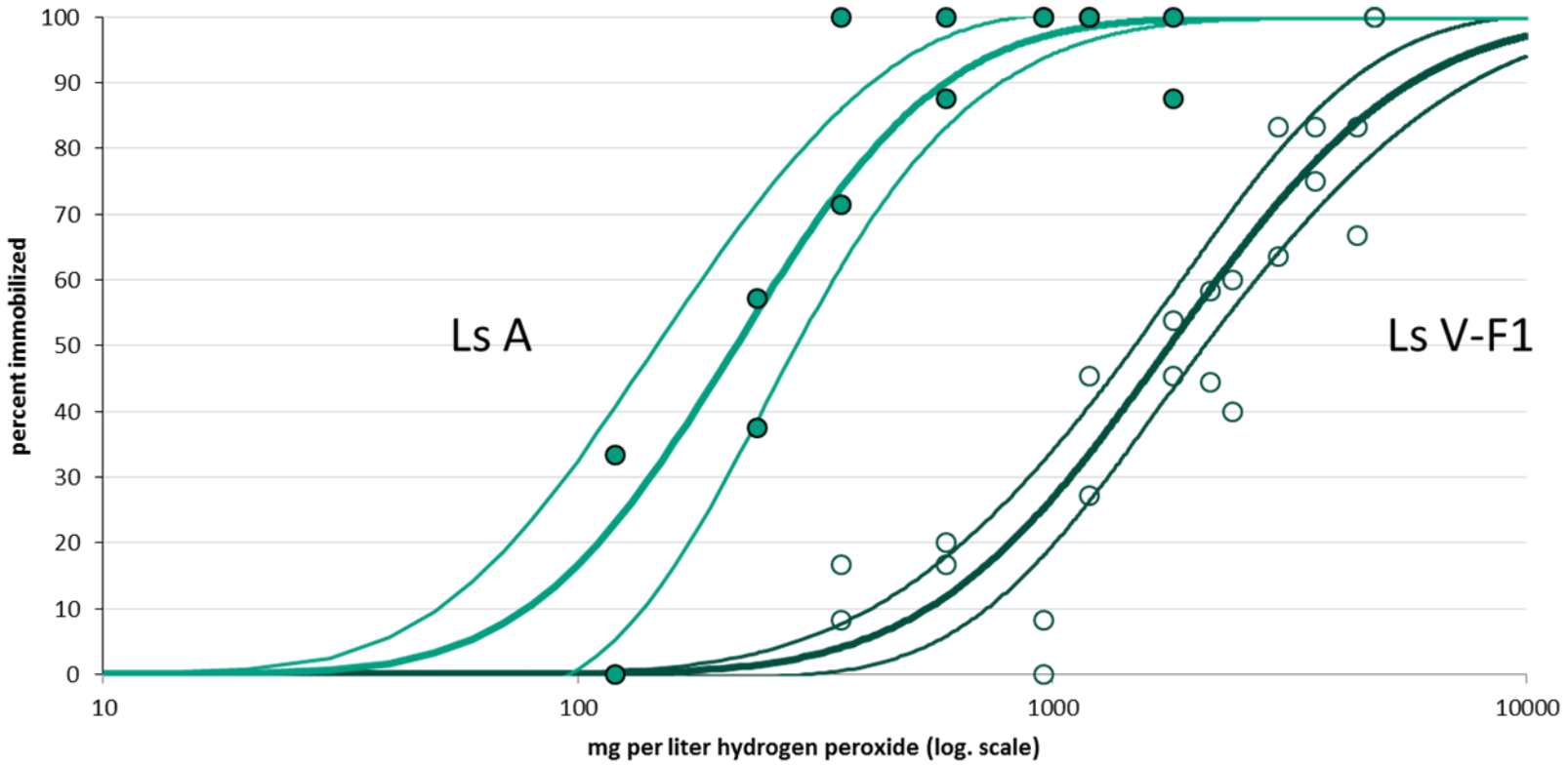

Helgesen et al, 2015

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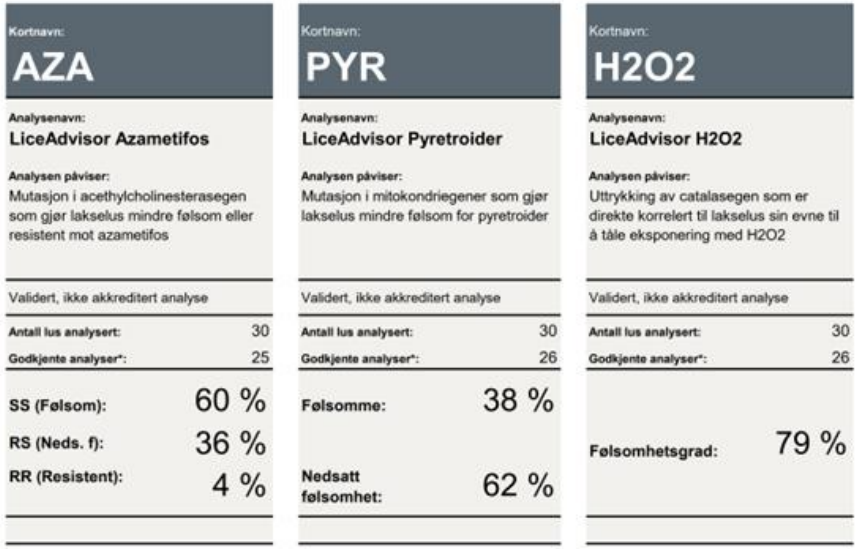
Molecular methods

- Available in Norway for resistance against
  - Organophosphates
  - Pyrethroids
  - Hydrogen peroxide
- The farms submit samples of dead lice to a commercial laboratory



Kortnavn: **AZA**

Analysenavn: **LiceAdvisor Azametifos**

Analysen påviser: Mutasjon i acethylcholinesterasegen som gjør lakselus mindre følsom eller resistent mot azametifos

Validert, ikke akkreditert analyse

Antall lus analysert:	30
Godkjente analyser*:	25
SS (Følsom):	60 %
RS (Neds. f):	36 %
RR (Resistent):	4 %

Kortnavn: **PYR**

Analysenavn: **LiceAdvisor Pyretroider**

Analysen påviser: Mutasjon i mitokondriegener som gjør lakselus mindre følsom for pyretroider

Validert, ikke akkreditert analyse

Antall lus analysert:	30
Godkjente analyser*:	26
Følsomme:	38 %
Nedsatt følsomhet:	62 %

Kortnavn: **H2O2**

Analysenavn: **LiceAdvisor H2O2**

Analysen påviser: Uttrykking av catalasegen som er direkte korrelert til lakselus sin evne til å tåle eksponering med H2O2

Validert, ikke akkreditert analyse

Antall lus analysert:	30
Godkjente analyser*:	26
Følsomhetsgrad:	79 %

Treatment efficacy

Treatment type	Effect on stages	This study. Data from 2017–2020			Study 2. Data from 2013–2018		Study 1. Data from 2011–2014	
		Est.	95%C.I.	95%D.I.	Est.	95%C.I.	Est.	95%C.I.
Emamectin benzoate	S, PA, A	35 ★	31–39	0–100				
Diflubenzuron	PA →A[a]	88	76–96	8–100				
Diflubenzuron	S → PA →A[b]	99	94–100	16–100				
Teflubenzuron	PA →A[a]	79	63–92	2–100				
Teflubenzuron	S → PA →A[b]	96	87–99	3–100				
Hydrogen peroxide[c]	PA, A	74	67–80	5–100	69[e]	59–78	99[e]	97–100
Pyrethroid[c]	S, PA, A	50 ★	43–56	0–100	71[e]	60–80	94[e]	89–98
Azamethiphos[cd]	PA, A	26 ★	13–43	0–94	44[e]	29–59	75[e]	64–86
Imidacloprid	S	99.9	99.6–100	99.6–100				
Imidacloprid	PA,A	98	95–99	79–100				
Thermal	S, PA, A	80	78–81	21–100	76	71–80		
Mechanical	S, PA, A	69	67–71	11–99	56	36–74		
Freshwater	S, PA, A	74	69–78	14–99	68	47–85		

Aldrin et al, 2023

Resistance surveillance

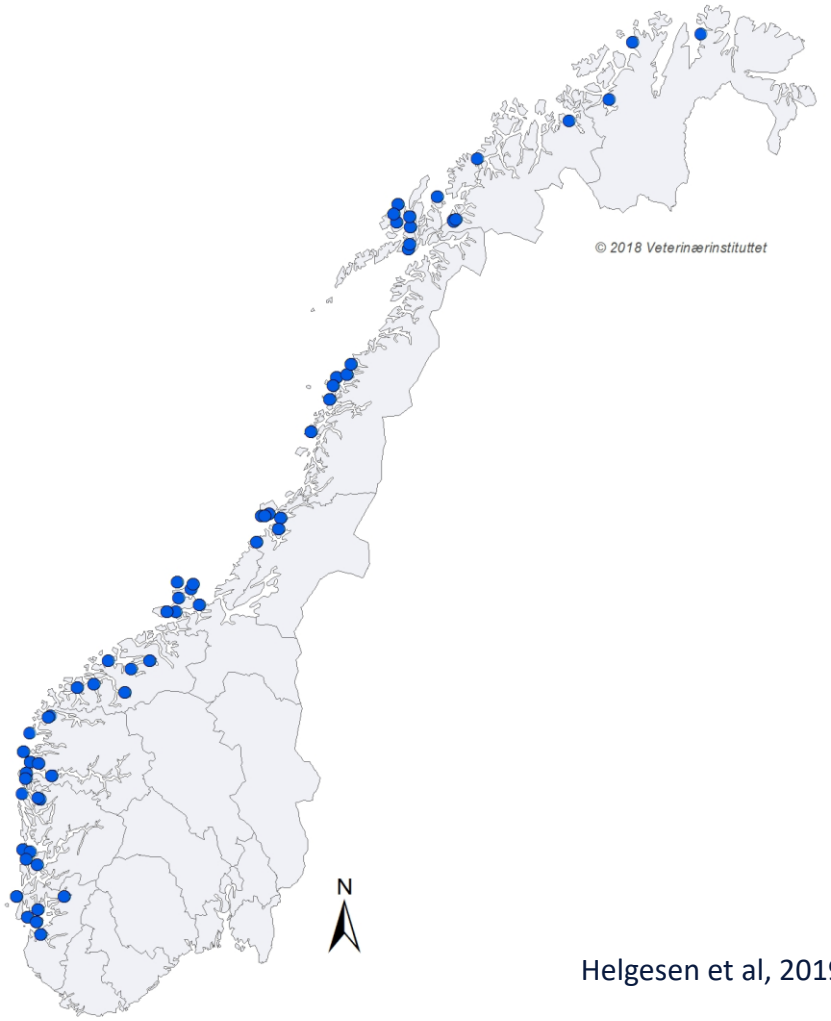
Aims in 2023

- The surveillance program aimed to
  - summarize the use of antiparasitics against salmon lice
  - describe the resistance status in *L. salmonis* towards the most important antiparasitics in Norway
  - Analyze whether fresh water tolerance varied with the farms' fresh water treatment history

Material and methods

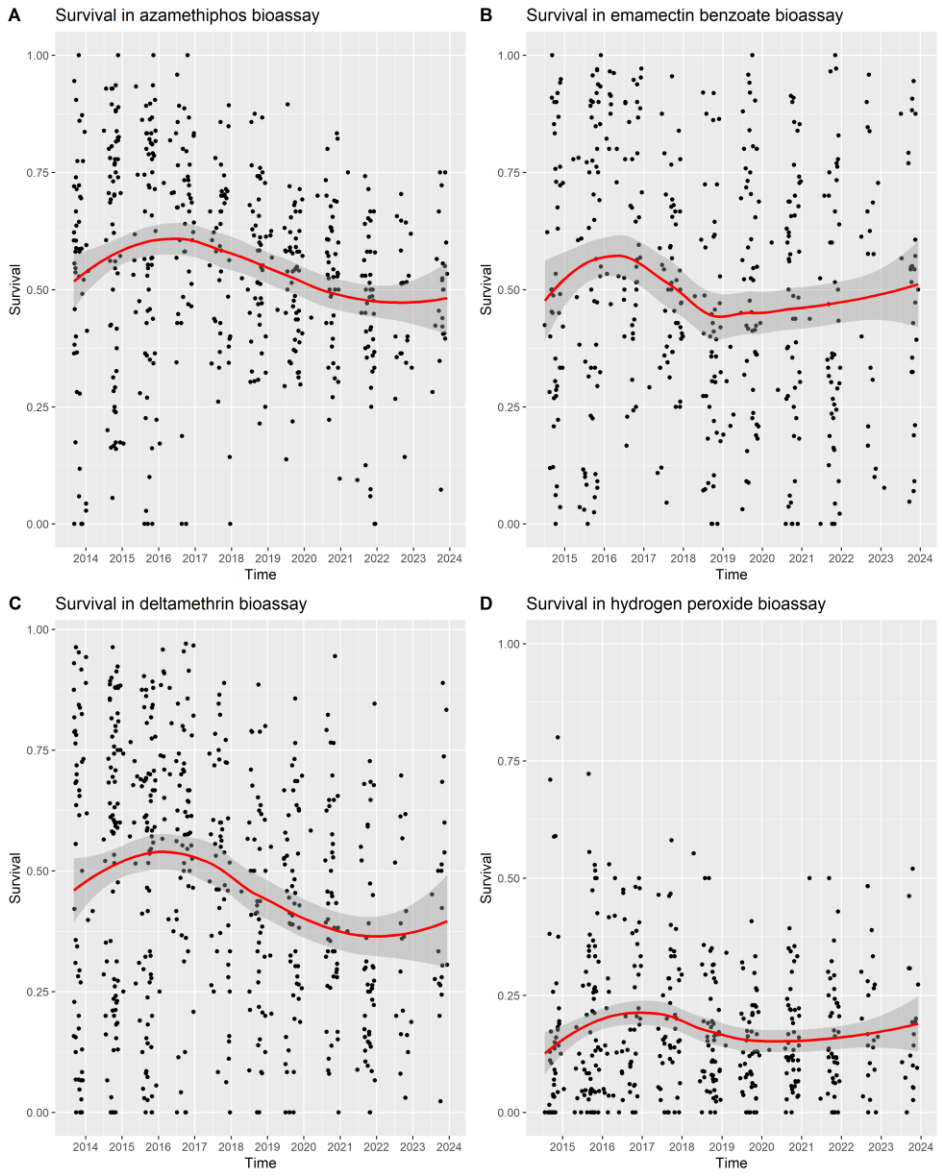
Year	Deltamethrin	Azamethiphos	Emamectin benzoate	Hydrogen peroxide	Fresh water	Imidacloprid
2013	X	X	X			
2014	X	X	X	X		
2015	X	X	X	X		
2016	X	X	X	X		
2017	X	X	X	X		
2018	X	X	X	X		
2019	X	X	X	X	X	
2020	X	X	X	X	X	
2021	X	X	X	X	X	
2022	X	X	X	X	X	X
2023	X	X	X	X	X	X

Along the Norwegian coast



Helgesen et al, 2019

Results



Helgesen et al, 2024

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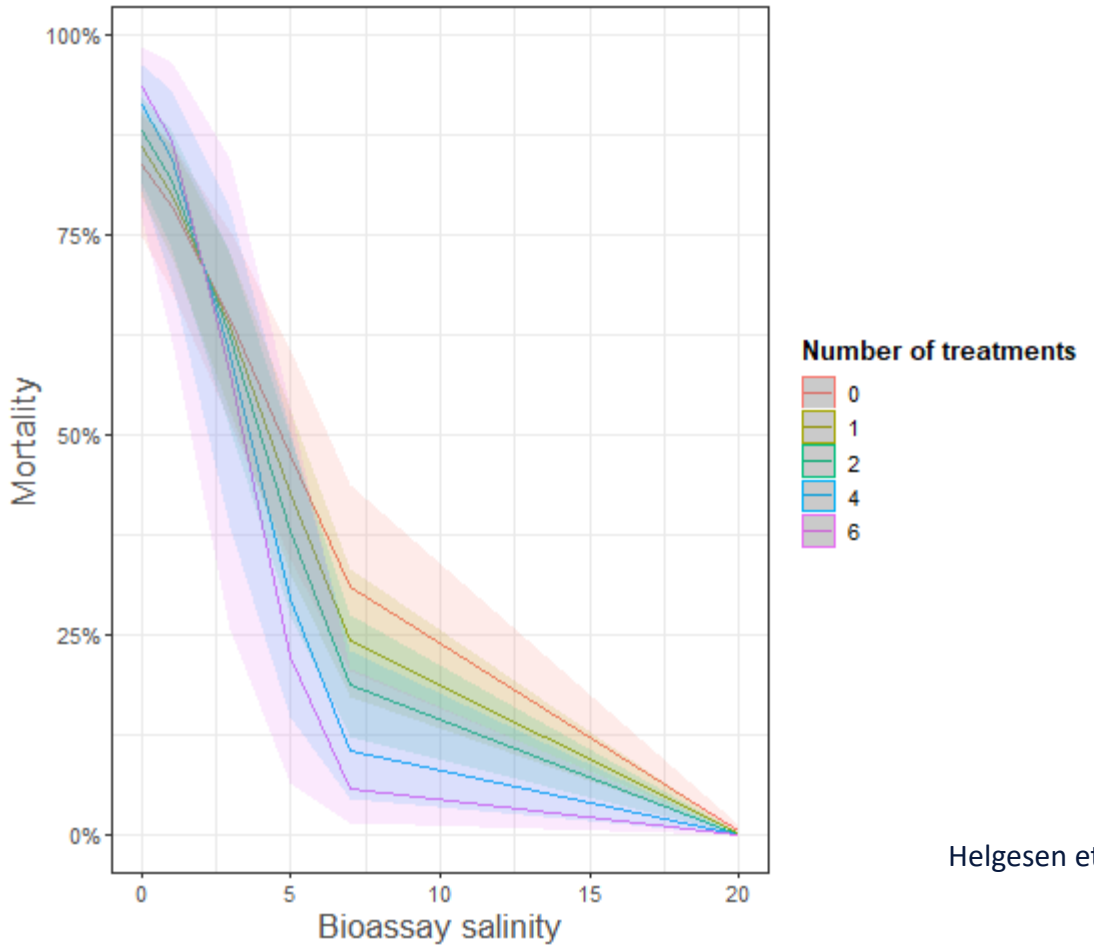
Results salinity



Helgesen et al, 2024

Where the aims atcheived?

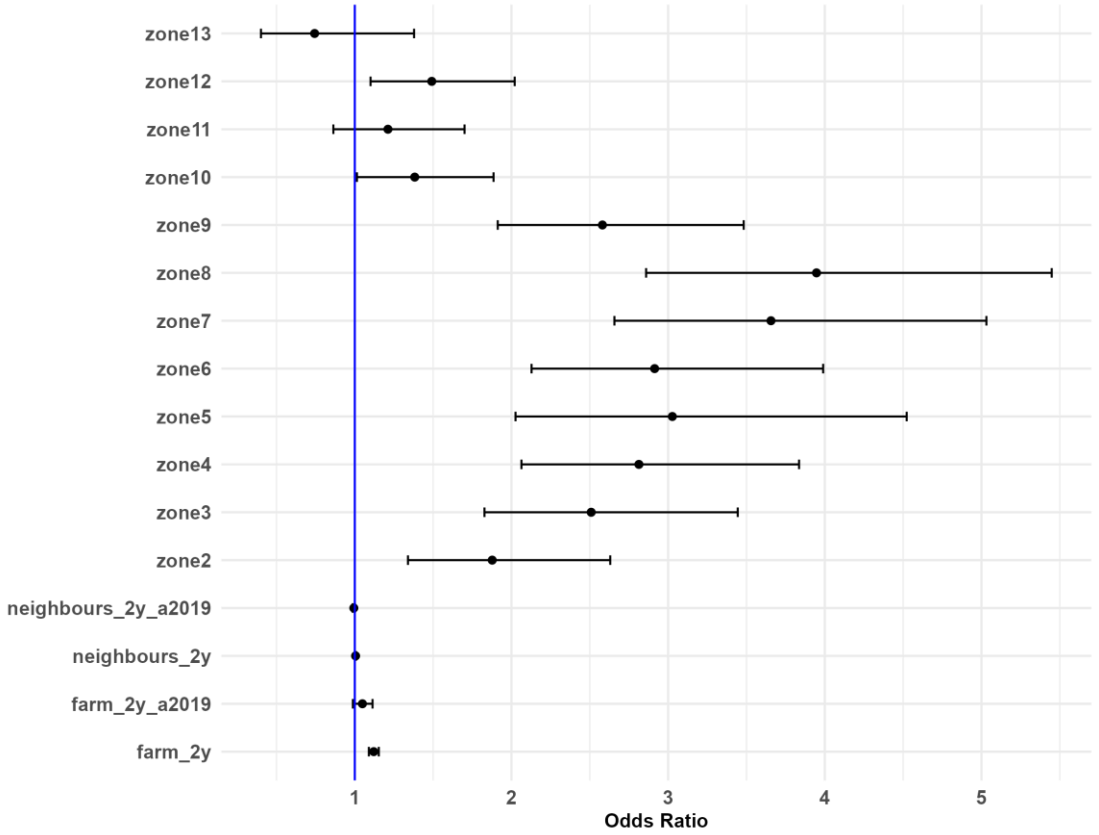
- The surveillance program
  - ✓ summarized the use of antiparasitics against salmon lice
  - ✓ described the resistance status in *L. salmonis* towards the most important antiparasitics in Norway
  - ✓ Investigated if fresh water tolerance varied with the farms' fresh water treatment history
- Where the results used?

Possible future surveillance

- Results from resistance tests
  - Performed for the fish farming companies
  - Require that reporting results become mandatory
- Treatment efficacy
  - Require that reporting of cage level lice counts and treatment data become mandatory
  - Also relevant for non-medicinal treatment methods
- Treatment patterns

Resistance modelling

Statistical models: analysis of data



Helgesen et al, 2025

Statistical models: scenario simulation

- Simulating resistance development
- Predict effects of lice management on resistance development
- McEwan et al., 2016
- Trombetta et al., 2023
- Coates et al., 2022
- Coates et al., 2023
- Xu et al., 2025

Future resistance

Resistance against medicinal treatments

- Learning from history:
  1. Lice are resistant
  2. Lice will become resistant
     - You can influence how fast

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Resistance against non-medicinal methods

- Fresh water, temperated water
  - Variance in tolerance against temperated water (Ljungfelt et al. 2017)
  - Variance in treatment efficacy (Aldrin et al. 2023)
  - Bioassay mortality varied with farms' fresh water treatment history (Helgesen et al. 2014)
- Submerged cages
  - Larval depth distribution differs if parents were from ordinary compared to from submerged cages (O'Neill et al. 2025)
- Resistance?

Will resistance disappear?

- History of organophosphate resistance in Norway
  - Organophosphates (NeguvonTM) introduced in 1978
  - Organophosphate resistance seen in 1991 => 13 years
  - No use of organophosphates 1999-2008
  - Initially good efficacy
  - Organophosphate resistance seen in 2009 => 1 year
  - Same mutation found in samples from 1998 as today

Summary

- Antiparasitics
  - Lice are or will become resistant
  - Treatment intensity influence the speed of resistance development
  - Your production area decides most of the farm's resistance level
- Non-medicinal treatment
  - Known variance in tolerance
  - Possible future development of resistance?
- Resistance testing
  - To avoid unsuccessful treatments
  - Beneficial for: Fish health, fish welfare, surrounding environment, non-target organisms and economy

Scientifically ambitious, forward-looking and collaborative – for One Health

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