The problem with sea lice on salmonids: wild and farmed

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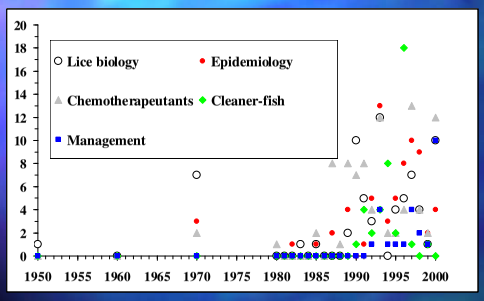
Sea lice make the front cover!

Highly cited
>5,700 hits
Google scholar

A highly published crustacean



>800 publications. Trends to 2002 = emphasis from chemical to biological control, and to Integrated Pest Management.

2006-2014:
quantitative modelling of lice larval dispersal and population dynamics, discoveries of lice resistance to parasiticides

Sea lice conferences

Peaks in publications in 1993, 1996, 2000 and 2002 were due to the publication of proceedings of conferences held in:

Paris, France (1992),
Oban, Scotland (1994),
Amsterdam, The Netherlands (1998)
Dublin, Ireland, (1999),
Aberdeen, Scotland (2001),
St Andrews, Canada, 2003
Puerto Mont, Chile, 2008
Victoria, Canada, 2010
Bergen, Norway 2012

Boxshall & DeFaye (1993),
Sayer, Treasurer, Costello (1996),
Boxshall & Costello (2000),
Costello & Boxshall (2000),
Mordue & Pike (2002),
Costello, Burridge, et al. 2004
Revie, Bravo, et al. (2008)
Roth and Smith (2011)
Boxaspen and Torrisen (2013)

Also *Caligus newsletter* No. 1-8,
ISSN 1393 452X

Talk outline

- The problem
  - sea lice pathogenicity
- Lice biology
- Lice transmission to hosts
- Do farm lice cause epizootics on wild fish?
- How control lice on farms?
  - Physical, chemical (bath, in-feed), cleaner-fish
- Persistence of problem

The sea lice problem

- **Most costly parasite in salmon farming**
- **Direct cost to industry €300 million / yr**

Ireland, Scotland, Shetland,
Norway, Faeroes,
Canada (Atlantic & BC),
Chile, Maine USA

- Kill host
- reduce growth
- reduce feeding
- lower food conversion
- disfigure fish
- cross infest other farms and wild fish
- facilitate disease transmission

Sealice damage to host

Caligus elongatus on rainbow trout, *Oncorhynchus mykiss.*
Photo: Alan Pike

Sealice damage to salmon

Can graze mucus, skin and flesh to the bone

Lepeophtheirus salmonis adults on farm Atlantic salmon, *Salmo salar.*
Photo: Alan Pike

Order Copepoda, Family Caligidae

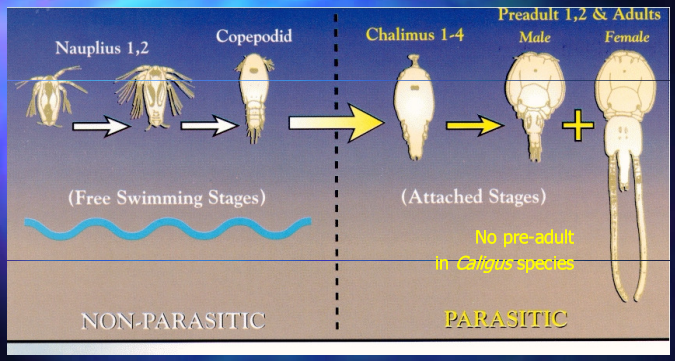
- *Lepeophtheirus salmonis*
  - specific to salmonid fish
- *Caligus*
  - smaller, not host specific, adults in plankton
- *C. elongatus, C. rogercresseyi, C. spinosus*

[N. Atlantic] [Chile] [Japan]

+ others in BC, Chile, Australia, Asia =

C. epidemicus, lalandei, chiastos .....

Life - cycle

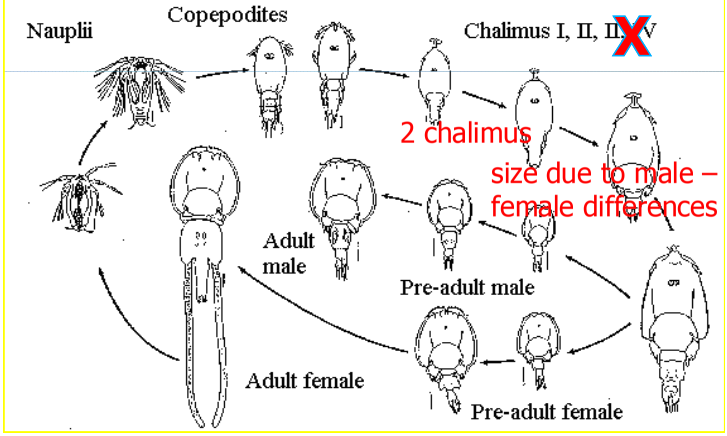


From: http://www.upei.ca/~anatphys/Sea_Lice/licecycl.htm

Life-cycle:

PLOS ONE
The Salmon Louse *Lepeophtheirus salmonis* (Copepoda: Caligidae) Life Cycle Has Only Two Chalimus Stages

Lars A. Hamre[1*], Christiane Eichner[1*], Christopher Marlowe A. Caipang[2*], Sussie T. Dalvin[1,2], James E. Bron[3], Frank Nilsen[1], Geoff Boxshall[4], Rasmus Skern-Mauritzen[2]
1 Sea Lice Research Centre, University of Bergen, Bergen, Norway, 2 Aquatic pathogens and diseases, Institute of Marine Research, Bergen, Norway, 3 Institute of Aquaculture, University of Stirling, Stirling, Scotland, United Kingdom, 4 Natural History Museum, London, United Kingdom



Free-living stages

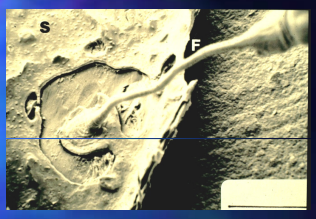
			days @ 10 °C
EGGS	in egg sacs	on female on fish	9
NAUPLII	in plankton	non feeding	4
COPEPODIDS	seek host	imbed in fish skin	10

= average of 14 days in plankton at 10°C

Photo: *Lepeophtheirus salmonis* copepodid and nauplius.
From: Alan Pike

Infective copepodite

Chalimus



Attachment stalk

Photo: *Lepeophtheirus salmonis* chalimus on host.
From: Alan Pike

Parasitic on fish

			days @ 10 °C
CHALIMUS	fixed	graze skin	25
PRE-ADULT	mobile	graze skin	20 - 26
ADULT MALE	mobile, grazes	Guards female, puts sperm in female sac	68
ADULT FEMALE	mobile, grazes	lays row 100+ eggs in pair sacs	74
	may lay < 11 sacs eggs, >1000 eggs/female		

Generation time *ca.* 2 months *L. salmonis*,
Less for *Caligus*
Adults may live 2-4 months

Life cycle dynamics

- Generation time
  - Shorter at warmer (summer) temperatures
  - Mature at smaller body size
- Egg production
  - Females grow larger in winter (longer generation time)
  - Larger females more eggs (in spring)

Pathogenicity

Graze mucus, irritation, erode skin, bleeding, physiological stress

Variable host sensitivity

Salmo spp (Atlantic salmon, sea-trout, char) more sensitive than *Onchorhynchus* (coho, rainbow/steelhead) to *L. salmonis* but different to lice species in Chile

Lice mouthparts

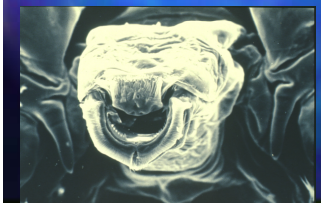
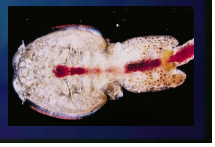


Photo: *Lepeophtheirus salmonis* mouthparts.
From: Alan Pike



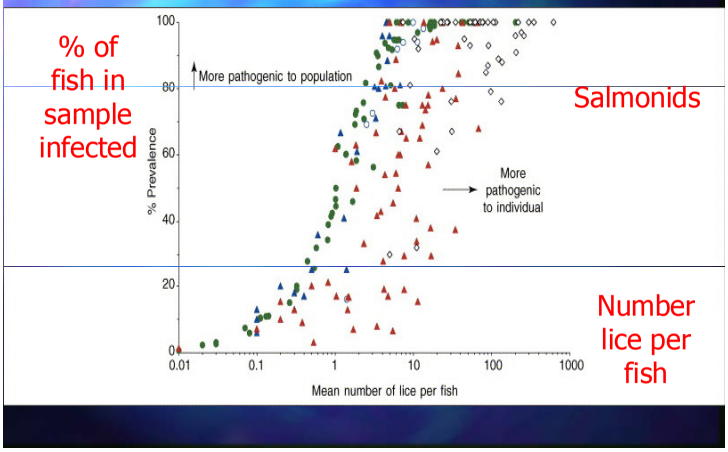
What does the fish experience?

- Irritation
- Distraction
- Physiological stress
- Few juvenile lice (chalimus)
- Few adult lice
- > 5 adult or ?30 chalimus (fish size dependent)

Pathogenicity

- Varies with
  - host size
  - host species and farm strain
- > 0.5 to 0.75 adult *L. salmonis* g^{-1} fish
- > 5 to 10 per fish (> 0.1 lice g^{-1} smolt)
- Epizootics >10-100 lice/fish

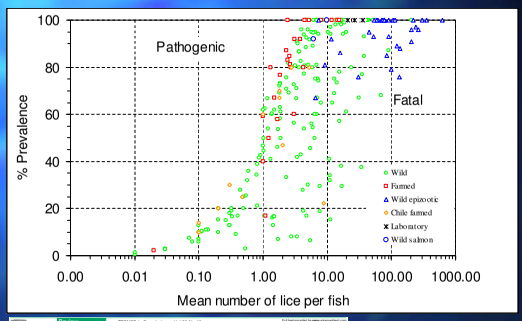
Lice distribution on host population

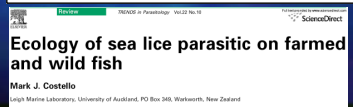


Patterns lice infestation on fish

Epizootics and lab infections show pathogenic levels

- And overlap with levels on some wild fish





Sea lice "epizootics"

- Mass infestations of lice
- Probably fatal to the host
- 1989 on sea trout (*Salmo trutta*) in Ireland
- 1990's
  - Scotland
  - Norway
  - British Columbia
  - ? Gulf of Maine

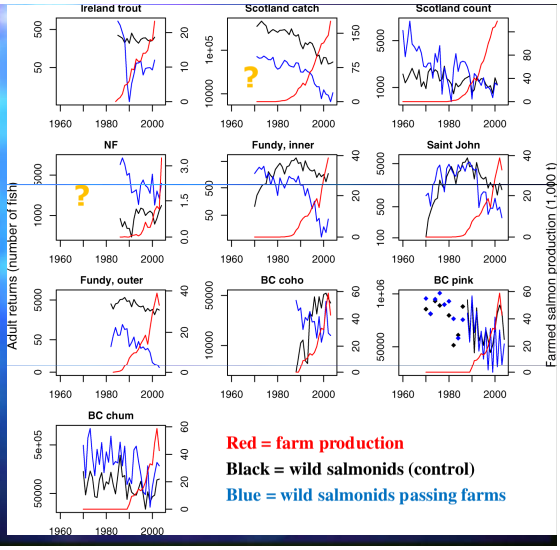
Sea lice epizootic characteristics

- Only
  - involved *Lepeophtheirus salmonis*
  - in areas with salmon farms
  - on migrating juvenile salmonids (smolts)
  - chalimus stages (so recent infection)
- Premature return of hosts to freshwater

Declines in wild salmonid abundance since late 1980's greater where salmon farms occur

Ford & Myers 2008 PLoS Biology

?



Are farms source epizootics?

1. Correlation ≠ cause
2. Common environmental conditions?
3. Other wild hosts?
4. Epizootics not always observed
5. Wild fish often 10's km from farms
6. *L. salmonis* copepodids concentrate in shallow water and near estuaries, often not near farms
7. Are epizootic levels pathogenic?
8. If pathogenic would host have died anyway (predation etc.)?
9. Wild salmonids declining already, so epizootic not main cause
10. Freshwater runoff would kill larvae in estuaries (as it does adults in farm cages near rivers)
11. No proof that lice on wild fish came from farm parents

Transmission

- Dispersal planktonic larvae
  - behaviour poorly known
  - distribution in ocean ?
- Redistribution adults
  Caligus elongatus adults common in plankton
- **Pathogenic infestations develop over months within a farm**

Clues

- Field studies
- Lice behaviour (lab, cages)
- Models of lice dispersal and transport
- Evidence pathogenicity (lab, field)
- Analysis trends wild salmonid populations with and without salmon farms
- Knowledge dispersal other planktonic larvae

Salmon cages in

SW New Brunswick, Canada

High density

Ireland

Low density but …

Clues – field studies

- Irish and Scottish sea inlets
  - Most nauplii at farm cages
  - Most copepodites along seashore and in estuaries
  - May imply release from two sources (farm and wild fish)?
  - If not, how explain estuarine concentration of sea lice larvae?

Clues – lice behaviour

- Laboratory observations
  - Copepodite swims towards fish movement
  - Adults similar behaviour
  - Nauplii in mid-water
  - Copepodite swim upwards during day
  - Copepodite concentrate on halocline
  - *L. salmonis* more tolerant of low salinity than other sea lice species

Especially papers by Heuch

Clues: dispersal + transport models

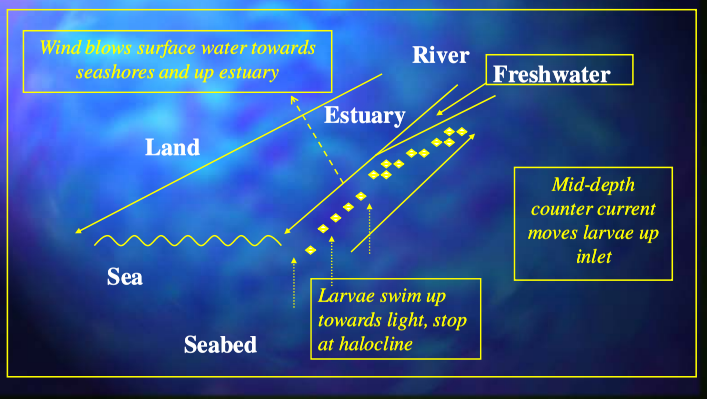
- Ireland and Scotland field data
  - Lice on sea trout correlated to lice on farms up to 30 km
- British Columbia model
  - Simple diffusion model predicts farms infest wild fish for 30 km downstream
- Scotland model
  - 3-D particle dispersal model shows tidal, freshwater, and wind driven currents may disperse larvae for 10's km and explain retention in inner estuary
  - Including larval behaviour significantly improved model match to field observations
- Literature review dispersal non-lice larvae
  - 60 km for mussel, 33-160 km for decapod & barnacle larvae
  - Average 27 km (10-50 km) predicted for larvae planktonic for 5-15 days

Models have not considered larva response to salinity and ran on small spatial and temporal scales

Additional studies support 20-30 km zone of effect

- Butler and Watt 2006
- Middlemas et al. 2013
- Aldrin et al. 2013
- Serra-Llindrin et al. 2014

Conceptual model of lice larval dispersal



Studies releasing treated smolts vs untreated controls

- Birkeland 1996 sea trout– Norway
- Atlantic salmon Europe
  - Krkosek et al. 2012
  - Gargan et al. 2012
  - Jackson et al. 2013
  - Skilbrea et al. 2013

All found significantly less smolts not protected against lice returning from sea

Control methods

Prevention

- fallowing
- year class separation
- distance between farms
- prophylactic treatment of smolts
- 'winter' treatment

Treatment

- biological - cleaner-fish, ?vaccine
- physical - light traps, fish distribution
- chemical - bath, in-feed parasiticides

Chemical treatments
(chemo-therapeutants)

1. Bath or dip method

Trichlorfon	Neguvon
Dichlorvos:	Aquagard, Nuvan
Azamethiphos:	Salmosan
Hydrogen peroxide:	Salartect, Paramove
Cypermethrin:	Exis
Deltamethrin	Alpha max Vet
Pyrethrum:	Py-Sal

Chemical treatments

2. "In-feed" (oral) method

Ivermectin:	**Ivomec Pre-mix pigs**
Emamectin:	**SLICE**
Teflubenzuron:	**Calicide, Ektoban**
Diflubenzuron:	**Lepsidon**

Others: garlic, onion

Treatment limitations

Bath
- **Variable dose in cage**
- **Impossible to treat all cages together**
- **Dangerous or not possible to use on large cages**

In-feed
- **Fish must feed**
- **High cost**

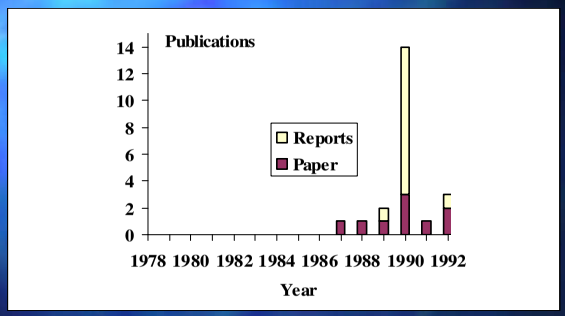
Pest resistance?

Problems with therapeutants

- Complex regulatory framework
- Medicines, pesticides or drugs
- Maximum allowable tissue residues
- Environmental discharges
- Uncertainty about ecosystem effects
- Staff safety
- Costs (direct + indirect) to prepare for market and use on farms
- Expensive, especially newer parasiticides

Costello *et al.* 2001. *J. Appl. Ichthyol.* 17, 173-180.
The control of chemicals used in aquaculture in Europe.

Nuvan used since 1978



Label: "dangerous to aquatic life – do not use near water"

Lice have developed resistance

To all major groups of parasiticides within few years of use:

- Organophosphates
- Permethrins
- Avamectins

Cleaner-fish (mainly wrasse)

5 North European species (Labridae) used

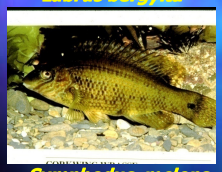
Goldsinny	*Ctenolabrus rupestris*
Corkwing	*Symphodus melops*
Rockcook	*Centrolabrus exoletus*
Cuckoo	*Labrus mixtus*
Ballan	*Labrus bergylta*

NE Atlantic wrasse (Labridae)

Labrus bergylta

Labrus mixtus (male)

Labrus mixtus (female)



Symphodus melops

Centrolabrus exoletus

Ctenolabrus rupestris

Photos: Bernard Picton

Goldsinny cleaning salmon

Photos:
J.E. Fosseidengen (left)
M. Costello (above)

Development cleaner-fish use

Norway

- **1987** aquarium and experimental cage trials
- **1988** commercial trials
- **1989** 20+ farms, 112 cages, 2.3m smolts, 50,000 wrasse
- **1997+** Norway 3.5 million wrasse used at 50% (400) farms

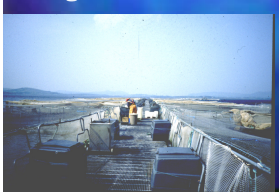
Outside Norway

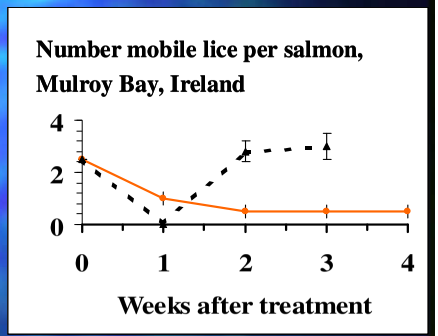
- **1988-89** trials Shetland & Scotland
- **1990** trials Ireland
- **Mid-1990's** use expands in Scotland
- **Late 1990's** declines Scotland, Shetland & Ireland

Comparison wrasse versus Nuvan

Many trials show that wrasse reduce lice slower than bath treatment,

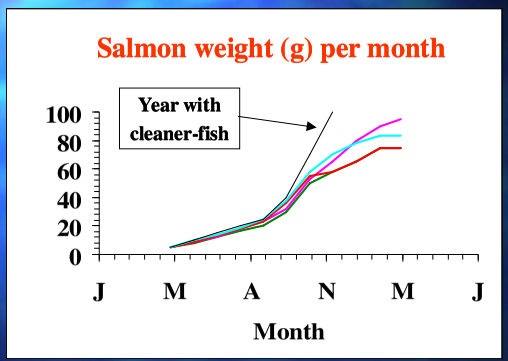
but keep lice numbers down for longer.





Farm trial, Mulroy Bay, Ireland

Benefits to salmon growth rate, Mulroy Bay



Cleaner-fish

Benefits

- Very effective
- Collected from wild
- control fouling on cage nets
- Larger species (ballan) cleans 2 kg salmon
- cheaper than drugs
- can use with other treatments

Limitations

- Regional availability
- High escapement
- Seasonal availability
- Concerns over pathogen transfer

Wrasse culture under development

Best control options

- Farm isolation (**20-30 km** between cage sites)
- salmon year class separation (no overlap)
- fallowing of sites and bays
- coordinated monitoring of lice on farms (cooperative farming)
- strategic (prophylactic preventative) treatment
  - 'winter' treatment
  - In-feed treatment smolts before stocking in cages
- stock with cleaner-fish

Lice persist on farms

- No decrease in lice problem in industry despite control measures
- Cost industry $ €100's millions, 5-10% product value

- Reservoir on wild and feral fish
- Farm salmonids present all year around so constant coastal host reservoir
- Produce 1,000 eggs / female so < 1% need to survive to maintain population
- Threaten new finfish culture from Australia to Asia

Wild fish impacts

Epizootics

.. of adult lice on adult wild fish rare

.. on juvenile salmonids frequent past 20 yr

- Ireland, Scotland, Norway, British Columbia
- Only in areas with salmon farms
- Almost entirely chalimus & copepodids
- Premature return host to freshwater
- On sea trout, charr, pink salmon

Salmo trutta, Salvelinus alpinus, Oncorhynchus gorbuscha

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1. Correlation repeated from local to regional scales in Atlantic & Pacific
2. Demise wild salmonids since late 1980s in areas with farms is not explained by fisheries or environment
3. Other wild hosts far fewer and/or temporary
4. Larvae disperse 10's km
5. *L. salmonis* intercept host migrating to sea from rivers
6. Epizootic infestations fatal to hosts
7. Larvae avoid freshwater entrainment
8. Farms release billions larvae, represent >90% hosts in Atlantic, and host lice all year around

Persistence of sea lice problem

- Common on wild fish worldwide
- No barrier to transmission in sea cage aquaculture
- All control measures have limitations
- Rapid development resistance to parasiticides
- Farms too close together to prevent cross-infestation
- Control on farms with million+ hosts may be insufficient to prevent pathogenic infestations onto wild fish
- Detection pathogenic infestations on wild-fish difficult
- Lice from farms can drive epizootics leading to decline of wild host populations

Confusion in literature

1. Epizootics not just characterised by number of lice
2. Lice life-stages not distinguished
   1. Mobile lice ~10 times more pathogenic than chalimus
3. Average # lice on farm fish is not a measure of lice numbers or production

Conclusions

- *Lepeophtheirus salmonis* specialised for intercepting migrating salmonids, common in North Atlantic and Pacific oceans, persistent on fish farms
- Lice impacts on wild salmonids underestimated
- Sea lice from farms provide best explanation for recent declines in wild salmonid populations in North America and Europe

- With development fish cage culture, might similar impacts occur with *Caligus* species?
  - Yes, already happening in Chile with *Caligus rogercresseyi*

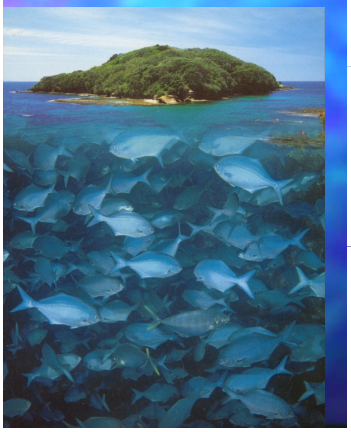
Outlook?

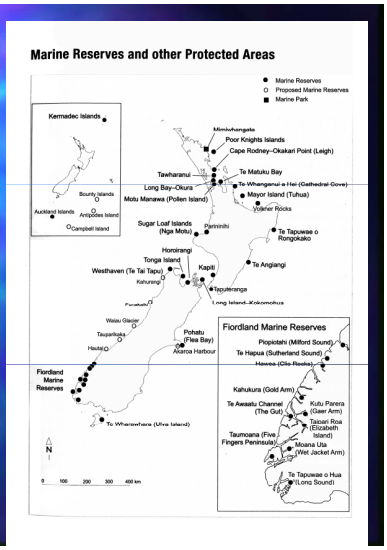
- How to balance growth of aquaculture with impacts on wild fish
- Sea lice demonstrate interaction
- Potential to occur with other species and pathogens
- Socio-economic and conservation issues

Wider context of lice problem

- Fishing has modified coastal ecosystems for centuries
- We do not know what "natural" coastal ecosystems are
- Might (no-take) Marine Reserves be part of a solution to healthier ecosystems ?

Marine Reserves in New Zealand





Why so popular?

- People see recovery of fish, lobsters and habitats
- Scientific research explains natural restoration of fished populations and ecosystem food webs
- Benefits to society become more obvious (ecotourism, education, recreation)
- Loss to fishery counter-balanced by spillover
- Despite NIMBY syndrome

Effects were not predicted

- First set up for scientific research
- Popularity with public
- Tourist attraction
- Fish lost fear people so can swim and dive close to them
- Rapid increase in size of fish and lobsters
- Trophic cascade through ecosystem