Distribution of Planktonic Larval Sea Lice in the Broughton Archipelago, British Columbia, Canada

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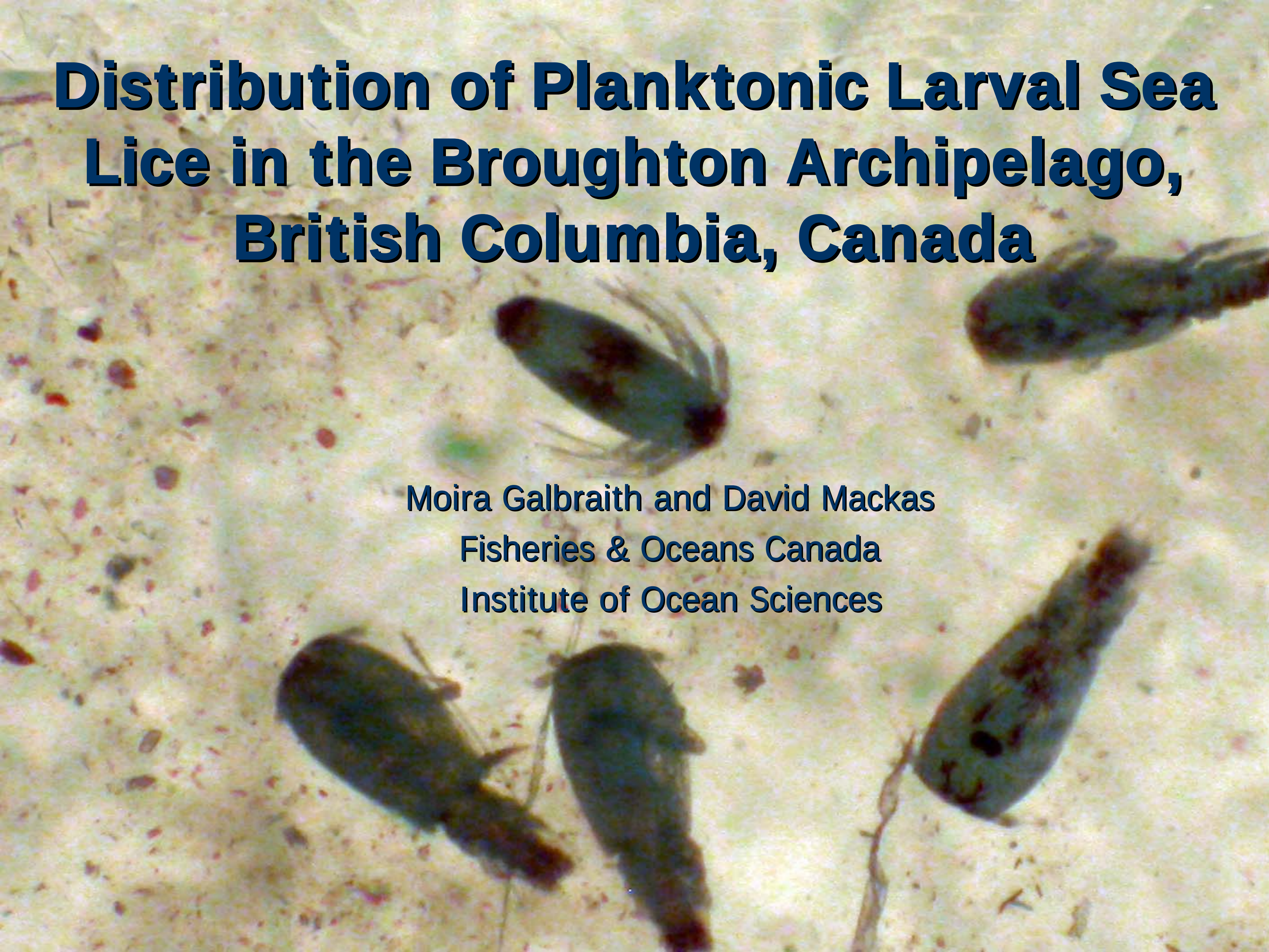
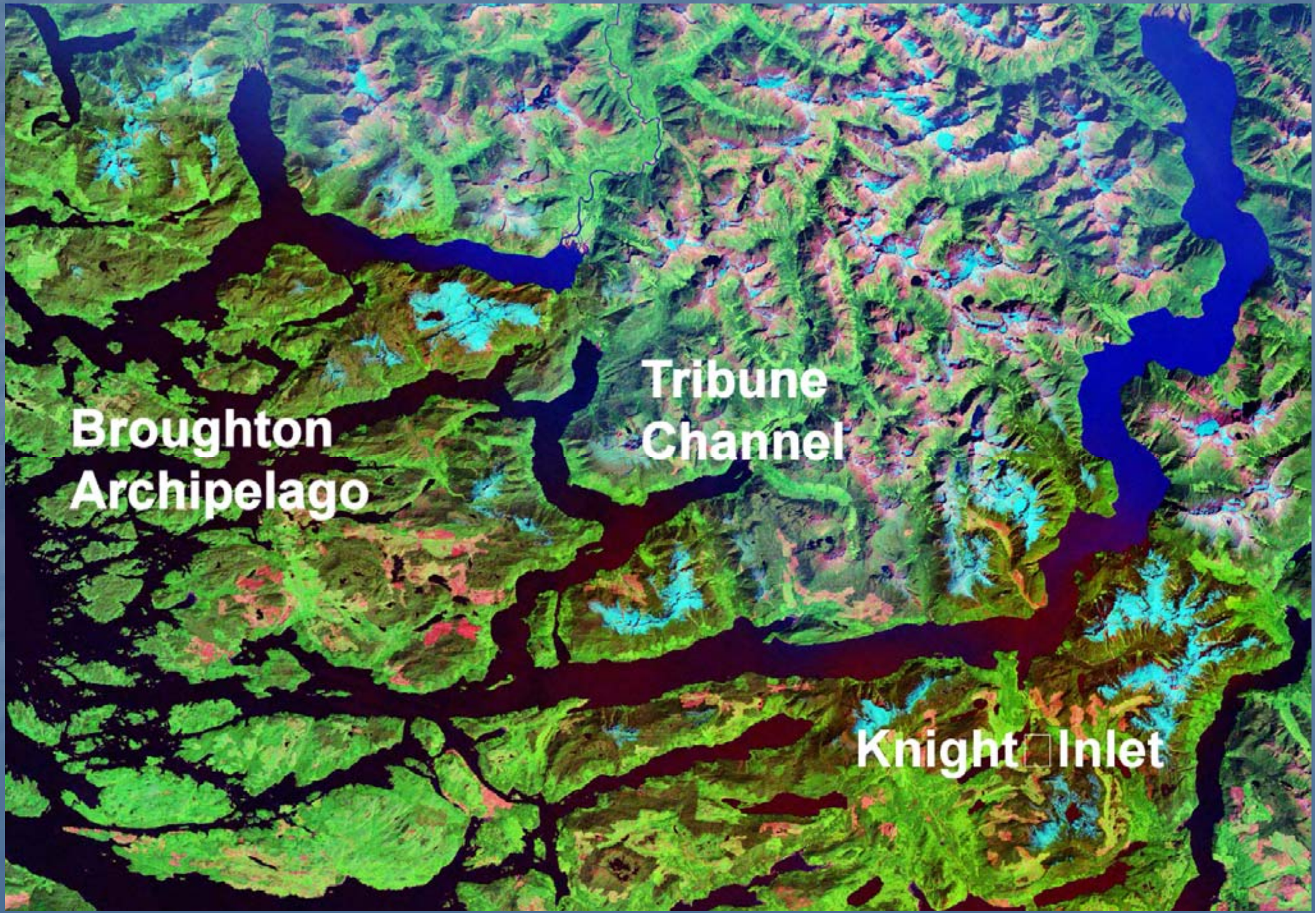


Our study site: a place where sea lice, wild salmon, and farmed salmon meet



- Major salmon farming area
- Large runs of wild salmon (especially pink & chum)

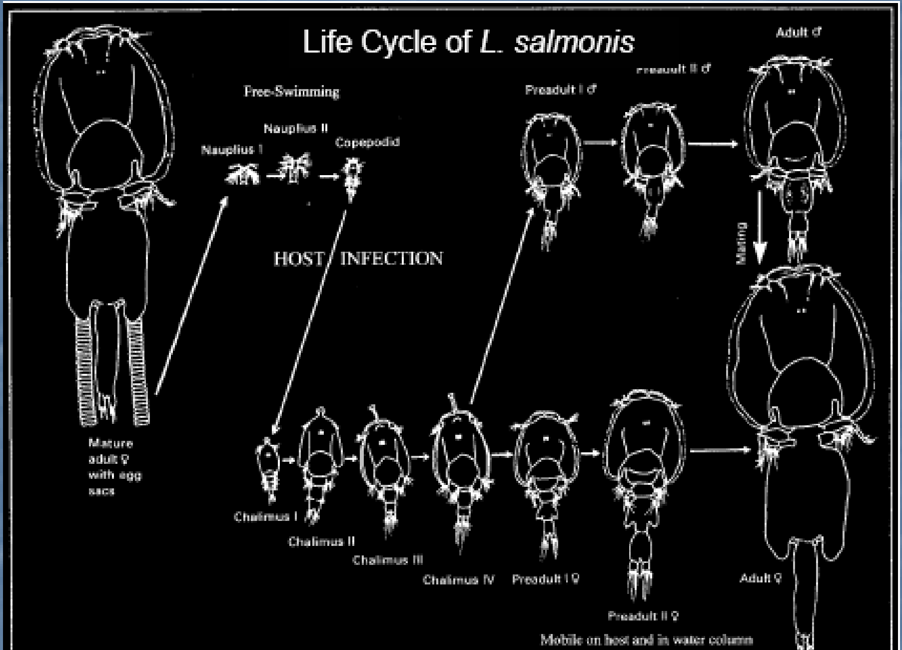
Fish farm, sea lice, wild salmon interactions: Two highly polarized views

- Wild salmon can/will coexist with fish farms
- Aquaculture production reduces pressure to overfish
- Fish farms are a source but not the dominant source of sea lice
- Lice loads on farm fish can be controlled by drugs and stocking plans
- Survival of wild stocks has been OK in most recent years, and observed infection levels on wild smolts are not a major health risk

- Wild stocks go extinct where fish farming is intensive
- Fish farms a year-round reservoir of infection, break seasonal isolation between infected wild adults and vulnerable smolts
- Drugs are a short term fix, and bring their own risks
- Lice on young fish increase mortality by several mechanisms (direct injury, poor growth, predation, disease)
- Wild survival has dropped since ~2001

Important aspects of the life cycle of the salmon sea louse *Lepeophtheirus salmonis*

- Entirely marine
- Generation time ~30 days, (but adults can live many months)
- Free-living planktonic stages are small (<1mm) and brief (~6-12 days each)
- Early parasitic stages also small & tethered to host
- Later parasitic stages are large (>1 cm), motile, specific to salmonids, and can be very damaging when host is small/young



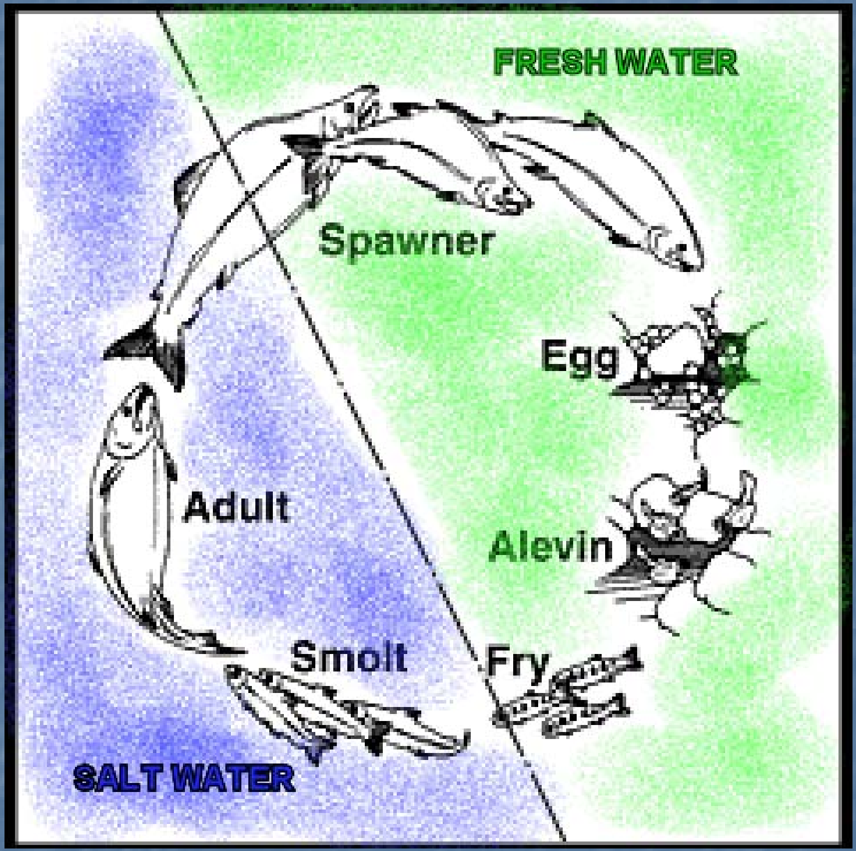
from Stewart Johnson

Figure 5.3 Diagram of the life cycle of the sea louse *Lepeophtheirus salmonis* on *Salmo salar*. (Drawn by A. Shinn.)

Alexandra Morton photo

Important aspects of the life history of Pacific salmon

- Anadromous (life cycle split between FW and ocean)
- Generation time 2-5+ years
- Clear cold freshwater provides fry with a refuge from predators and disease (but not much food)
- Smolts enter the ocean for more food (but must grow fast to avoid becoming food for someone else)



Pink salmon (*Oncorhynchus gorbushka)*

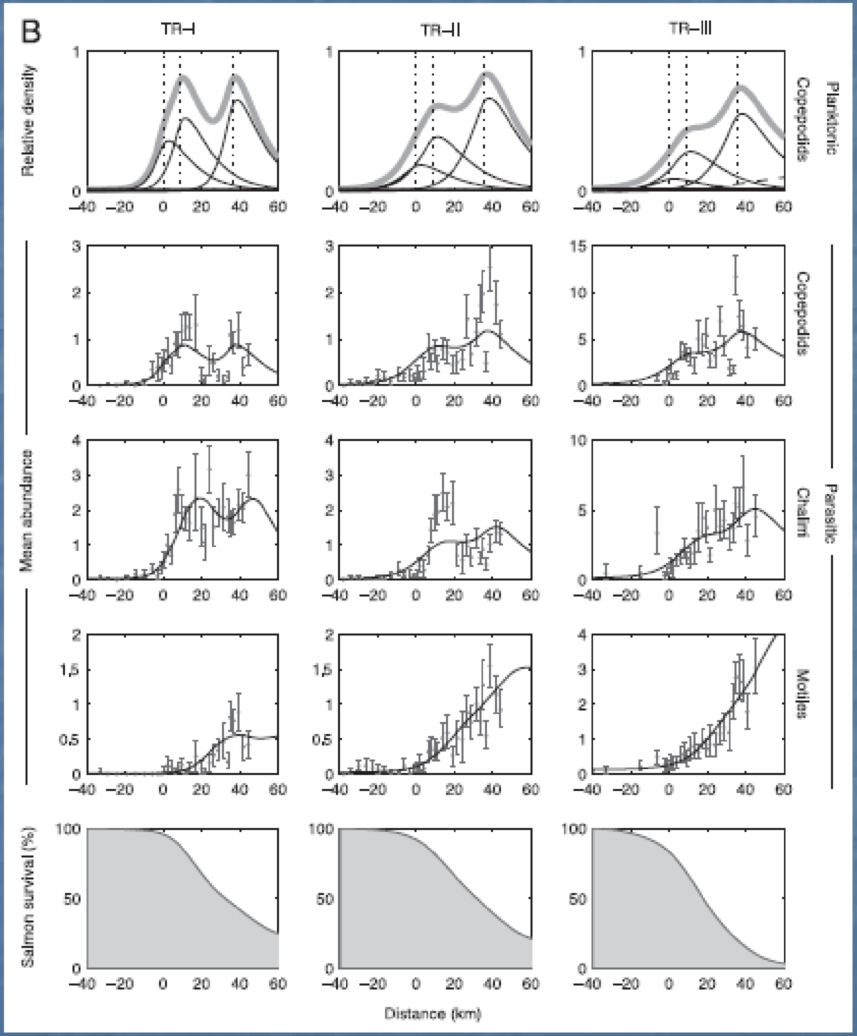
Dominant wild species in Knight/Broughton region

Key traits:

- Life cycle is 2 years
- Smolts leave FW early (spring of 1st year)
- Very small size at ocean entry (~3 cm, 0.25 g) increases smolt vulnerability to both predators and parasites
- Rear through spring and summer of first year in coastal ocean, leave for open ocean in fall
- Adults return in fall of 2nd year (~ 2-2.5 kg), often heavily infected with adult sea lice

Painting by H. Heine, from Groot & Margolis 1991

How/why we got involved:



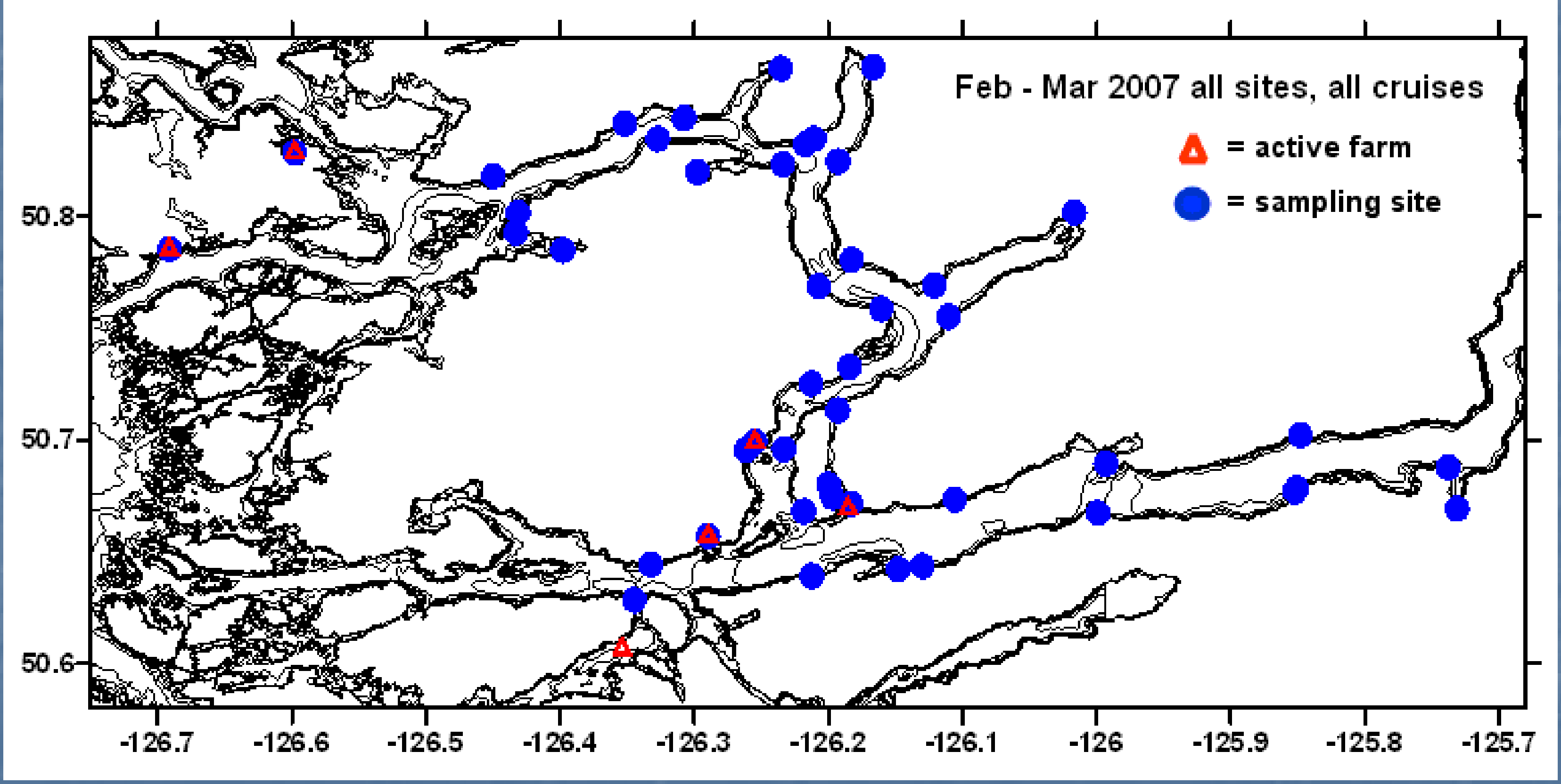
- Krkosek et al (2006) observed parasite density on smolts vs. location and date (3 middle panels) and modeled fish survival rate (bottom) and density of the infective planktonic stages (top)
- Concluded that infection occurs close to active farms (vertical lines)
- But no direct observation of distribution of the infective stage.
- Are they where Krkosek et al predict? Are the #s high enough to produce heavy infection?

Our Objectives

- Develop methods for sampling planktonic sea-lice
- Determine the level of effort needed to discriminate between ‘low’ and ‘zero or near-zero’ abundance
- Map the distributions of planktonic-stage sea lice along Knight Inlet -Tribune Channel before & during the spring season out-migration of wild pink and chum salmon
- Compare observed distributions to surface water properties and proximity to active fish farms

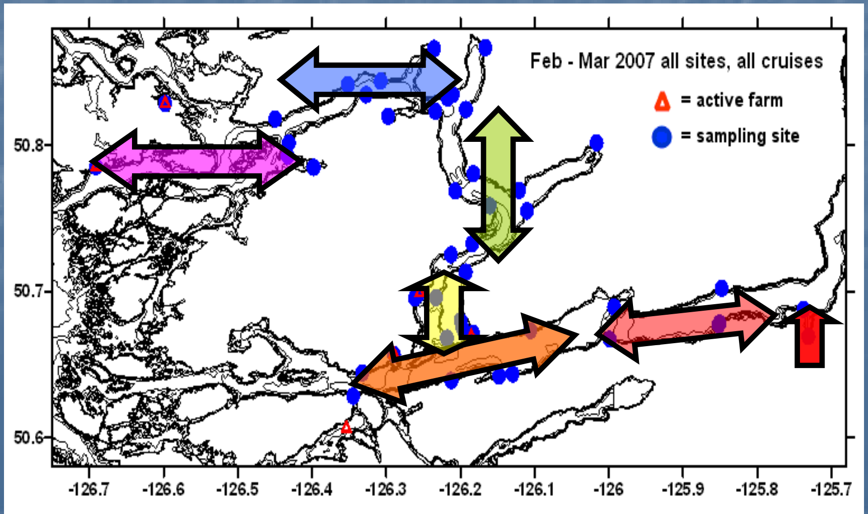
Sampling Design:

Both sides of Knight/Tribune from Glendale Cove seaward to Broughton Island



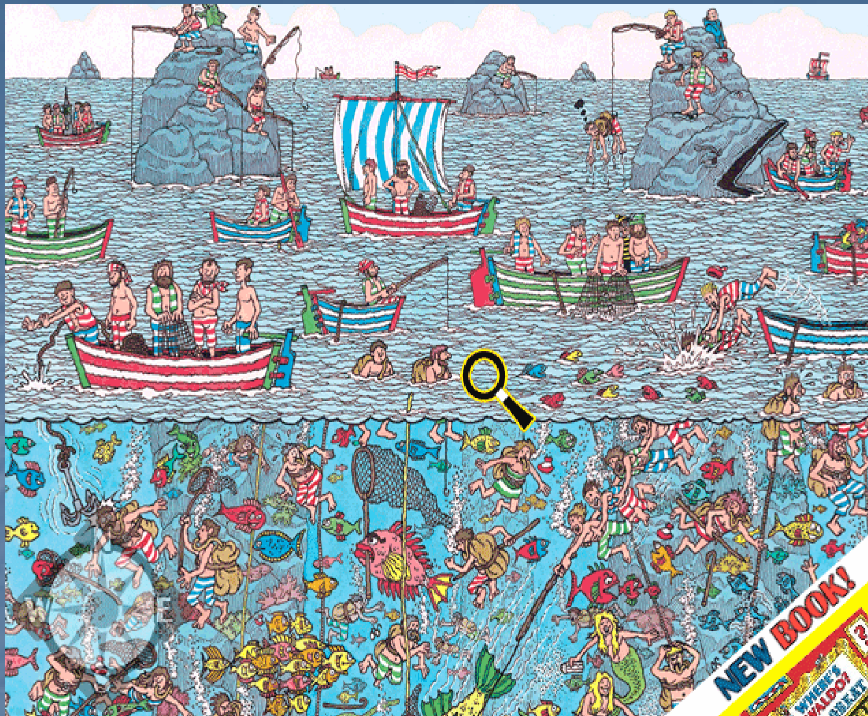
2007 Sampling Effort vs Location & Date 2008

Feb 12-15	Feb 27-Mar 2	Mar 13-15	Mar 27-31	Early April	Apr 24-26	Zone	Feb 12-14	Feb 25-29	Mar 12-14	Mar 25-29	Apr 7-9	Apr 21-22
7	2	2	4				3	3	3	1	4	1
7	3	5	0				6	1	6	5	5	2
6	6	8	2	Boat	Dense		6	3	7	6	6	2
8	6	7	6	out-of-	Phyto		8	7	8	7	8	6
2	6	6	0	service	bloom		6	7	7	7	7	5
0	4	4	1				4	4	4	2	4	0
0	6	3	3				2	2	2	0	2	0



Sampling method: Horizontal plankton tows, near shore in surface layer

- This is where the juvenile pinks & chum are migrating
- Studies elsewhere show nearshore/surface is where lice are most dense.
- Volume filtered 40-60 m^3 per sample



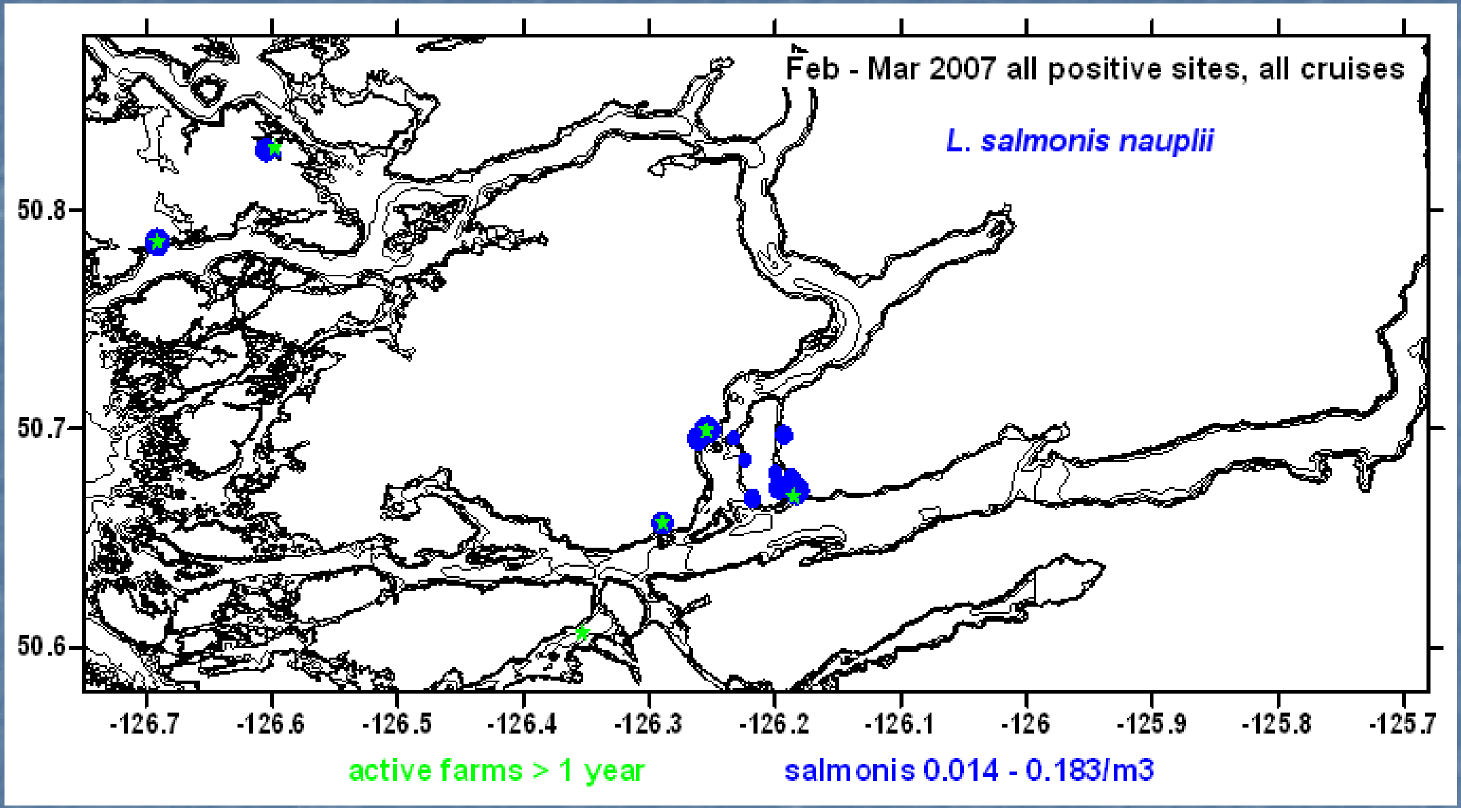
Laboratory ID & Counting: Playing ‘Where’s Waldo?’

- Each sample jar contains several thousand ‘other zooplankton’, many similar in size and shape to the larval sea lice
- Sea lice #s were much lower, so needed to search all of every sample

Results:

- Found 3 types: *Lepeophtheirus salmonis* nauplii, *L. salmonis* copepodites, and *Caligus clemensi* copepodites
- Abundances per sample were low, ranging from zero (the most common) to nine
- Compared catch rate to:
  - 2007 - ‘Distance to farm(s)’ = 1/(average of [1/r])
  - 2008 - As above but distances weighted to account for variability among farms in production of sea lice eggs

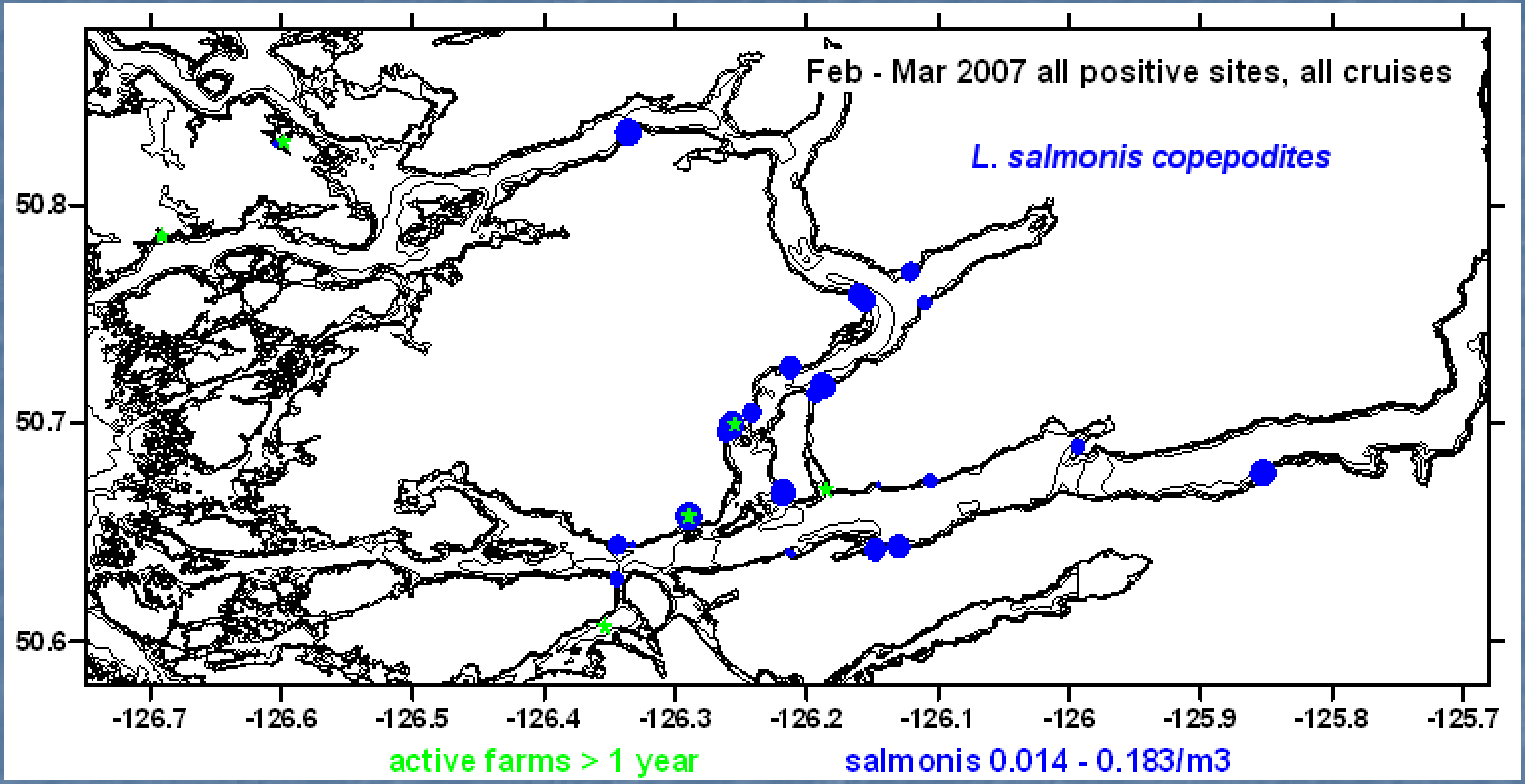
Spatial distributions in 2007: *L. salmonis* nauplii



• Most abundant near active farms

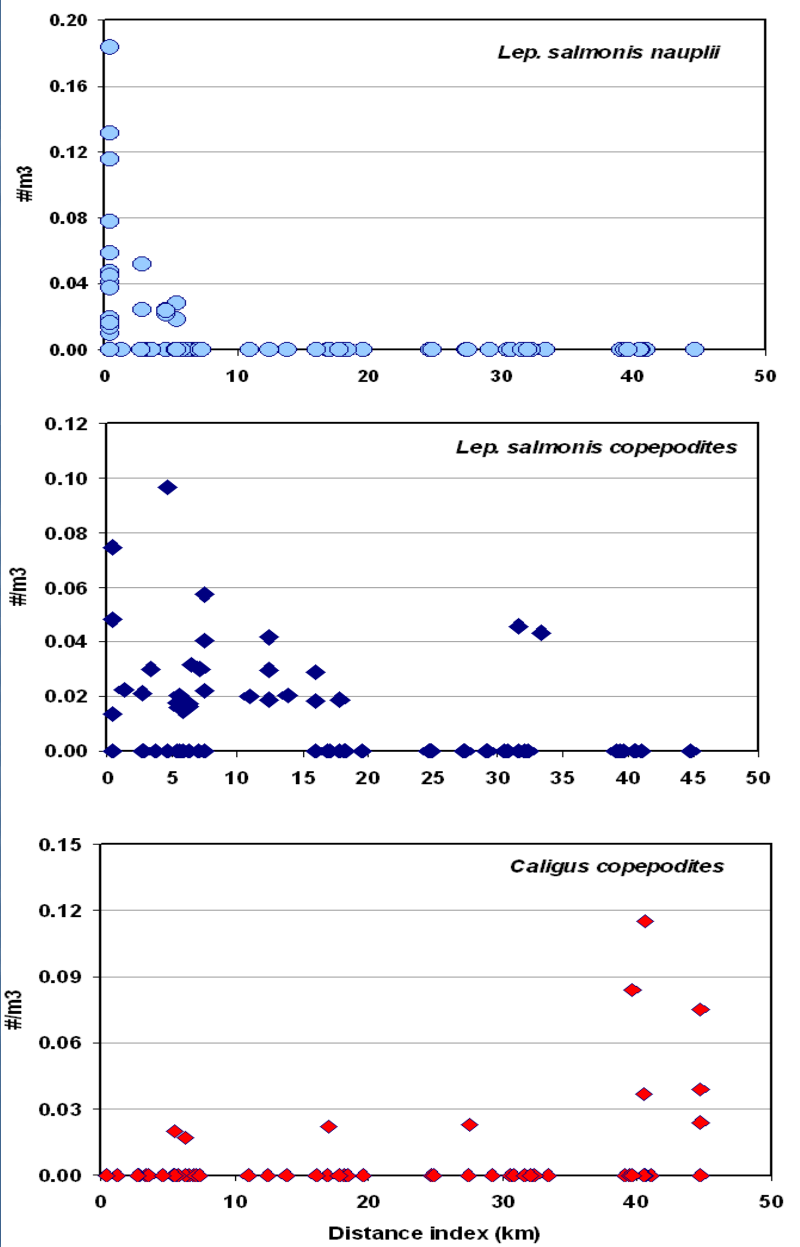
• Absent where distance-to-farm exceeded ~8 km (low salinity sites, but many high $S^{o}/_{oo}$ sites as well)

Spatial distributions in 2007: *L. salmonis* copepodites



- Distribution similar to nauplii but MUCH broader
- Mostly <20 km distance to farm, 2 samples ~30 km
- No evidence that the center-of-distribution is shifted seaward relative to distribution of the nauplii

2007 plots of abundance vs. distance-to-farm index



Tests of association (degrees of freedom)

L.salmonis nauplii	Test	p
Rank correlation	r= -0.60 (113)	<0.001
Pres-abs X 4 distance classes	X^2=58.7(3 df)	<0.001
3 # classes X <>10 km	X^2=32.2(2 df)	<0.001

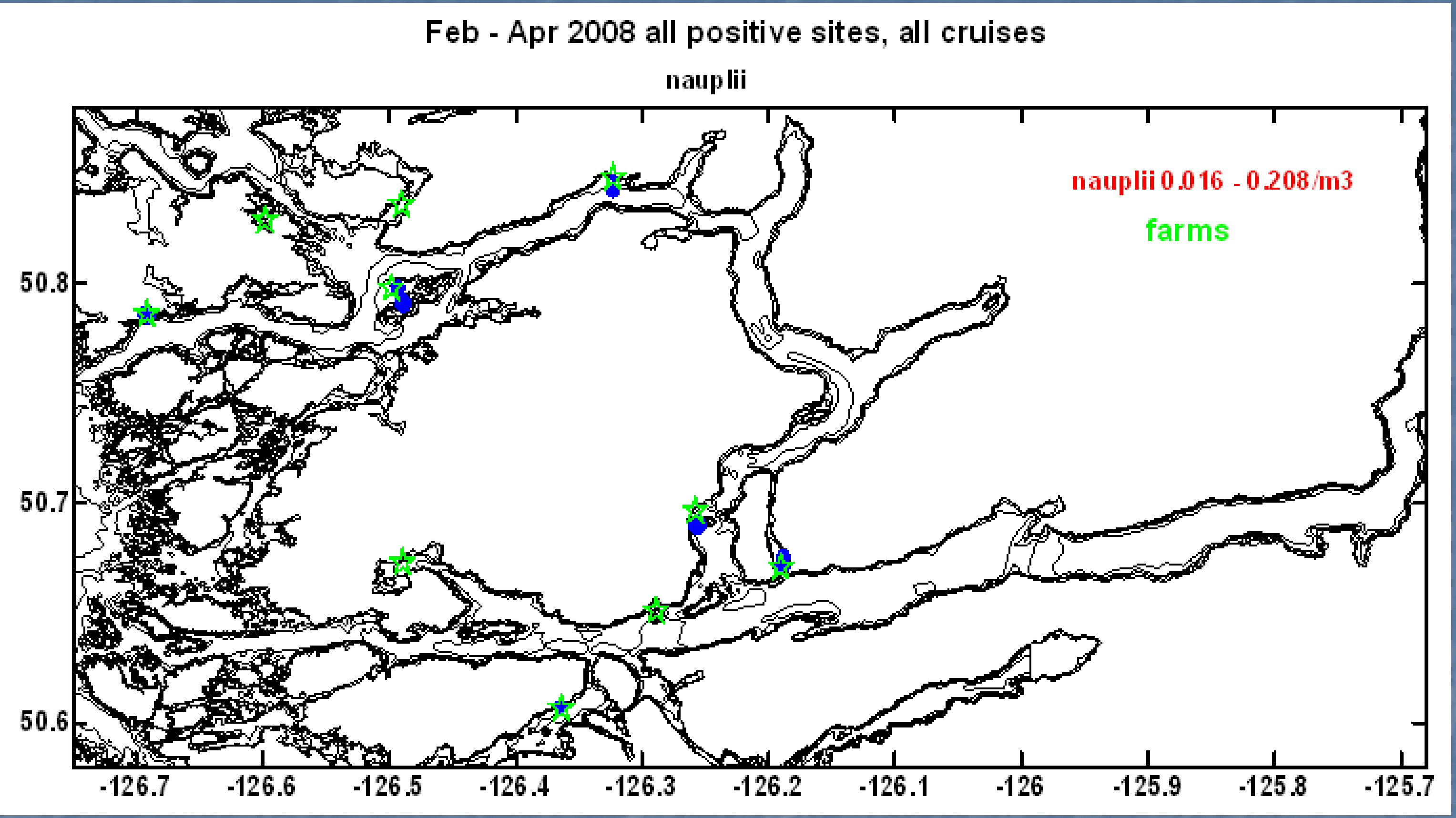
L.salmonis copeps	Test	p
Rank correlation	r= -0.26 (113)	<0.01
Pres-abs X 4 distance classes	X^2=35.0(3 df)	<0.001
3 # classes X <>10 km	X^2=16.2(2 df)	<0.001

Caligus copeps	Test	p
Rank correlation	r=+ 0.27(113)	<0.01
Pres-abs X 4 distance classes	X^2=10.9(3 df)	<0.05
3 # classes X <>10 km	n.a.	n.a.

Differences in 2008

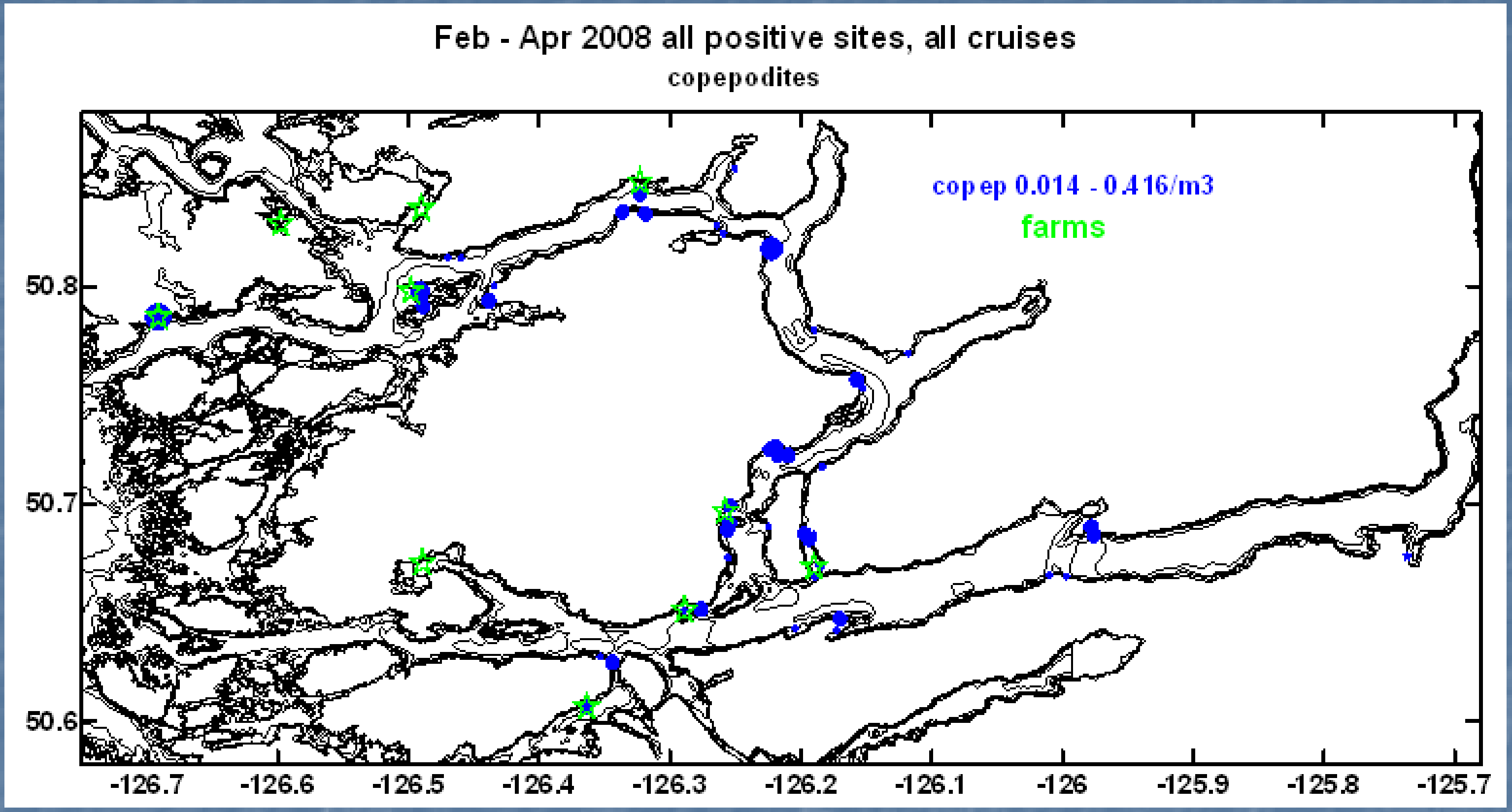
- Longer observation span (6 surveys vs 4)
- More farms in total, but also more controls (SLICE, harvest) on farm lice output
- Nevertheless, results broadly similar to 2007

Spatial distributions in 2008: *L. salmonis* nauplii



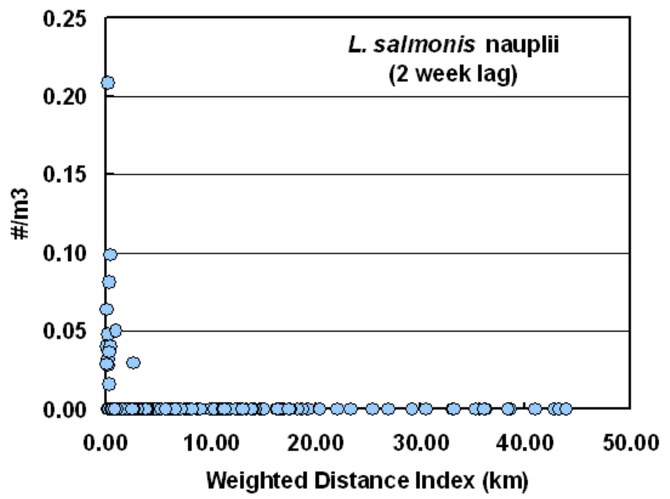
- Found only at sites very close to active farms (<5 km)
  - Lower occurrence rates, lower abundance than the *L. salmonis* copepodites

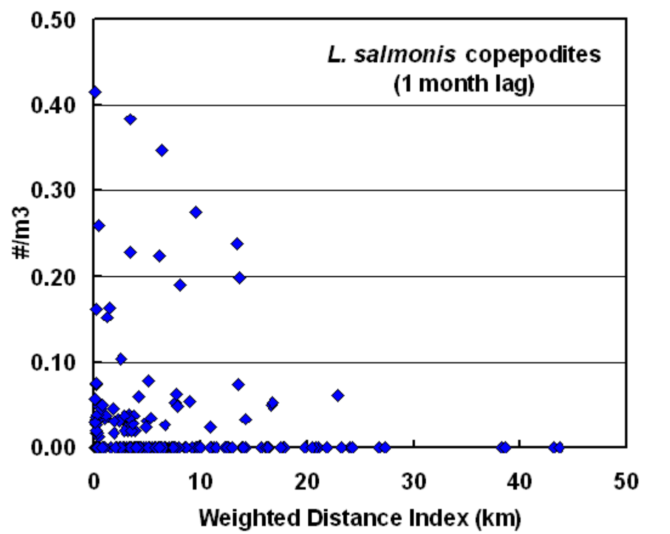
Spatial distributions in 2008: *L. salmonis* copepodites



- Distribution again much broader than nauplii
- Up to 30 km from 'recently' active farms (best fit is to farm egg output lagged by 4-6 weeks)

2008 plots of abundance vs. distance-to-farm index





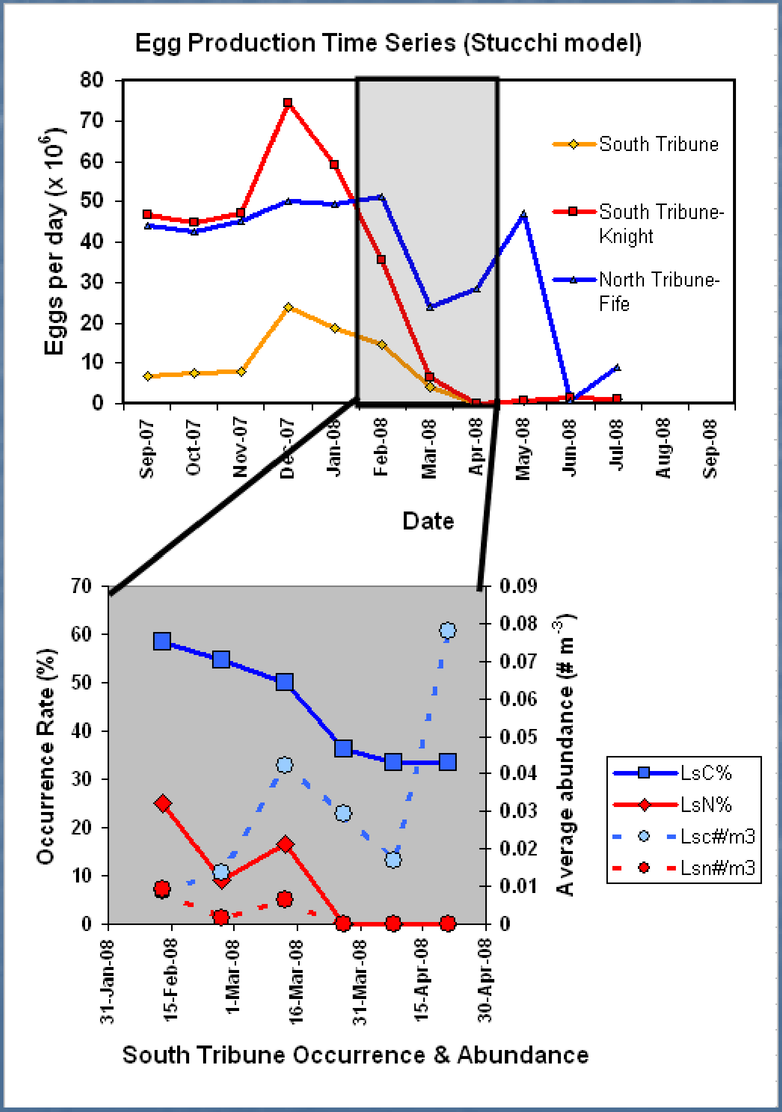
Tests of association (degrees of freedom)

L.salmonis nauplii	Test	p
Rank correlation	r= -0.45 (178)	<0.001
Pres-abs X 4 distance classes	X^2=32.3 (3 df)	<0.001
3 # classes X <>10 km	X^2=10.3 (2 df)	<0. 01

L.salmonis copeps	Test	p
Rank correlation	r= -0.35 (178)	<0.001
Pres-abs X 4 distance classes	X^2=37.9 (3 df)	<0.001
3 # classes X <>10 km	X^2=13.1 (2 df)	<0.005

(*Caligus* larvae were very rare in 2008 samples)

Time lag between egg production and larval occurrence/abundance



- Treatment/harvest of farms in and near south Tribune Channel began late January-February
- Sea lice egg production (and abundance of naupliar stage larvae) approaching zero by mid-March BUT
- Abundance/occurrence of copepodite stage larvae persisted through April

Summary of our work

- *L. salmonis* larvae were relatively rare (observed range 0 - 0.4 m^{-3}, mean 0.01-0.03 m^{-3}), but their occurrence rates and abundances were higher near active fish farms
- Abundance of *L. salmonis* copepodites in the inlet lags the within-farm production of *L. salmonis* eggs by 4-6 weeks (nauplii lag by ~ 2 weeks)
- Although *L. salmonis* presence/abundance were also positively correlated with surface salinity in Knight/Tribune, this association is considerably weaker than the spatial/temporal association with active farms.

Implications of our results? (our present opinions):

- Fish farms DO appear to be the main source of larval sea lice (*L. salmonis*) during the spring out-migration of wild smolts
- Goal for farm management action (drug additions/ fish removals) should be to limit density of the infective larval stage (copepodite) outside the pens, not just adult density within the pens.
- 4-6 week lag between egg production and copepodite abundance suggests that copepodites may survive longer than generally expected, and that management interventions could be more effective if done earlier in the year.

Next step:

- Estimate cumulative encounter rates for salmon fry from sea lice abundance (also need to know encounter radius & exposure distance along the salmon migratory path)

(lice abundance)(encounter area)(path length)

$$(0.01\ m^{-3})x(pi(0.07)^2\ m^2)x(40km)$$

$\approx$ 6 per fish?

Enough to infect a large fraction of the smolts?