Preying on the weak? Possible non-additive effects of seal predation and stress-related mortality in juvenile coho and Chinook in the Salish Sea

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Pacific Salmon Foundation

Fisheries and Oceans Canada

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Salish Sea Marine Survival Project

Additive or Non-Additive Mortality Rates…

- "Effect of non-additivity in mortality rates on predictions of potential yield of forage fishes" (Walters & Christensen, *Ecological Modeling*, submitted 2019 – in review)
- Ecosystem models that account for trophic interaction effects on prey mortality rates typically represent mortality rates as a sum of independent or additive component rates

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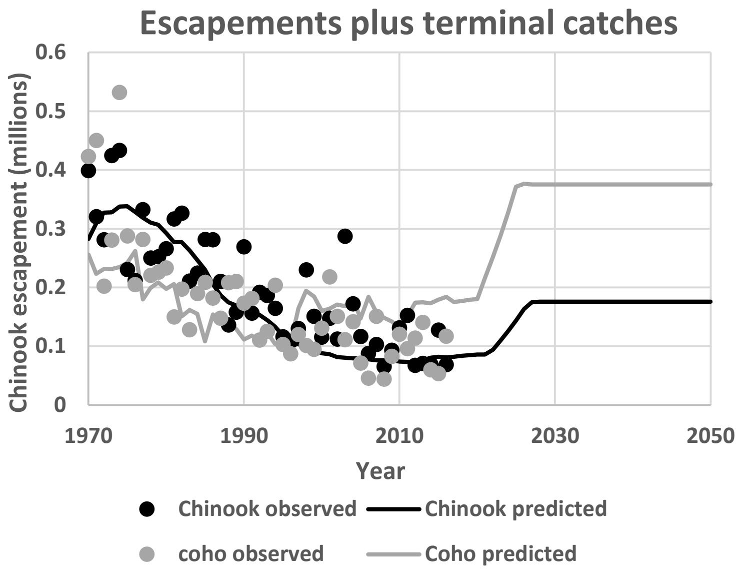
$$\frac{\partial N}{\partial t} = -ZN$$

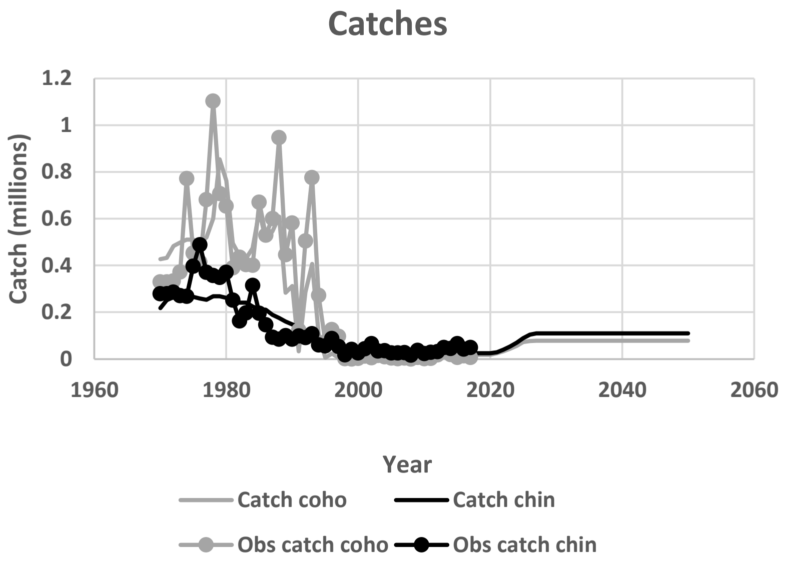
$$N_t = N_0 e^{-Zt}$$

$$Z = F + M$$

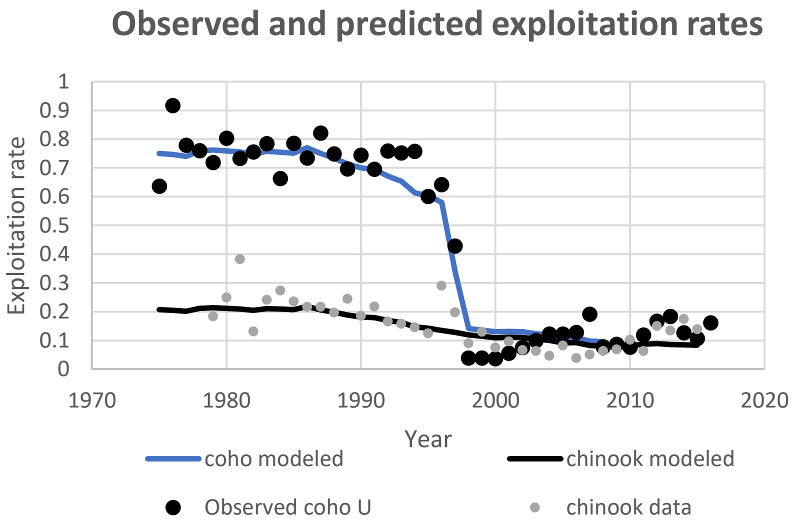
N = Number of fish alive
Z = Total mortality
M = Predation mortality
F = Fishing mortality

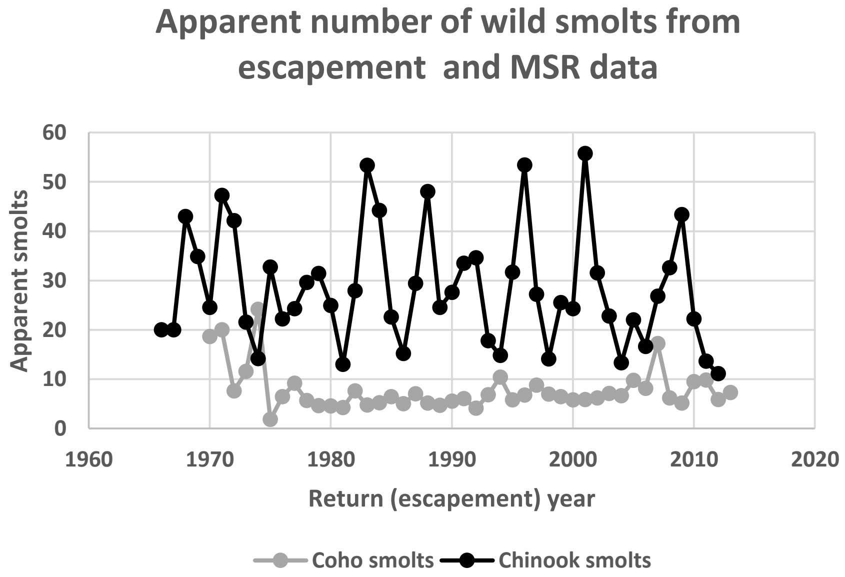
Case Study: Historical and Predicted Changes in Georgia Strait Sport Fishery Indicators, Salish Sea Marine Survival Project Model (Walters)



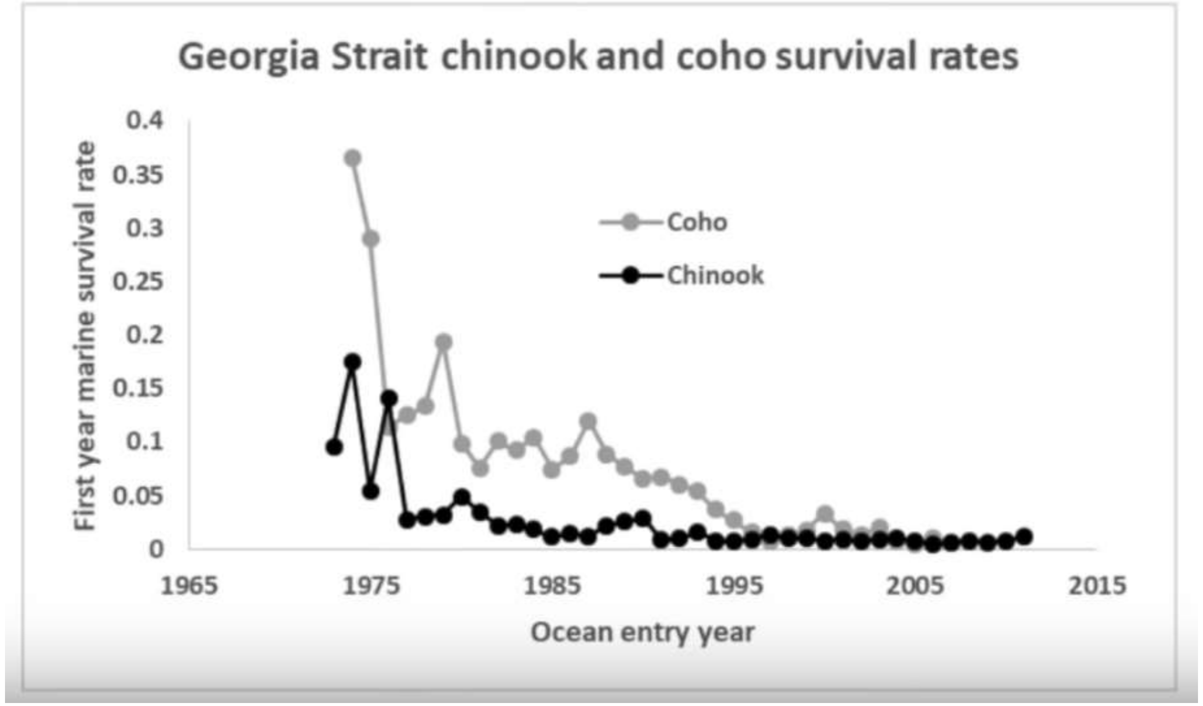


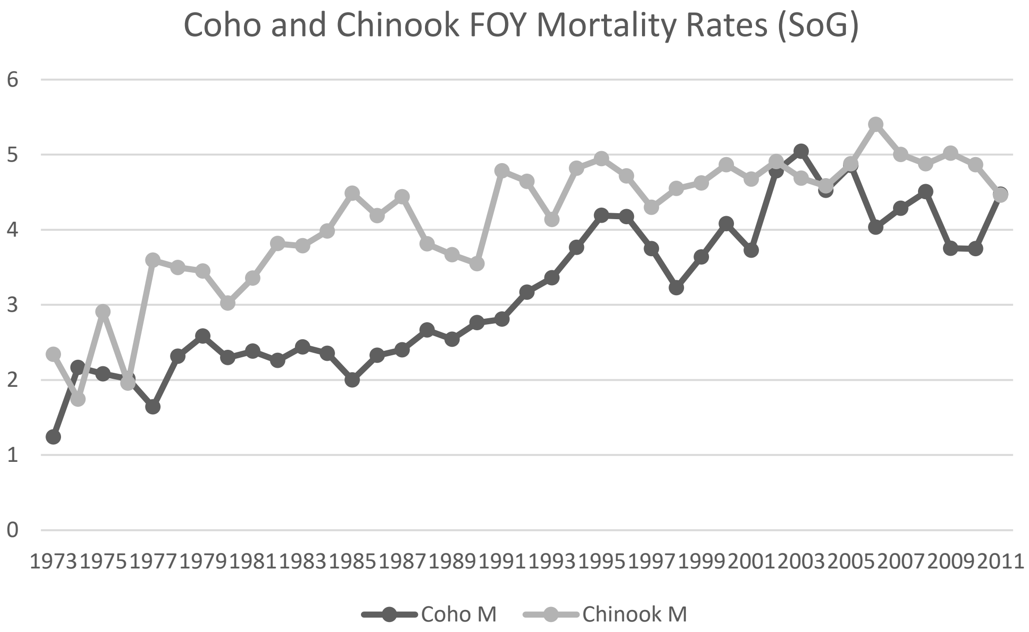
Data from Coded-Wire Tag (CWT) and recovery for a variety of stocks (Ruff et al., 2017; Zimmerman et al., 2015). Model: Carl Walters.





Dramatic Decline Observed in Coho and Chinook First Ocean Year Survival since the 1970s

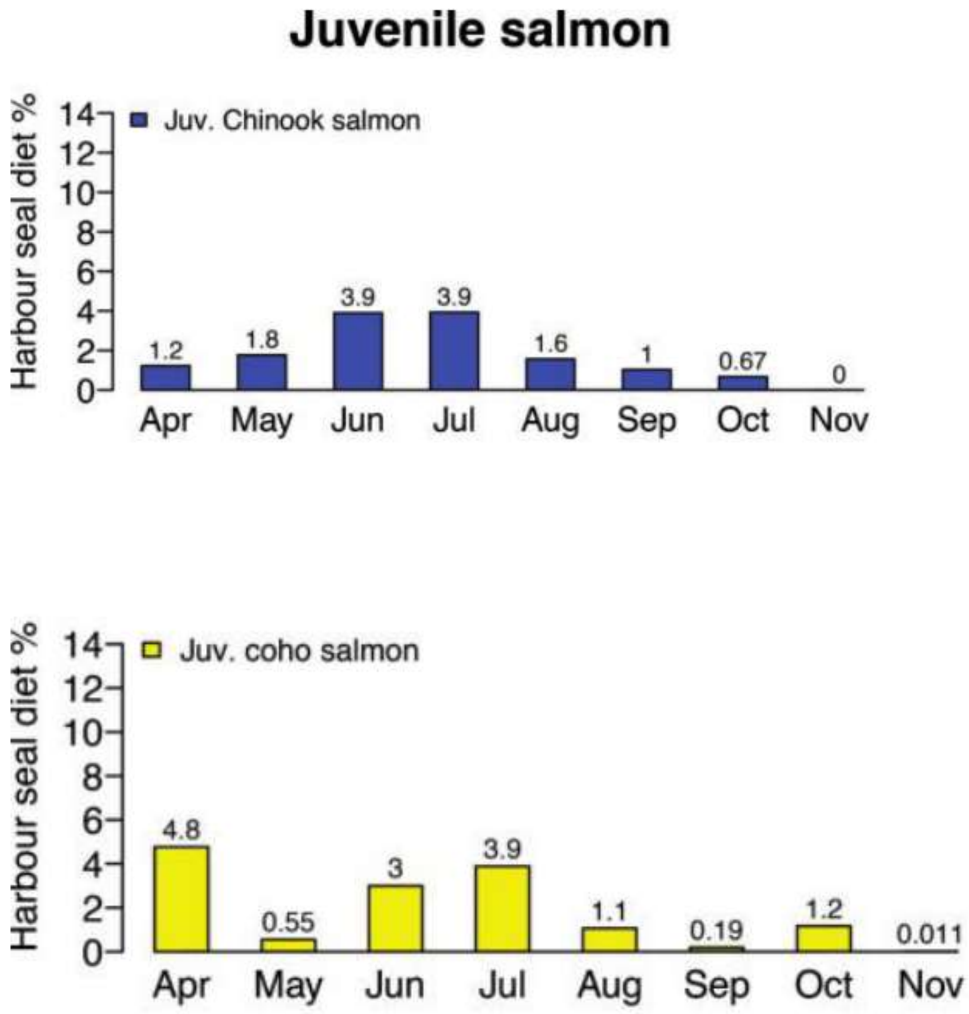




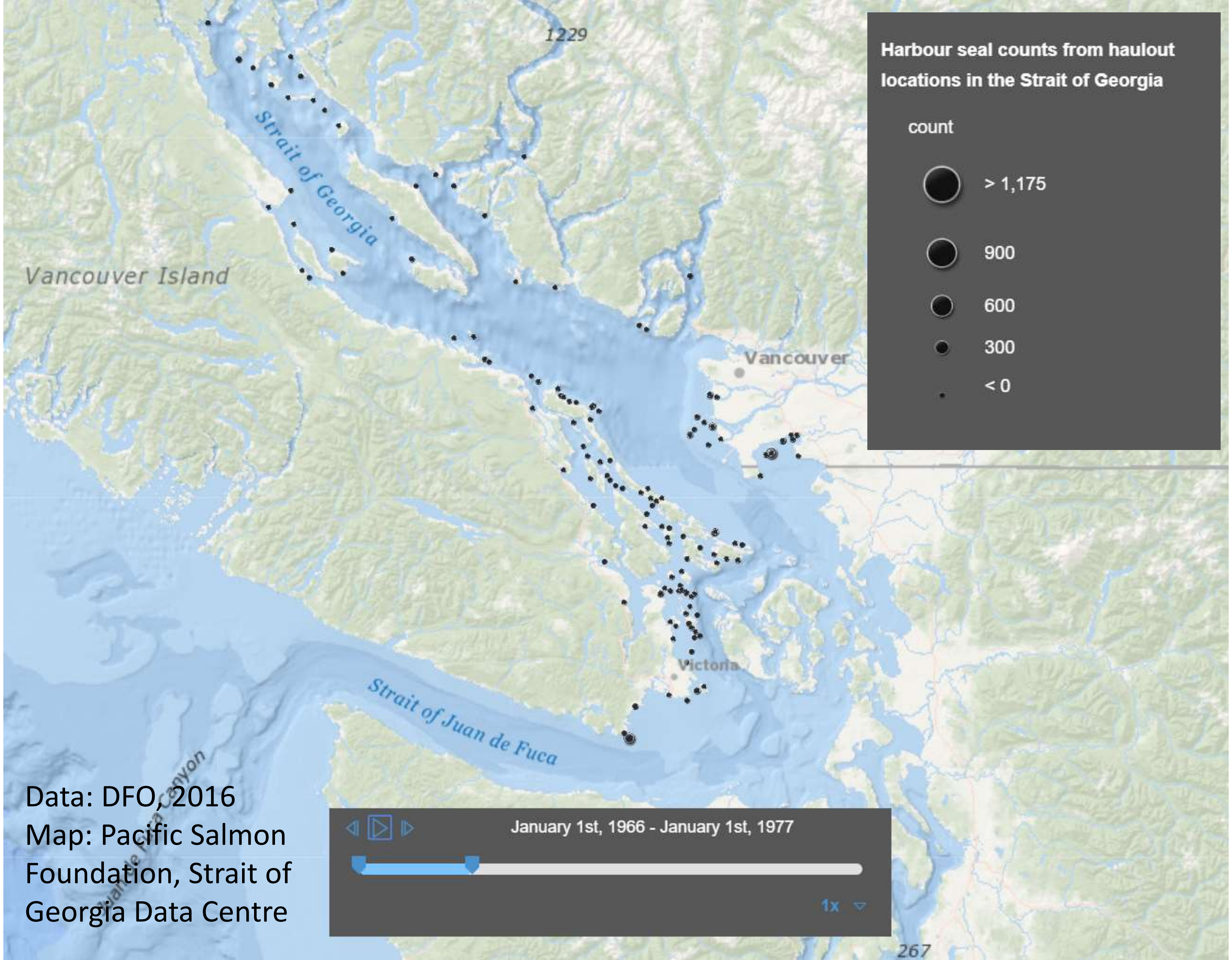
(Mortality = -ln(Survival))

Highlights of Canadian Research on Declines

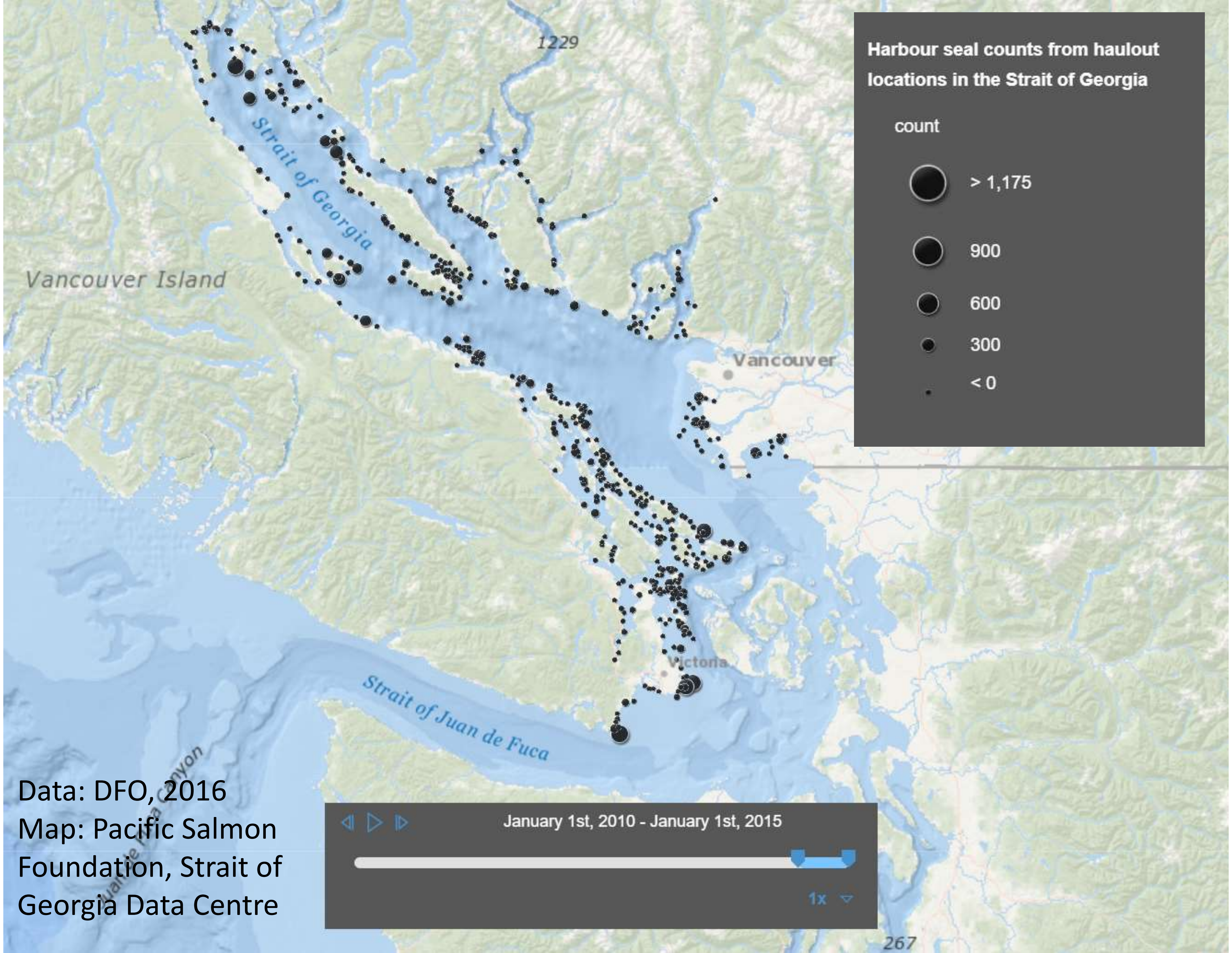
- Late 1980s: blamed on increase in hatchery production (Beamish, Walters)
- Late 1990s: Beamish et al. investigate 'bottom up' hypotheses (food, ocean changes); sport fisherman blame seals (Harling)
- Early 2000s: Olesiuk seal data released, ecosystem models support predation impact hypothesis
- 2012: Pacific Salmon Foundation organizes US-Canada teams to examine wide variety of hypothesis. UBC focuses on predation, DFO on food
- 2015: Thomas et al. (2017) seal diet studies (2012-2013) show large numbers of juvenile chinook and coho eaten by seals, predation impact focused upon
- Today: still controversy about *why* so many juveniles are being consumed (additive predation versus predation driven by other factors like hunger and disease



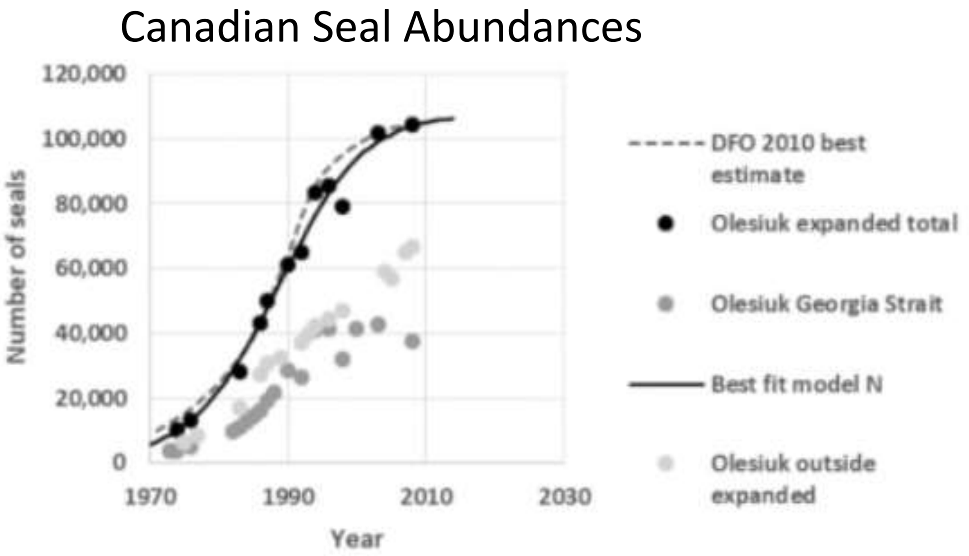
Thomas et al. (2017)



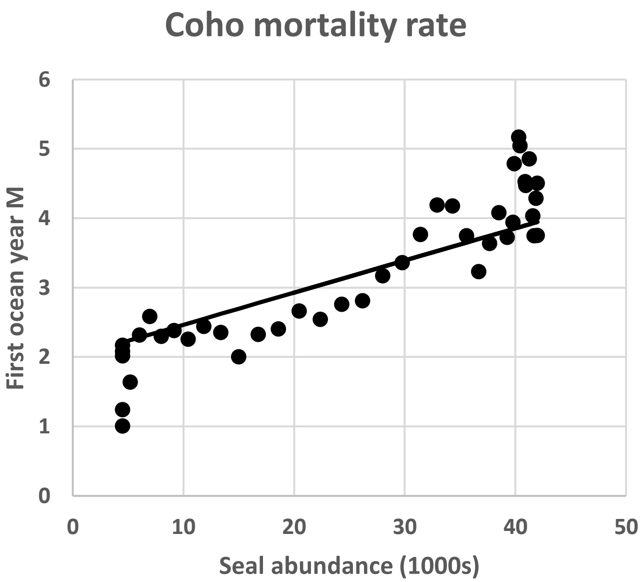
Data: DFO, 2016
Map: Pacific Salmon Foundation, Strait of Georgia Data Centre

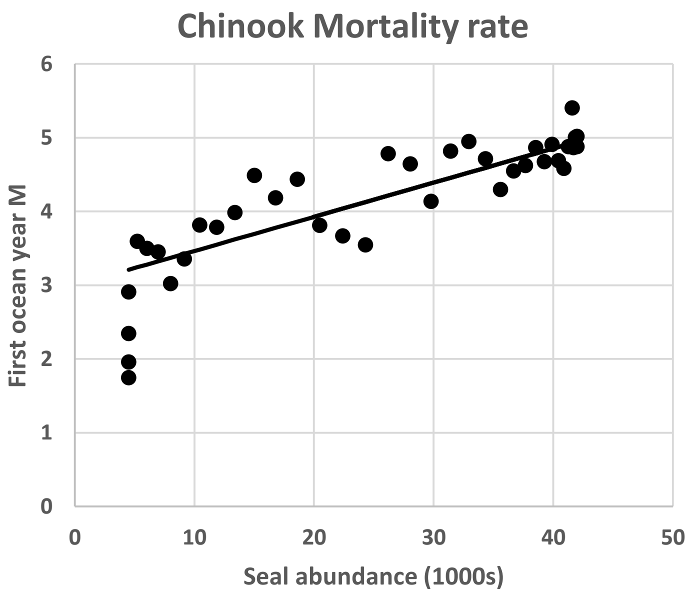

Harbour seal counts from haulout locations in the Strait of Georgia
count
> 1,175
900
600
300
< 0
January 1st, 2010 - January 1st, 2015
1x
Vancouver Island
Strait of Georgia
Strait of Juan de Fuca
Vancouver
Victoria
1229
267
Data: DFO, 2016
Map: Pacific Salmon Foundation, Strait of Georgia Data Centre

Three lines of evidence point to high predation rates by seals

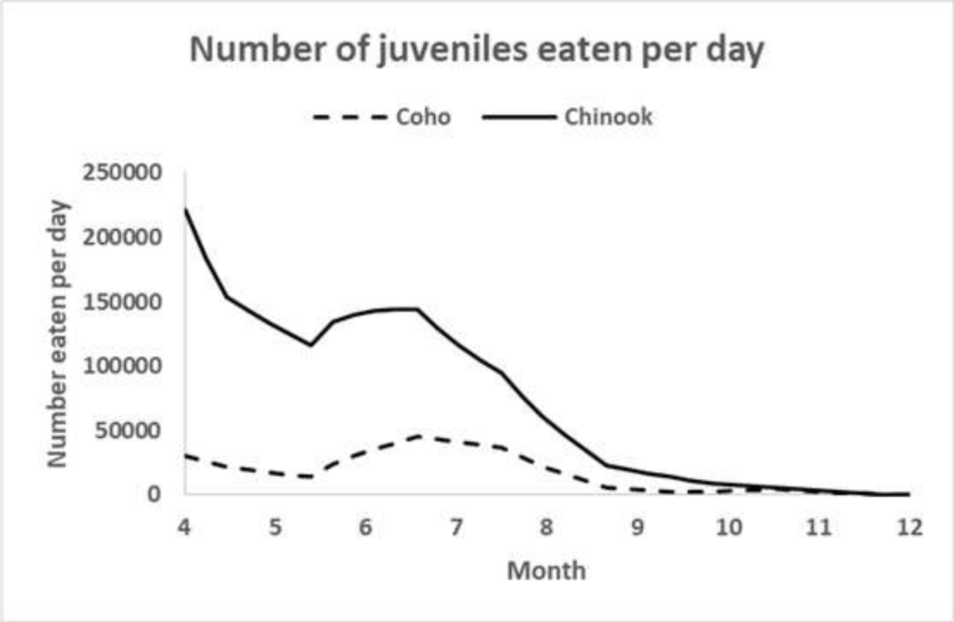


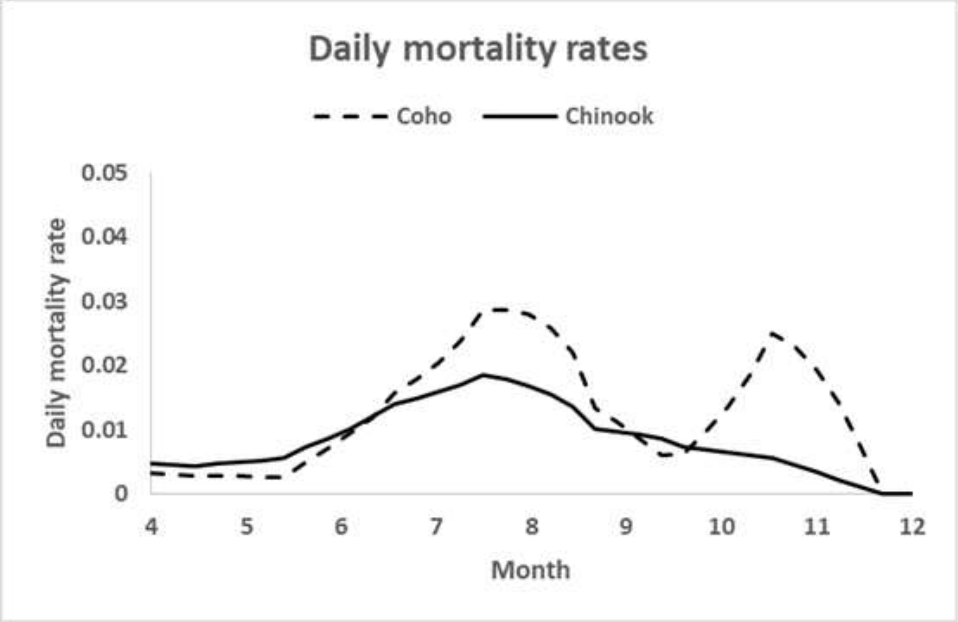
1. Regressions of mortality rates on seal abundance
2. Estimation of daily predation rates from seal abundance and diet data
3. Analysis of seal foraging behaviour





Diet data from Thomas et al. (2017) used to calculate how many juveniles eaten and daily mortality rates (not just a problem of mortality concentrated at river mouths by "problem seals")





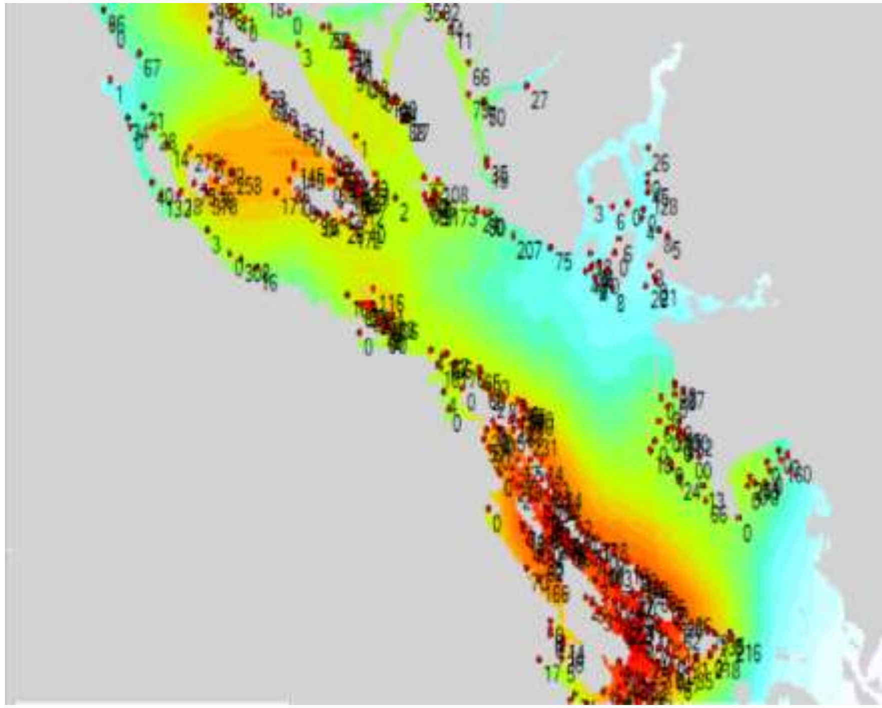
Estimation of daily predation risk from seal foraging information

Component of calculation	Estimate	Source
(1) Seal swimming speed (m/sec)	1	seal tracking data, various sources
(2) Seal reactive distance (m)	5	guess based on sensory (visual, smell) acuity
(3) Potential volume searched/day (m^3)	6785840	π x (1) x $(2)^2$ x seconds/day
(4) Volume of top 30m (m3) per km^2	30000000	
(5) Potential swept volume/surface volume/se	0.226	ratio of (3) to (4)
(6) Proportion of day spent surface foraging	0.025	From Allegue (2017) foraging time allocation
(7) Daily encounter risk per seal per km^2	0.00565487	product of (5) and (6)
(8) Seal density (numbers/km^2)	3	from census data and Georgia Strait area
(9) Daily encounter risk	0.017	product of (7) and (8)
(10) 120 day summer mortality risk (M)	2.04	120 times (9)

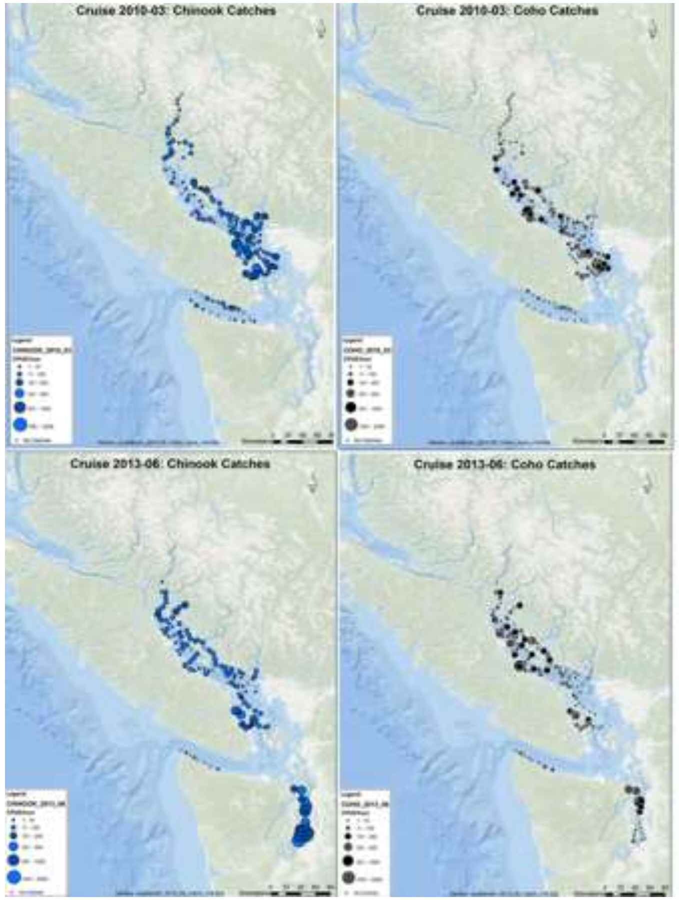
Seals do not seem to be particularly targeting juvenile salmon, it seems they are swimming around looking for food in general and when they see a baby salmon they eat it!

Juvenile densities are concentrated in areas of high seal predation risk

Predation risk from haulout data (SSMSP IBM model)



June juvenile densities, DFO surveys (Neville)



Proposal – Revive the Seal Harvest

- Proposal from the ‘Pacific Balanced Pinniped Society’ to re-establish sustainable harvesting of pinnipeds by Indigenous people, at levels likely prevalent before first contact, as a commercial enterprise aimed at providing incomes from meat, hides, and oil

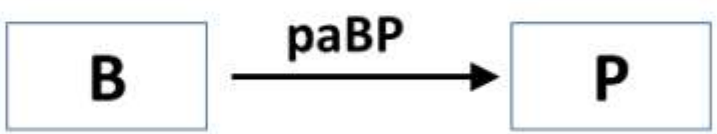
- Reduce and maintain pinniped abundances at near pre-contact levels (estimated to be 50% of current), so as to improve survival rates of chinook and coho salmon over their first year of ocean life with resulting benefits for fisheries and southern resident killer whales

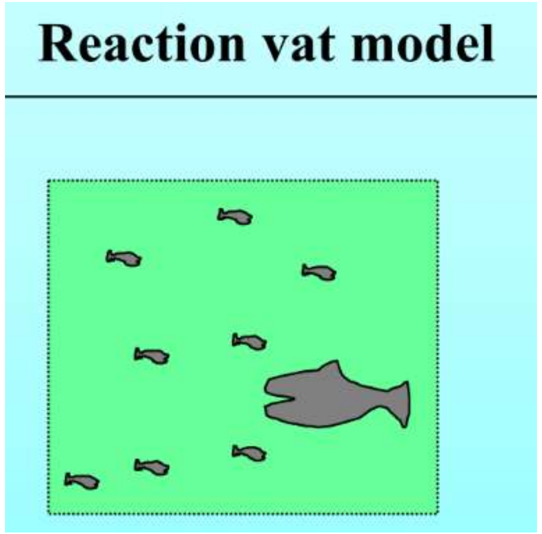
- Evaluated sustainable harvest, salmon increase, ecosystem impacts, tourism impacts, economic viability, regulatory approach

- ***How to predict response of prey fish – juvenile coho, chinook?***

Modeling Predator-Prey Interactions – Typical Approaches

1. Mass-action flow rate

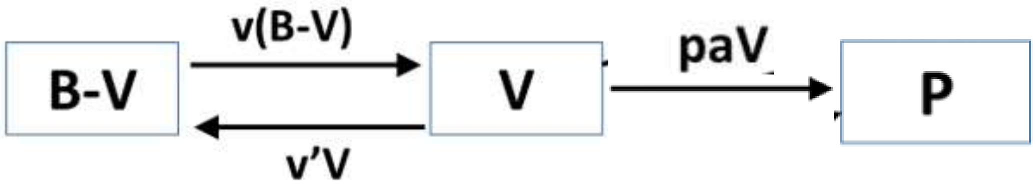


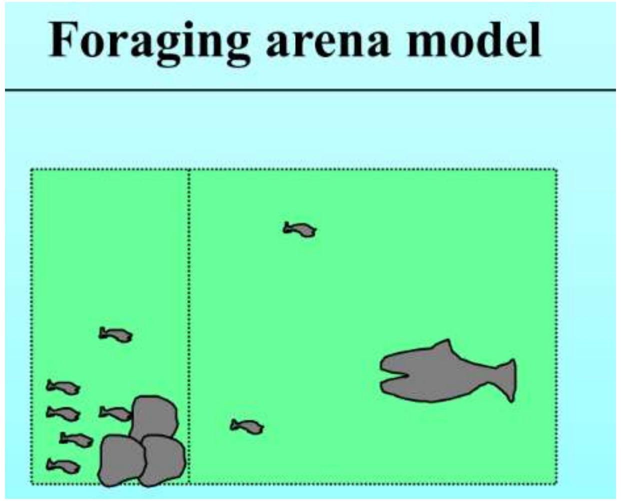


e.g., Essington and Munch (2014)

B = Prey biomass
P = Predator biomass
p = proportion of time spent foraging (pred)
a = predator search rate
V = vulnerable prey biomass
v = Rate at which prey become vulnerable to mortality
v' = Rate at which prey recover or move to safe states

2. Vulnerability exchange flow rate



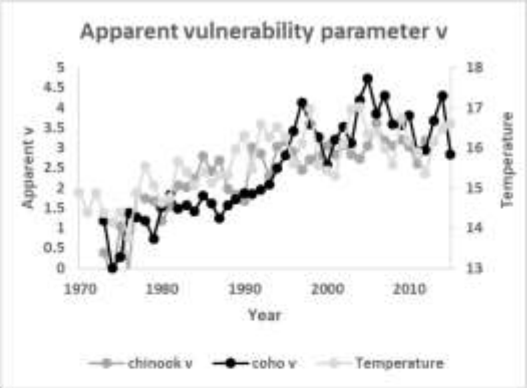


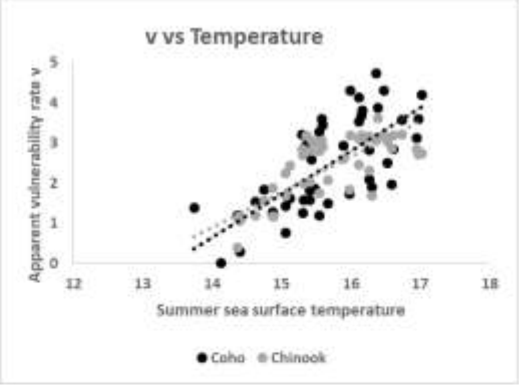
(Walters & Juanes, 1993; Walters et al., 1997; Ahrens et al., 2012)

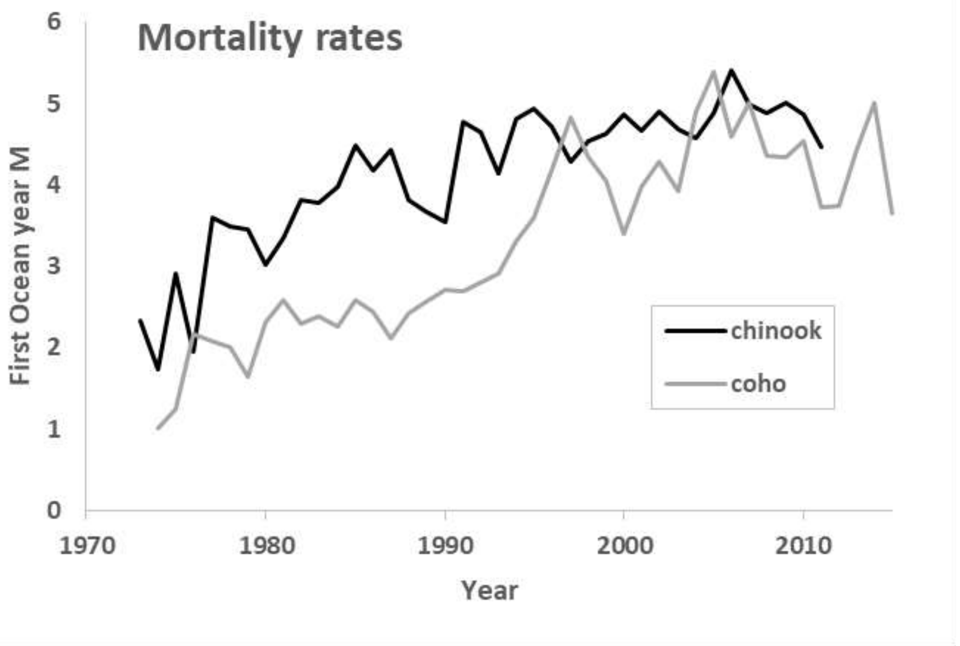
Preying on the Weak?

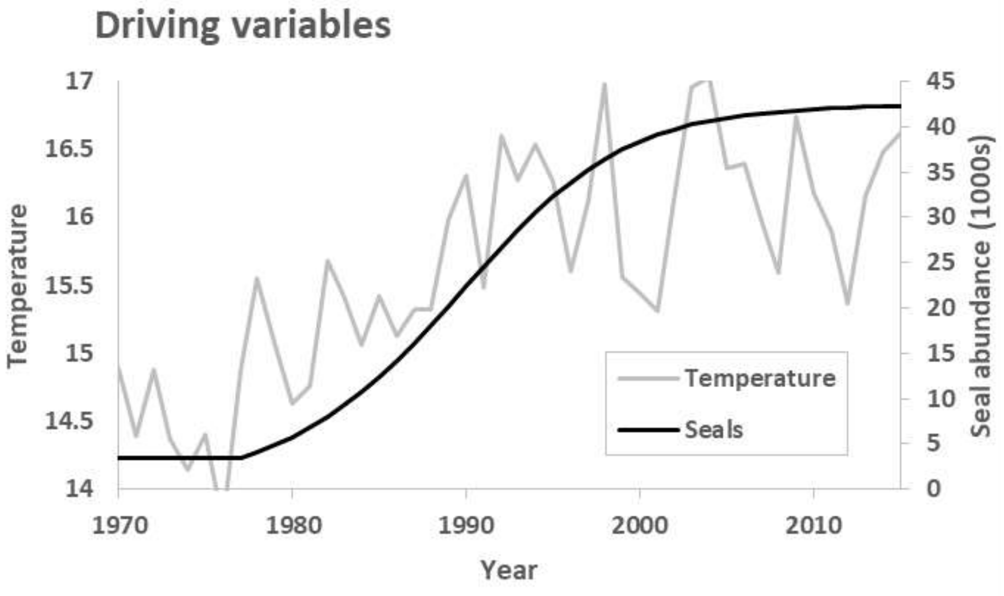
- Another correlated change has been increases in sea surface temperature
- Increased temperature can increase juvenile salmon vulnerability by various means
- Using a back-calculation technique, apparent increases in juvenile coho and chinook vulnerabilities have tracked temperatures
- This effect is missing from the models…

Apparent vulnerability has varied with temperature



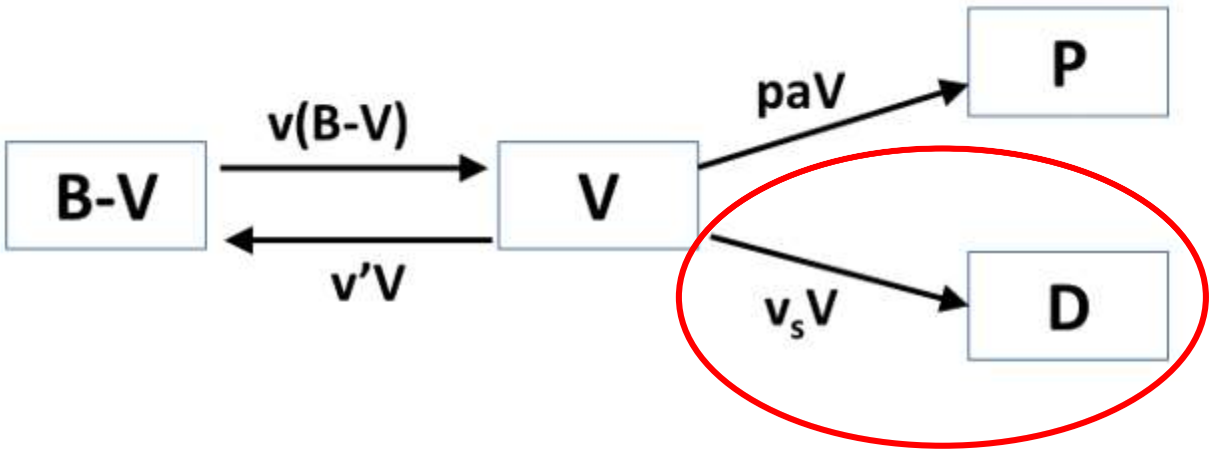






Modeling Predator-Prey Interactions – Adding Stress (Non-additive Mort.)

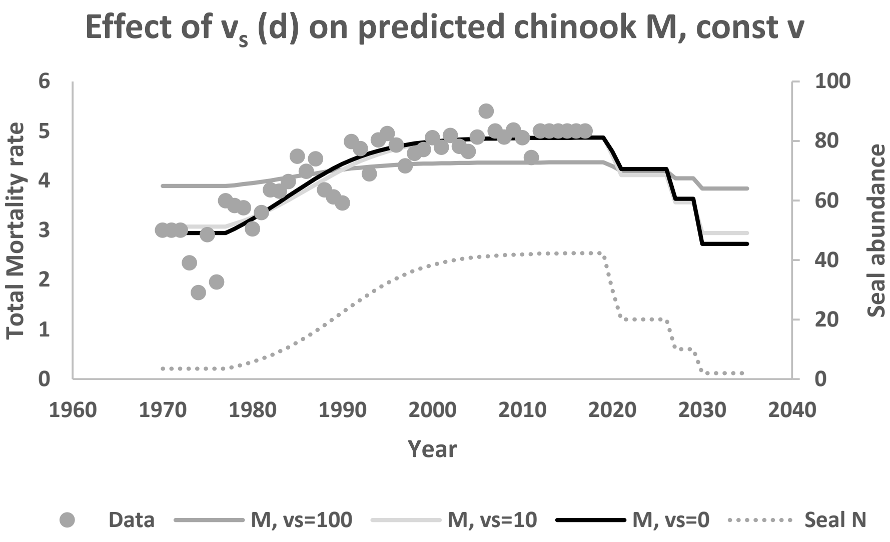
3. Vulnerability exchange flow with stress component $v_s V$

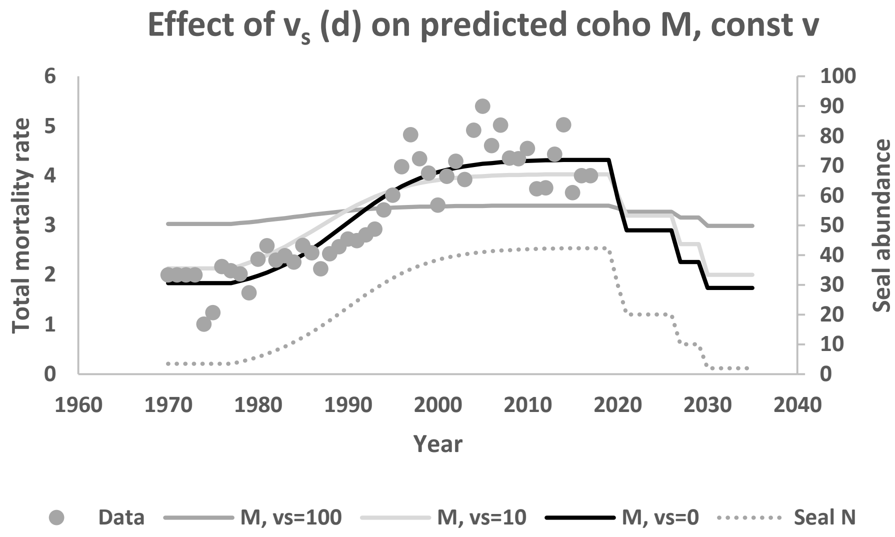


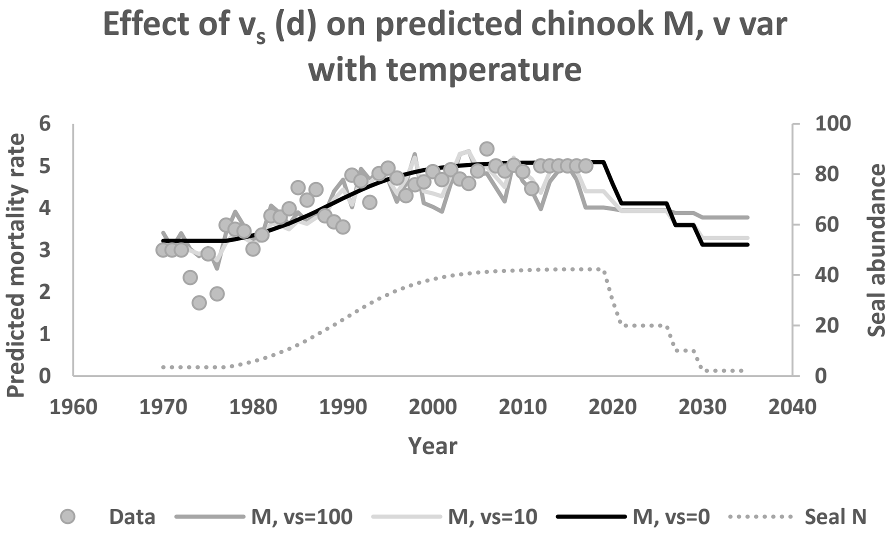
B = Prey biomass
P = Predator biomass
p = proportion of time spent foraging (pred)
a = predator search rate
V = vulnerable prey biomass
v = Rate at which prey become vulnerable to mortality
v' = Rate at which prey recover or move to safe states
v_s = Rate at which vulnerable prey die due to stress factor(s)
D = detritus biomass (dead prey)

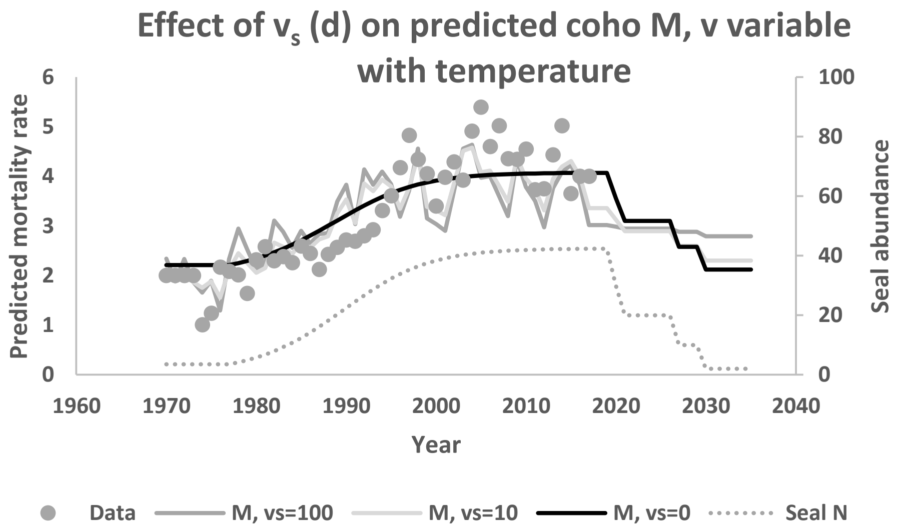
Non-Additive Mortality Rates Lead to Different Predictions

- **This leads to alternative predictions about how much mortality rates will decrease if seal abundance is reduced**









Final Thoughts and Next Steps

- Continued climate change will quite possibility result in substantial changes in trophic interaction patterns (Lynam et al., 2017) through “hidden” effects due to temperature-related changes increases in disease expression or physiological impact.
- Such changes may be “masked” …. nasty surprises in store?
- Ecosystem models built around simplistic assumptions about additivity of mortality components will not suffice

How to proceed in the Salish Sea with any action to reduce seal predation?

- Make it a well-planned *adaptive management experiment*.
- Use continued CWT monitoring to measure M(t)!
- Efforts are now underway to make the capability available in Ecopath with Ecosim (EwE 6) to represent stress effects directly by including v_s parameters in the dynamic equations.

Thanks to:

Washington-British Columbia Chapter AFS

The University of British Columbia
Institute for the Oceans and Fisheries

Pacific Salmon Foundation

Fisheries and Oceans Canada

Mitacs

Salish Sea Marine Survival Project

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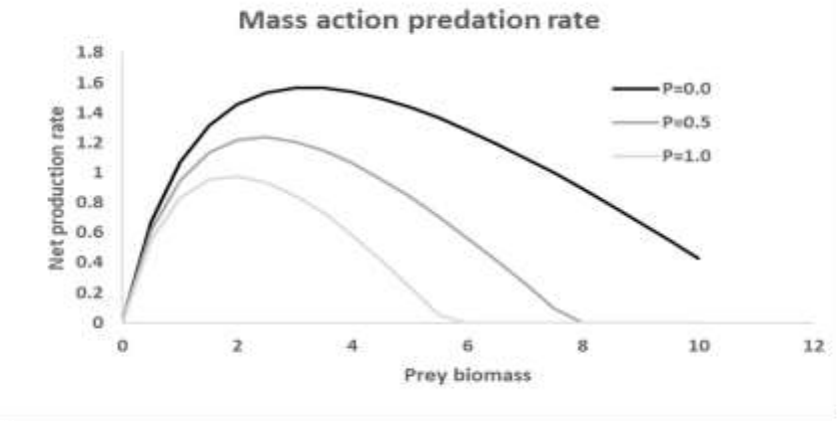
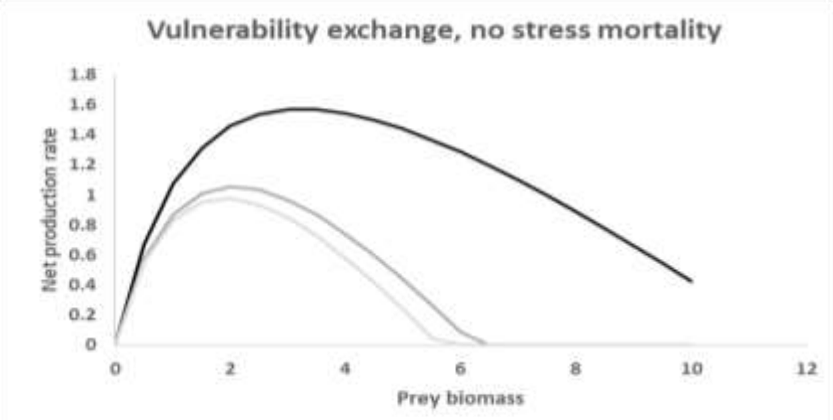
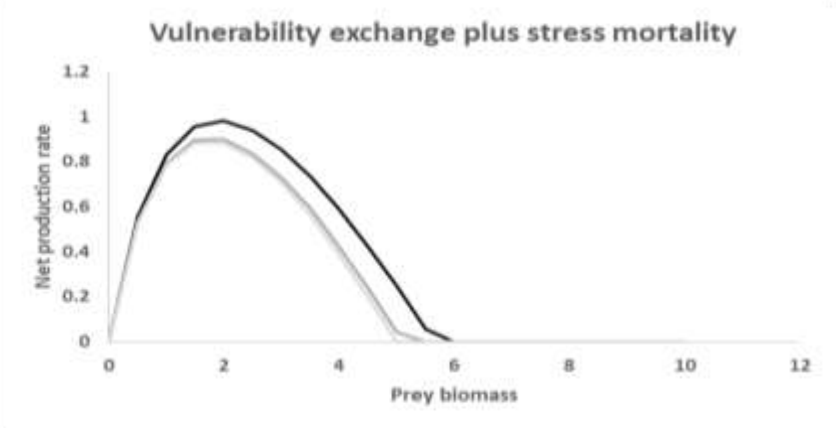
Supplemental Slides

Accounting for stress-related prey vulnerability leads to very different predictions for prey response to







Georgia Strait seal abundance, 50% proposed reduction over 2019-23 period

MSY estimate is just the annual population growth for population at 50% of maximum abundance