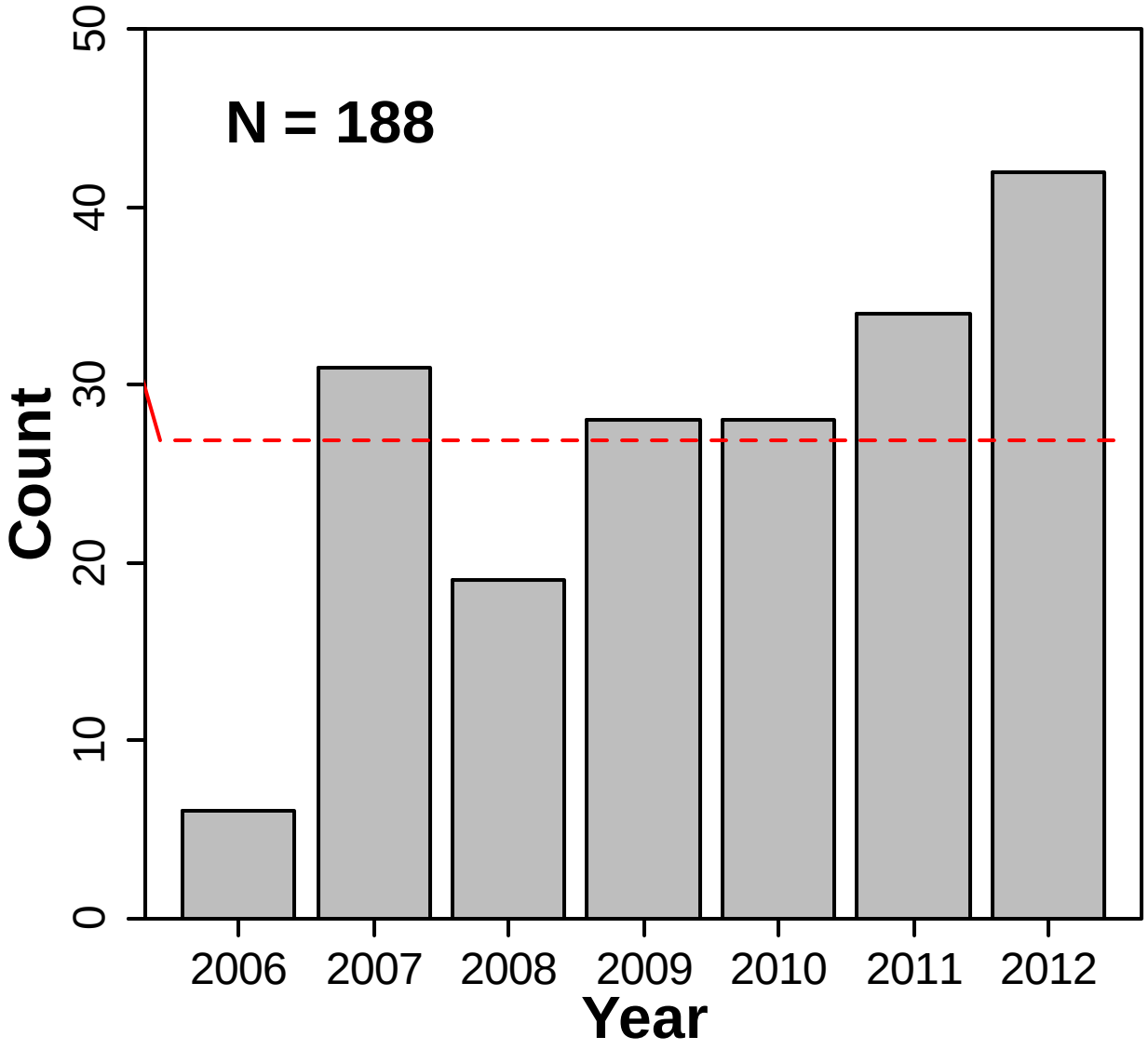
Recent advances in marine juvenile Pacific salmon research in North America

Marc Trudel[1,2] & Eric Hertz[2]
[1]Fisheries and Oceans Canada, Nanaimo, BC
[2]University of Victoria, Victoria, BC

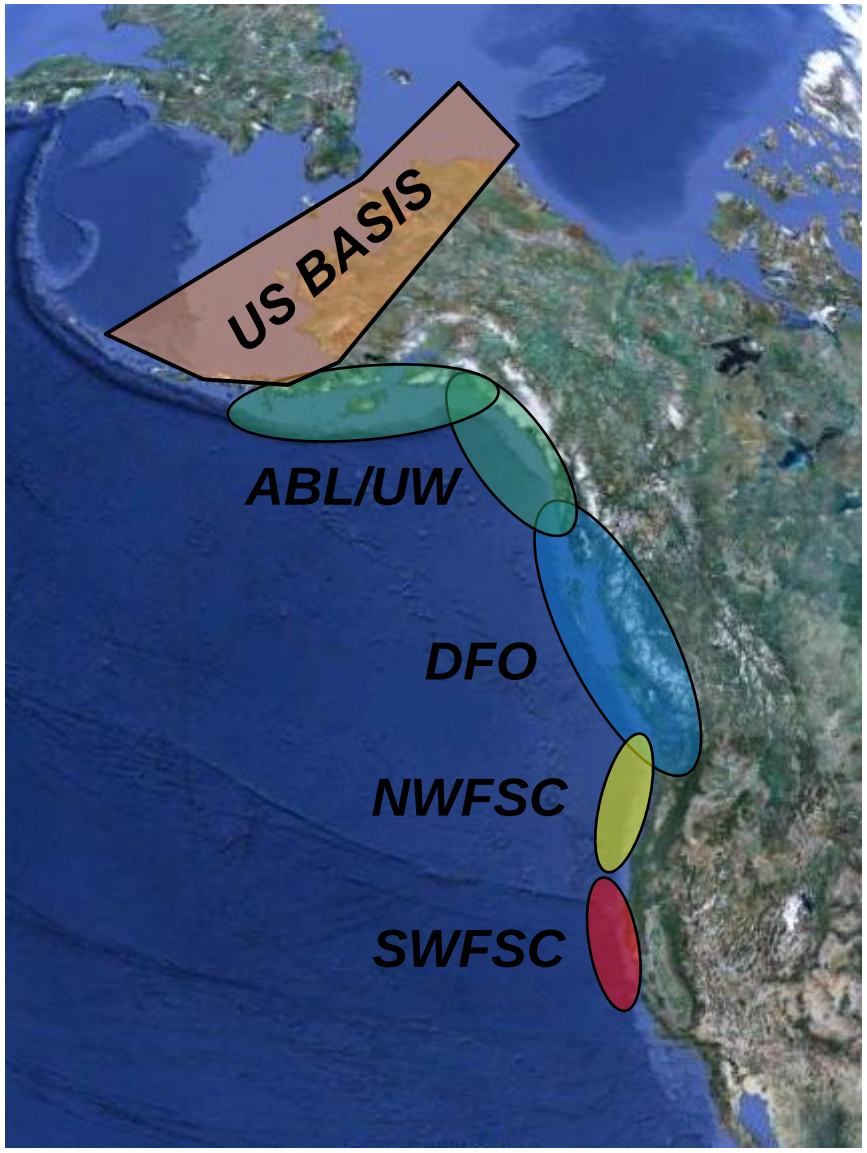
The 2006 Workshop in Sapporo

North American Contribution	N
National Overview	2
Distribution & Migration	2
Feeding & Growth	2
Climate Change	1
Winter Ecology & Survival	1
Survival Rates & Mechanisms	1
Total	9

The task is colossal!



Field Programs: Trawl Surveys



Map from Google Earth

Programs/Organizations:

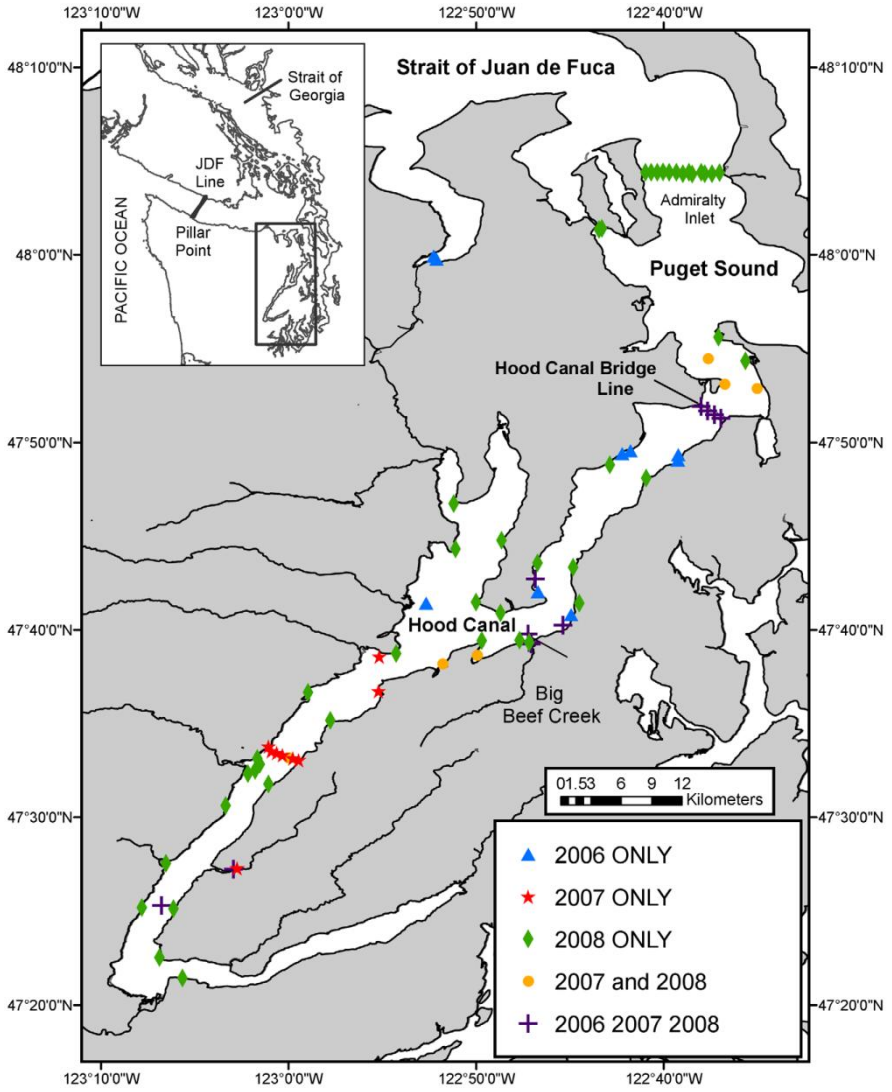
- BASIS: Bering-Aleutian Salmon International Survey (NOAA)
- ABL/UW: Auke Bay Lab. (NOAA) and Univ. of Washington
- DFO: Department of Fisheries and Oceans Canada
- NWFSC: Northwest Fisheries Science Center (NOAA)
- SWFSC: Southwest Fisheries Science Center (NOAA)
- Other sampling programs

Field Programs: Acoustic Telemetry

Pacific Ocean Shelf Tracking (POST)

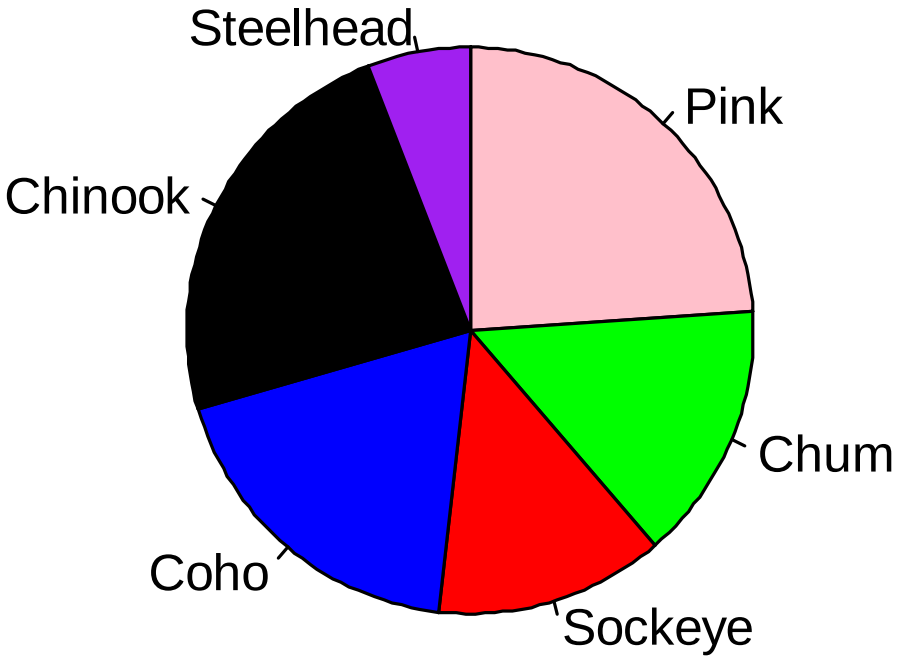
Figure from Welch et al. 2011. Proc. Nat. Acad. Sci.

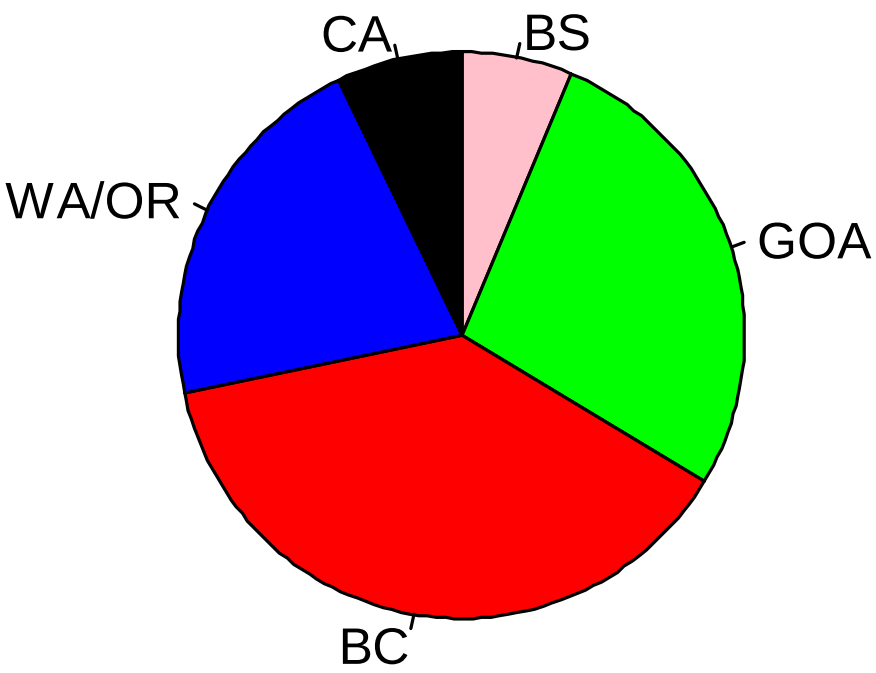
Puget Sound



Moore et al. 2010. PLoS

Species & Regions Investigated



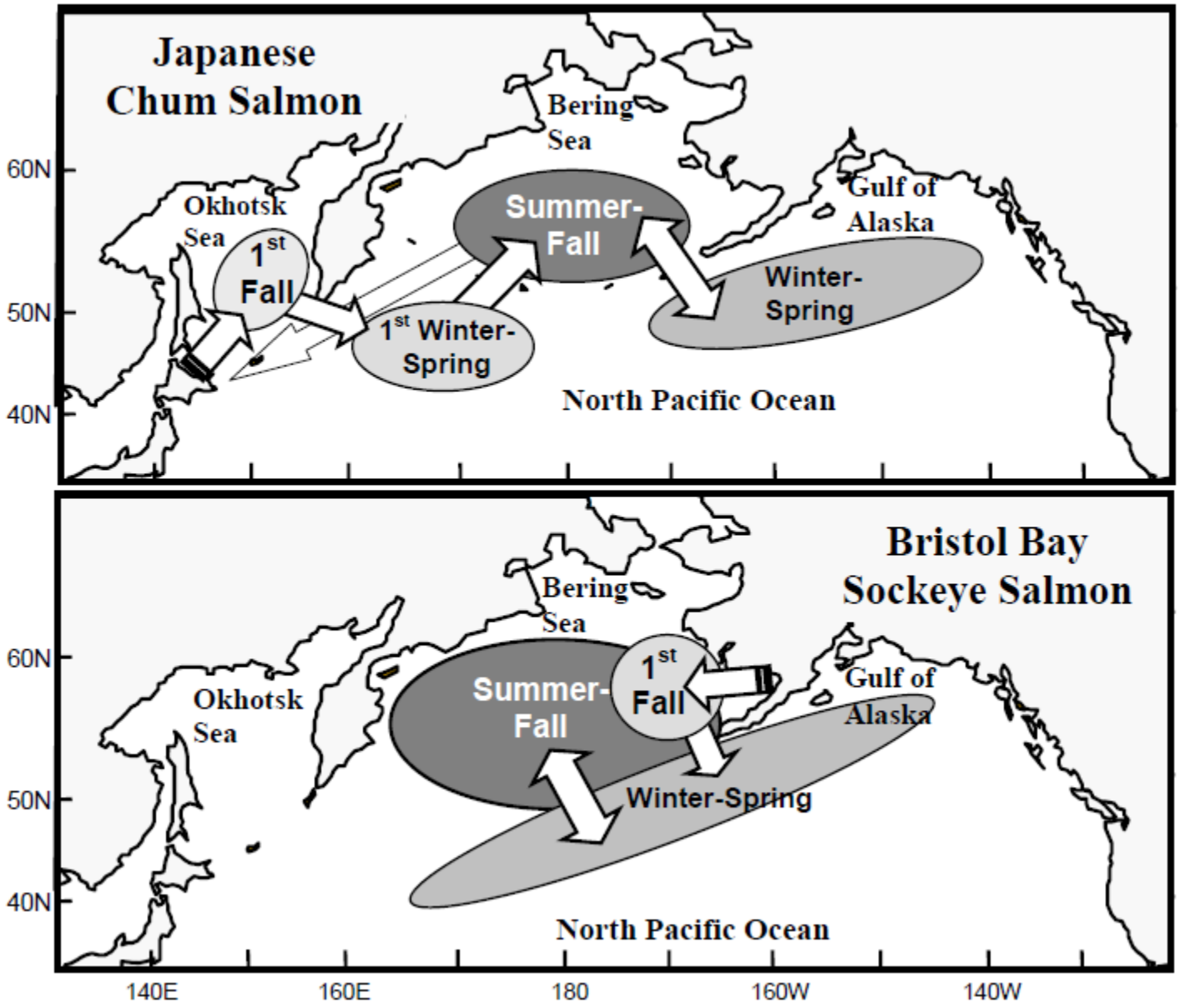


Topics Investigated

Topic	N
Distribution & Migration	60
Climate & Physical Oceanography	45
Bioenergetics, Growth & Physiology	55
Diet & Trophic Interactions	36
Ecological Interactions	25
Pathogens & Disease	50
Winter Ecology & Survival	4
Survival Rates & Mechanisms	90

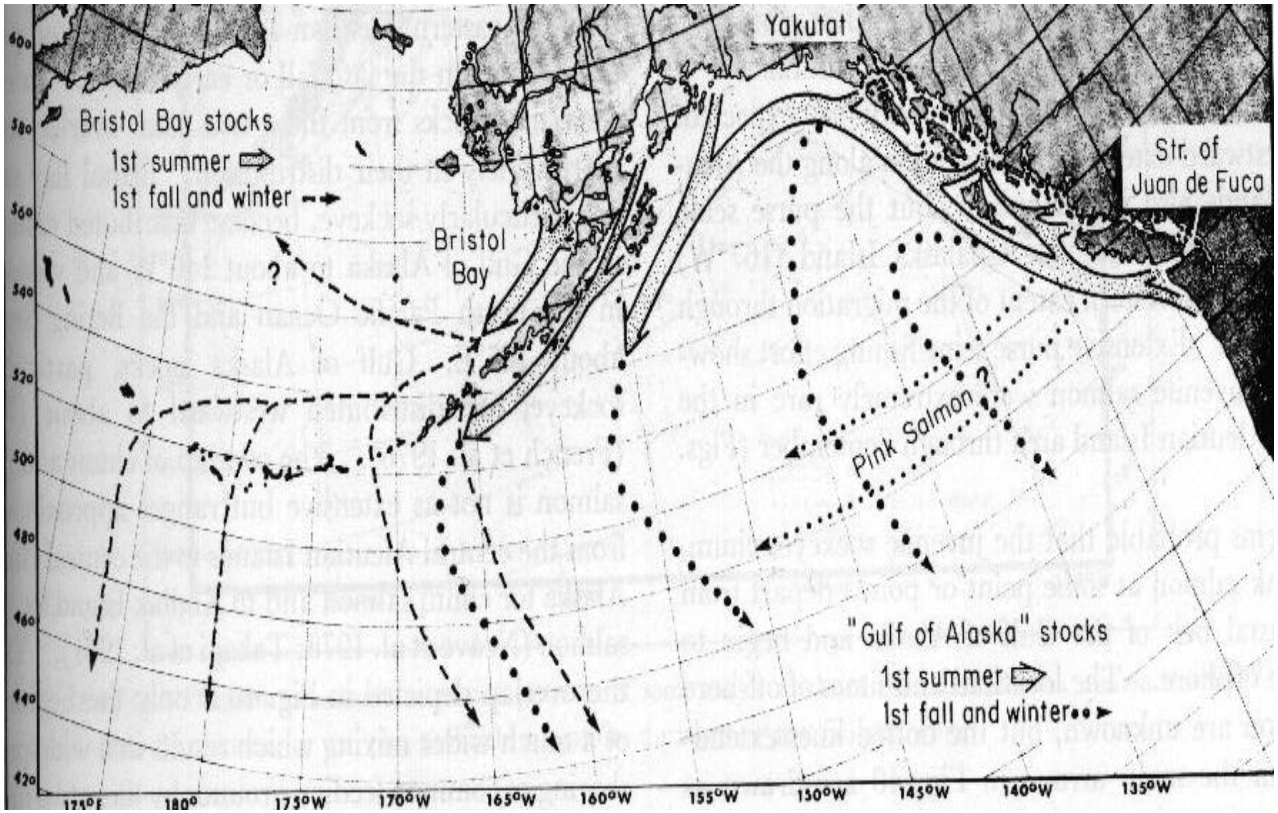
Distribution & Migration

Why Study Distribution & Migration?



Chum: Urawa. 2004. NPAFC. Tech. Rep; Sockeye: Myers et al. 2007. NPAFC Bull

Eastern North Pacific Paradigms



Hartt and Dell (1986)

- Rapid counter clockwise migration on the continental shelf

Healey (1983)

- Ocean-type Chinook inshore vs Stream-type offshore

Number of juvenile salmon recoveries

Species	HD86	CWT	DNA	Acoustic
Pink	56	--	--	--
Chum	6	--	1625	--
Sockeye	41	3	8942	1275*
Coho	244	914	2344	417
Chinook	12	2546	8688	3125
Steelhead	1	--	--	1863

*Includes 96 kokanee

Distribution & Migration: Some Key Findings

West Coast of Vancouver Island

Figure from Tucker et al. 2012. Mar. Ecol. Prog. Ser.

Bering Sea Sockeye

Figure from Farley & Trudel. 2009. J. Mar. Biol.

- Migration behaviour varies by species, stocks & life-histories, with resident, slow and fast migrating strategies
- Migration routes may be genetically programmed, but juvenile salmon distribution along their migration trajectory is affected by local conditions
- Migration behaviour of hatchery and wild fish is different at small scales (i.e. early marine life), but similar at large scales
- General support for the migration model of Hartt and Dell, but there are exceptions (i.e. Harrison River Sockeye)
- Chinook salmon migration does not consistently conform to the stream-type and ocean-type designation

Climate & Oceanography

Climate Effects on Salmon:

Physics -> … -> Fish

Figures from Wells et al. 2006. Fish. Oceanogr.

Climate & Oceanography: Some Key Findings

Northern California Current

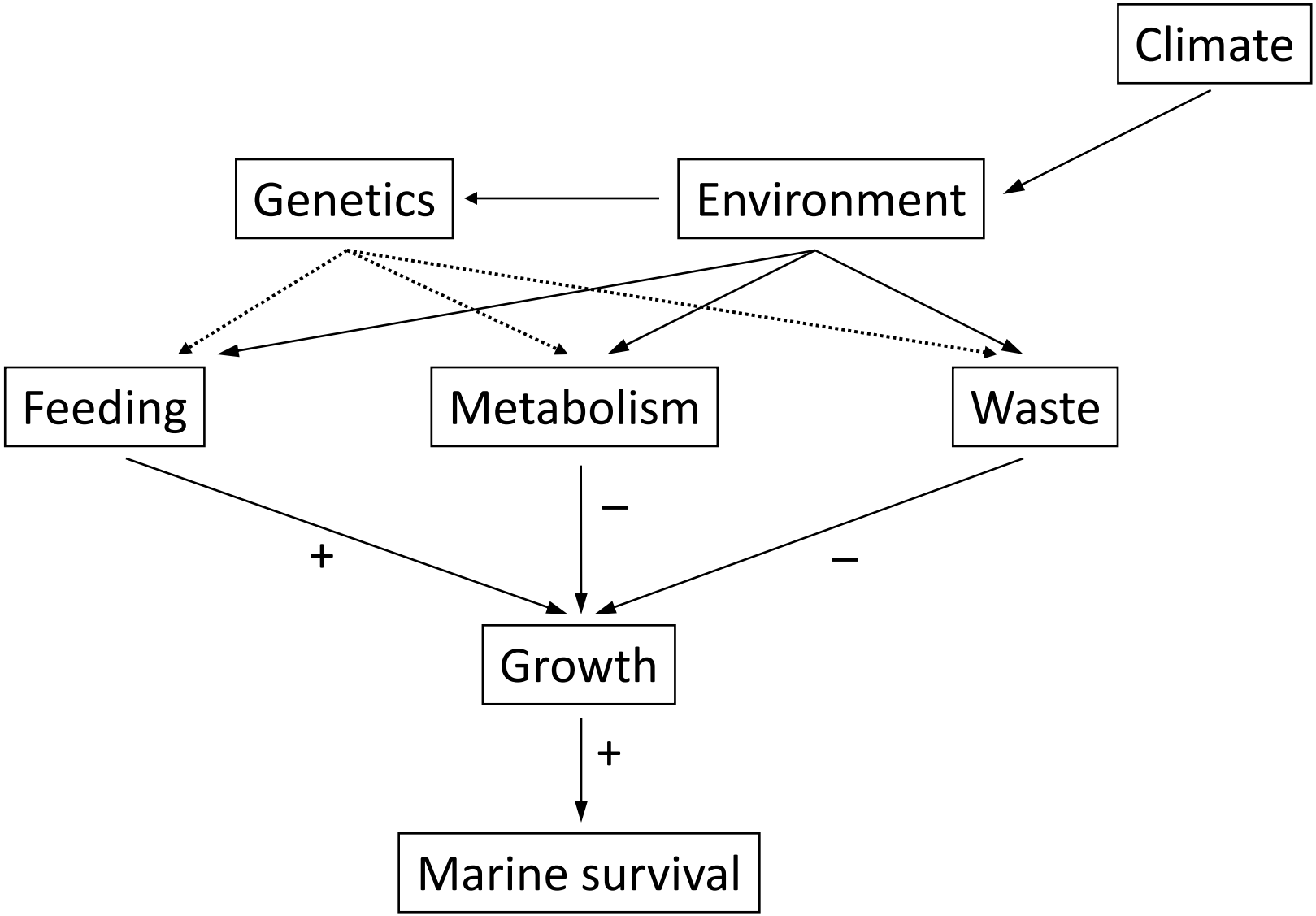
Figures from Bi et al. 2011. Geophys. Res. Let. 38, L12607

Effects of climate are largely species, stock or region specific but there are some general trends:

- Climate effects on salmon survival may be mediated through changes in juvenile salmon growth and changes in the abundance and distribution of predators
- Changes in ocean production, prey availability and prey quality has been linked to changes in ocean currents, winds and climate in the California Current System and Strait of Georgia
- No consistent patterns in Alaska, with both positive and negative effects of SST
- Local scale processes can also be important and affect survival

Bioenergetics & Growth

Growth & Salmon Survival



Bioenergetics & Growth: Some Key Findings

Figure from Beauchamp. 2009. Am. Fish. Soc. Symp. Ser.

Columbia River Chinook Salmon

Figure from Tomaro et al. 2012. Mar. Ecol. Prog. Ser.

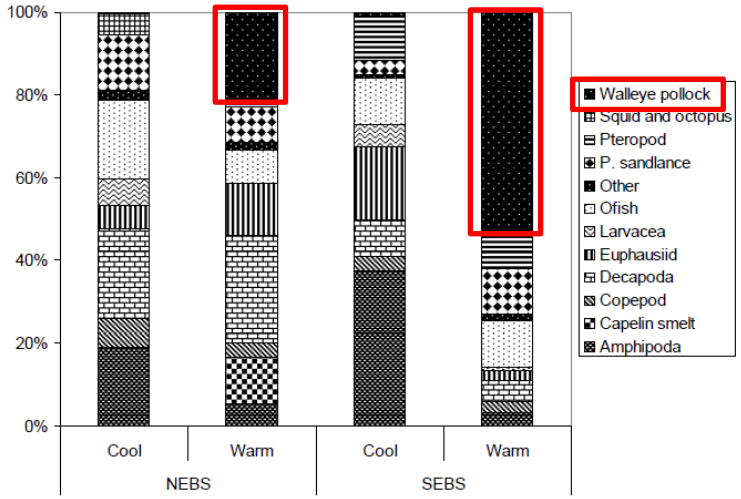
Fundamental link to critical size-critical period and to size-selective mortality theories

- Prey quality and quantity may be more important than temperature for growth and survival, which may be driven by changes in ocean currents, upwelling, and timing of production
- Temperature effects on juvenile salmon growth are likely to be indirect
- Competition for food may also affect juvenile salmon growth and survival
- Laboratory experiments are needed to develop new bioenergetics model parameters for all species

Diet & Trophic Interactions

Diet & Trophic Interactions: Some Key Findings

Bering Sea Pink Salmon



Andrews et al. 2009. NPAFC Bull 5: 183-189

NCC Chinook Salmon

Figure from Daly et al. 2012. Environ. Biol. Fish. 94: 117-134

Fundamental link between oceanography and growth and survival of salmon

- Highly variable in space and time
- Pink, chum and sockeye: Generally planktivorous feeding, but piscivory important in some regions
- Chinook, coho, and steelhead: Primarily shift to piscivory, but plankton can remain an important part of their diet
- Hatchery and wild salmon often feed on different prey in the nearshore environment but on similar prey offshore
- No consistent factors affecting juvenile salmon diet (SST, El Nino)
- Link to survival not frequently examined

Ecological Interactions

Ecological Interactions: Some Key Findings

Strait of Georgia Coho Salmon

Figure from Beamish et al. 2008. Trans. Am. Fish. Soc.

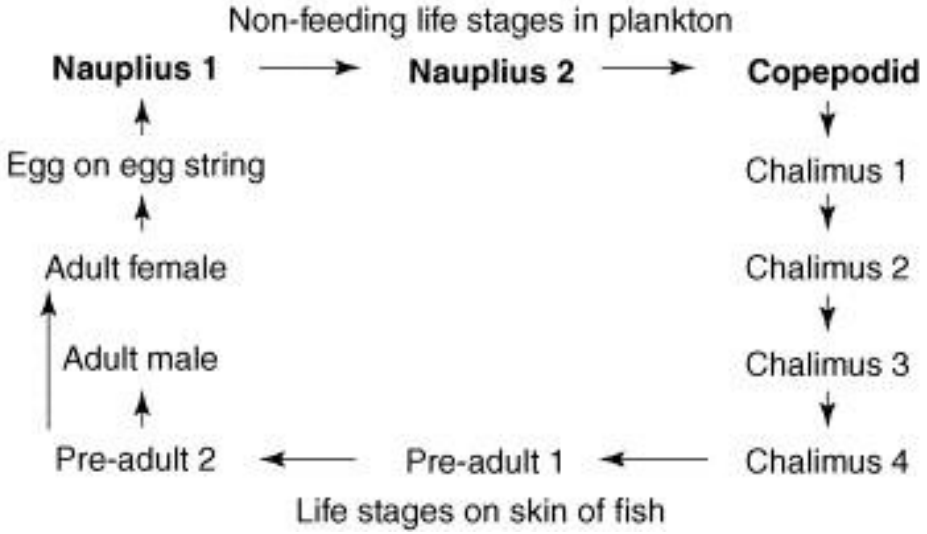
Oregon Coho Salmon

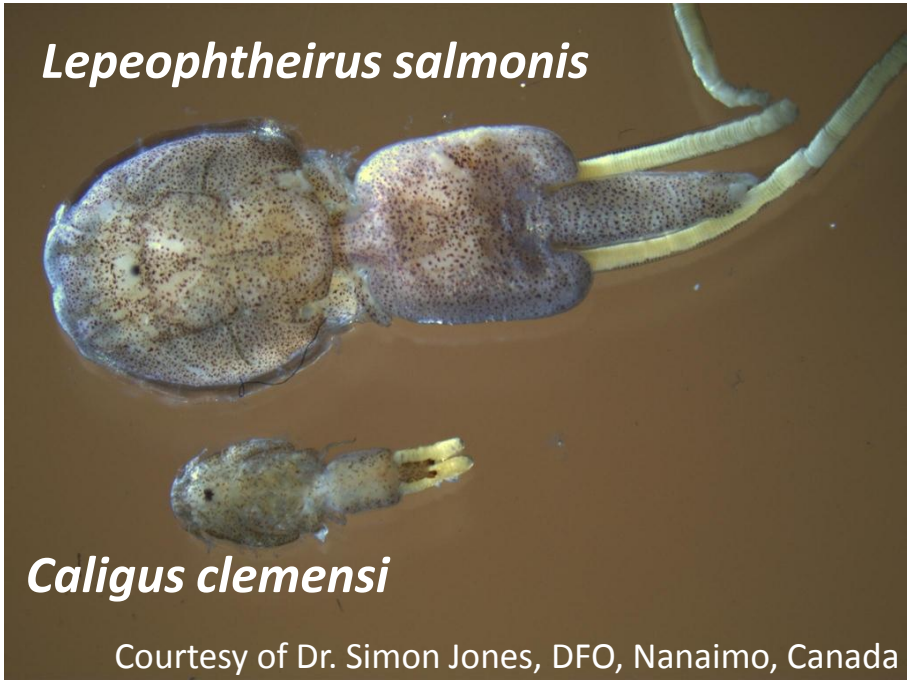
Figure from Emmett et al. 2006. Prog. Oceanogr.

- No consistent effects of hatchery on wild salmon in the marine environment despite the similarity of their diet
- Interactions with pink salmon are context dependent: may compete with other salmonids in some regions or buffer them against predation in other regions
- The impacts of predators on juvenile salmon may be modulated by the abundance of alternative prey (i.e. forage fish), though few salmon have been reported in the stomachs of predators

Pathogens & Disease

Salmon Farms in British Columbia





Parasites & Pathogens: Some Key Findings

Broughton Archipelago Pink Salmon

Figures from Marty et al. 2010. Proc. Nat. Acad. Sci.

- Susceptibility to lice infection is size- and species-dependent
- Adult wild salmon can contribute to lice on farmed salmon
- Farmed salmon contribute lice to wild juvenile salmon, though other sources and species may contribute lice as well
- Lice species on farmed salmon varies by location and year: mostly *L. salmonis* in the Broughton Archipelago and *C. clemensi* in the Discovery Islands
- Impacts of aquaculture on wild salmon is equivocal
- Lice species not always identified on the host

Survival Rates & Mechanisms

Early Marine & Winter Survival

Species	Survival	Sources
Chum	20-50%	1
Sockeye	20-50%	2-3
Chinook	2-30%	4-5
Chinook*	10-40%	6
Coho	2-20%	7-8
Steelhead	10-80%	9-11

*Winter

References: 1. Wertheimer and Thrayer 2007; 2. Welch et al. 2009; 3. Wood et al. 2012; 4. Beamish et al. 2012; 5. Rechisky et al. 2013; 6. Trudel et al. 2012; 7. Beamish et al. 2010; 8. Melnychuk et al. 2012a; 9. Moore et al. 2010, 2012; 10. Melnychuk et al. 2012b; 10. Welch et al. 2004.

Survival Rates & Mechanisms: Key Findings

Bristol Bay Sockeye Salmon

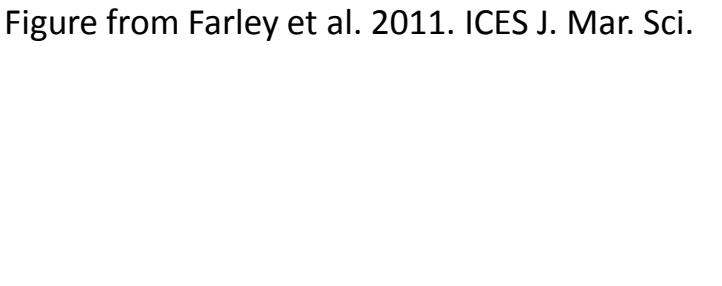


Figure from Farley et al. 2011. ICES J. Mar. Sci.

- A significant and variable portion of the "marine mortality" occurs in freshwater
- Early marine and winter mortality can be large, though these estimates are uncertain
- Size-selective mortality during summer or winter is not always apparent
- Causes of mortality remain poorly known

Puget Sound Chinook Salmon

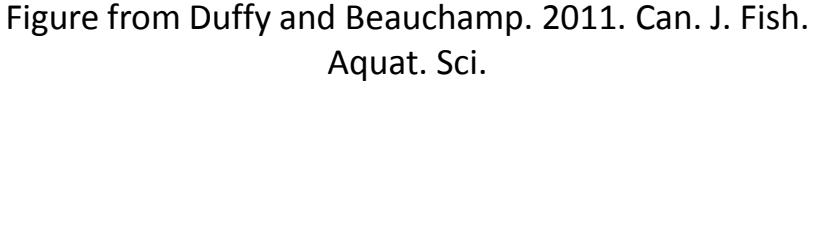


Figure from Duffy and Beauchamp. 2011. Can. J. Fish. Aquat. Sci.

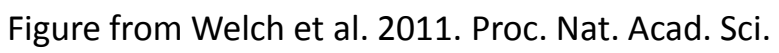


Figure from Welch et al. 2011. Proc. Nat. Acad. Sci.

Challenges for the Future

- When and where significant mortality events occur in the marine environment?
- How do these mortality events contribute to the variability in marine survival?
- What is causing mortality of salmon in the ocean?
- Physics -> … -> Fish: Correlation is not causation