Factors affecting the marine survival of Puget Sound steelhead

NOAA FISHERIES
Northwest Fisheries Science Center

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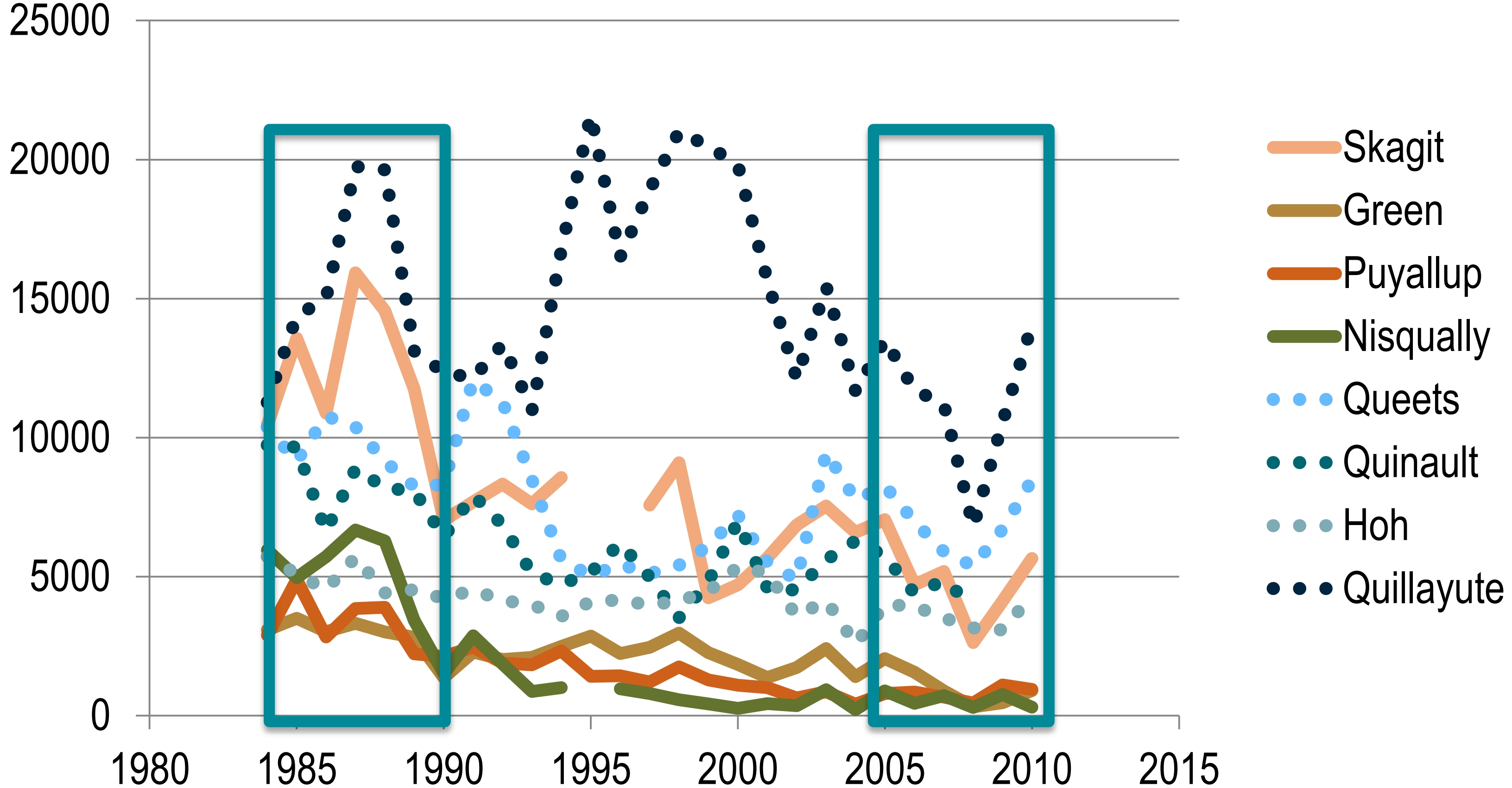
And

Salish Sea Marine Survival Steelhead Workgroup

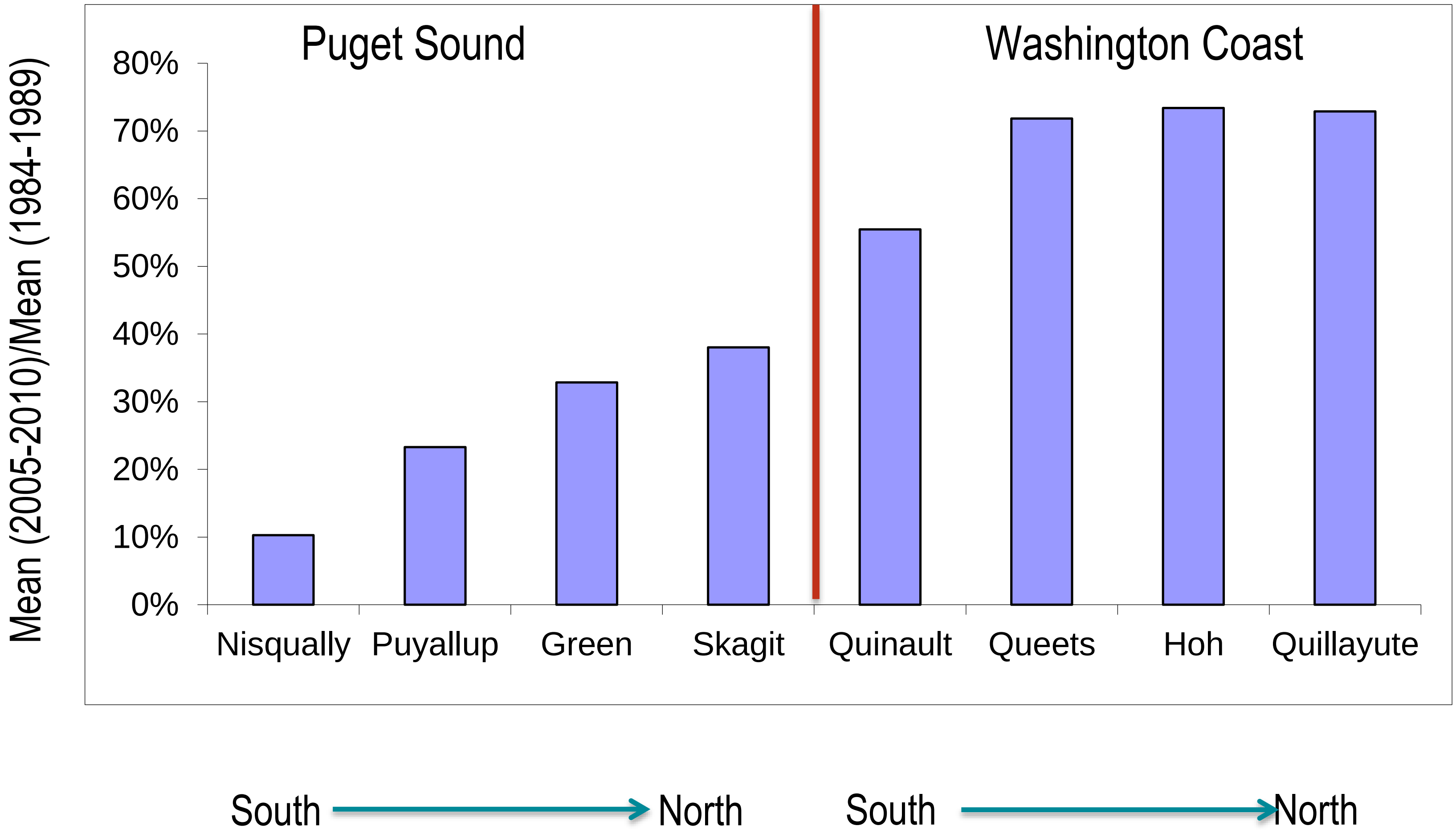
Puget Sound Steelhead

- Predominantly winter-run populations (late fall – spring)
- Roughly 1.5 M hatchery-reared fish released annually
- ESA-listed ‘Threatened’ in 2007
- Factors in listing decision
  - Declines in abundance and productivity
  - Habitat (dams, urbanization, water quality)
  - Artificial propagation

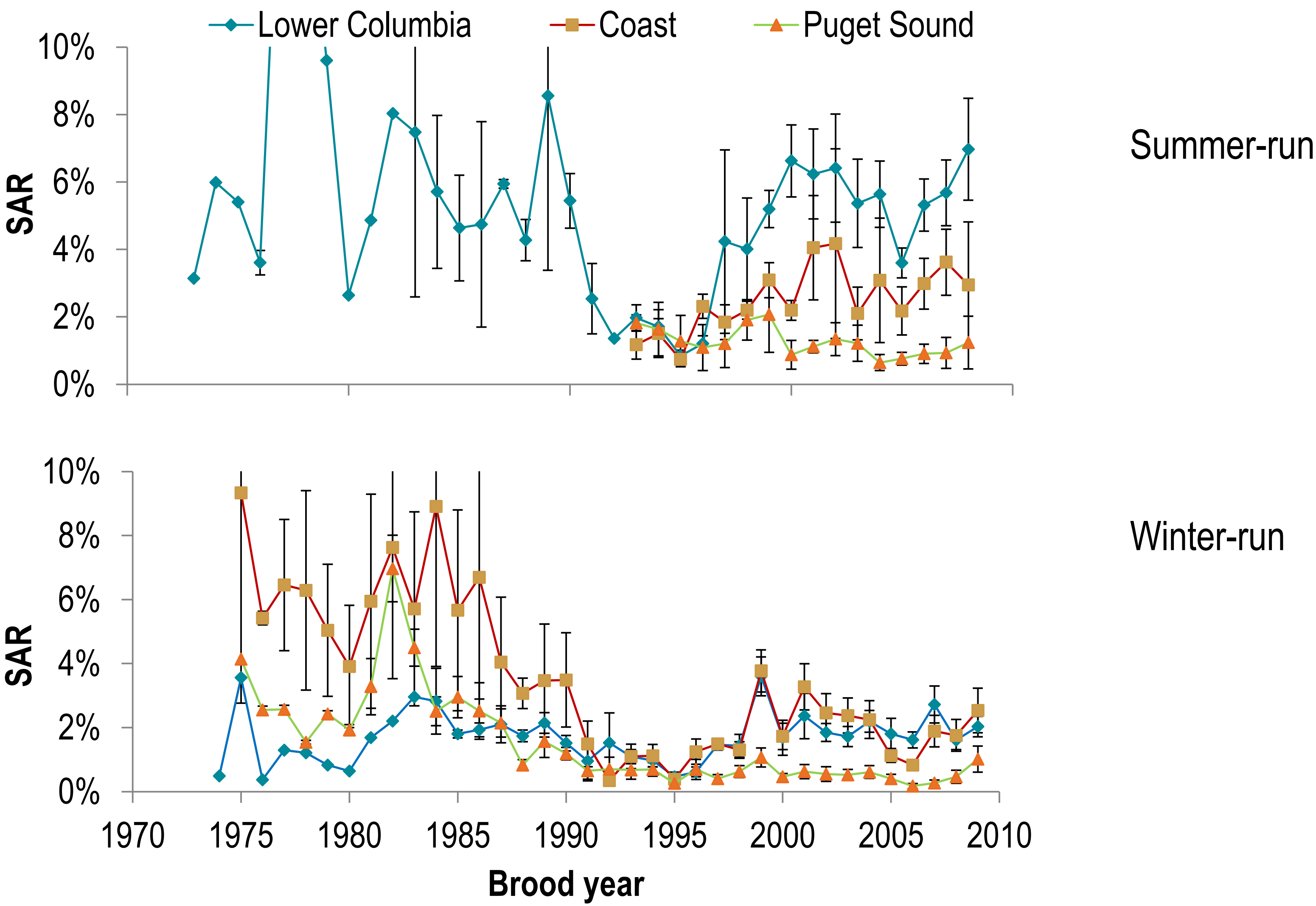
Abundance of Puget Sound and WA coast populations



Abundance trends



Marine (smolt-to-adult) survival

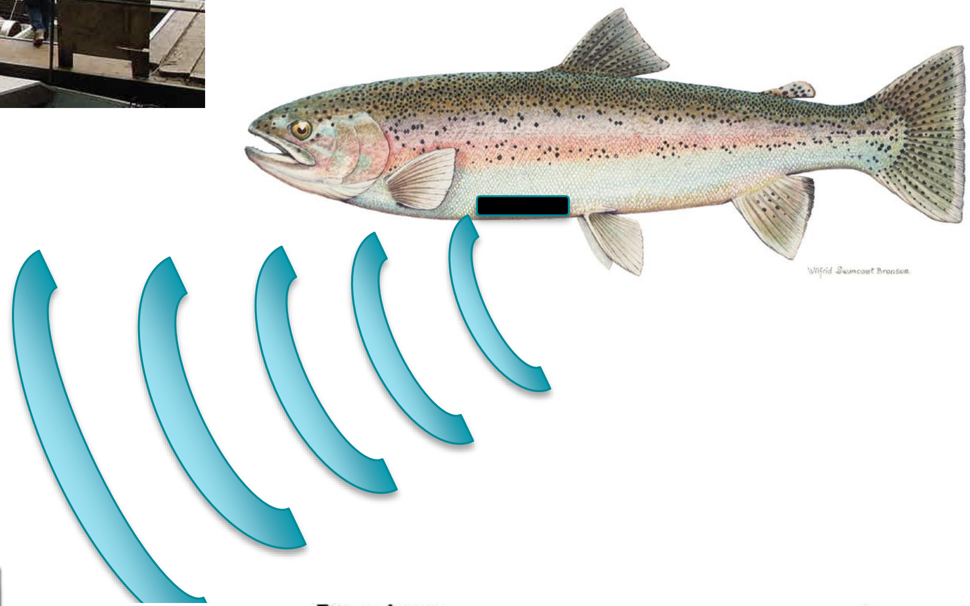


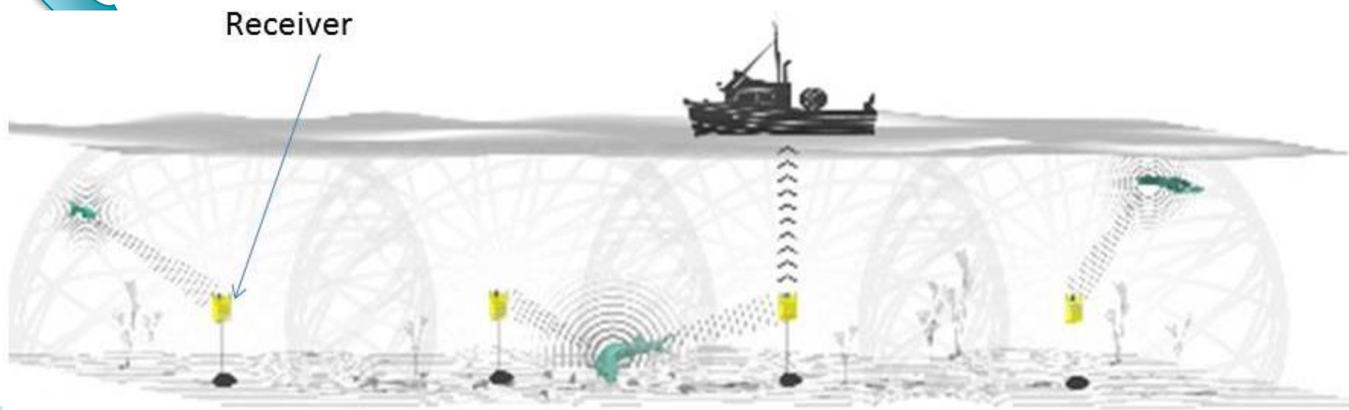
Source: Puget Sound Steelhead Marine Survival Draft Workplan

Where does this lead us?….

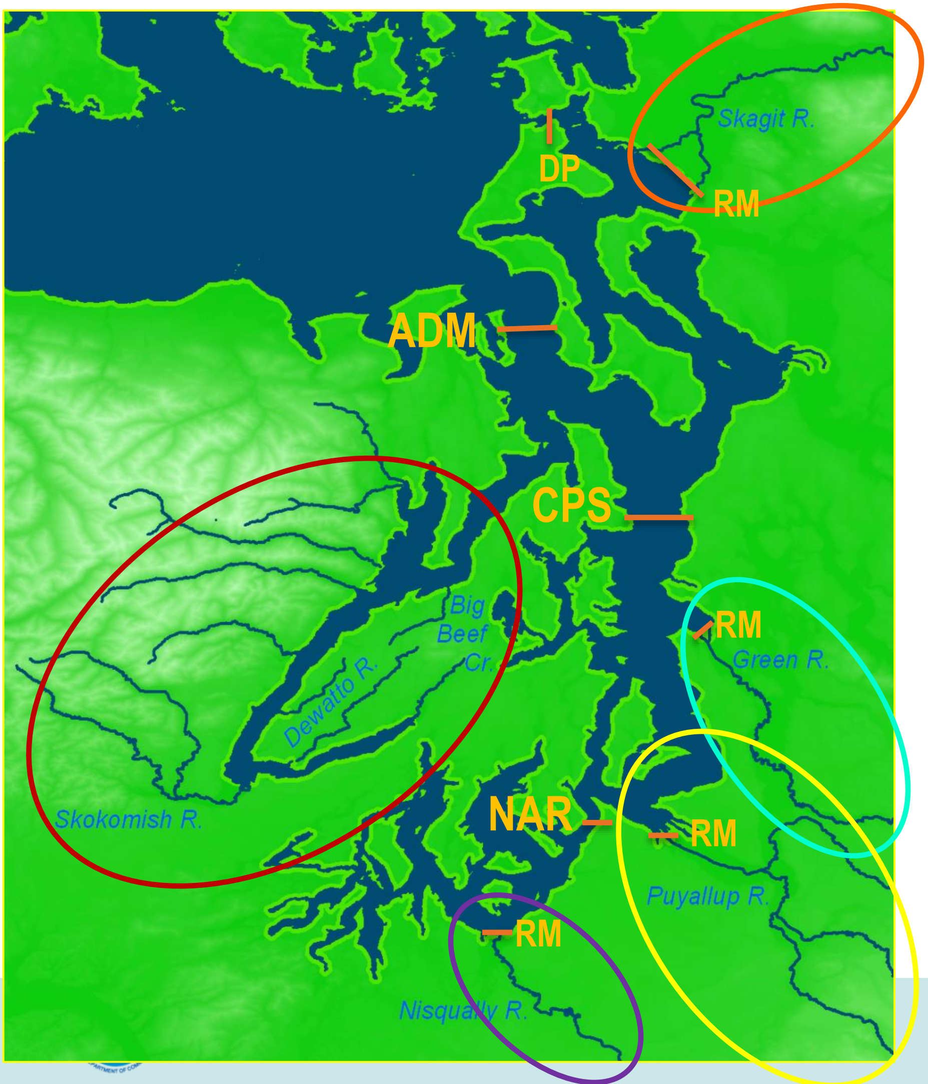
- Abundance and SAR trends point to:
  - Strong marine signal
  - Different signal within Puget Sound than elsewhere (lower survival), particularly since early1990's
  - Possibly worse conditions in southern Puget Sound
- What is different about Puget Sound that might reduce marine survival relative to other regions?
  - Puget Sound freshwater stream effects on smolt characteristics
  - Migration routes in the Pacific Ocean
  - Puget Sound marine conditions

Acoustic telemetry





Puget Sound Telemetry ‘Study’



Hood Canal Rivers: 2006-2010
Moore, Berejikian, et al. (NWFSC)

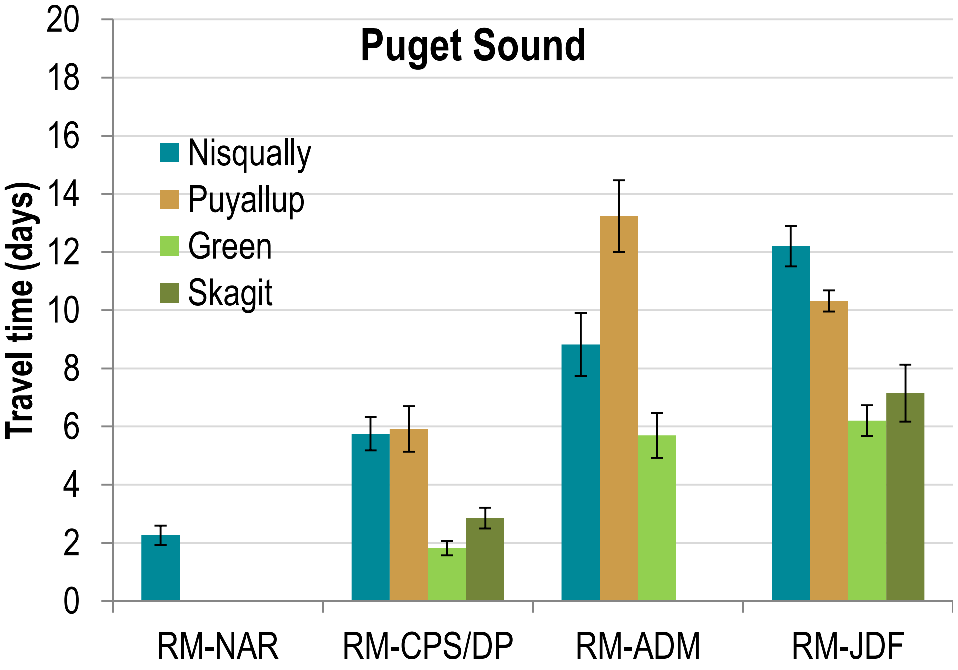
Green River: 2006-2009
Fred Goetz, Tom Quinn et al (UW, ACOE)

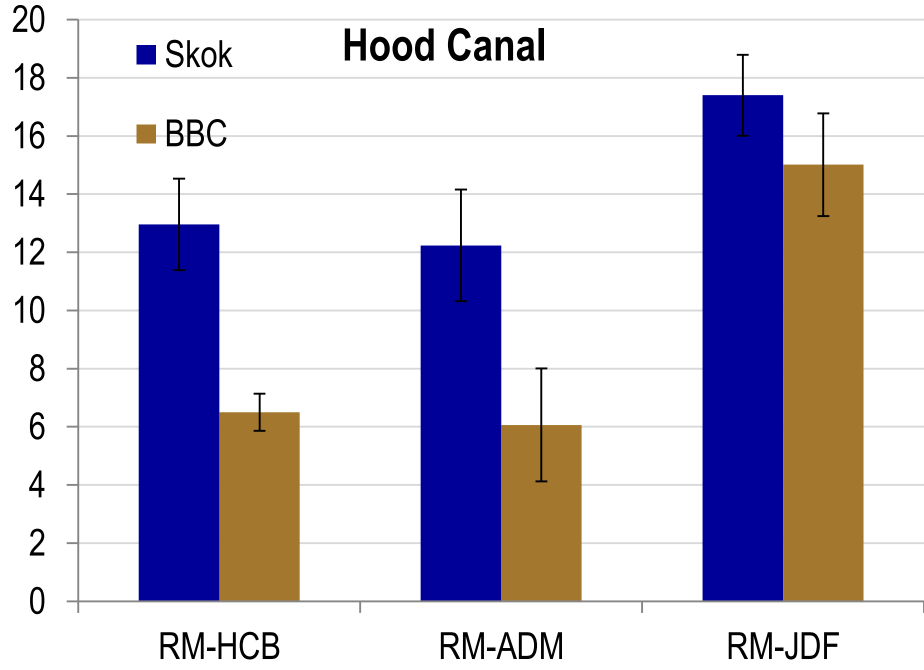
Puyallup River: 2006, 2008-2009
Andrew Berger et al. (Puyallup Tribe)

Nisqually River: 2006-2009
Sayre Hodgson et al. (Nisqually Tribe)

Skagit River: 2006-2009
Ed Conner et al. (Seattle City Light)

Travel time


Puget Sound
Nisqually
Puyallup
Green
Skagit
Travel time (days)
20
18
16
14
12
10
8
6
4
2
0
RM-NAR
RM-CPS/DP
RM-ADM
RM-JDF


Hood Canal
Skok
BBC
20
18
16
14
12
10
8
6
4
2
0
RM-HCB
RM-ADM
RM-JDF

Mark-Recapture Survival Estimates: Cormack-Jolly-Seber

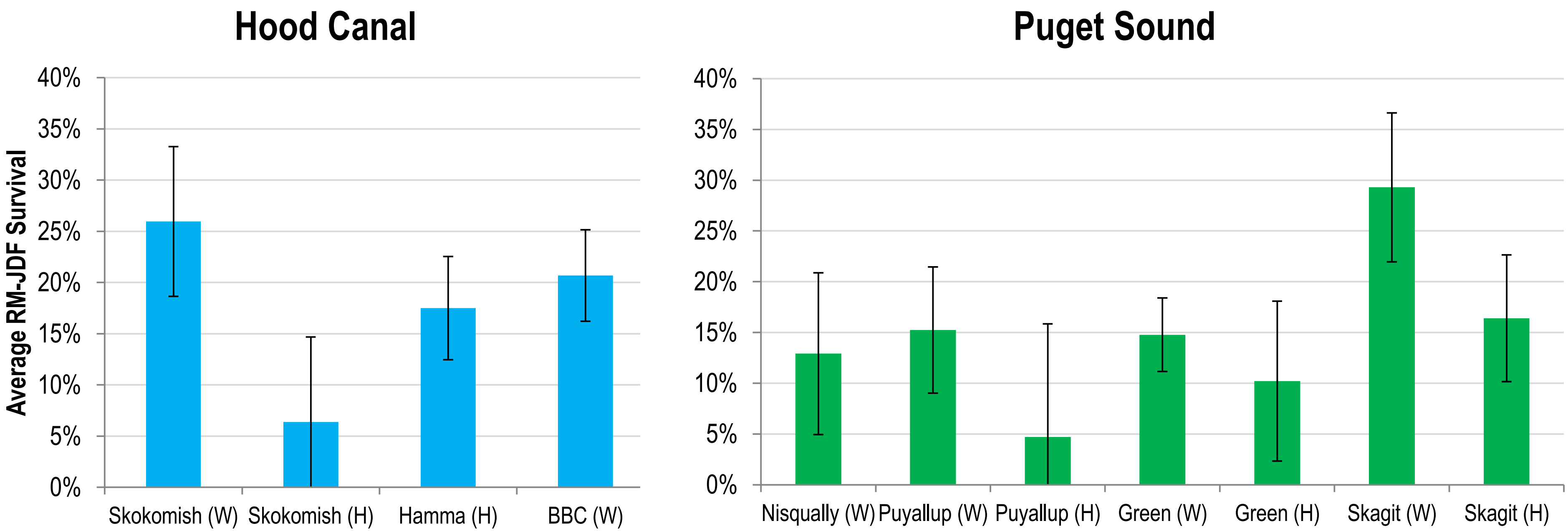
Population	N_{2006}		N_{2007}		N_{2008}		N_{2009}	
	W	H	W	H	W	H	W	H
Hood canal	73	33	123	47	67	42	105	59
Green	100	50	39	50	48	50	50	-
Nisqually	55	-	49	-	14	-	69	-
Puyallup	25	25	-	-	-	90	-	66
Skagit	23	-	47	-	50	50	25	55
TOTAL (N = 1,393)	**334**		**355**		**411**		**293**	

Categorical variables
- Population
- Region (HC, SS, Skagit)
- Rear type (H/W)
- Migration Segment
- Year
- Tag Type

Continuous variables
- Distance travelled
- Body Length

Model with lowest AICc = ~(Segment x population)+ (year)+ (rear type H/W)

Survival of steelhead smolts from river mouths to the ocean



W = Wild H = Hatchery

Combined early marine survival estimate = 17% (hatchery = 12% , wild = 20%)
Assumes 68% detection rate at Pillar Point….and a bunch of other things

Moore et al. 2010, 2012, in prep, Goetz et al. in press

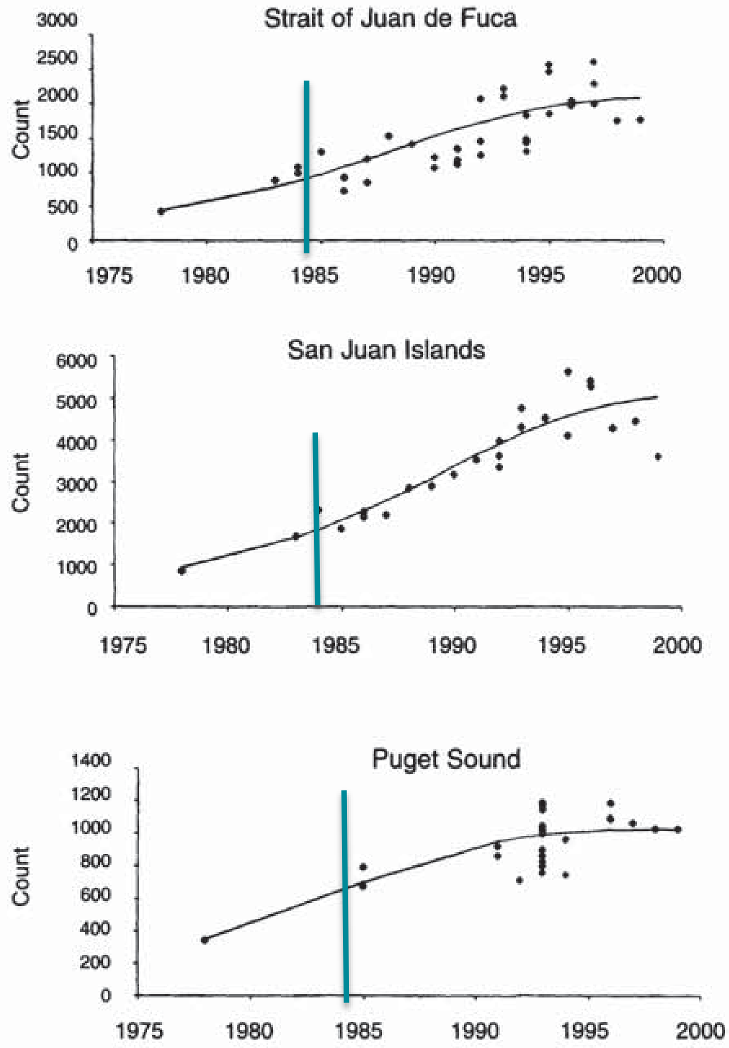
Potential factors affecting marine survival (why do so many steelhead die so quickly)

- Freshwater influences
  - Reduced diversity ('Portfolio effect': e.g., *Schindler et al. 2012. Nature*)
  - Hatcheries (genetic or ecological)
  - Water quality (toxic contaminants)
  - Disease-causing pathogens (*nanophyetus*)

- Changes in the Puget Sound ecosystem that have influenced predator-prey dynamics
  - Avian predators: cormorants, Caspian terns, common mergansers, and loons
  - Mammalian predators: harbor seals, harbor porpoise
  - Fish predators: *Meh*…

Predator-prey interactions (harbor seals)

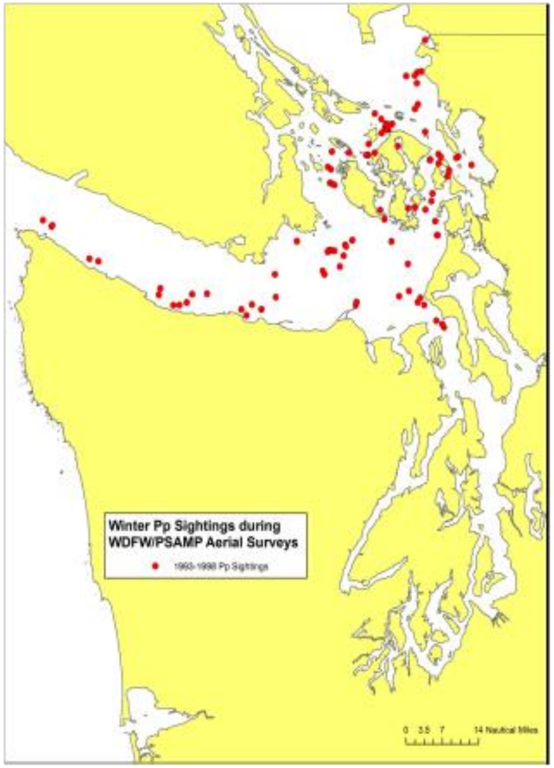
Harbor seal counts



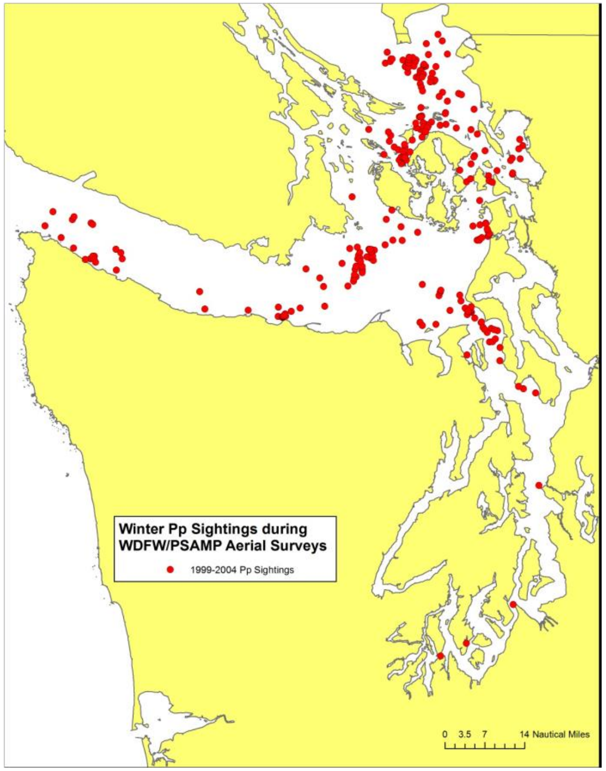
Jeffries et al. 2003 J. Wildlife Manage.

Predator-prey interactions (harbor porpoise)

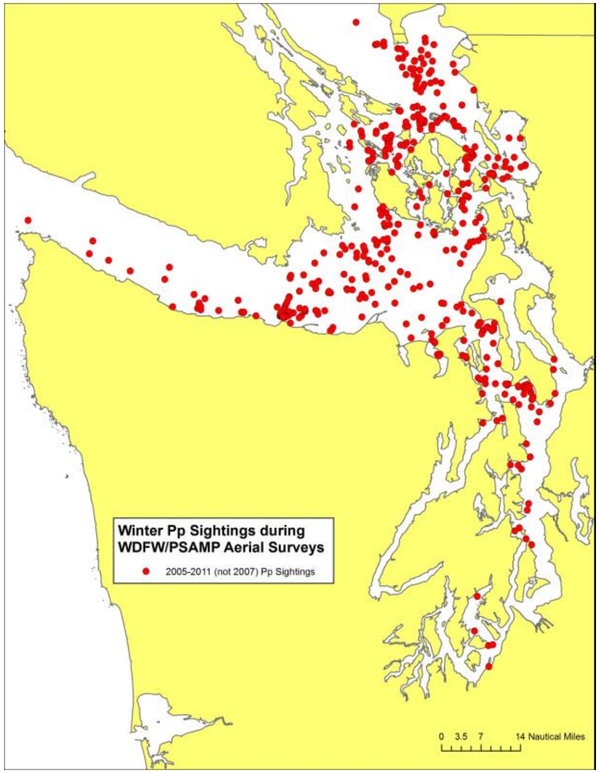
1993-1998



1999-2004



2005-2011



(J. Evenson, WDFW, 2013, unpublished data)

Herring biomass

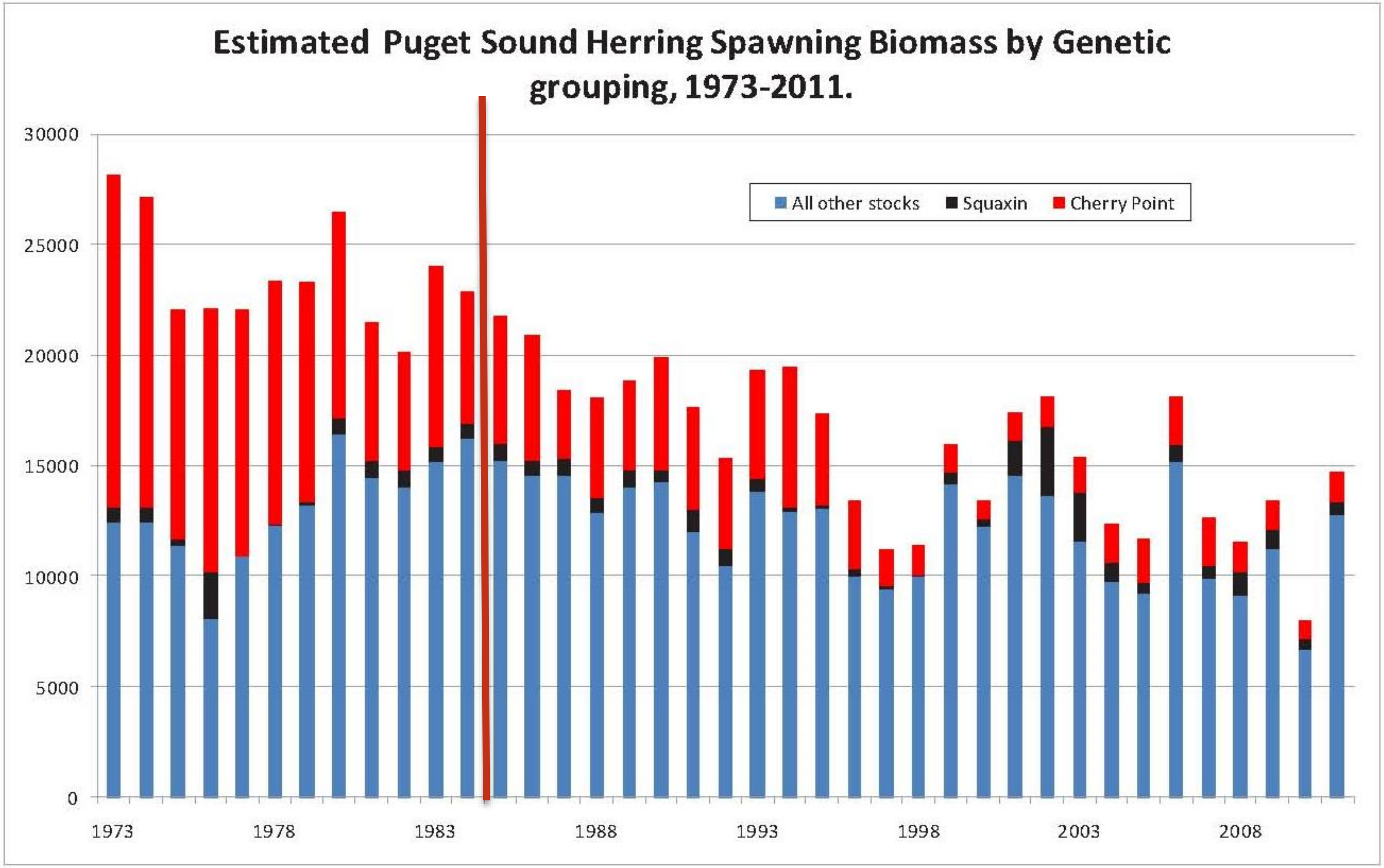
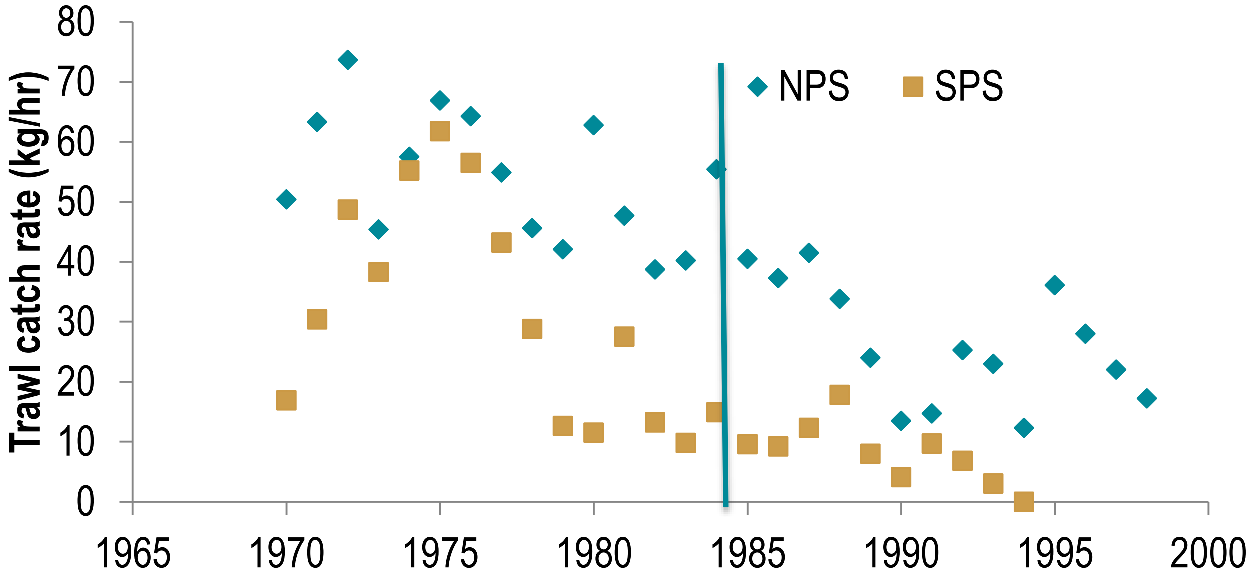
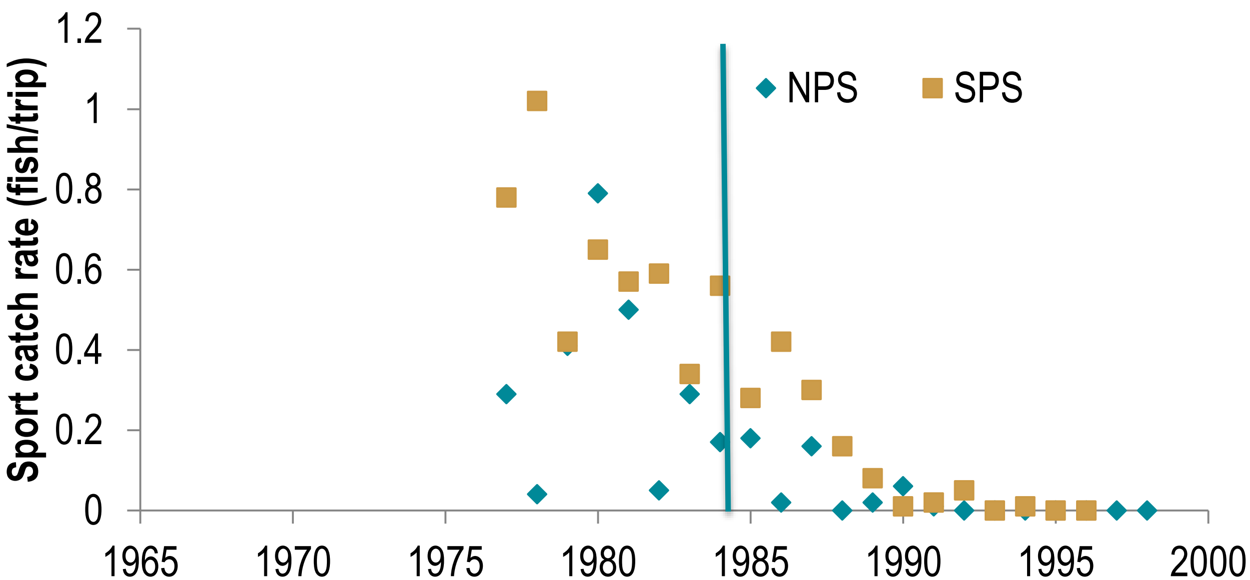


Figure 5. Estimated herring spawning biomass, 1973-2011.

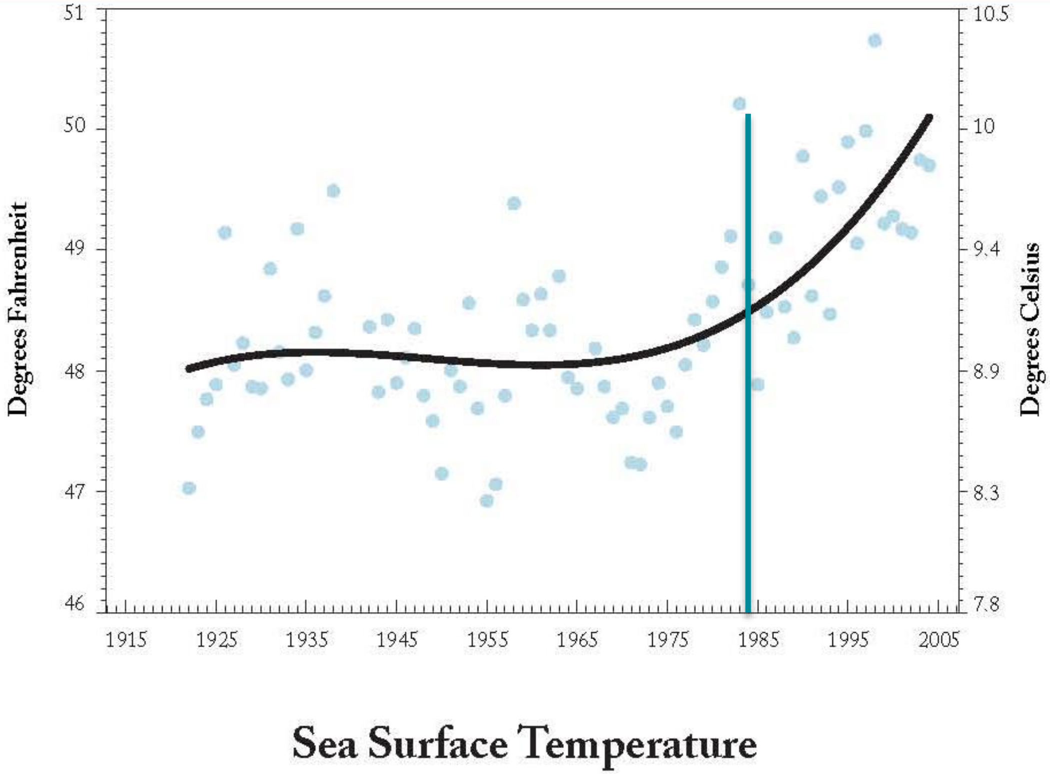
Pacific cod abundance





Data source: Palsson et al. via NMFS 2000 Status Review

Temperature in Puget Sound (Strait of Juan de Fuca)



Snover, A. K., P. W. Mote, L. Whitely Binder, A.F. Hamlet, and N. J. Mantua. 2005. Uncertain Future: Climate Change and its Effects on Puget Sound. A report for the Puget Sound Action Team by the Climate Impacts Group.

Summary

- Low early marine survival rates are consistent with low SAR for Puget Sound steelhead?
- Some indications that southern Puget Sound populations impacted more than northern populations
- Puget Sound is warming and has undergone a major ecosystem shift concomitant with the declines in steelhead abundance and SAR.

Telemetry Summary

- Low early marine survival rates consistent with SARs and abundance of Puget Sound steelhead
- Instantaneous daily mortality rates are high (i.e., mortality occurs very quickly)
- Rapid travel times (1 – 3 weeks from river mouths to ocean entry)
- Hood Canal and Puget Sound steelhead exhibit different patterns
- Central Puget Sound may represent a mortality hotspot

Limitations/considerations for acoustic telemetry

- Handling and tag effects never fully known (some negative effects on growth)
- Tag loss in seawater 2% (V7) - 12% (V9), but not until after outmigration
- Seals can hear them (Cunningham et al. in review)
- Detection range of receivers varies depending on currents, noise, water quality etc.
- Expected to under-estimate natural survival rates

Steelhead Research Planning: thought process

Steelhead dying at high rate in PS

Predation **IS** proximate/ direct cause of mortality

Predation **IS NOT** proximate/ direct cause of mortality

Predator-prey interactions

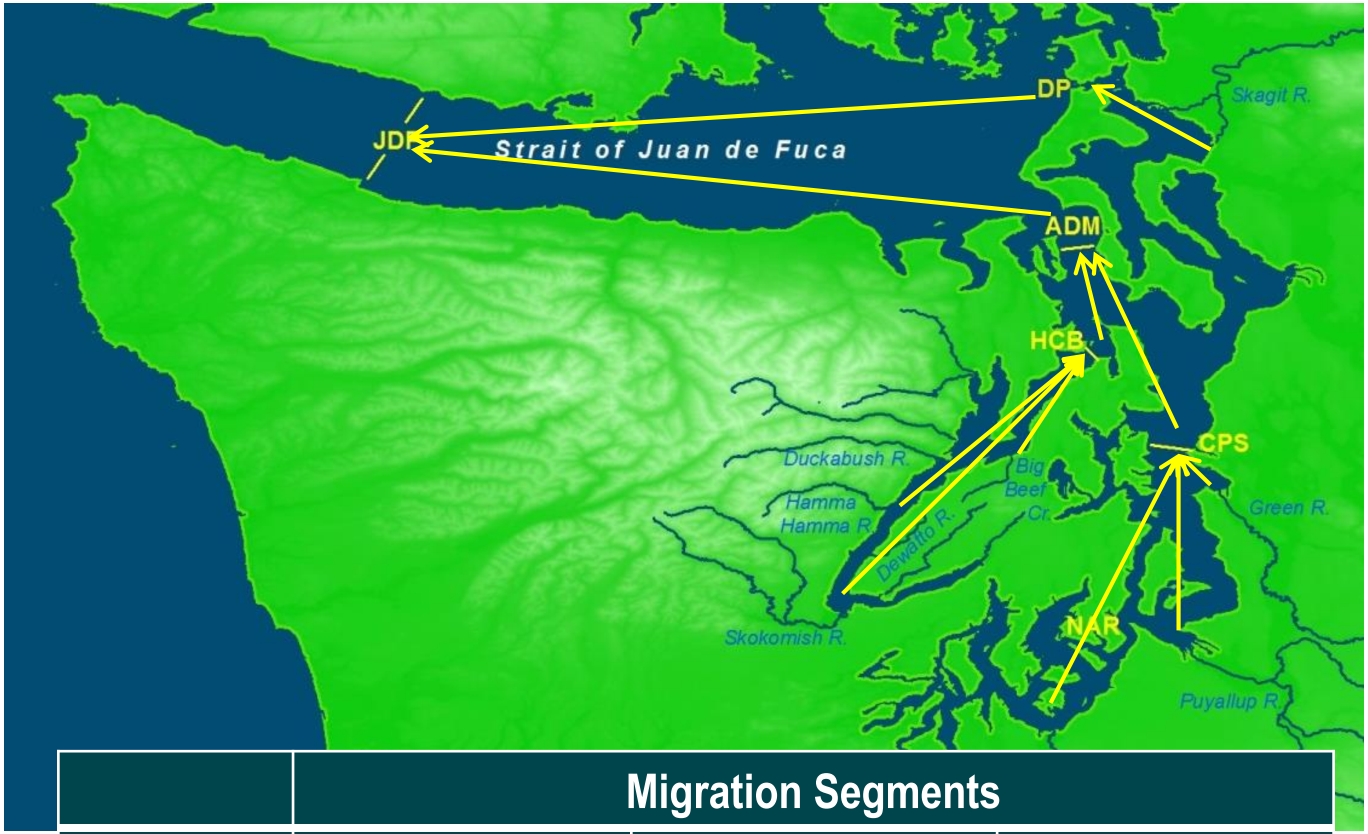
1. Depensation
2. Increase in key predator populations
3. Decrease abundance of other prey

Poor fish condition and/or altered behavior:

freshwater (F) or marine (M) effect (ranked)

1. Disease (M/F)
2. Poor water quality/toxics (M/F)
3. Genetic fitness loss (F)
4. HABs (M)
5. Foraging/Starvation (M)
6. Portfolio (outmigrant size or timing -F)
7. Structural changes in marine habitats (M)

Telemetry array



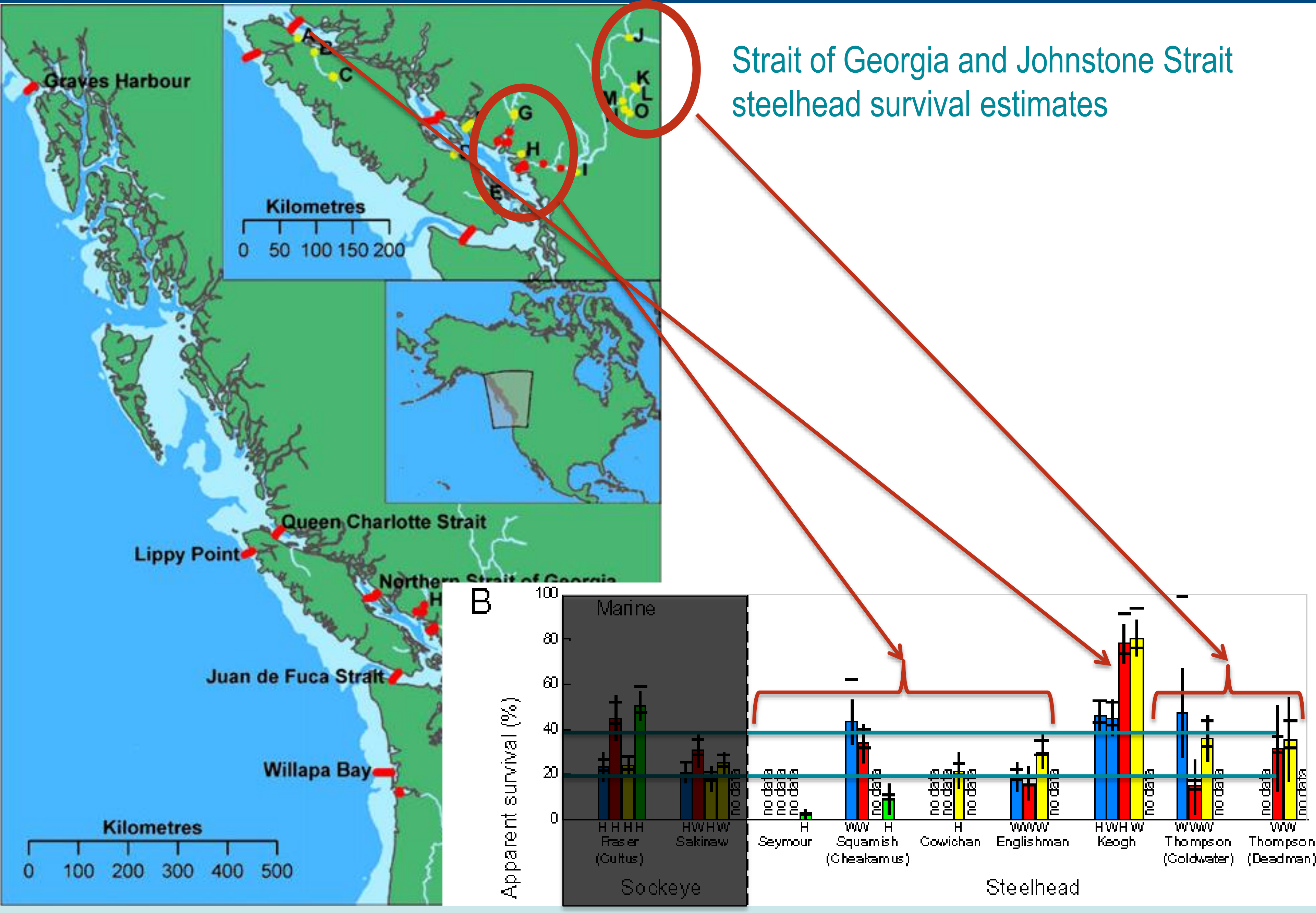
	Migration Segments		
	Hood Canal	**Puget Sound**	**Skagit**
1st segment	River Mouth - HCB	River Mouth - CPS	River Mouth - DP
2nd segment	HCB – ADM	CPS – ADM	
3rd segment	ADM – JDF	ADM – JDF	DP - JDF

Steelhead in the marine environment

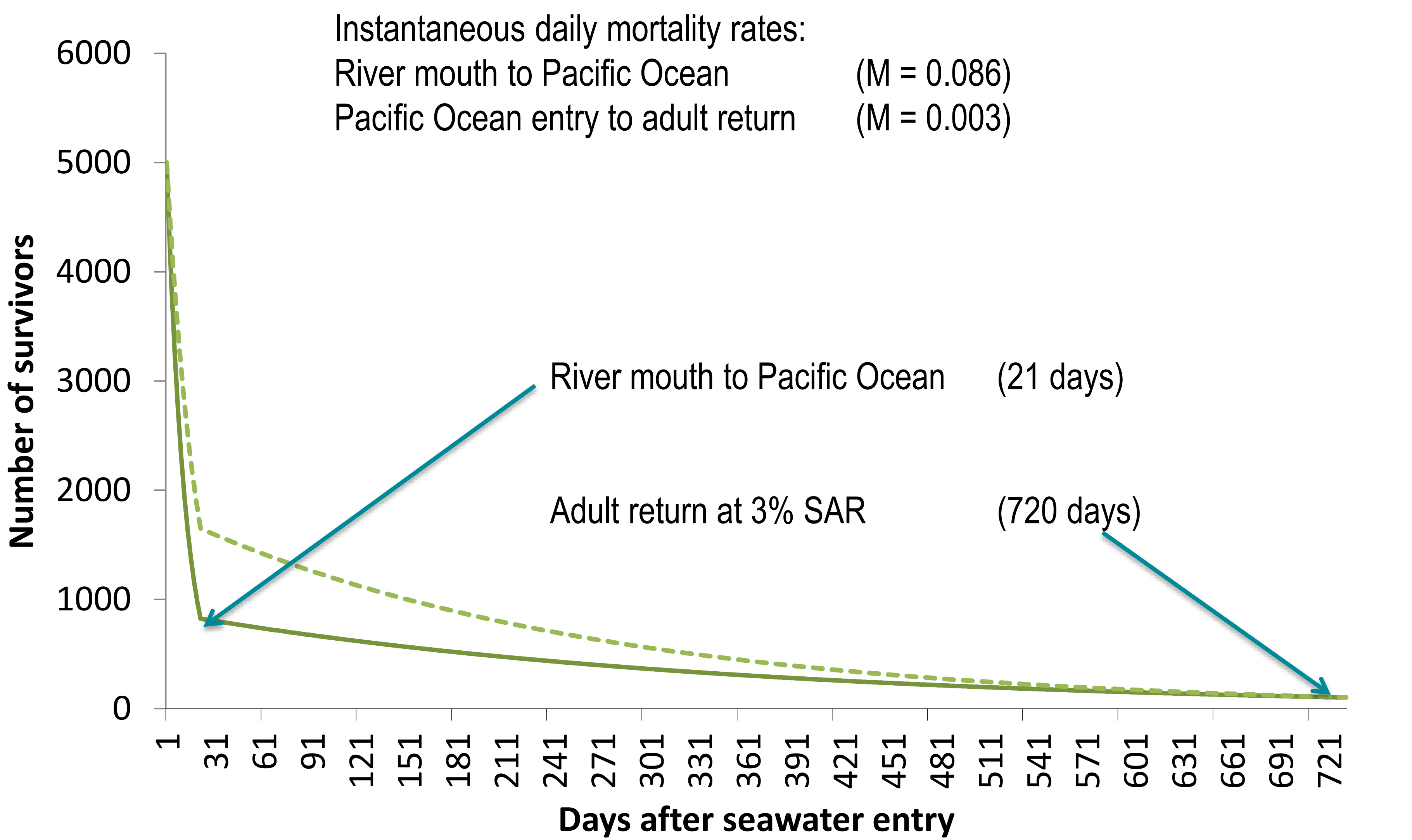
- Pacific Ocean migratory patterns and distribution

- Puget Sound migratory behavior and survival

Strait of Georgia and Johnstone Strait steelhead survival estimates

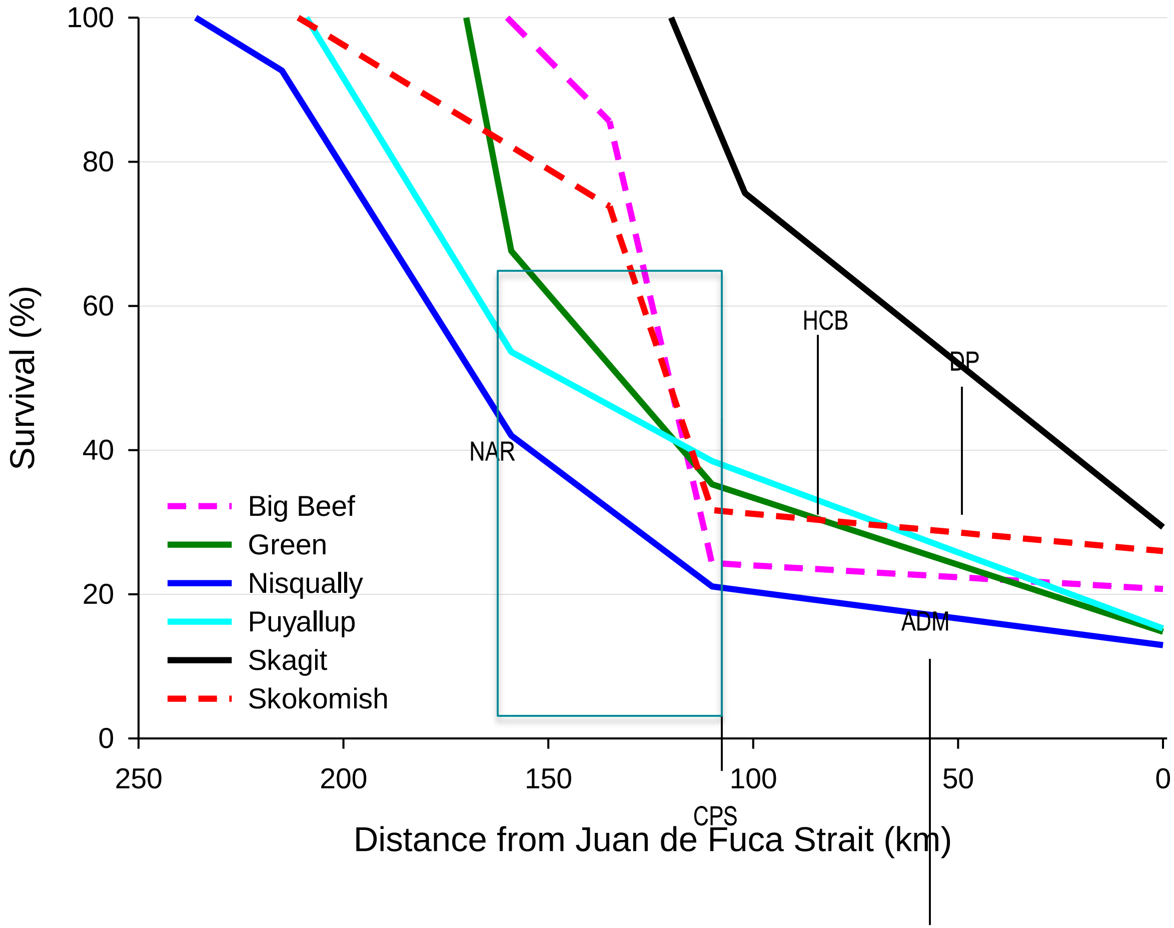


Source: Welch et al. PNAS 108: 8708-8713



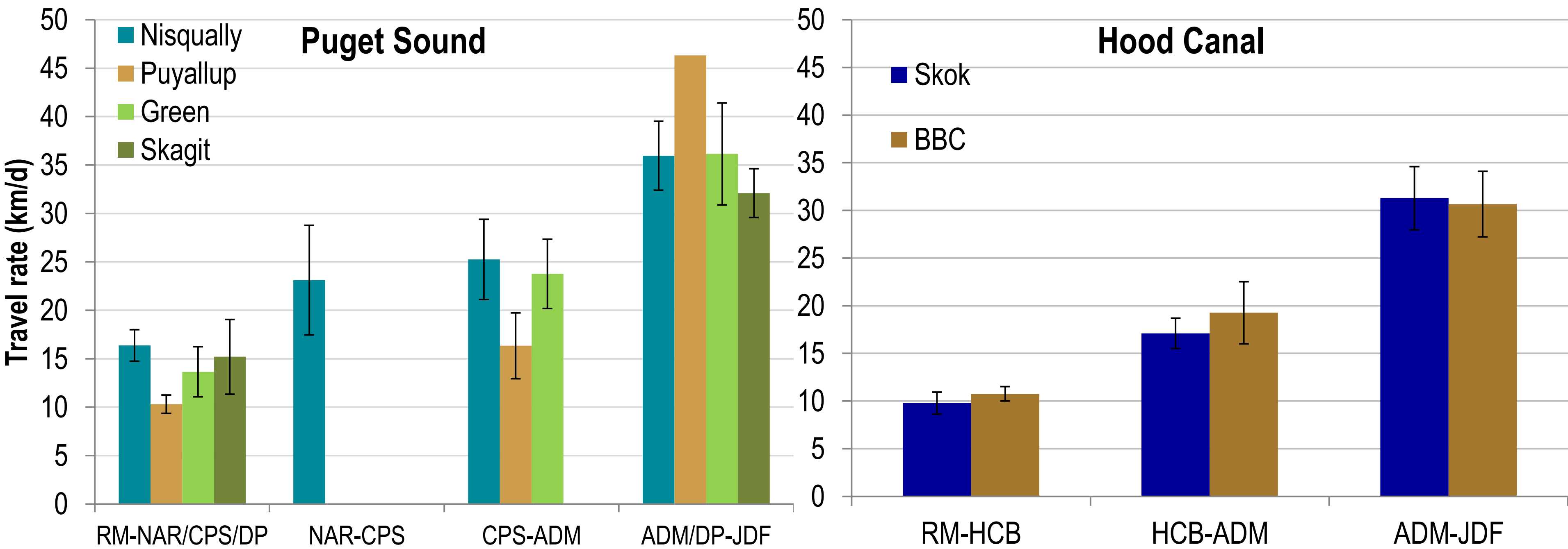
Instantaneous daily mortality rates:
River mouth to Pacific Ocean (M = 0.086)
Pacific Ocean entry to adult return (M = 0.003)
River mouth to Pacific Ocean (21 days)
Adult return at 3% SAR (720 days)
Number of survivors
6000
5000
4000
3000
2000
1000
0
1
31
61
91
121
151
181
211
241
271
301
331
361
391
421
451
481
511
541
571
601
631
661
691
721
Days after seawater entry

Can we identify mortality 'hot spots'?



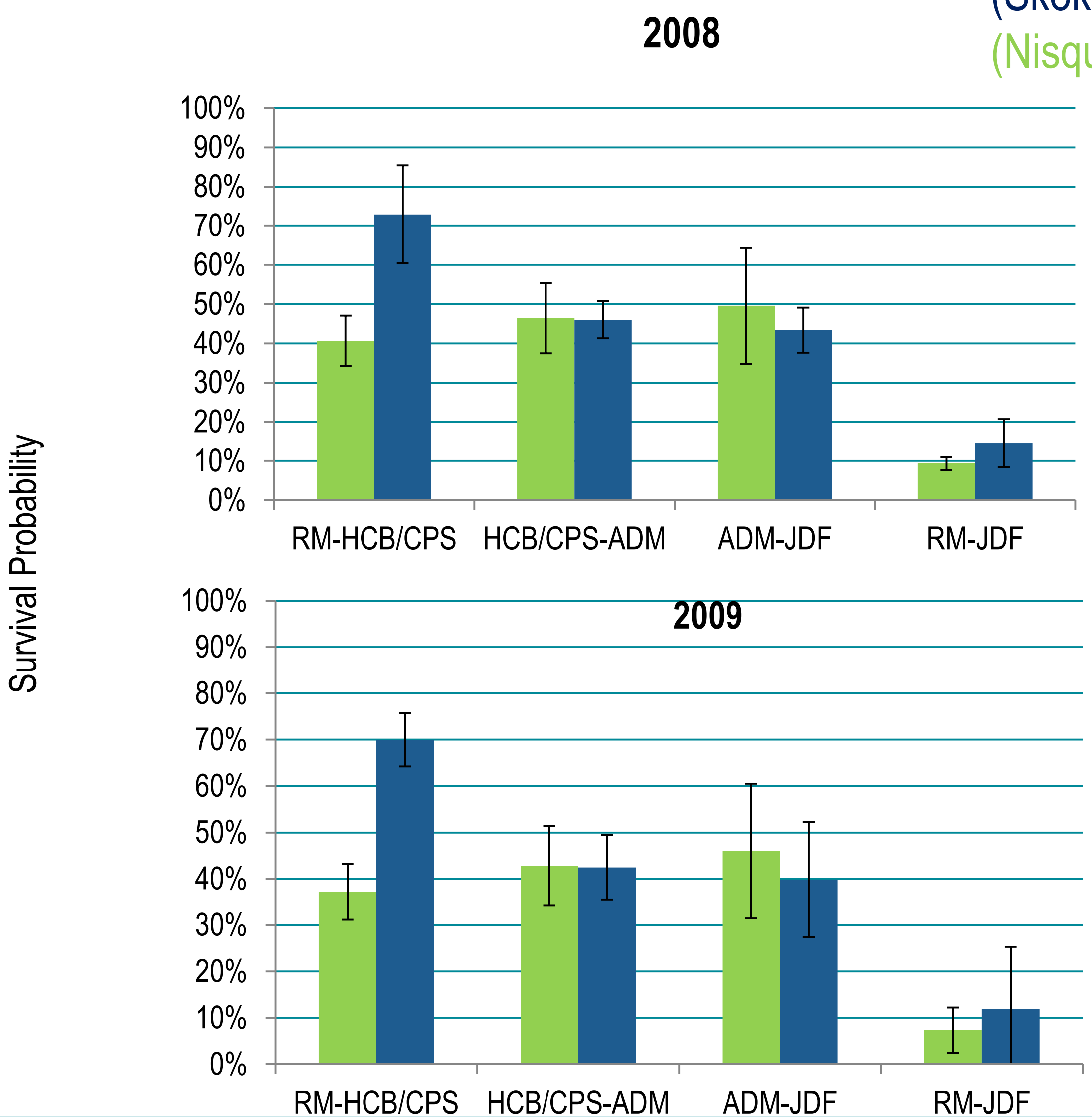
NAR = Tacoma Narrows
CPS = Central Puget Sound
ADM = Admiralty Inlet
HCB = Hood Canal Bridge
DP = Deception Pass

Travel rates

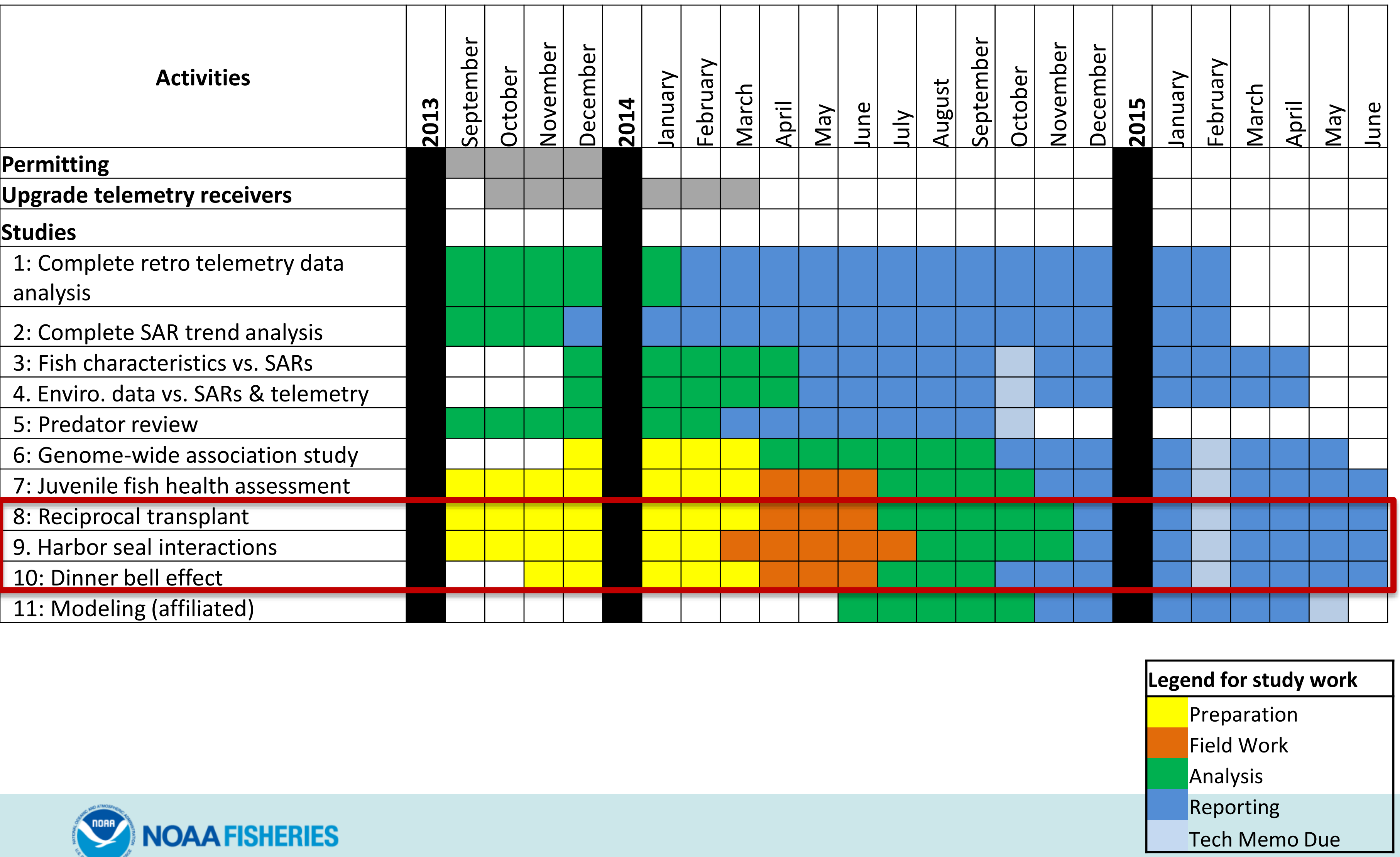


Comparing Puget Sound to Hood Canal

(Skokomish RM-HCB = **66 km**)
(Nisqually RM – CPS = **67 km**)



2013-2015 Steelhead Marine Survival Study



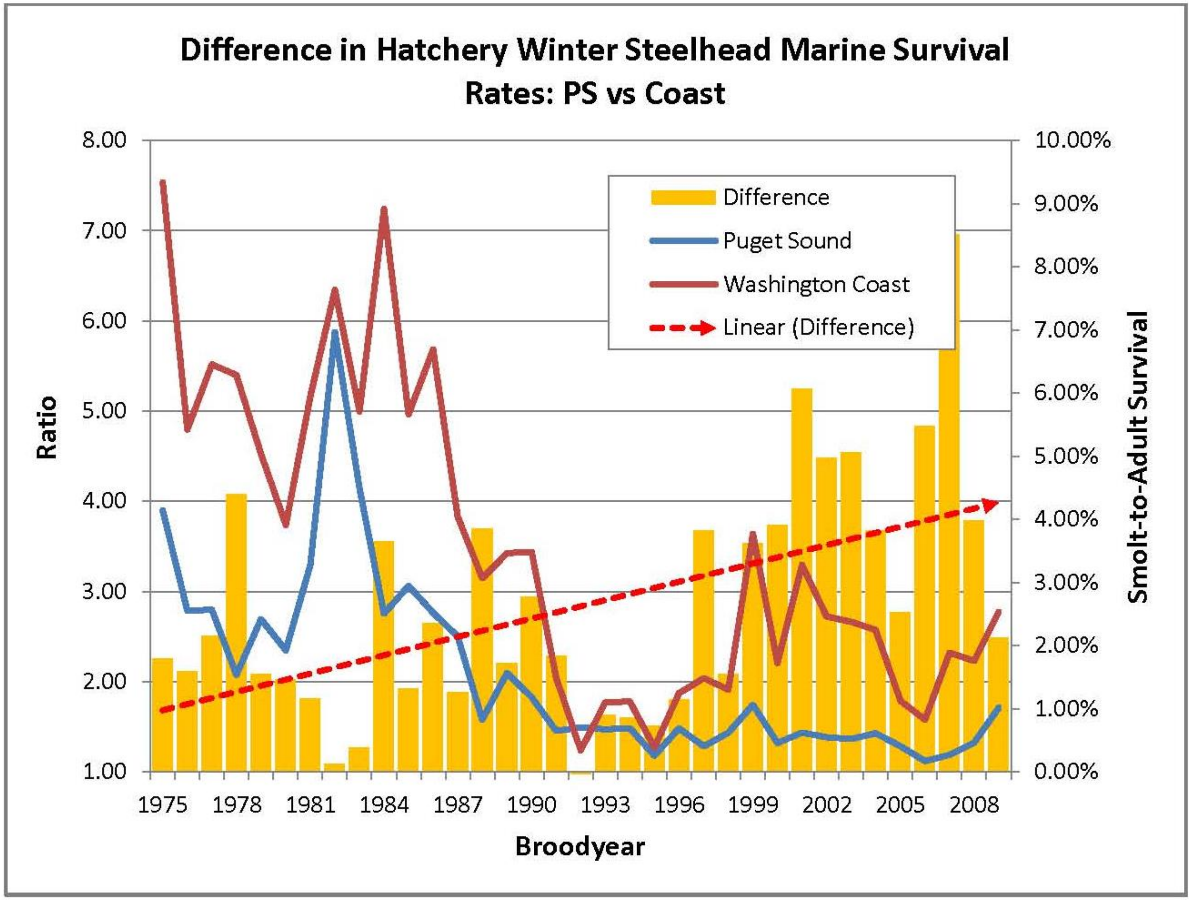
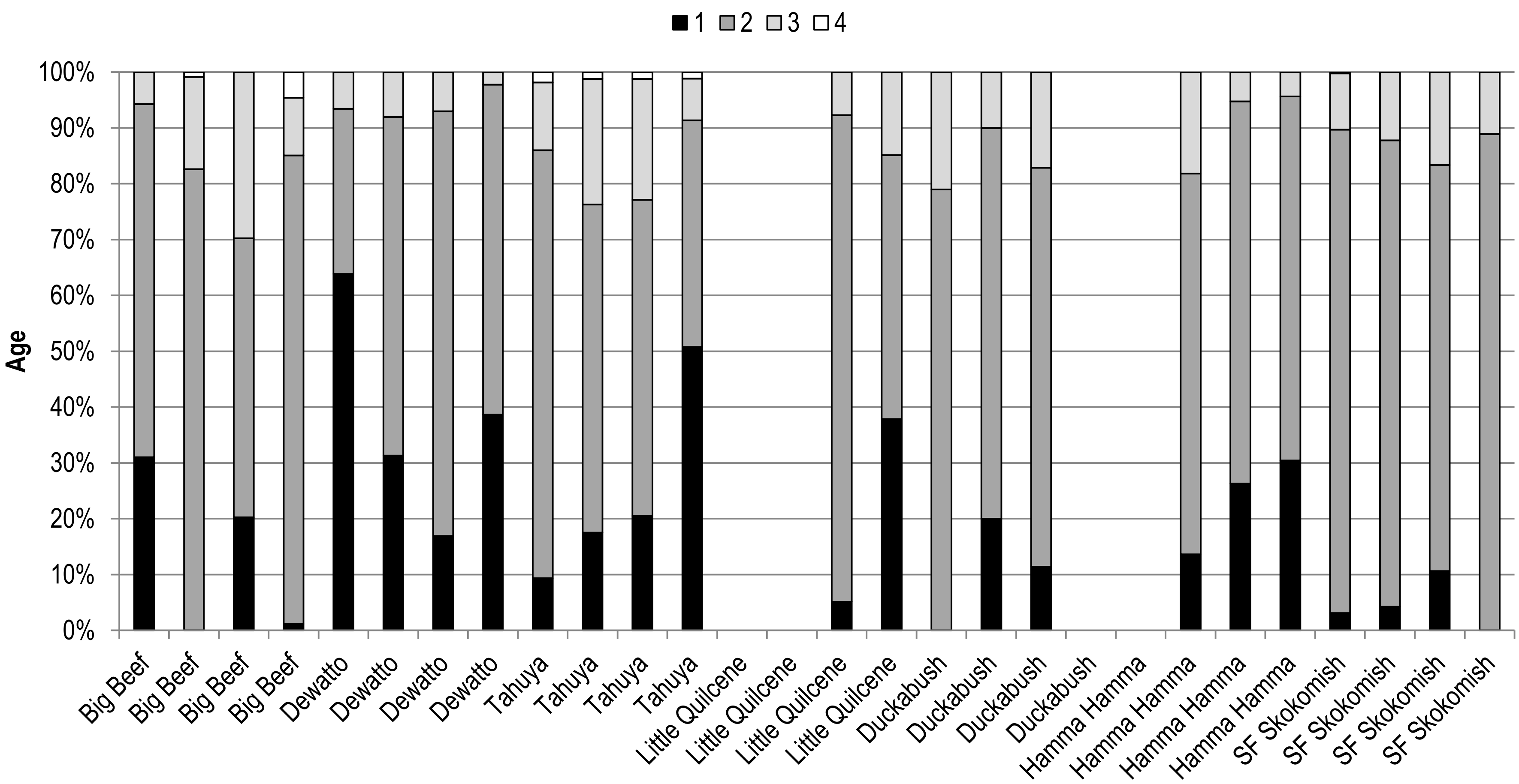


Figure 4. The difference between Puget Sound and Washington Coast marine (smolt-to-adult) survival has increased, one potential indication of increased mortality in Puget Sound (produced by Schmidt, LLTK, using the Kendall et al., WFDW, 2013 unpublished data. See Appendix A for the list of stocks used to create these Figures).

Freshwater: Age-at-smoltification



NOAA FISHERIES

Source: Hood Canal Steelhead Project

Salish Sea Marine Survival Project (Steelhead Workgroup)

Puget Sound Steelhead Marine Survival Workgroup Participants

- Neala Kendall, WDFW
- Megan Moore, NWFSC
- Barry Berejikian, NWFSC
- Scott Pearson, WDFW
- Ken Warheit, WDFW
- Erik Neatherlin, WDFW
- Chris Ellings, Nisqually Indian Tribe*
- Sandie O'Neill, WDFW
- Mike Crewson, Tulalip Tribes*
- Ed Connor, Seattle City Light

Contributing Experts

- Steve Jeffries, WDFW
- Bruce Stewart, NWIFC
- Paul Hershberger, USGS
- John Kerwin, WDFW
- Dave Beauchamp, UW
- Linda Rhodes, NWFSC
- Lyndal Johnson, NWFSC
- Gina Yitalo, NWFSC
- Penny Swanson, NWFSC
- Brian Beckman, NWFSC
- Andy Goodwin, U.S. Fish and Wildlife Service
- Joy Evered, U.S. Fish and Wildlife Service
- Kym Jacobson, NWFSC
- Mary Arkoosh, NWFSC
- Joe Dietrich, NWFSC

Project Management and Facilitation

- Michael Schmidt, Long Live the Kings
- Iris Kemp, Long Live the Kings

Predator-prey interactions

Identifying potentially important predators on steelhead smolts

Criteria:

1. Spatial and temporal overlap,
2. Known to eat steelhead
3. Known to eat similarly sized salmon or other fish
4. Increasing or stable abundance,

Avian predators (S. Pearson, WDFW, review in prep)

- cormorants (most abundant)
- Caspian terns
- common mergansers
- loons
- rhinoceros auklets (feed on smaller prey)

Mammalian predators

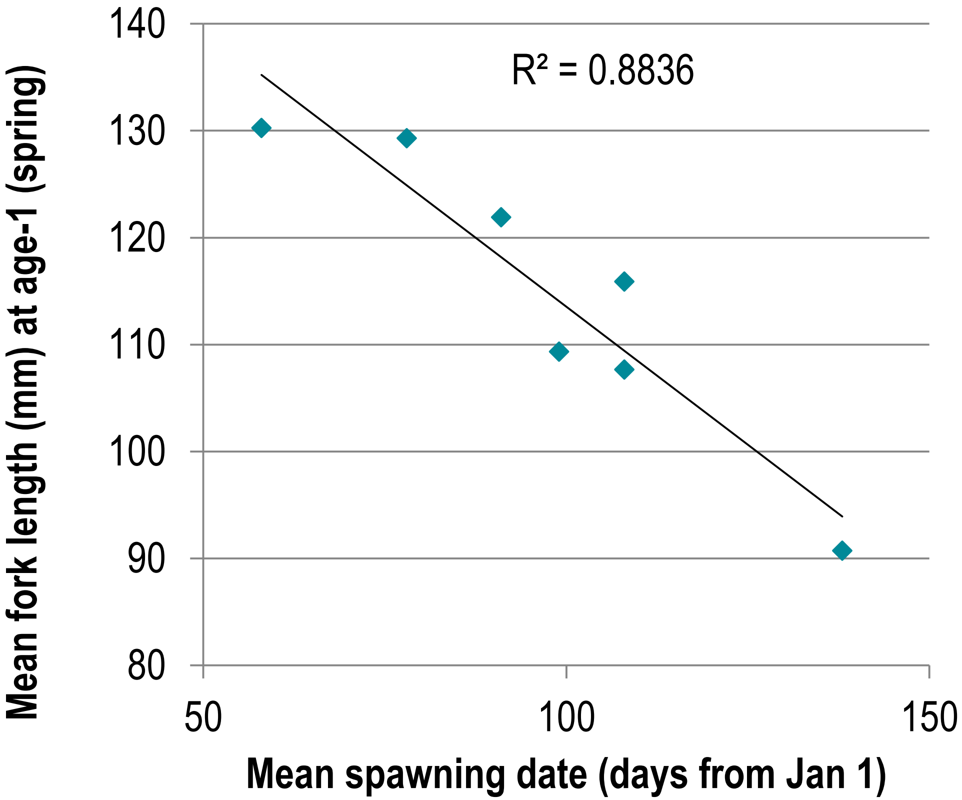
- Harbor porpoise
- Harbor seals

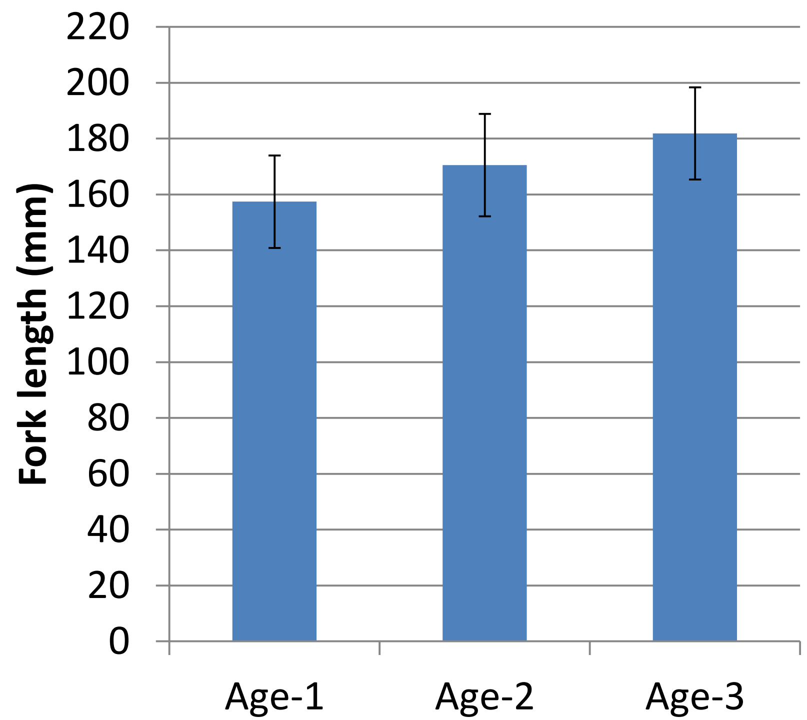
TABLE 2. Fish taxa captured by surface trawls at 52 sites in greater Puget Sound during ***May–August 2003***; taxa are ranked in order based on highest to lowest frequency of occurrence. (Rice et al. 2012. Marine and Coastal Fisheries 4: 117-128)

SPECIES	% frequency
1. Chinook salmon Oncorhynchus tshawytscha	**65.6**
2. Pacific herring *Clupea pallasii*	57.6
3. Threespine stickleback *Gasterosteus aculeatus*	51.5
4. Surf smelt *Hypomesus pretiosus*	50.0
5. Chum salmon *O. keta*	**35.4**
6. River lamprey *Lampetra ayresii*	25.4
7. Pacific sand lance *Ammodytes hexapterus*	22.4
8. Coho salmon *O. kisutch*	**11.7**
9. Bay pipefish *Syngnathus leptorhynchus*	11.2
10. Pacific sandfish *Trichodon trichodon*	9.0
11. Starry flounder *Platichthys stellatus*	8.8
12. Shiner perch *Cymatogaster aggregata*	6.1
13. Steelhead *O. mykiss*	**3.7**

**species ranked 14-33 not shown

Freshwater: Spawn timing and size at age





More Acknowledgements…..

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Survival Modeling Support
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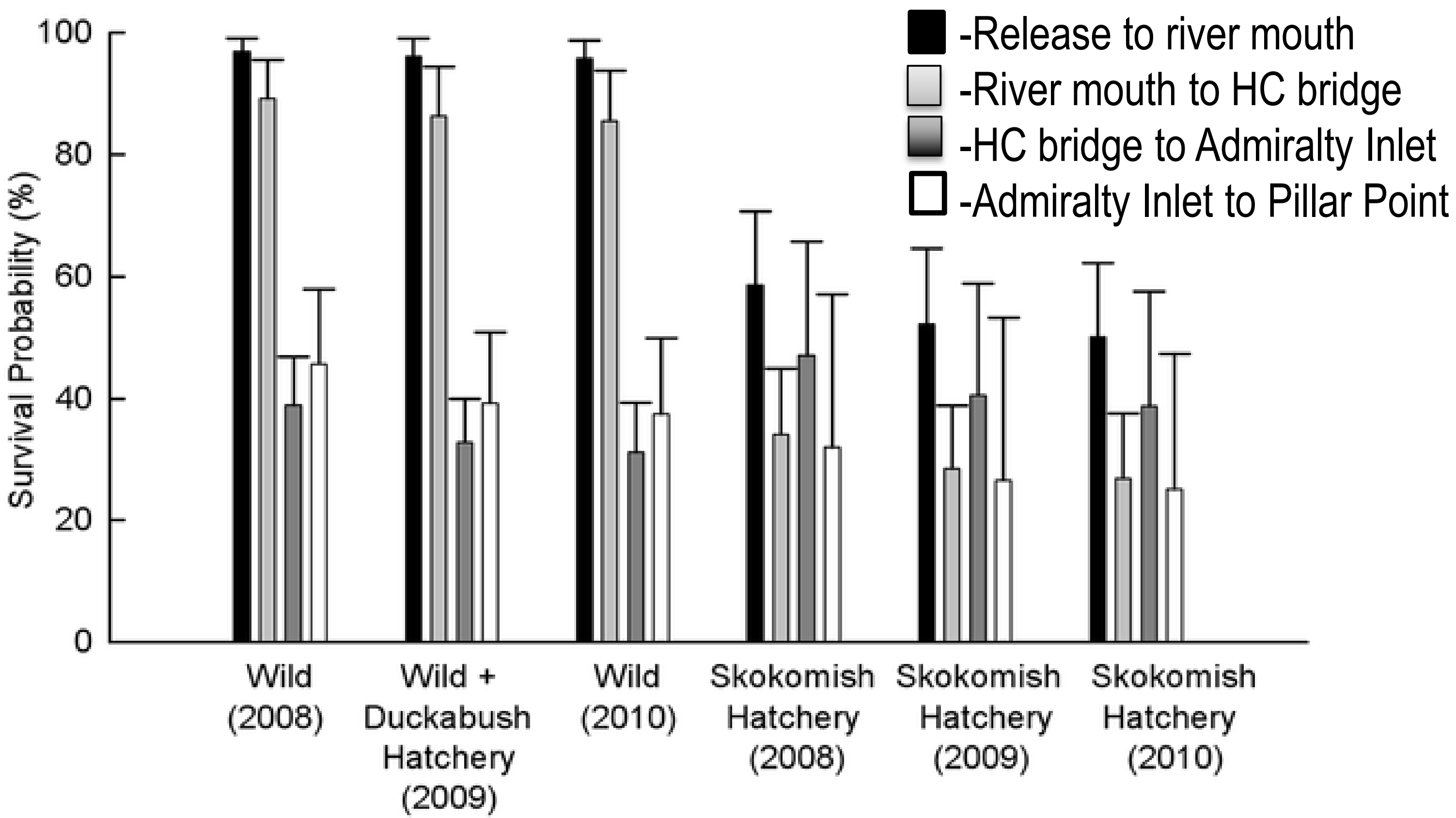
Field/Logistic Support
Long Live the Kings ▪ Hood Canal Salmon Enhancement Group ▪ Mat Gillam ▪ R2 Resource Consultants ▪ Bob Leland ▪ Kelly Kiyohara ▪ Pat Michael Brody Antipa ▪ Pete Topping ▪ Deborah Feldman ▪ Kelly Andrews ▪ John Blaine ▪ Jim Deveraux ▪ Skip Tezak Correigh Greene ▪ Anna Kagley ▪ Shawn Larson ▪ Jeff Christiansen ▪ John Rupp ▪ Chuck Ebel ▪ Jose Reyes-Tomassini ▪ Jennifer Scheurell ▪ Chris Ewing Dawn Pucci ▪ Kurt Dobszinsky ▪ Paul Winchell ▪ David Welch ▪ Debbie Goetz ▪ Jose Gimenez ▪ Aswea Porter ▪ Emiliano Perez ▪ Craig Smith ▪ Tim Wilson ▪ Florian Leischner ▪ Christopher Ellings ▪ Scott Steltzner

Telemetry useful for estimating survival (especially relative survival)

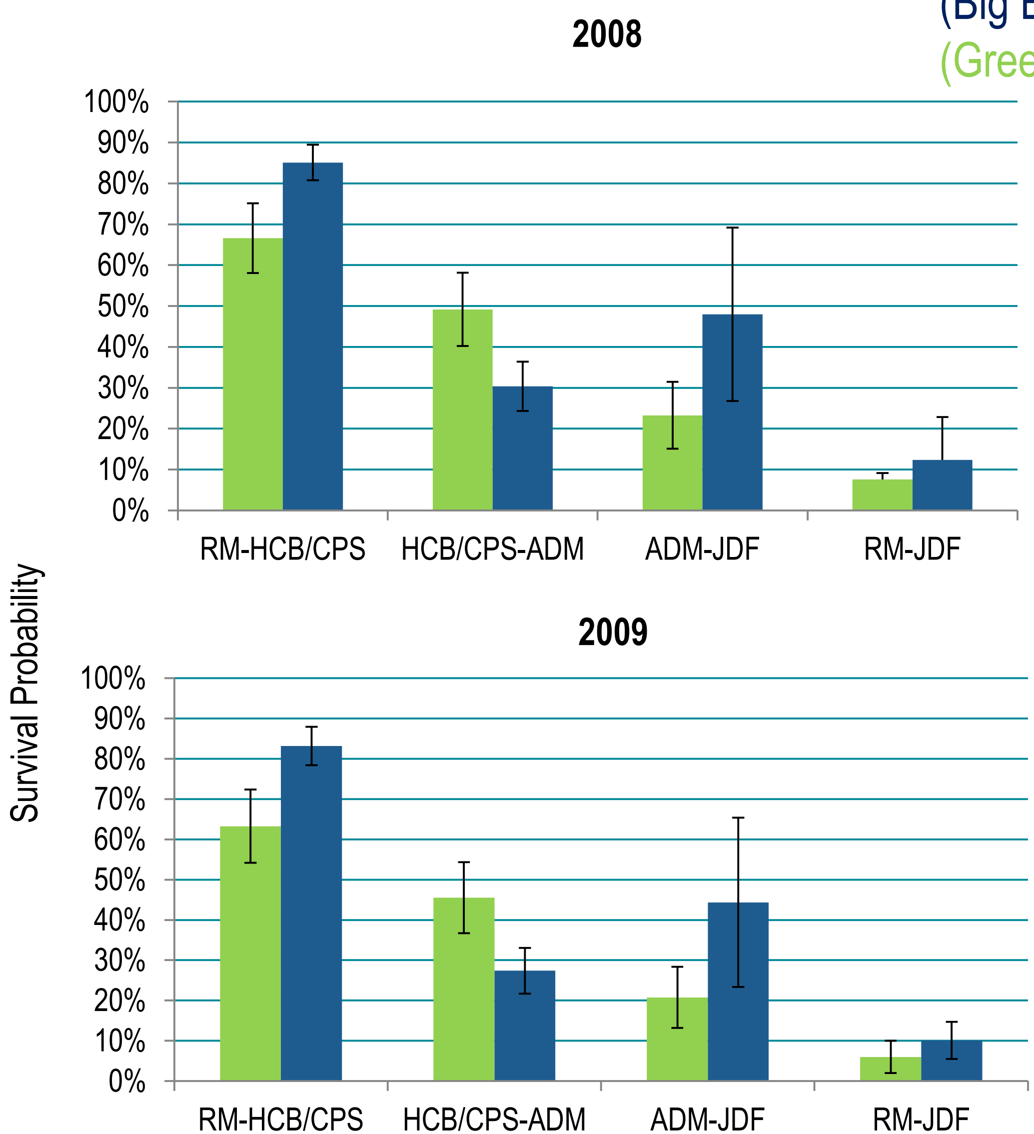
- **Figure 2. Survival estimates for smolts migrating through fresh- and saltwater migration segments.**



Moore M, Berejikian BA, Tezak EP (2012) Variation in the Early Marine Survival and Behavior of Natural and Hatchery-Reared Hood Canal Steelhead. PLoS One 7(11): e49645. doi:10.1371/journal.pone.0049645
http://www.plosone.org/article/info:doi/10.1371/journal.pone.0049645

Comparing Puget Sound to Hood Canal

(Big Beef RM-HCB = **25 km**)
(Green River RM-CPS = **11 km**)



Quantifying encounter and predation rates

- **Spatial overlap**: seal and steelhead detections on same receivers
- **Temporal and spatial overlap**: ***concurrent*** pings on same fixed (moored) receivers
- **Potential encounters**: pings detected on mobile (seal-mounted) receivers
- **Putative predation events**:
    - recurring continuous pings on seal-mounted receivers, perhaps followed by...
    - Stationary tags (defacated tags) connected to seal movements/locations

Puget Sound Chinook salmon

- Residency in Puget Sound = weeks to years.
- Very abundant in Puget Sound spring through summer (Beauchamp and Duffy 2011, Rice et al. 2012)
- Spring/summer growth rate and body size strongly correlated with survival (in hatchery stocks: Duffy and Beauchamp 2011)
- Foraging opportunities, diet composition, and competition (including comp. with hatchery Chinook salmon) likely influence survival.

San Francisco Bay

20 fish were released and 6 were detected at the Point Reyes Array. That's 30% survival over 137 km

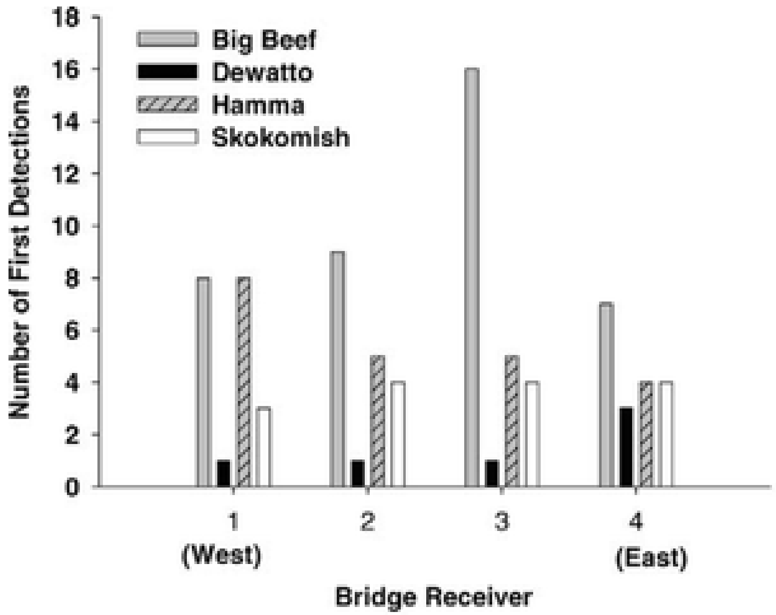
12 (60%) were detected traveling from the river mouth through San Pablo Bay and through San Francisco Bay (77 Km), 2 went south of the Bay Bridge Array, and 10 that entered the ocean were detected at point reyes.
Sundstrom et al 2013

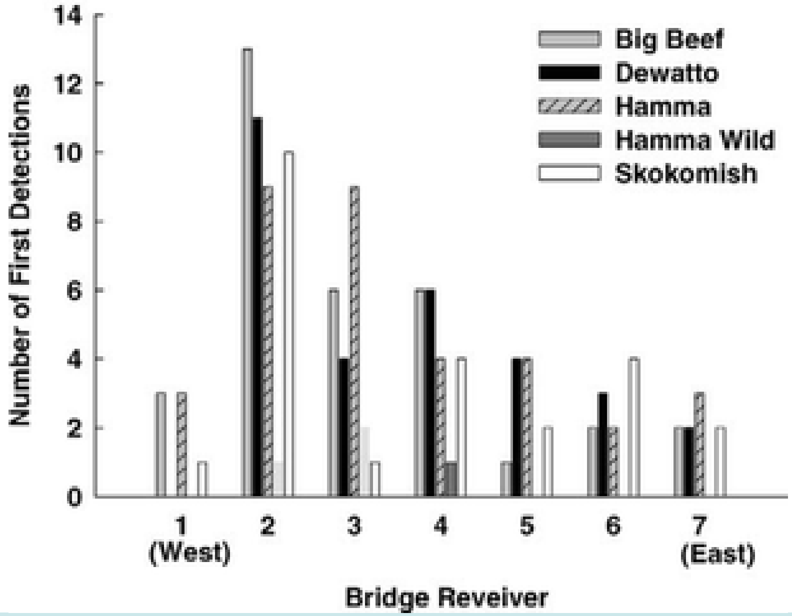
Oregon estuaries, lose about 50% in < 20 km or even shorter distances. Steepest losses in areas where there's been documented high predation rates

Is the estimate 20% EMS high or low?

Species	Year	Release date	Release size (mm)	Duration (weeks)	Detected (Chinook) Survival est (Sthd)	Instantaneous daily mortality
Chinook (Hatch)	2008	May 9	190-233	~14	43%	M = 0.008
Sthd (Wild)	2008	April 16 – May 27	170-190	~ 2 ~ 1 ~ 3	89% RM to HCB 18% HCB to JDF 16.5% RM to JDF	M = 0.008 M = 0.242 M = 0.086

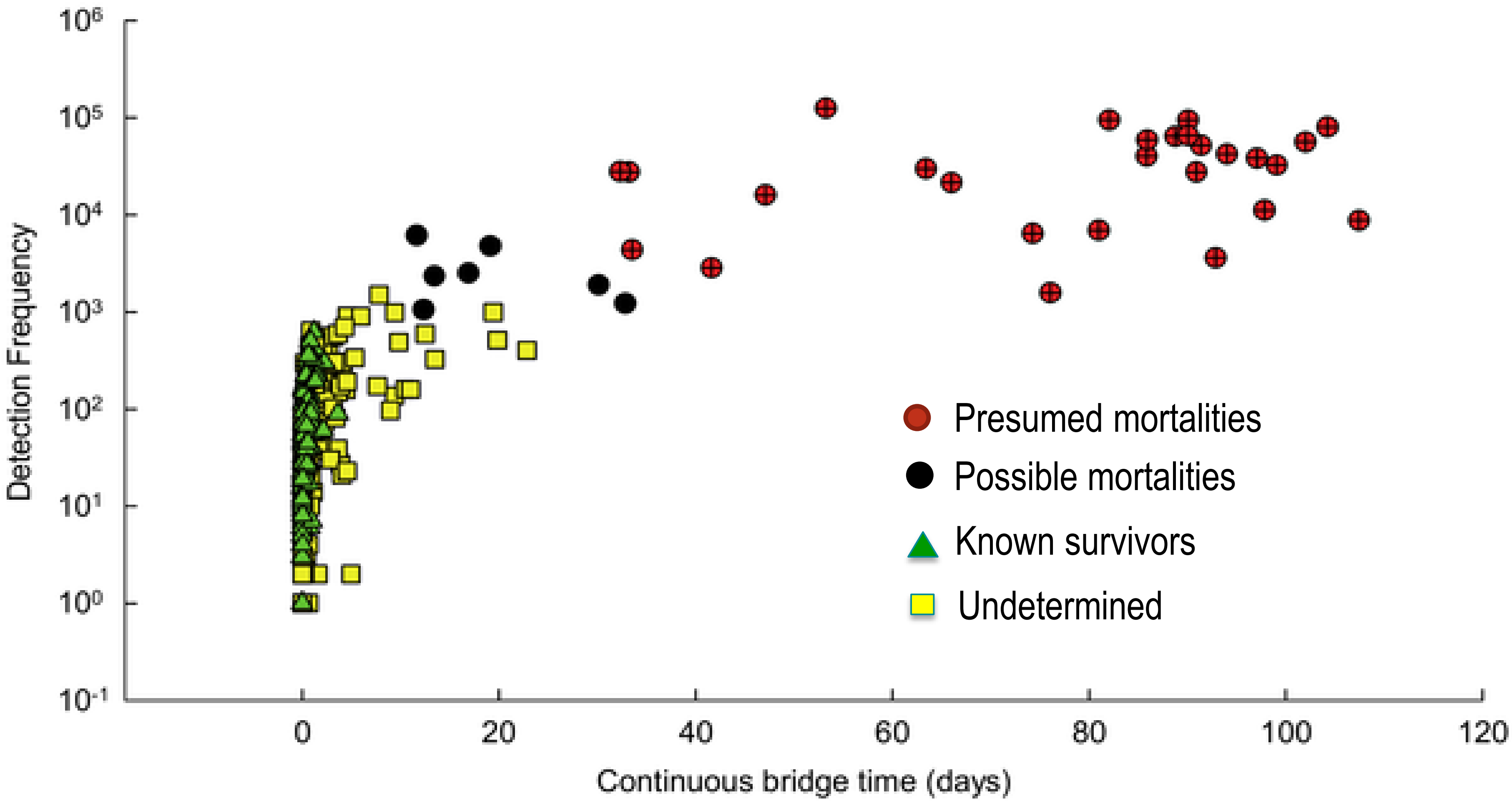
Chamberlain et al. 2011 TAFS and Moore et al. 2012 PLOS One





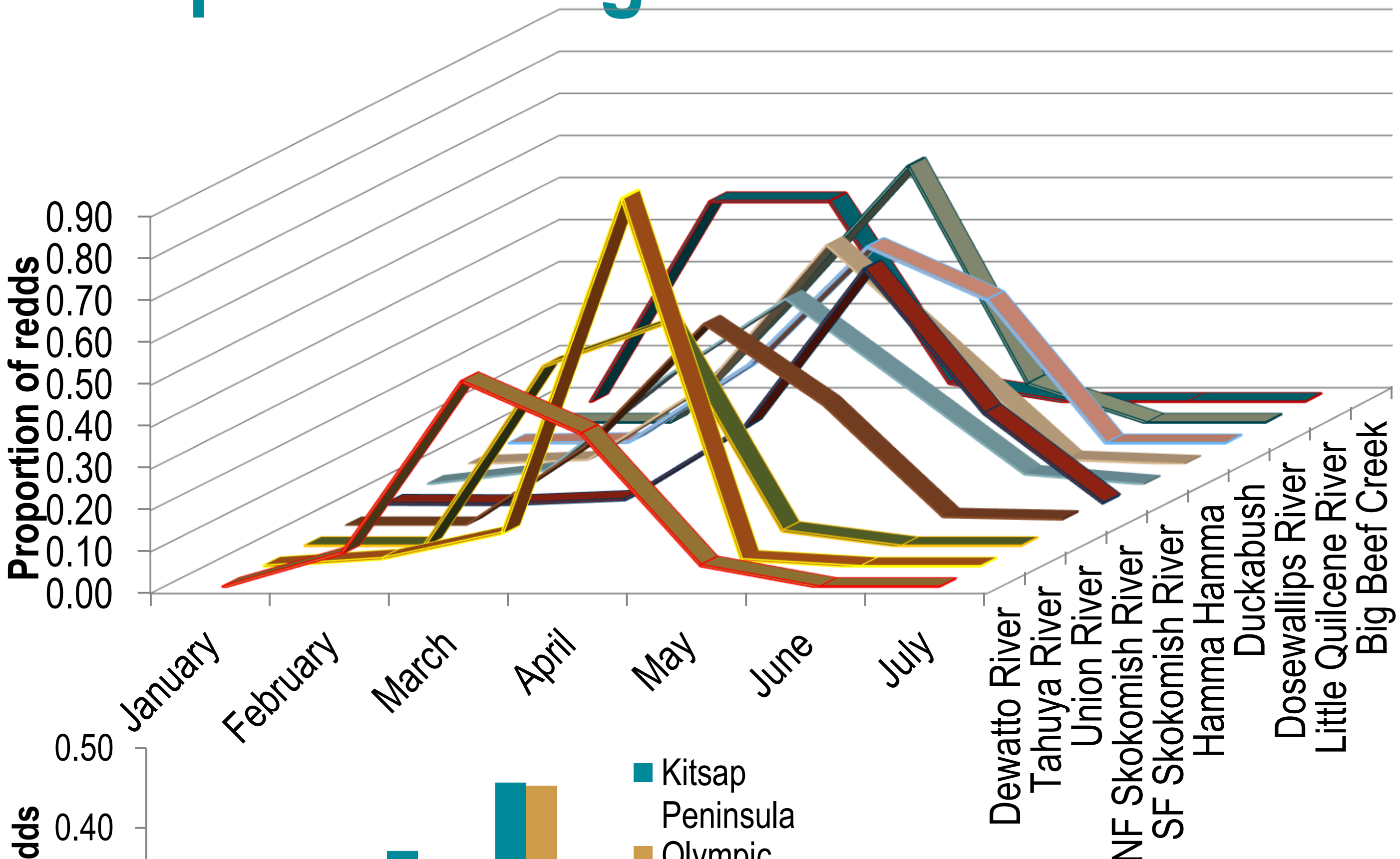
Moore et al. 2010a. Trans. Am. Fish. Soc.

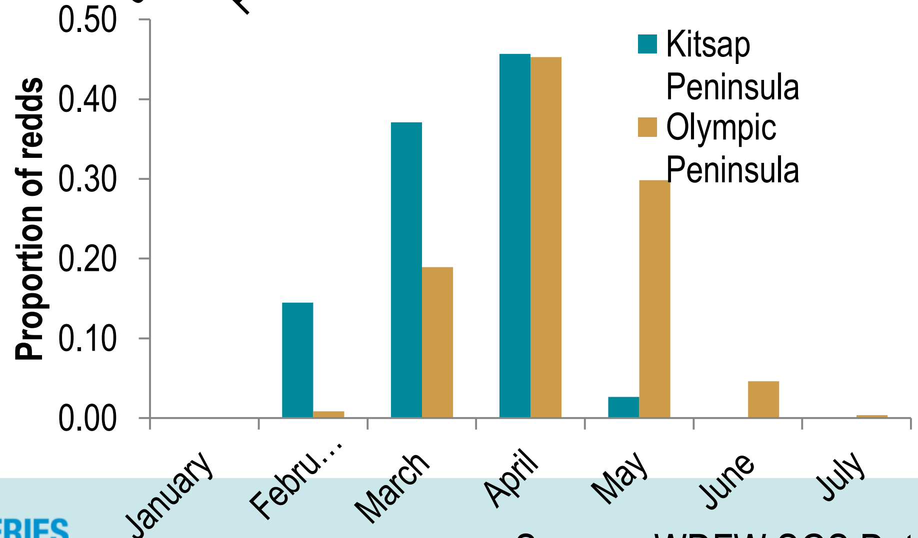
Telemetry useful for identifying hotspots



Moore M, Berejikian BA, Tezak EP (2013) A Floating Bridge Disrupts Seaward Migration and Increases Mortality of Steelhead Smolts in Hood Canal, Washington State. PLoS ONE 8(9): e73427. doi:10.1371/journal.pone.0073427
http://www.plosone.org/article/info:doi/10.1371/journal.pone.0073427

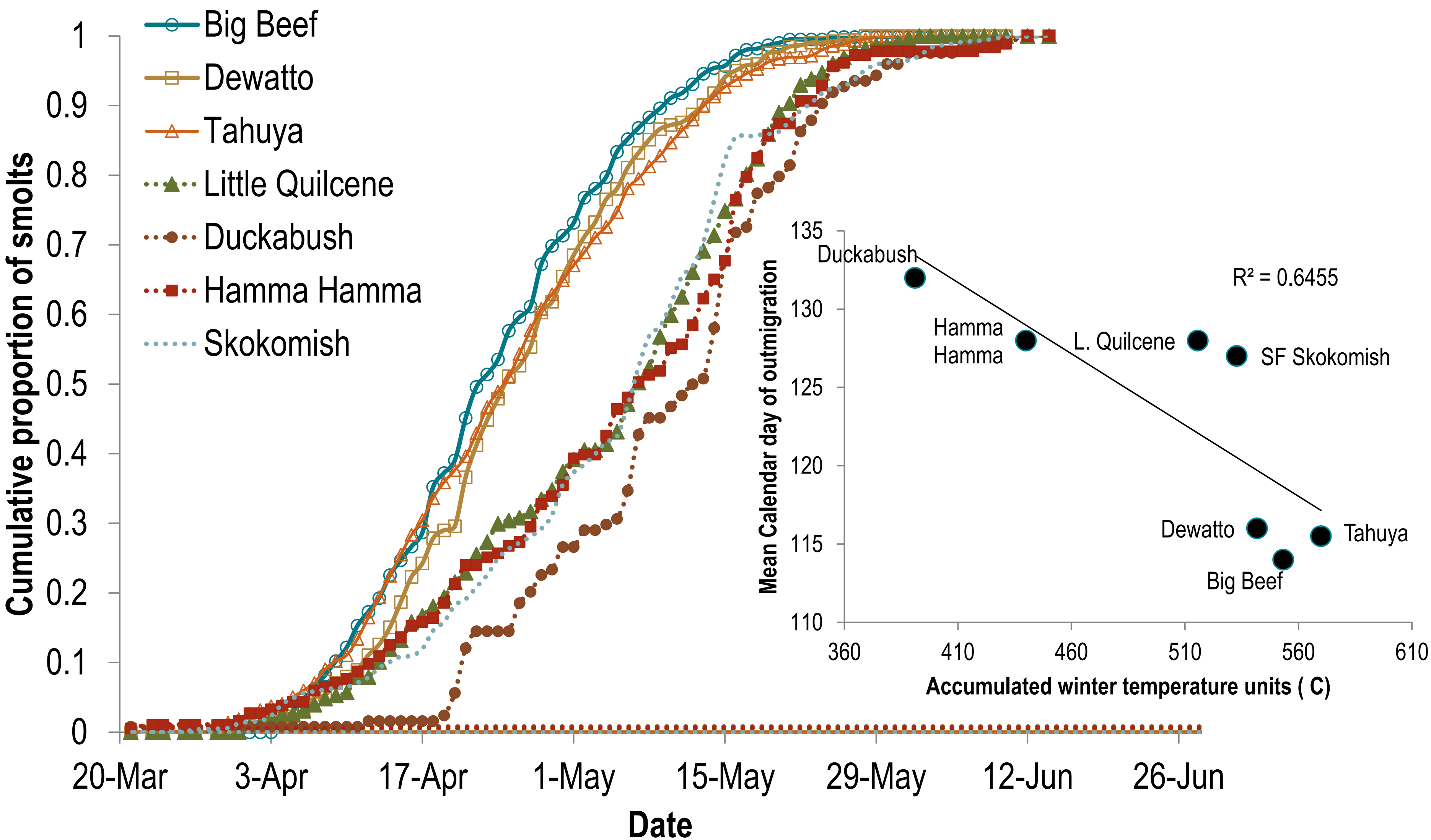
Freshwater: Spawn timing





Source: WDFW SGS Database & Hood Canal Steelhead Project

Freshwater: Smolt migration timing



Source: Hood Canal Steelhead Project

Other freshwater effects

Hatcheries may have both ecological and genetic effects:

- Notably, no steelhead released into the Nisqually River since 1980

Water Quality/toxics:

- Toxic contaminant exposure data for steelhead is lacking
- Nisqually considered most pristine in main basin of Puget Sound

Disease:

- *Nanophyetus*: more prevalent in south than north Puget Sound
- Rapid infections; can affect swimming performance