Use of the Cormack-Jolly-Seber (CJS) Model for Wind River Steelhead Life Cycle Modeling

Dan Rawding,
Thomas Buehrens,
and Charlie Cochran

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GOALS & NOTES

- Use tag data from Wind River steelhead parr, smolt, and adult PIT tagging to estimate life stage survival and capture probabilities using Cormack-Jolly-Seber (CJS) model

- In CJS model survival (ϕ)= apparent survival, which is survival in the study area. In this case, if we PIT tagged resident o. *mykiss* parr that do not emigrate as smolts survival estimates are biased low.

Steelhead Life Stages

- **PARR** –juvenile steelhead that is age one or older and will migrate to the ocean in the spring of future years
- **SMOLT** – a juvenile steelhead that is migrating to the ocean that year
- **ADULT** – a steelhead that has spent at least 1 winter in the ocean
- **KELT** – an adult steelhead that is migrating to the ocean after spawning
- **REPEAT SPAWNER** – an adult steelhead that is returning to freshwater after spawning at least once

Wind River Steelhead

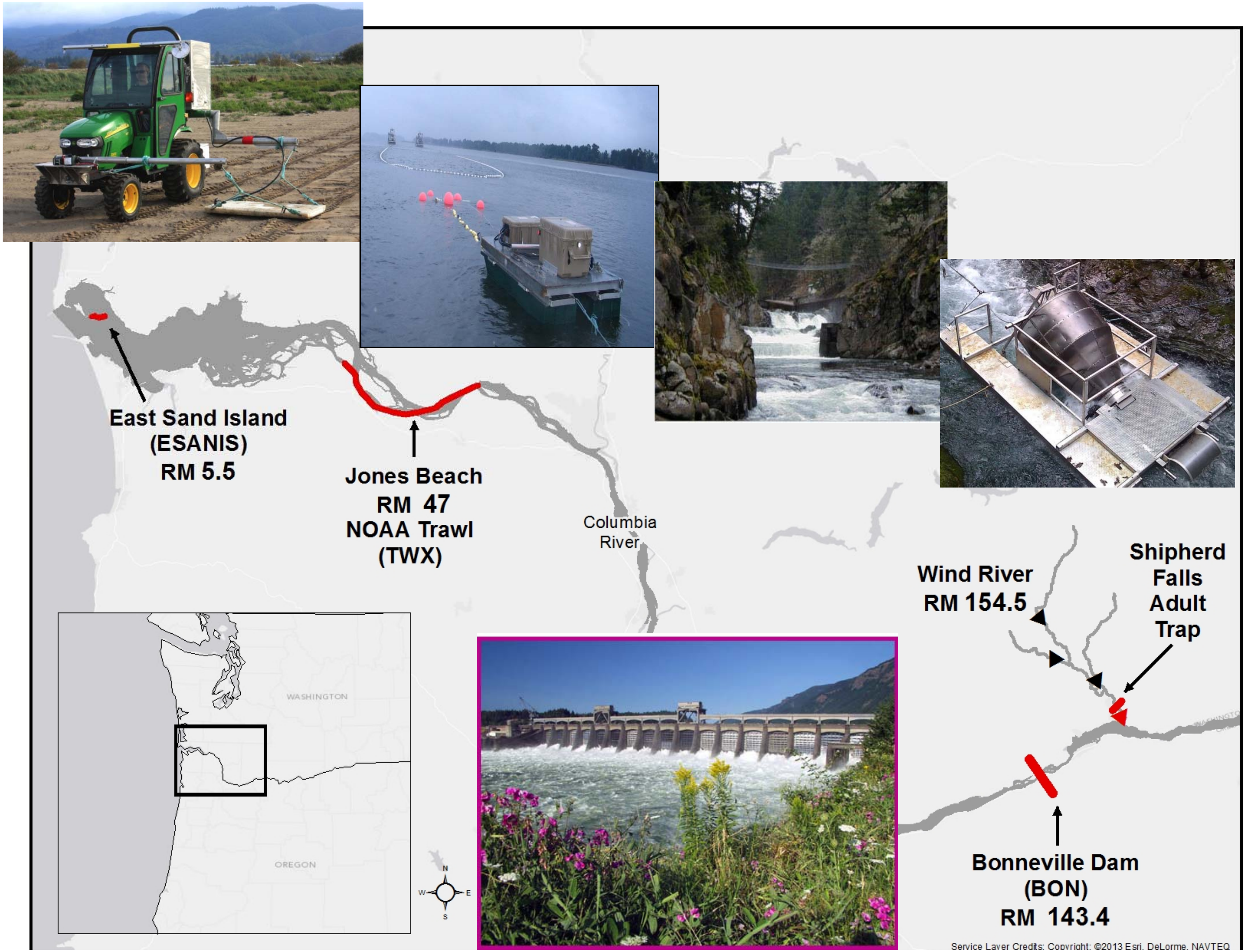
- Located at RM 153 ~ 11 mile upstream BON
- Wild steelhead sanctuary since 2000
- Escapement (range 200-1500);mean (600+)
- Summer steelhead - 95% to 99% of escapement
- Freshwater Age - age 2 ~75% & age 3 ~ 25%
- Marine Age- age 1<5%, age 2~85%, age 3<10%
- Annual (2.2s) and Skip Repeat Spawners (2.2s1)

Wind River Steelhead

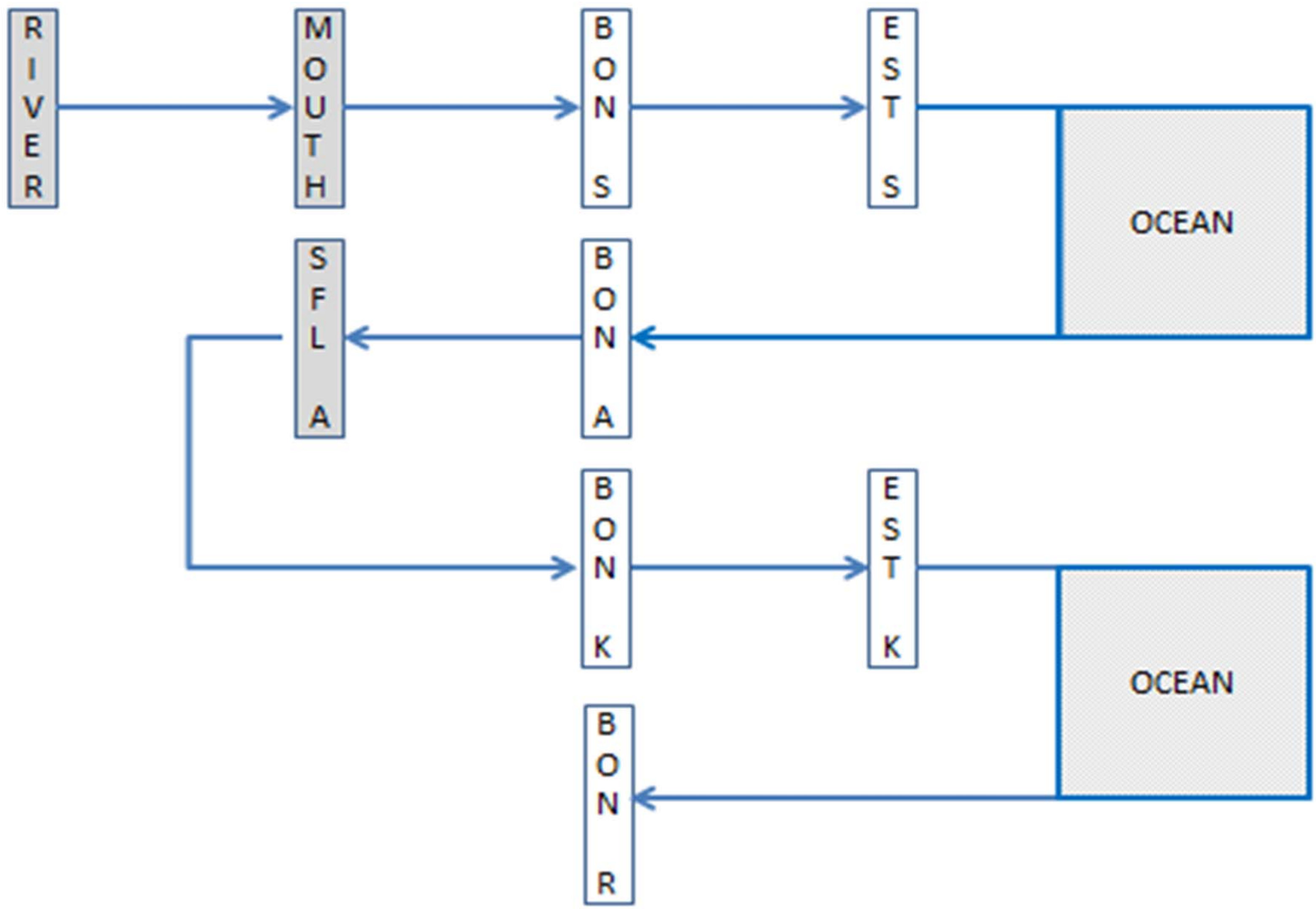
- PIT Tagging
  - ~22,000 PIT tags applied in 9 outmigration years
  - smolts since 2003 annual tag range (1100-2500),
  - parr since 2007 tag annual range (300-600), &
  - adults since 2008 annual tag range (30-300)

CJS Model

- This CJS model is life cycle model using tagging, detection, and recapture sites to partition life stage survival.
- Assume all parr tagged in spring emigrate as smolts following year.
- Most fish are PIT tagged at the smolt stage & CJS model tracks smolt outmigration cohorts
- Adults tagged at Shipherd Falls ladder added to appropriate smolt outmigration year based on scale ages.


East Sand Island
(ESANIS)
RM 5.5
Jones Beach
RM 47
NOAA Trawl
(TWX)
Columbia
River
Wind River
RM 154.5
Shipherd
Falls
Adult
Trap
Bonneville Dam
(BON)
RM 143.4
WASHINGTON
OREGON
N
W
E
S
Service Layer Credits: Copyright: ©2013 Esri, DeLorme, NAVTEQ

Wind River Steelhead Life Cycle



CJS Wind River m-array

- Create individual capture histories (0,1) at each site based on PTAGIS query
- Sum individual capture histories to create m-array for analysis

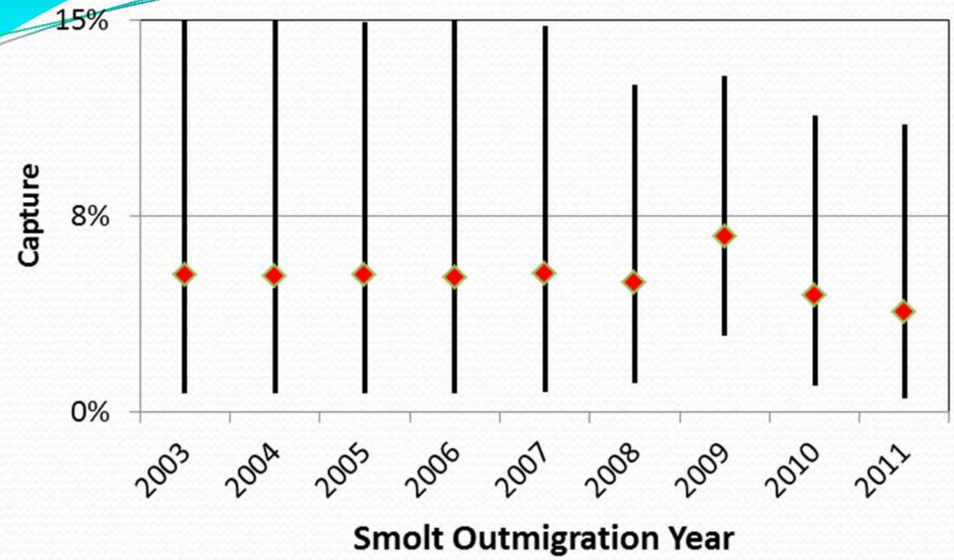
Node	LW_ST	BONsm	TWX/ES	BONma	SFTma	BONk1	TWXk1	BONr1	Not Seen
UR_ST	1	0	4	3	0	0	0	0	299
LW_ST	0	187	145	64	0	0	0	0	761
BONsm	0	0	34	15	0	0	0	0	138
TWX/ES	0	0	0	3	0	0	0	0	24
BONma	0	0	0	0	10	5	1	2	67
SFTma	0	0	0	0	0	45	1	17	211
BONk1	0	0	0	0	0	0	0	9	41
TWXk1	0	0	0	0	0	0	0	0	2
BONr1	0	0	0	0	0	0	0	0	16

Model Selection

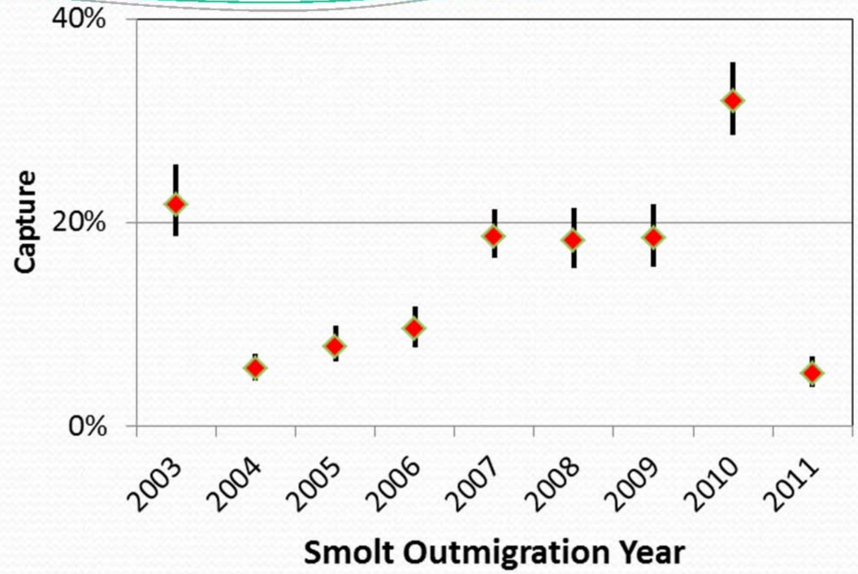
- Deviance Information Criteria (DIC), a Bayesian analog for AIC that can be used to evaluate hierarchical models, was used for model selection (lower values provide better fit).

- Models
  - 9 smolt cohorts (2003-11).
  - Eight survival estimates per cohort (survival from parr through repeat spawners to BON)
  - Seven capture estimates per cohort (Wind River smolt trap to repeat spawners at BON)
  - Evaluated nine models

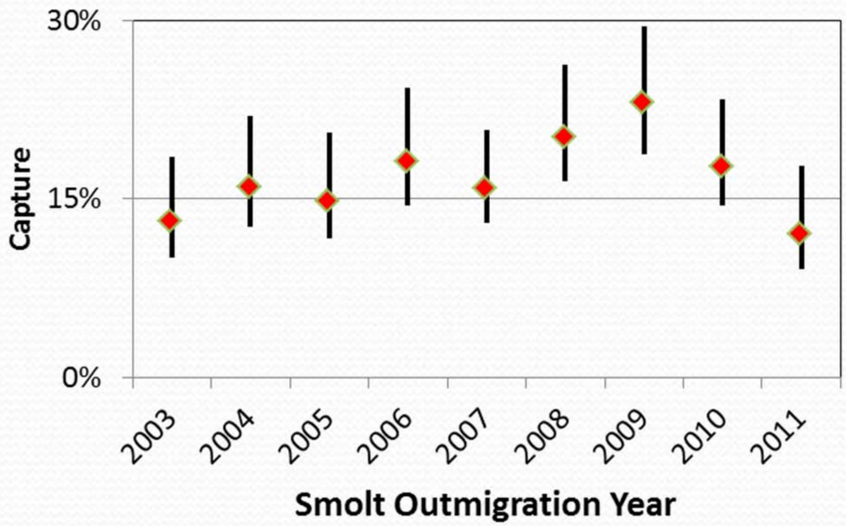
Smolt Detection @ Wind

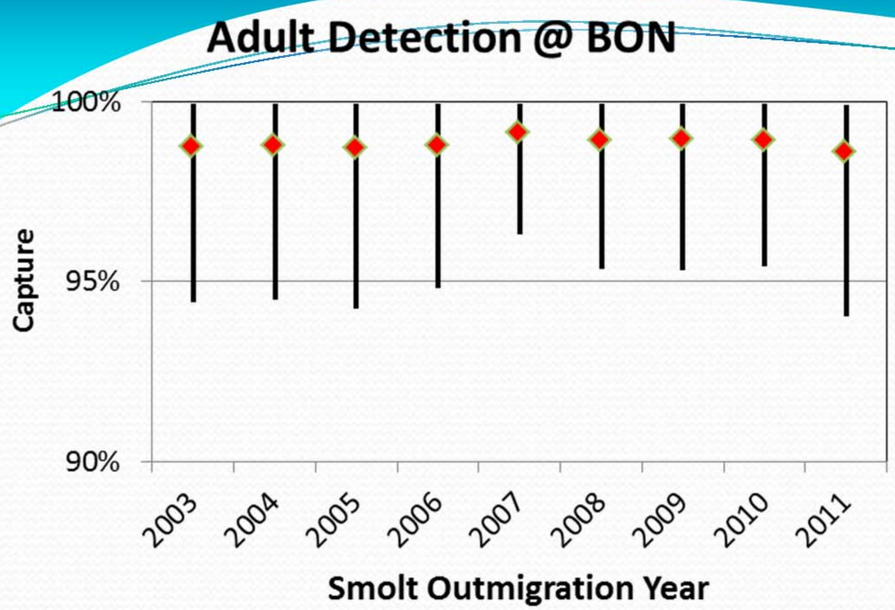


Smolt Detection @ BON

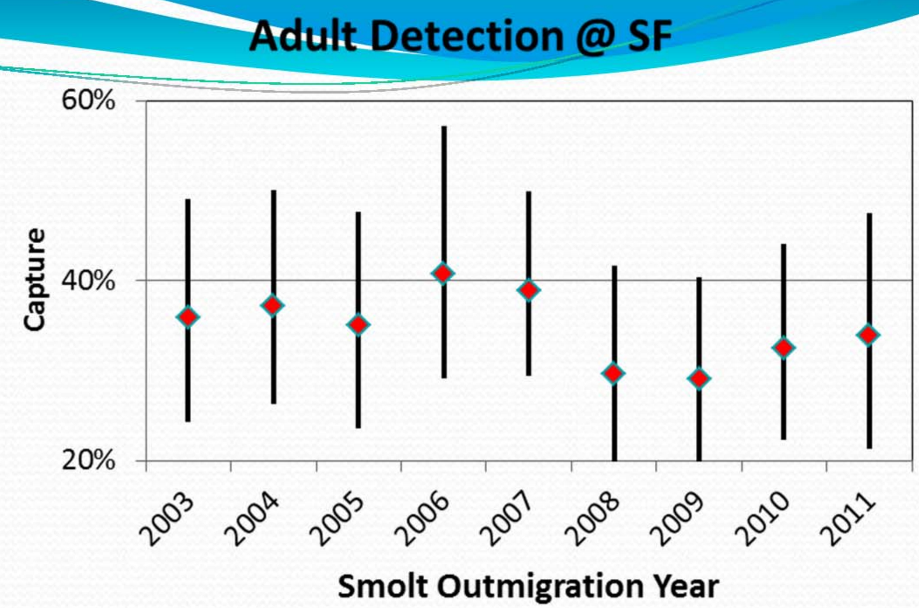


Smolt Detection, Estuary

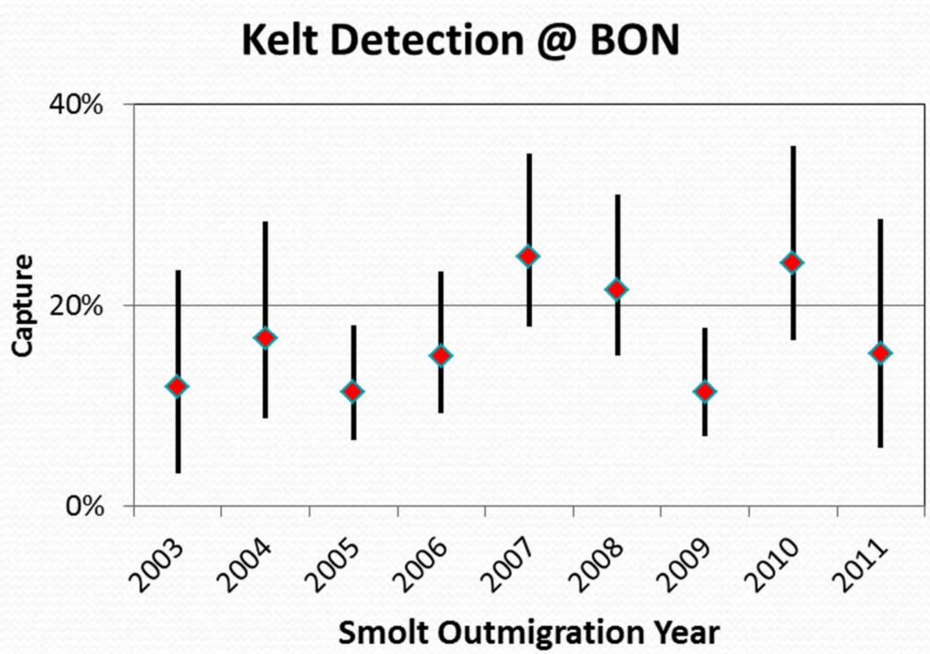




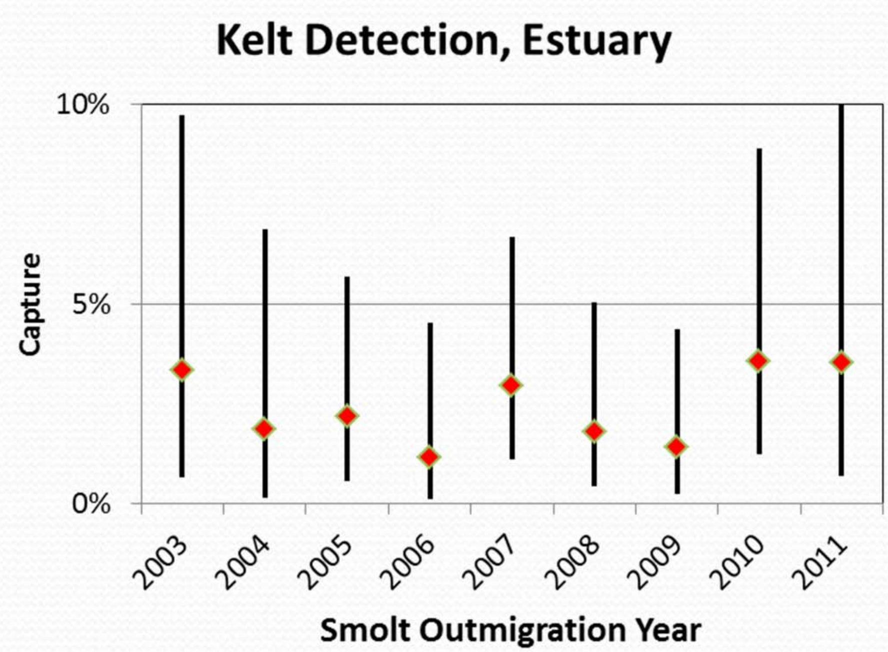
Adult Detection @ BON
100%
95%
90%
Capture
2003
2004
2005
2006
2007
2008
2009
2010
2011
Smolt Outmigration Year



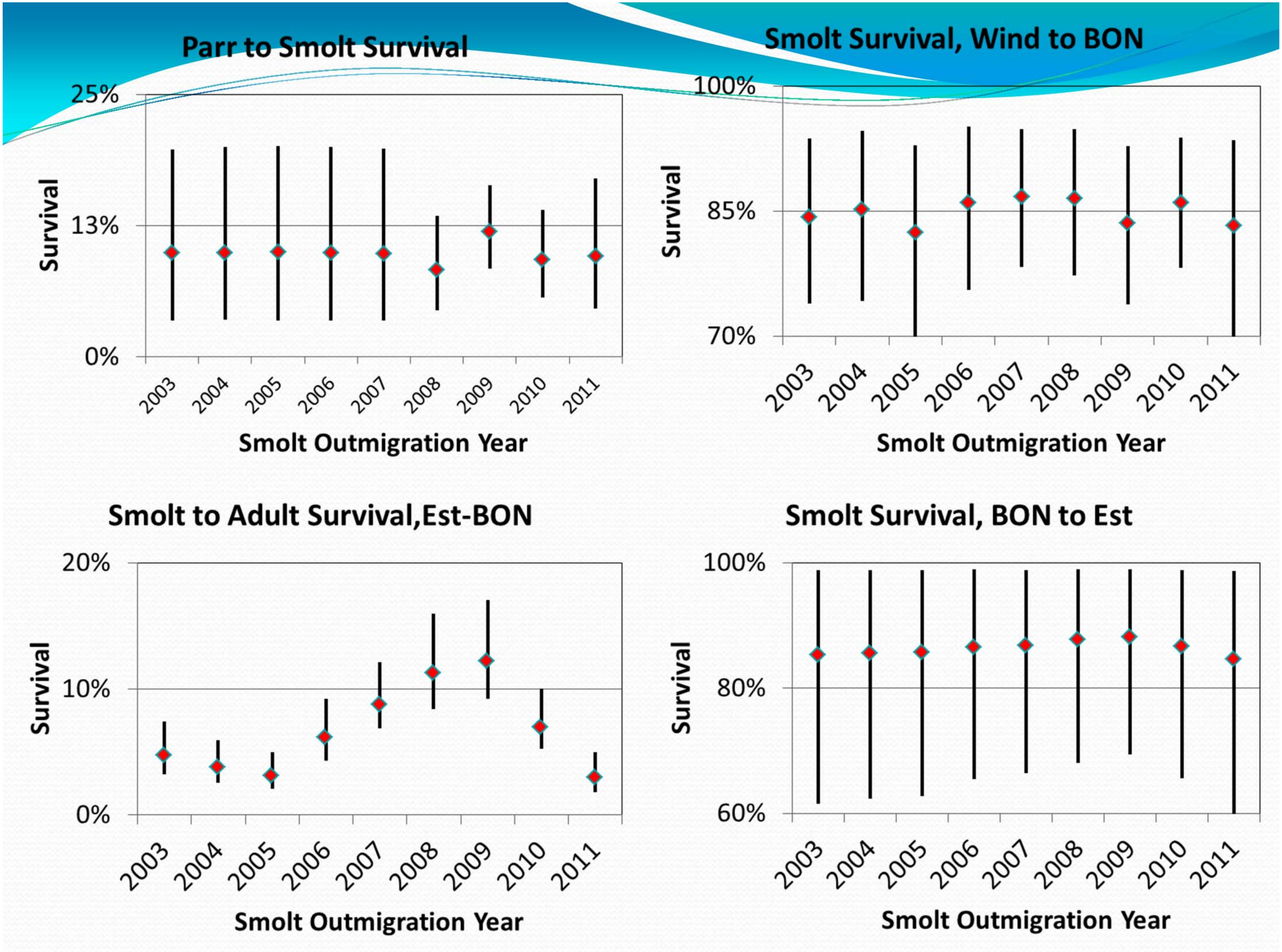
Adult Detection @ SF
60%
40%
20%
Capture
2003
2004
2005
2006
2007
2008
2009
2010
2011
Smolt Outmigration Year



Kelt Detection @ BON
40%
20%
0%
Capture
2003
2004
2005
2006
2007
2008
2009
2010
2011
Smolt Outmigration Year

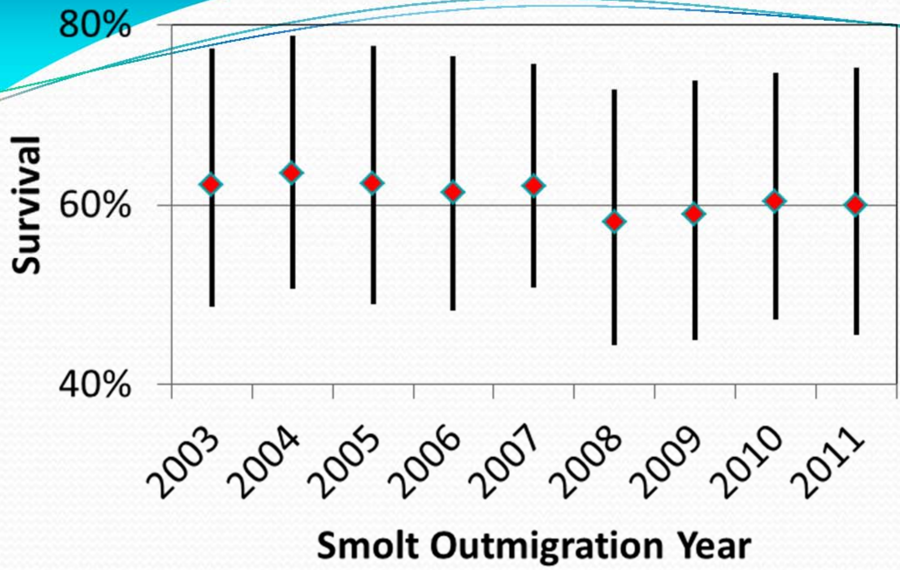


Kelt Detection, Estuary
10%
5%
0%
Capture
2003
2004
2005
2006
2007
2008
2009
2010
2011
Smolt Outmigration Year

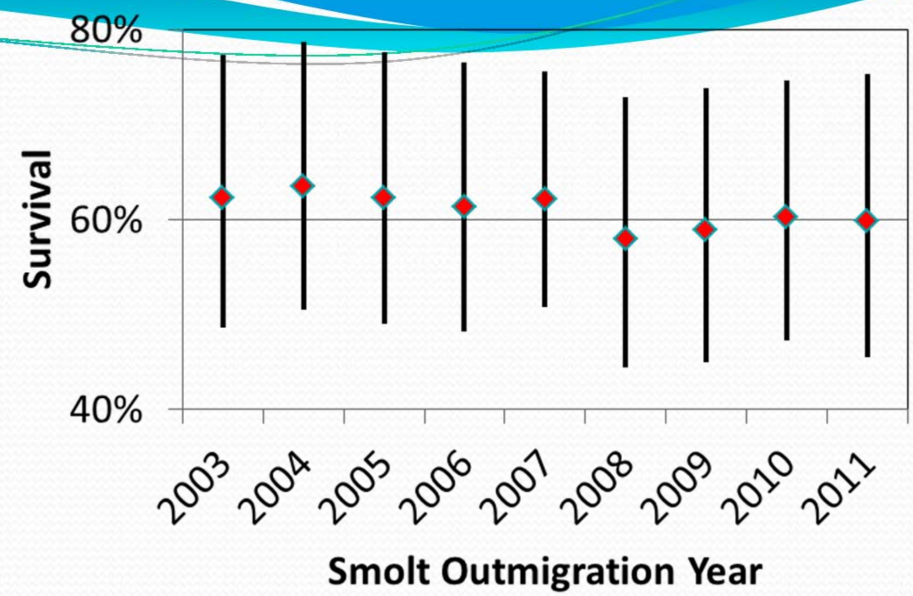


Parr to Smolt Survival
25%
13%
0%
Survival
2003
2004
2005
2006
2007
2008
2009
2010
2011
Smolt Outmigration Year
Smolt Survival, Wind to BON
100%
85%
70%
Survival
2003
2004
2005
2006
2007
2008
2009
2010
2011
Smolt Outmigration Year
Smolt to Adult Survival,Est-BON
20%
10%
0%
Survival
2003
2004
2005
2006
2007
2008
2009
2010
2011
Smolt Outmigration Year
Smolt Survival, BON to Est
100%
80%
60%
Survival
2003
2004
2005
2006
2007
2008
2009
2010
2011
Smolt Outmigration Year

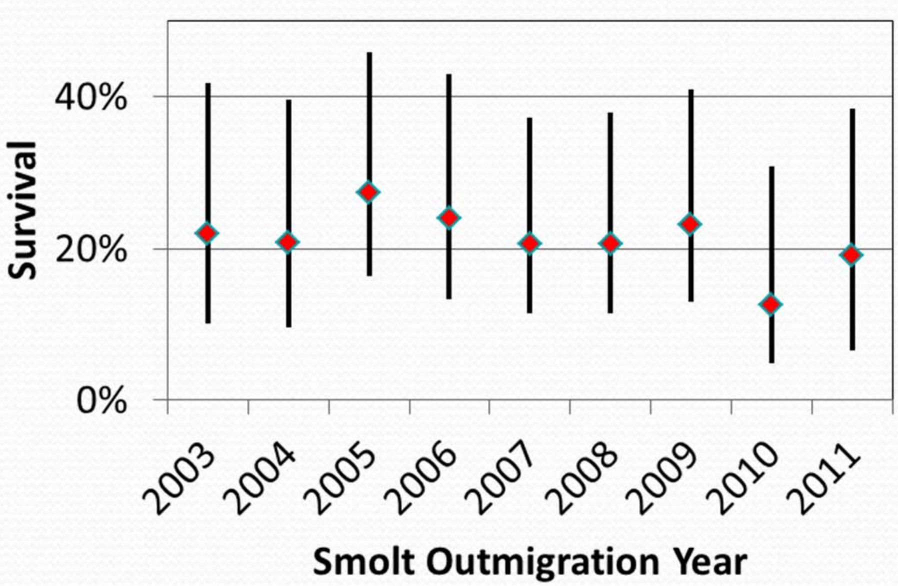
Adult Survival, BON to Wind



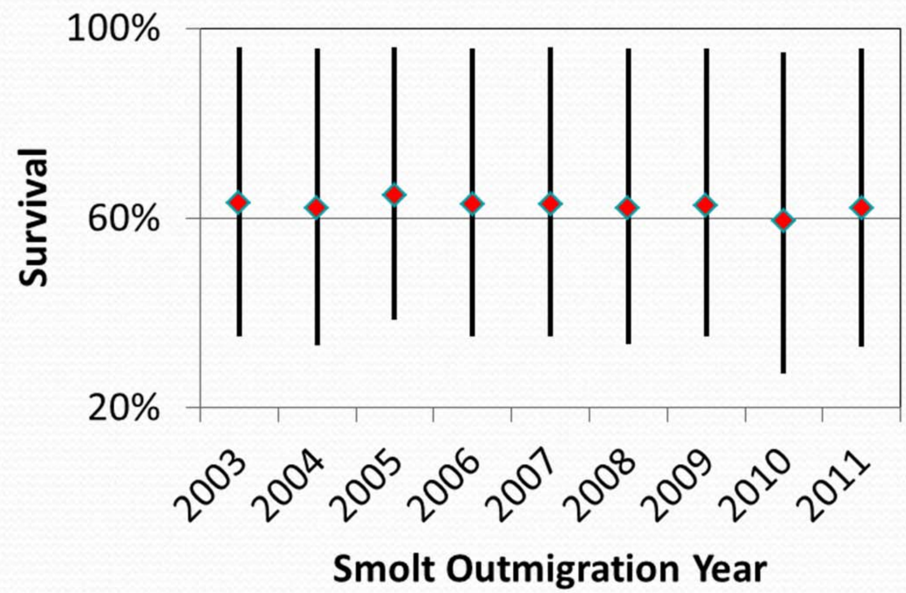
Ad/Kelt Survival, Wind-BON



Repeat Spawner, Est to BON



Kelt Survival, BON to Wind



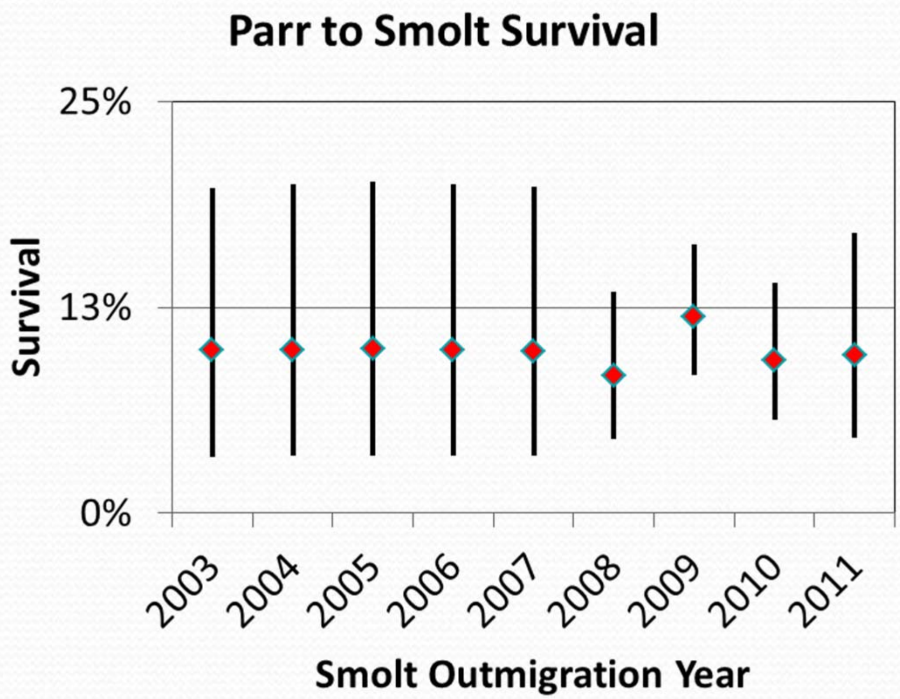
CJS Assumptions

- Every marked fish present at sampling period *i* has the same prob. of capture (*p*). Every marked animal present at sampling period *i* has the same prob. of survival (ϕ) to the next period.
  - Based on omnibus Bayesian GOF test (*P*-values [0.07-0.68], median = 0.42) assumption is met. Similar GOF tests in the program MARK.
- Marks are not lost/overlooked and correctly reported.
  - Short-term tag loss in Wind parr and smolt from double tagging experiments ~1%.
  - Knudsen et al. (2009) identified tag loss and mortality (2% juveniles & 18% adults) with PIT tags for hatchery spring Chinook salmon; so our survival estimates are likely biased low through adult stage at BON if Knudsen results are applicable to steelhead.

CJS Assumptions

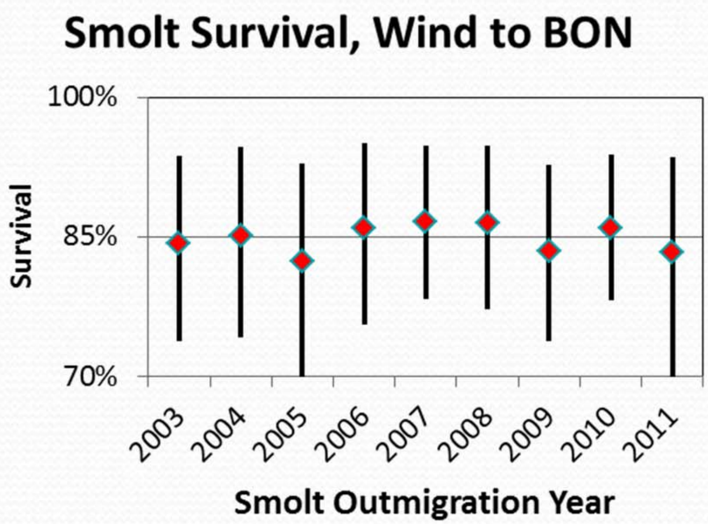
- Sampling is instantaneous and all fish are released immediately after capture.
  - Spatial model so tagging or detection site is short compared to distance between sites
  - Simulations by Hargrove and Borlund (1994) suggests parameters not too sensitive to the instantaneous sampling assumption.
- The fate of each fish with respect to capture and survival probability is independent of the fate of other fish.
  - If this assumption not met this leads to overdispersion; estimates will be unbiased but variance will be underestimated.

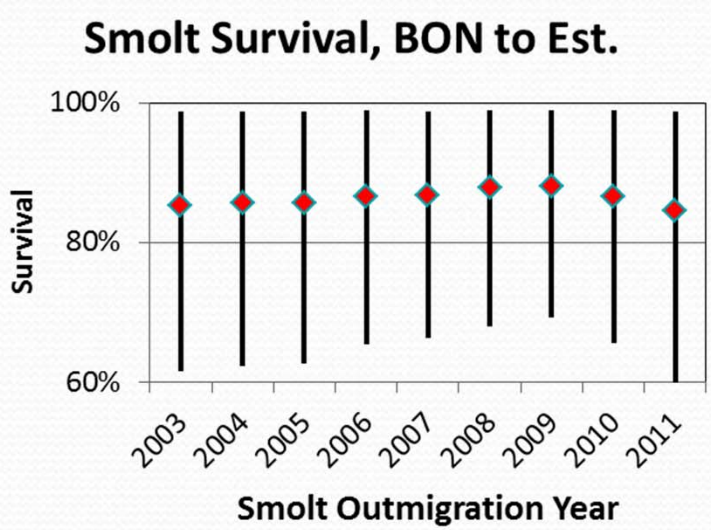
Management Implications



- Apparent survival for parr to smolt is ~ 10% for primary rearing area between upper and lower traps.
- Density dependence & parr residualization may contribute to the low survival for this life stage.
- Low survival suggest habitat restoration opportunities

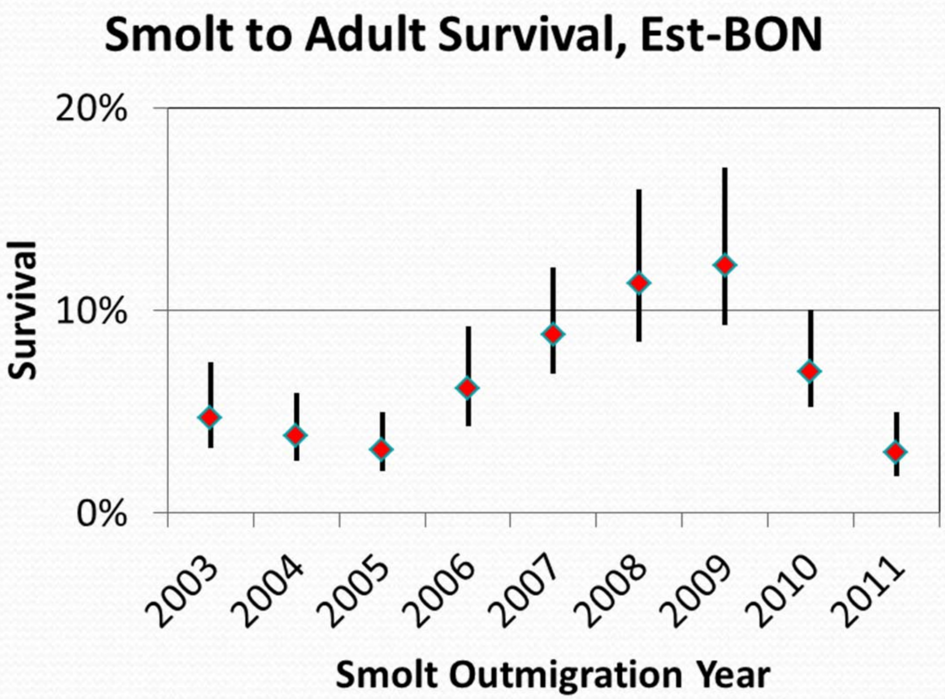
Management Implications





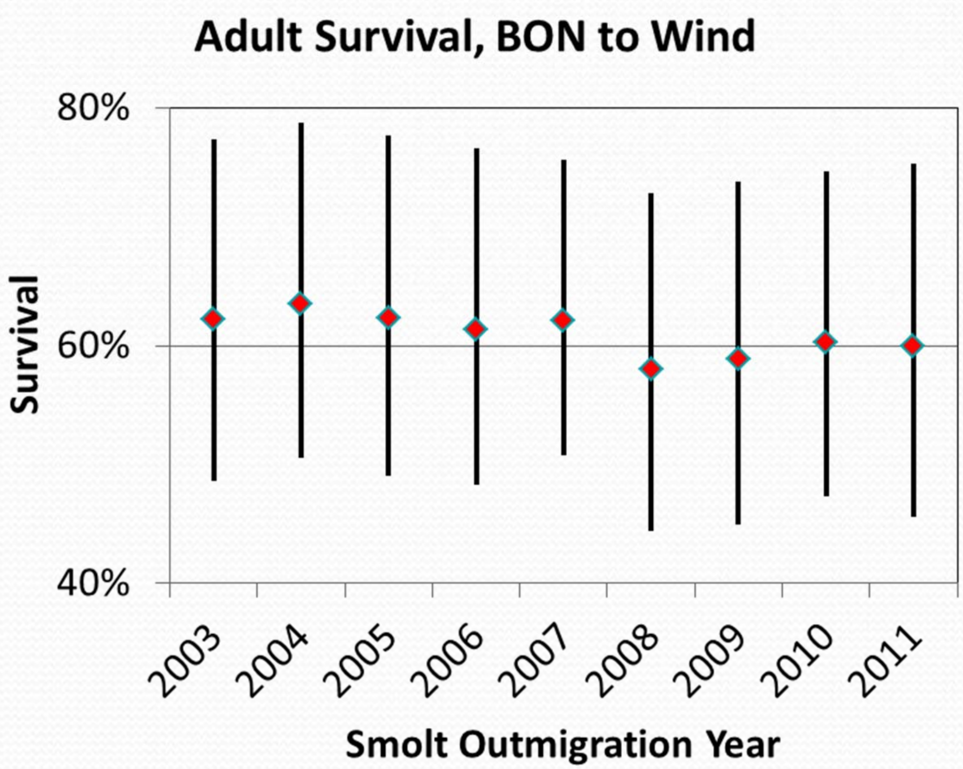
- Columbia River Survival is high from Wind to BON to Estuary
- If BON was not present survival would increase from ~85 to 89% from Wind mouth to BON area
- Survival would increase from low to high 80% if no predation from bird colonies in estuary
- Correlation between total survival and BON-Est survival had second highest correlation (0.85)

Management Implications



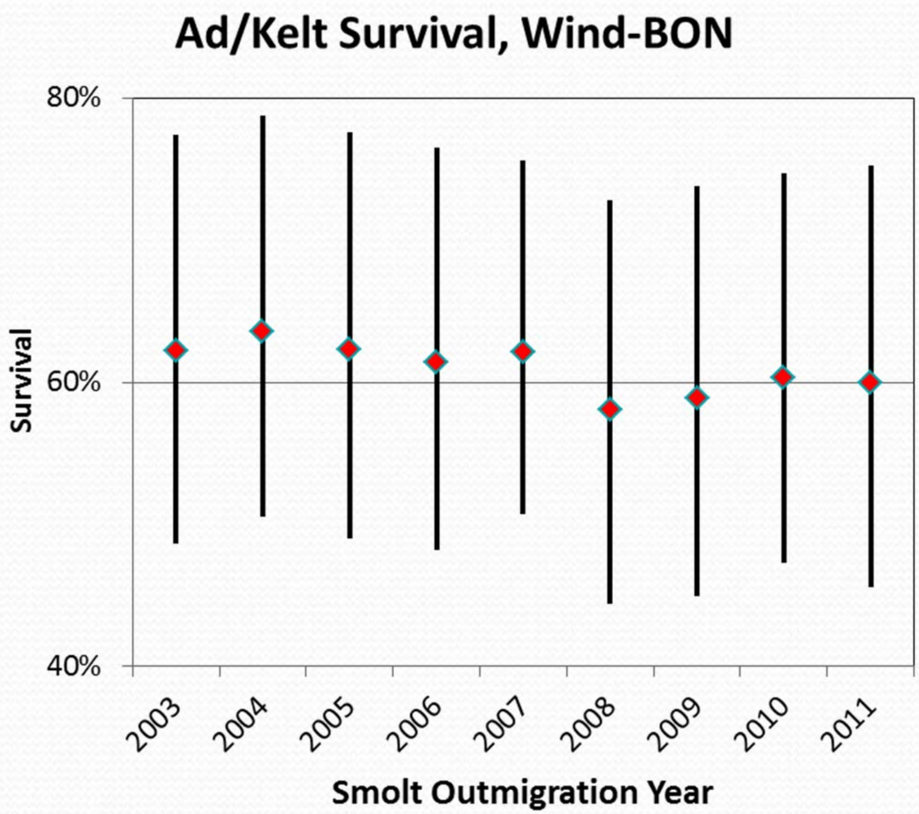
- Wind River SAR were the most variable survival parameter we measured
- Wind River SAR had highest correlation with total cohort survival (0.88).
- SAR explains most of the variation in survival from parr to repeat spawner

Management Implications



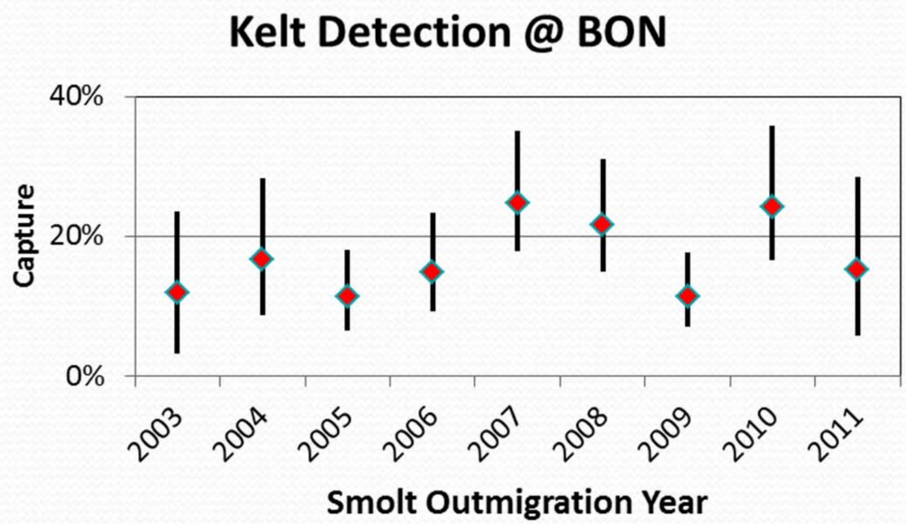
- Few Wind steelhead detections at other PIT sites
- ~37% of the Wind River steelhead do not survive the 13 miles (BON to SF).
- Wind River PIT tag Z6 fall harvest rate~ 7% in 2010 & ~12% in 2011
- Harvest rates are unknown in other Z6 fisheries and recreational wild release fisheries.
- BON pool can be in excess of 22 degrees, which exceeds the 1 & 7-day average maximum of 22 & 17 degrees

Management Implications

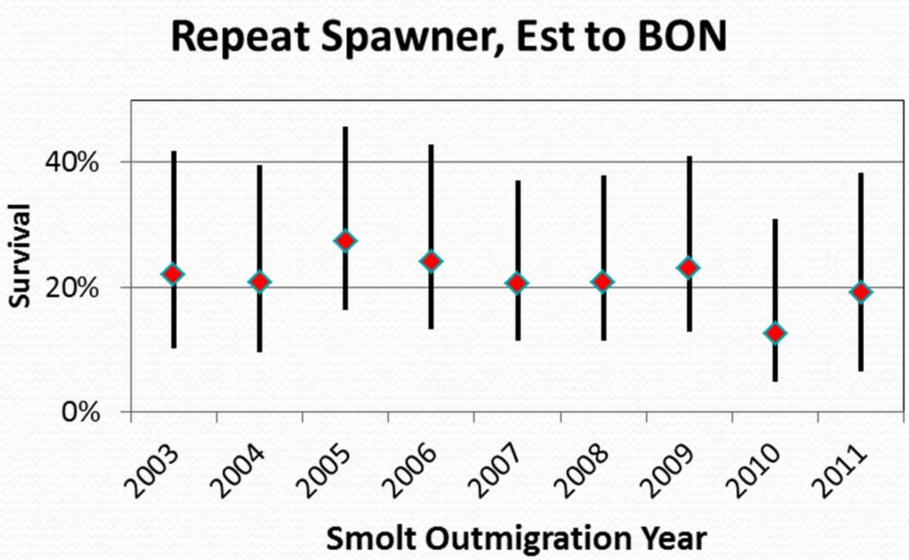


- Limited estimates of survival for this life stage for steelhead range wide
- About 60% of the steelhead survive from entering the Wind to emigrating as kelts to BON

Management Implications



- Approximately 17% (range 5% to 30%) of the kelts are detected at BON; most are detected in the corner collector or ice and trash sluiceway.



- Approximately 20% of the kelts (range 13% to 27%) survive from entry into the estuary as kelts to returning adults (repeats) at BON.

Columbia R. Kelt Survival Rates

Kelt to Adult Return (KAR)	Kelt Tag Location	Repeat Recovery Location	Reference
1%	LWG	BON	Keefer et al. 2008
6%	MCN	BON	Keefer et al. 2008
6%	JDA	BON	Keefer et al. 2008
14%	BON	BON	This presentation

- Travel Time of Kelts from Radio Tracking Studies
  - 43-54 km/day-Skeena
  - 100 km/day - Frazier
  - 99-111 km/day –Columbia @Hanford Reach
  - 13-16 km/day – Snake (Impounded)
  - 39 km/day – Upper Columbia (Impounded)

Management Summary

- Unaccounted for loss of adult steelhead is >20% between BON and Wind. If loss was reduced to zero, the population in the Wind would immediately increase >35%
  - Likely mortality sources include natural mortality, increased mortality due to temperature in BON, and unaccounted fishery mortality
- Odds of a Wind River kelt surviving to a repeat spawner are 2.5 to 14 times higher than those reported by Keefer et al. 2008.
  - Delay in travel time is likely due to difficulty in kelts locating passage routes at dams, impoundments delaying travel time, and reduced spring freshet due to water storage.
  - Delayed travel time of kelts leads to later ocean entry, which may not be synchronized with ocean food supply and environmental conditions that lead to high survival.

Summary

- CJS model is typically applied to in the Columbia River to estimate juvenile reach survival but can be used to estimate survival/mortality by life stage for anadromous fish.
- This approach allows an estimate of survival by life stages/migration periods to identify limiting stages. I have only discussed a fraction of the life cycle information available.
- When few tags are releases or when detection rates are low, hierarchical models can improved the precision of estimates given the assumption of exchangability.

Acknowledgements

- Bryce Glaser (WDFW) – project management.
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