

Breeding success of alternative male reproductive phenotypes and implications for broodstock management of Pacific salmon

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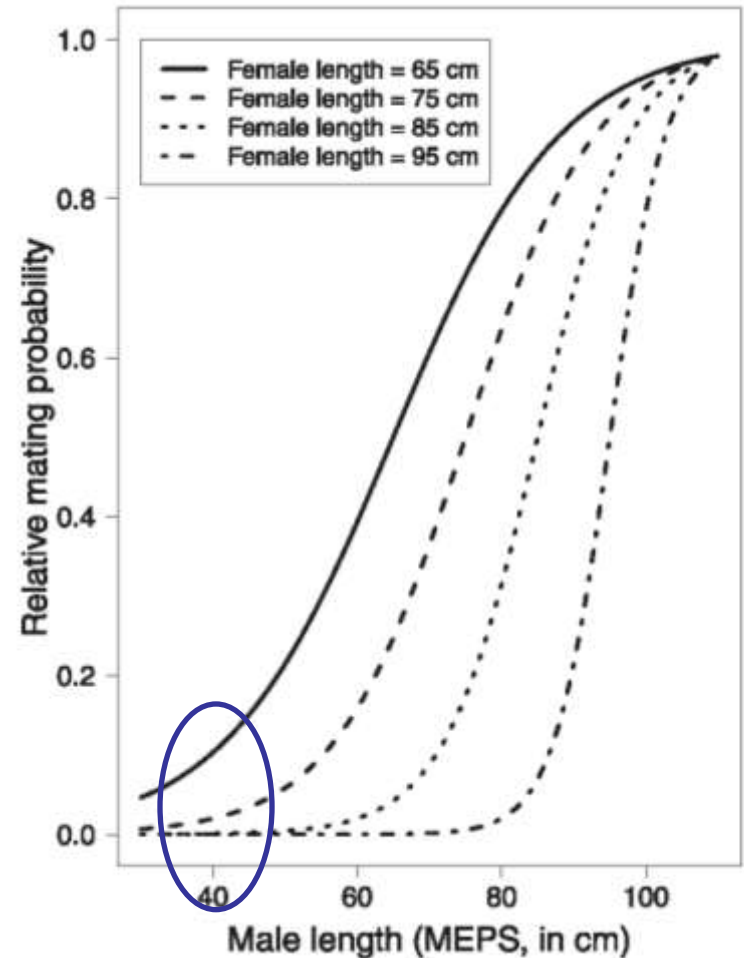


How are jacks currently used?

- Cle Elum Hatchery HGMP: Jacks (age 3 males) are currently used **in proportion to their representation in the natural population** on a broodyear basis.
- WNFH HGMP:...**all males are used at least once including jacks**. Some adult males are used twice, but no more than twice, to compensate for the differing sex ratio. Backup males are only used when a problem is noticed with the milt (blood, water, etc.).
- WDFW HEAT: The HSRG recommends jack usage according to their occurrence of **up to 10% (if available) of the total males & females** for a given spawn day. **The 2% past standard may apply** in most Chinook programs but is currently recommended as a minimum level. Other levels may be warranted...
- ODFW Lower Snake AOP: **A maximum of 10% of the eggs can be fertilized with three year old males.....**
- ODFW Elk River AOP: Adults are collected from throughout the run and spawned entirely using the full factorial matrix method. **Age composition of spawned males is 5-10% jacks.....**
- HSRG: Jacks should be spawned according to their occurrence among returning adults **up to a maximum of 10%**, with the exception of coho salmon where **a minimum of 10%** jacks among male spawners should be used.

How should jacks be incorporated in hatchery broodstocks?

- Gene flow models (HSRG 2004)
- Models based on heritability for age-at-maturity and inferred mate selection (and fishery selection; Hankin et al. 2009)
- Based on natural breeding success



Terminology

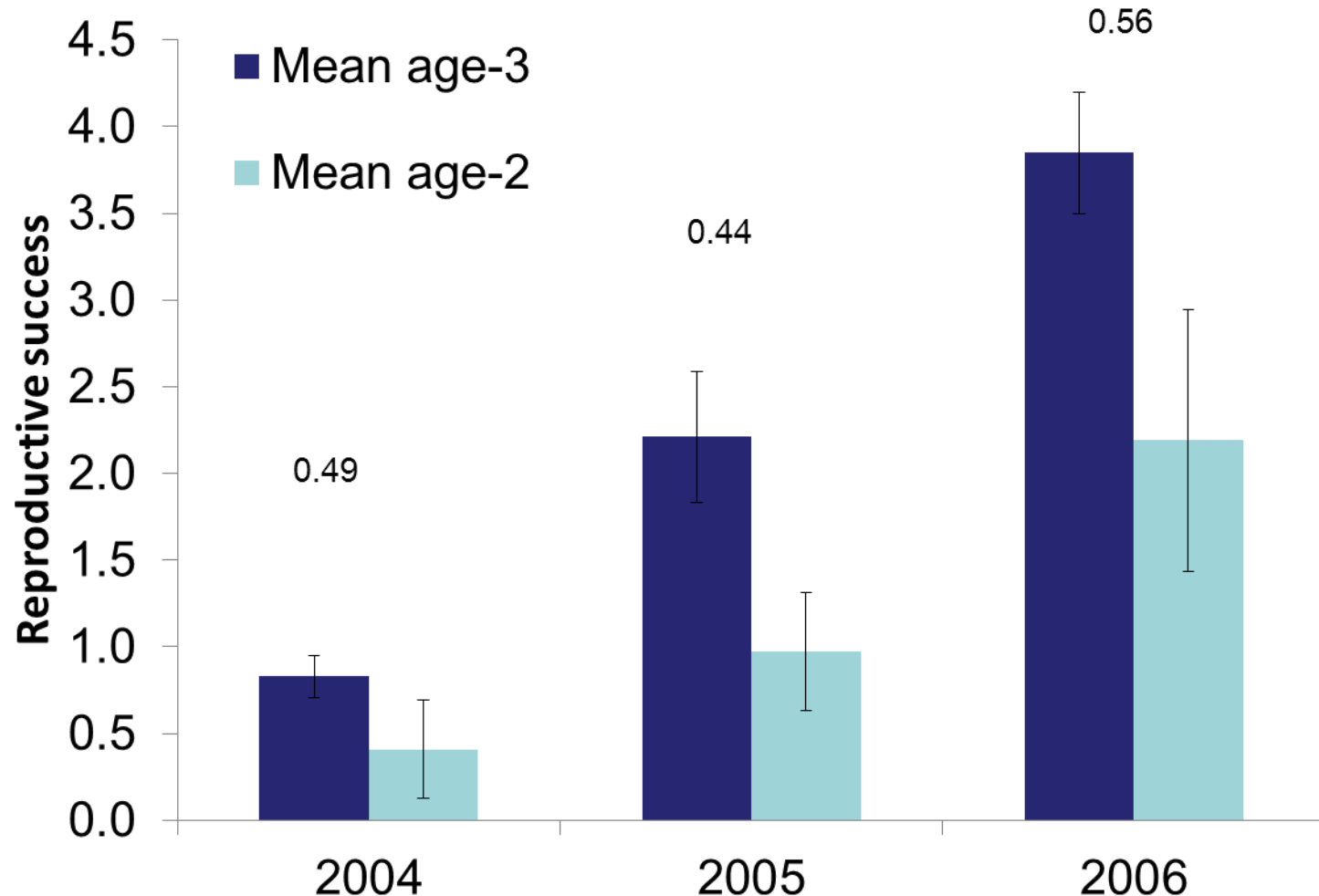
- *Breeding success (BS)*: number of juvenile offspring (fry, parr or smolt) per spawner
- *Reproductive success (RS)*: number of adult offspring per spawner
- $RBS = \text{Mean BS(jacks)} / \text{Mean BS(adults)}$
- $RRS = \text{Mean RS(jacks)} / \text{Mean RS(adults)}$

How reproductively successful
are jack males?

Sockeye salmon jack male breeding success

- Foote et al. 1997. Can. J. Fish. Aquat. Sci.
 - Compared fertilization success in small cages containing one adult and one jack male
 - Jack males fertilized 42% ($\pm 8.1\%$) of eggs in 12 spawning events ($n = 7$ jack males).
 - RBS = 0.72

Coho salmon jack male reproductive success

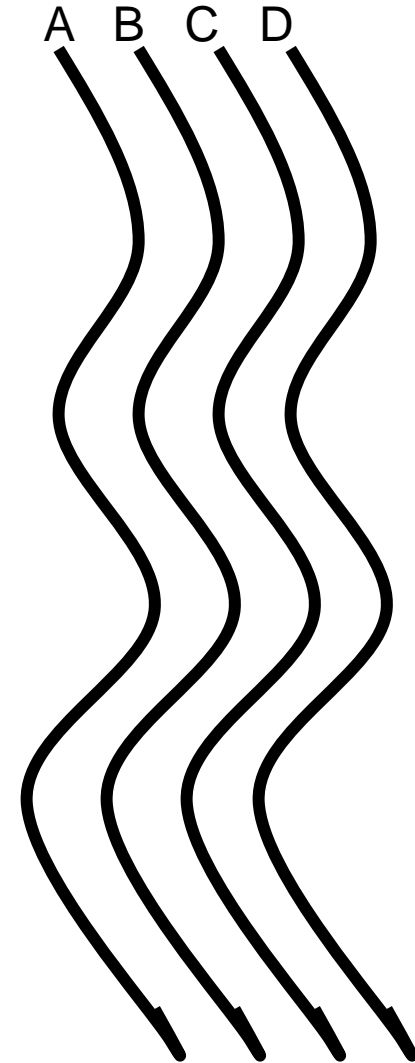


Chinook salmon jack male breeding success

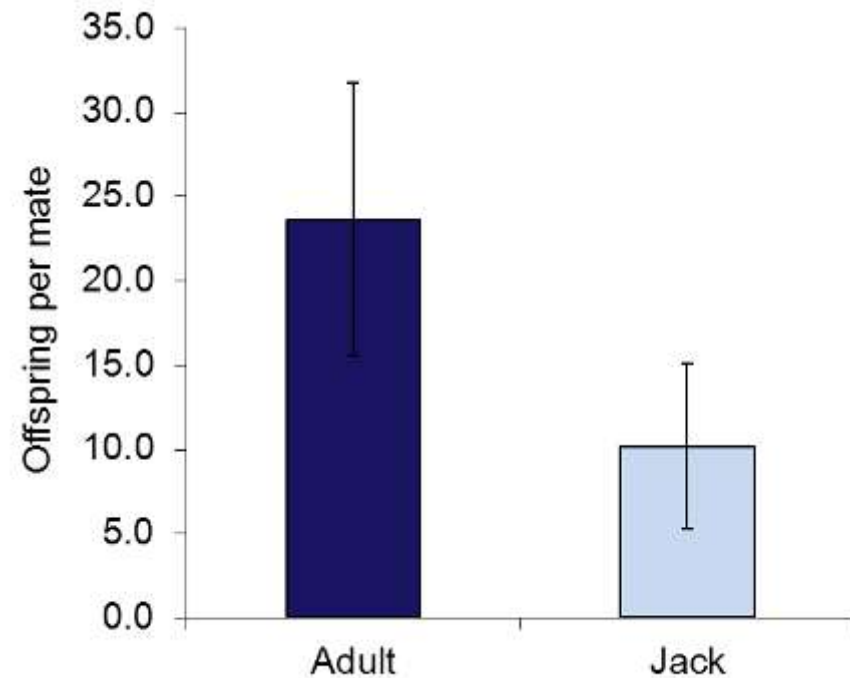
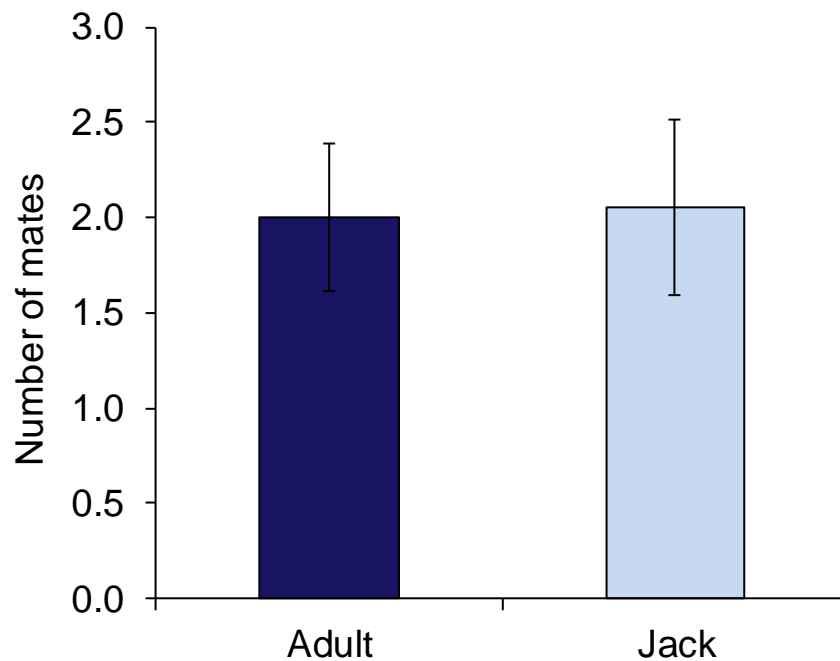
Study	Breeding groups	Jacks in population	Offspring from Jacks $f(RS \times N)$		Relative Breeding Success (BS jack/BS adult)	
			Mean	Range	Mean	Range
Berntson et al. unpubl	5	10 - 14%	7%	2 – 13%	0.61	0.22 - 1.09
Williamson et al 2010	2	10 - 61%	27%	8 - 47%	0.45	0.18 - 0.71
Schroder et al 2011	7	7 - 13%	3%	1- 5%	0.25	0.14 - 0.47
Berejikian et al 2010	4	25 - 50%	20%	9 - 33%	0.56	0.15 - 1.00
OVERALL	18	7 - 50%	14%	1 - 47%	0.50	0.14 – 1.09

Ocean-type Chinook salmon Breeding Success (Oregon Hatchery Research Center)

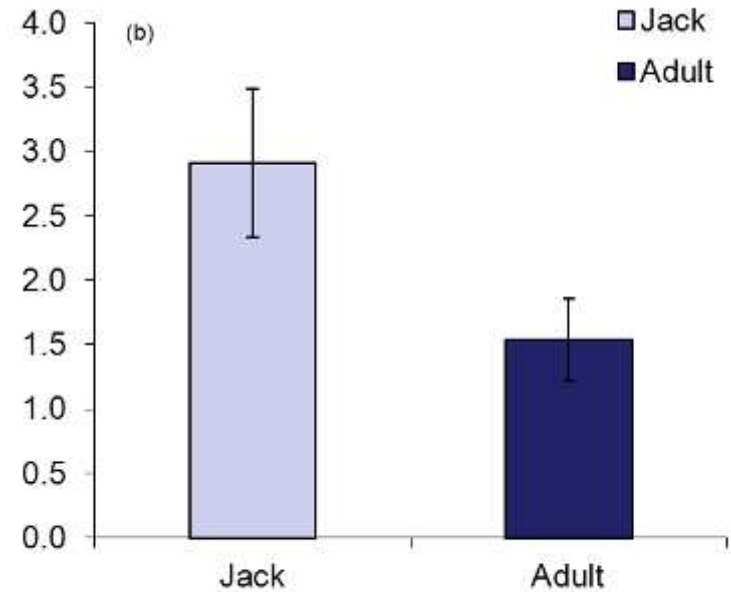
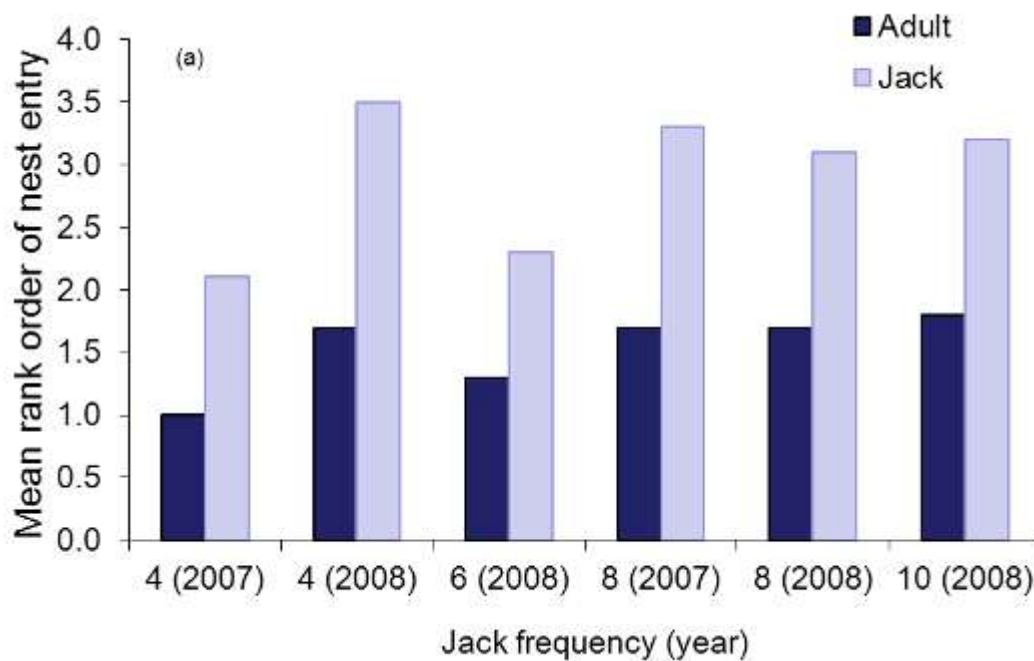
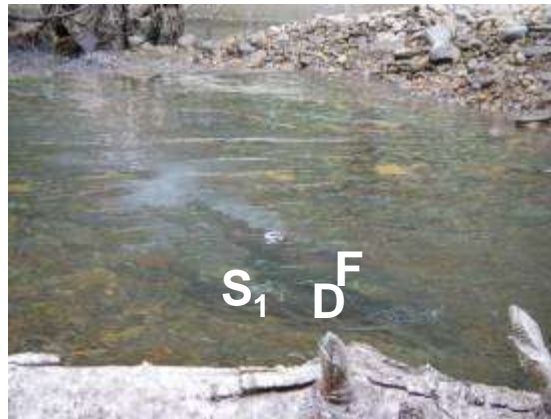
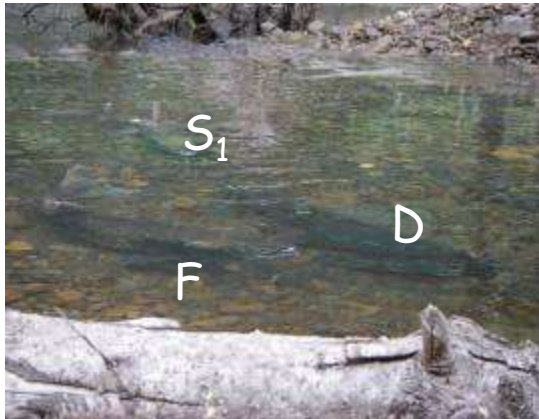
- Trask River Hatchery Chinook Salmon
- 6 ♀ + 16 ♂ into each of four replicate channels each year
- Two years = 8 breeding populations
- Variable jack frequency
- Behavioral observations (dawn to dusk)
- DNA pedigree analyses (adult to fry in 2007)
- DNA pedigree analysis within each nest (adult to embryo in 2008)



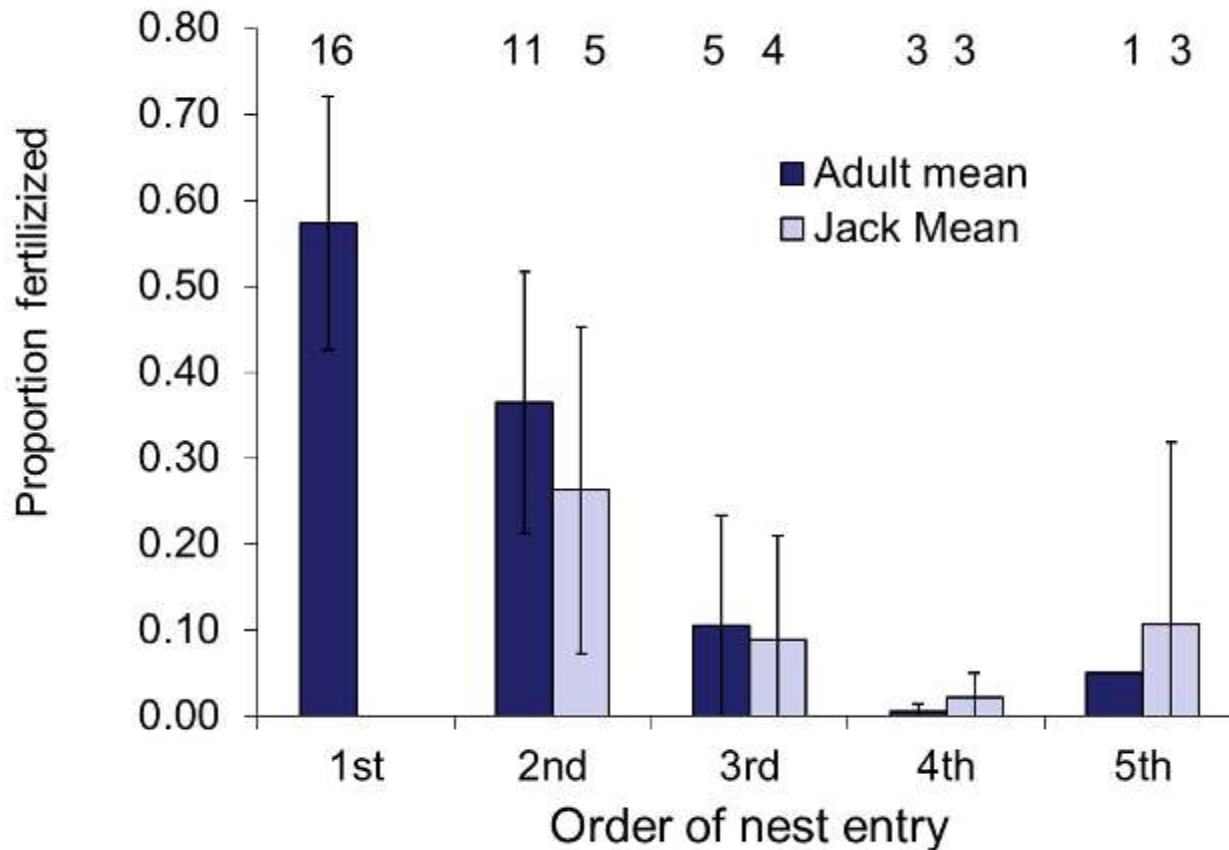
Why is jack male breeding success half that of adult males?



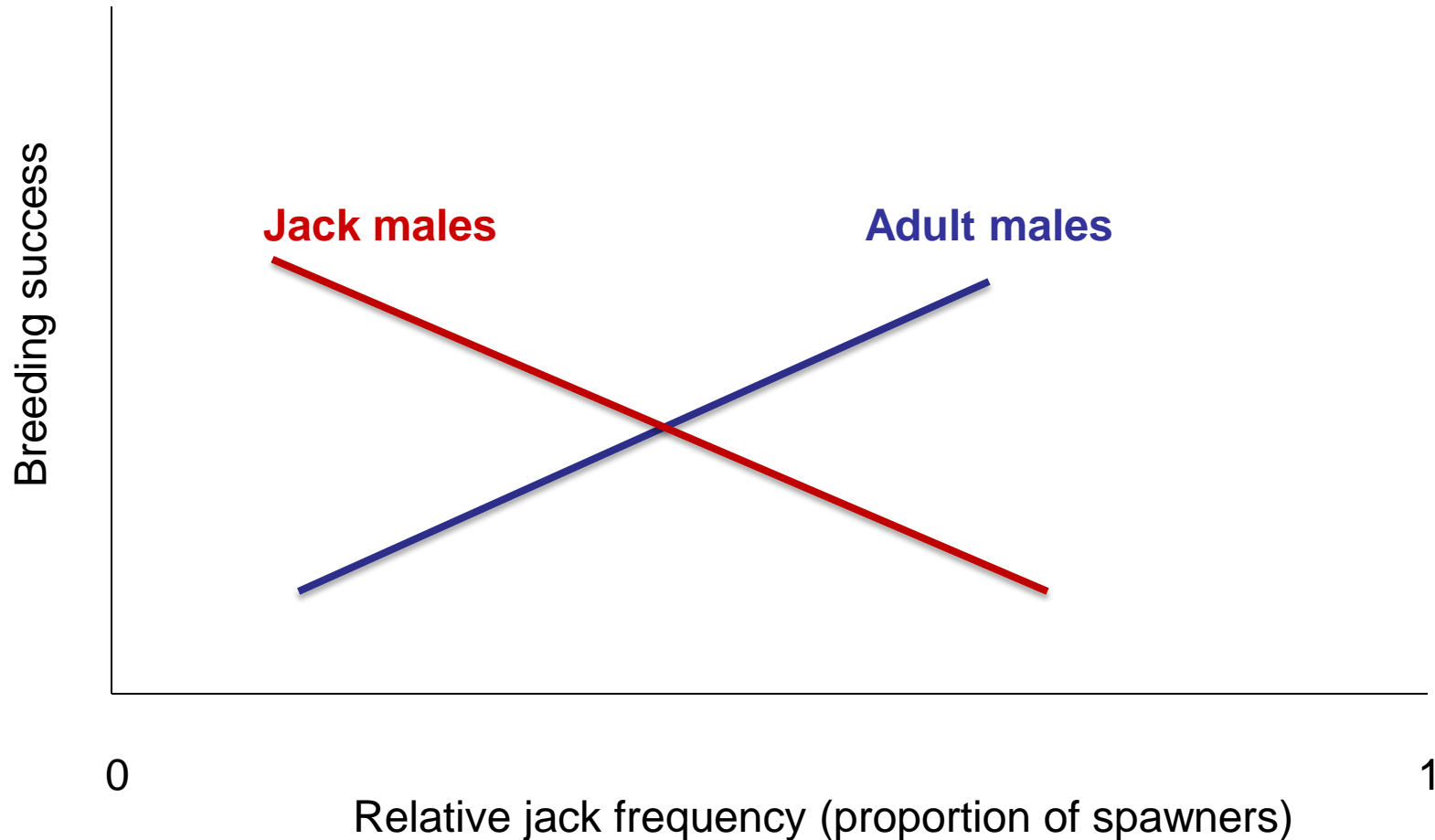
Rank order of nest entry



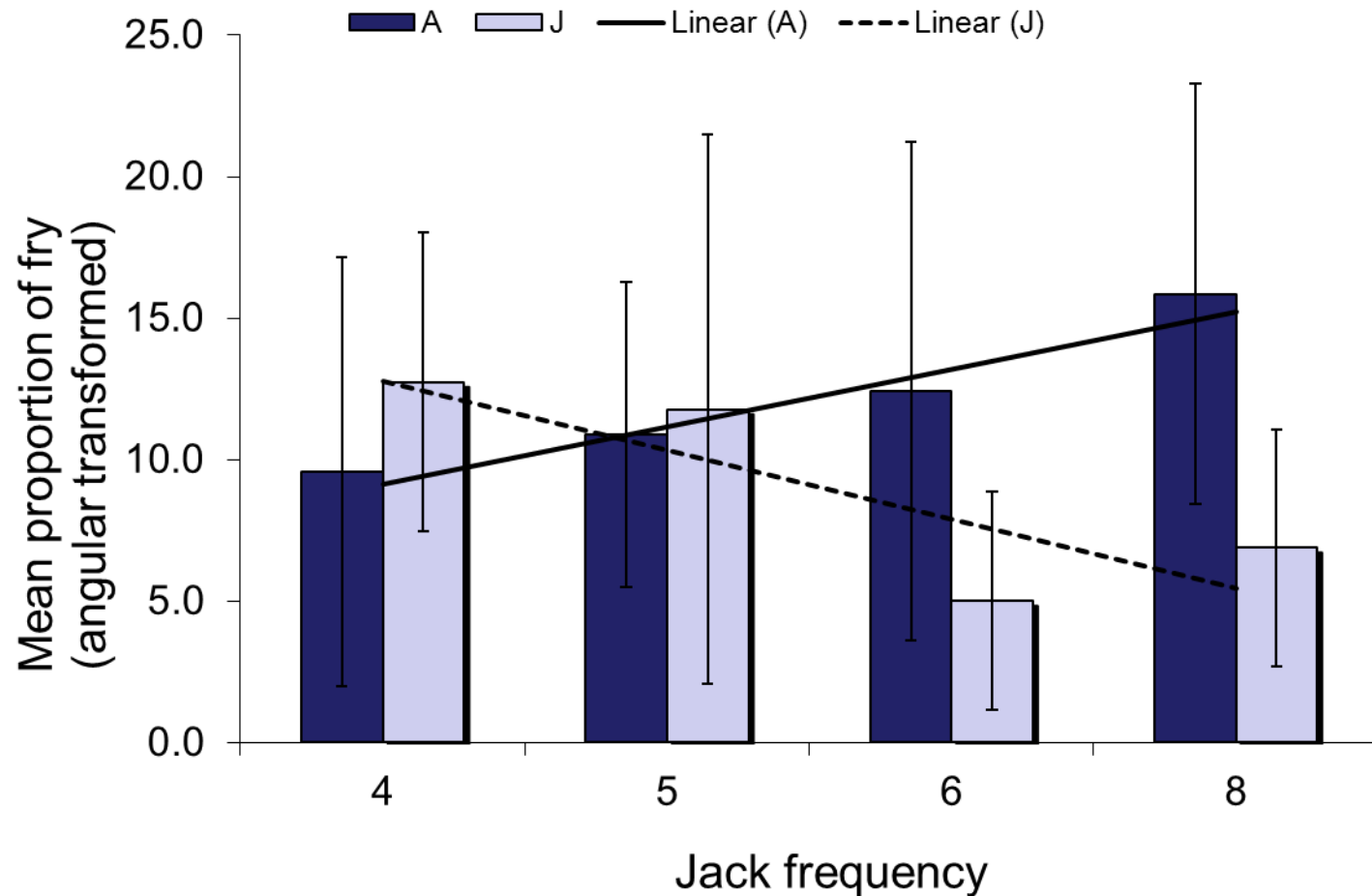
Sperm precedence



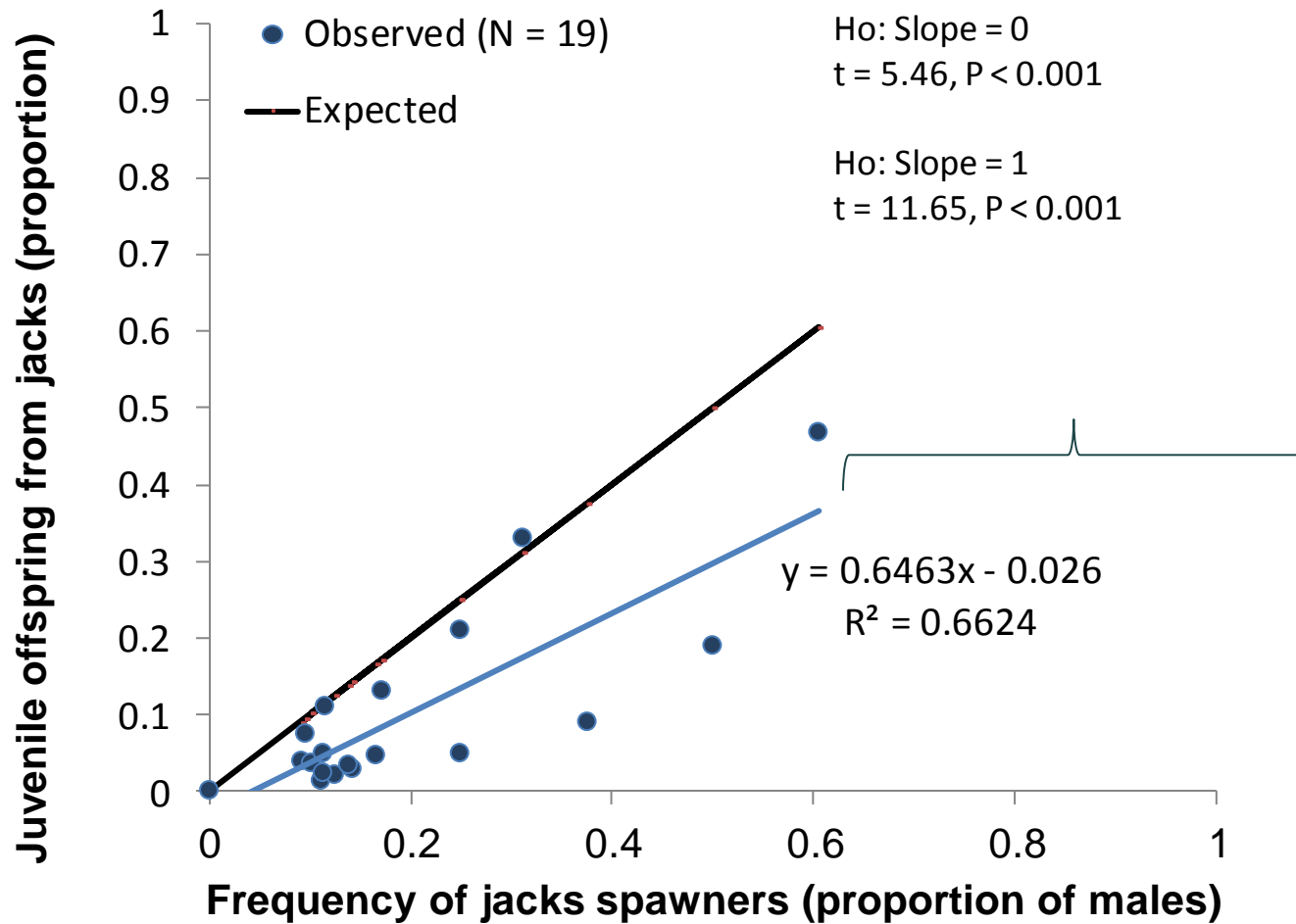
Frequency-dependent selection



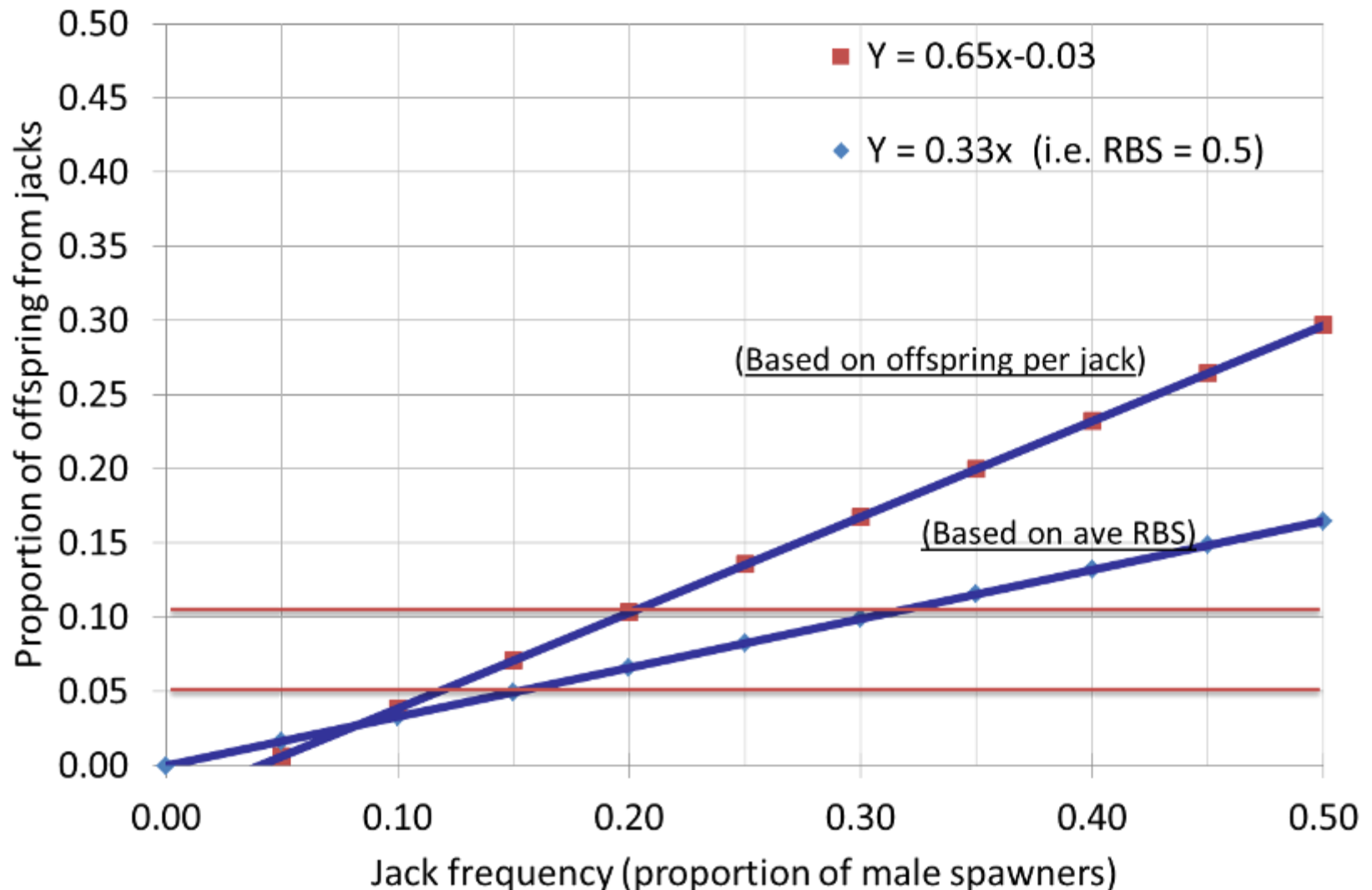
Adult to Fry Reproductive success (2007)



Further evidence of FDS?



Sliding scale for jack use in hatchery broodstocks



Summary

- Jack male breeding success > 0 under all ratios;
- Jack males participated almost exclusively by sneaking;
- Adult males have an advantage in timing of nest entry and fertilization success;
- Individual jack male breeding success is expected to
 - 1) average about half that of adult males
 - 2) decrease at higher jack frequencies
- Sliding scale approach would not be too different from many current approaches that center around 10%.
 - May fall below geneflow based guidelines at low jack frequencies
 - Would need to consider other factors (e.g., hatchery jacks = 2x wild)

Acknowledgements

- Oregon Hatchery Research Center Staff
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- NWFSC Behavioral Ecology Team
- Don Van Doornik (NWFSC), Tim Hoffnagle (ODFW), Veronique Theriault,

Some additional considerations

- Intrasexual selection acts on phenotype but genetic response to selection requires heritability for the trait (age-at-maturity).
- Density-dependence and operational sex ratios may change the nature of the frequency-dependent relationship

What's known about the BS and RS of jack males spawning naturally?

Species	Pre 2009	Current
Chinook salmon	no published data	<ul style="list-style-type: none">• Berejikian et al. 2010• Schroder et al. 2011• Williamson et al. 2010• Berntson et al. in prep
Coho salmon	Van Doornik and Teel (2002)	<ul style="list-style-type: none">• Van Doornik and Teel (2002)• Theriault et al. 2011/unpublished
Sockeye salmon	Foote et al. (1997; n = 9)	<ul style="list-style-type: none">• Foote et al. (1997; n = 9)

Berejikian et al. 2010. Can. J. Fish. Aquat. Sci. 67:1933-1941

Foote et al. 1997. Can. J. Fish. Aquat. Sci. 45: 1785-1795.

Schroder et al. 2011. Environ. Biol. Fish. doi: 10.1007/s10641-011-9789-z

Theriault et al. 2011. Molec. Ecol. doi:10.1111/j.1365-294x.2011.05058.x

Van Doornik et al. 2002. Trans. Am. Fish. Soc. 131:1007-1019

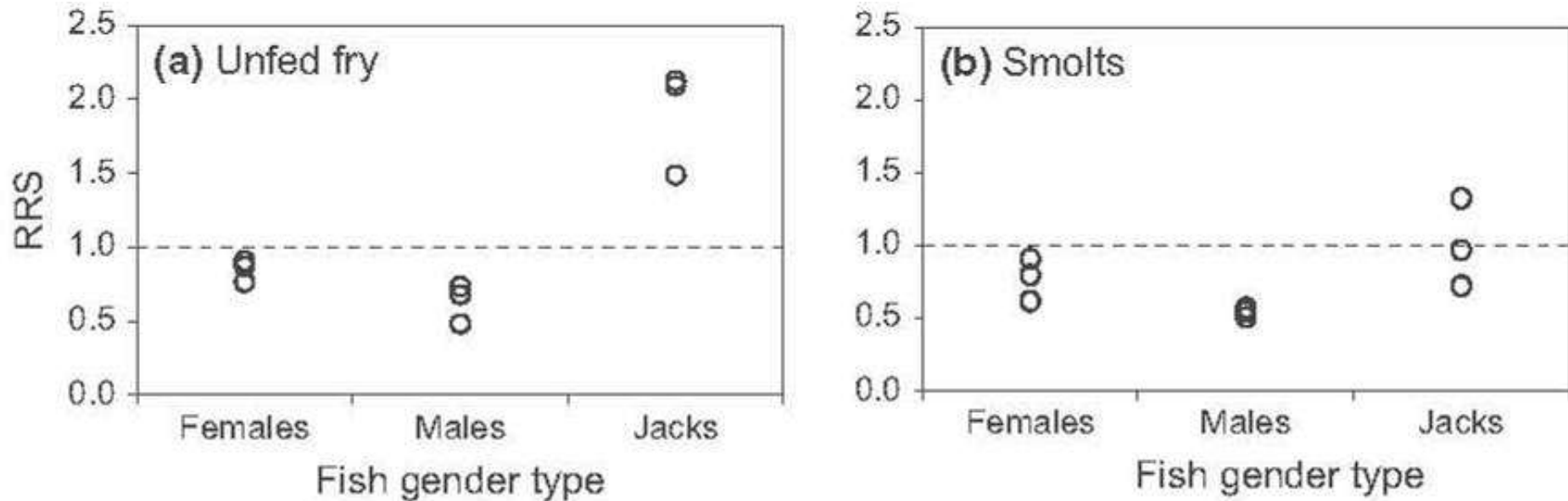
Williamson et al. 2010. Can. J. Fish. Aquat. Sci. 67:1840-1851

Coho salmon RS

Population	Reproduction	Effective proportion of age-2 (jack) breeders
Grizzley Creek (Snoqualmie R)	Natural	0.35
Ennis Creek (Samish R)	Natural	0.35
Soos Creek Hatchery (Green R)	Hatchery	0.02

Coho salmon RS

$$\text{RRS} = \text{RS}(\text{Hatchery}) / \text{RS}(\text{wild})$$

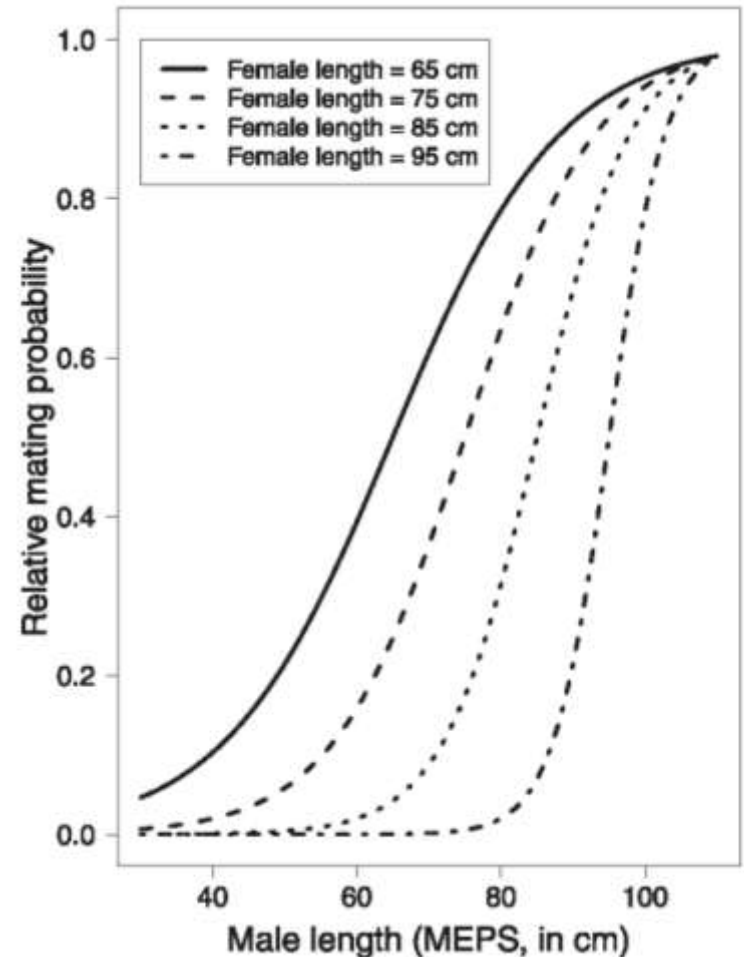


Offspring growth and survival

- Ha: Offspring of jack males will show higher growth rates than offspring of older males.
 - Why? Attainment of a size threshold at key developmental periods may trigger early male maturation.
 - However,
 - No male age effect on emergence timing or fry size (Beckman et al. TAFS 2008)
 - No male size effect on offspring growth or survival in the hatchery (Pitcher & Neff 2006) – jacks not included

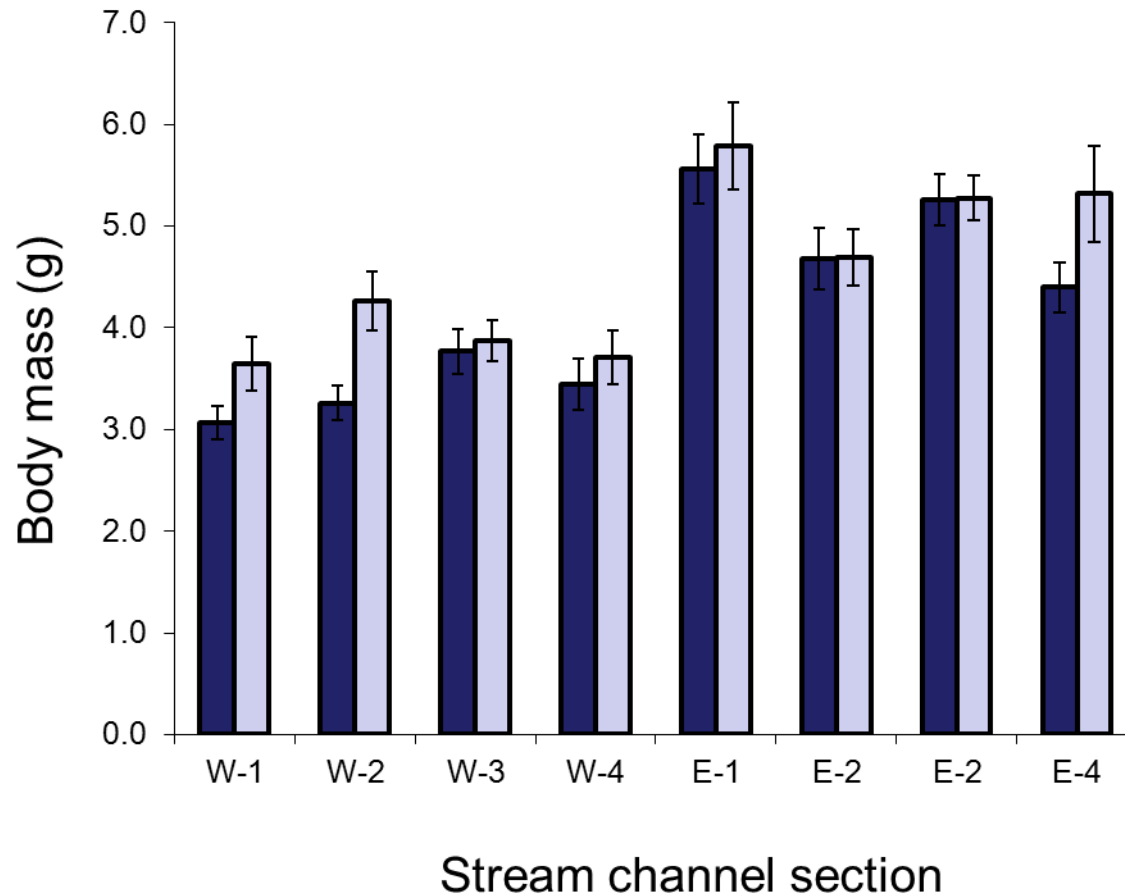
Some next steps

- Test the BS/RS of jack males at jack frequencies greater than 0.6
- Use data from the Chinook BS/RS studies to test key assumptions in the Hankin et al. 2009 model
 - Mate selection
 - Size assortative mating
 - Frequency-dependence
- How would changes in the size-dependent mating functions affect model outputs



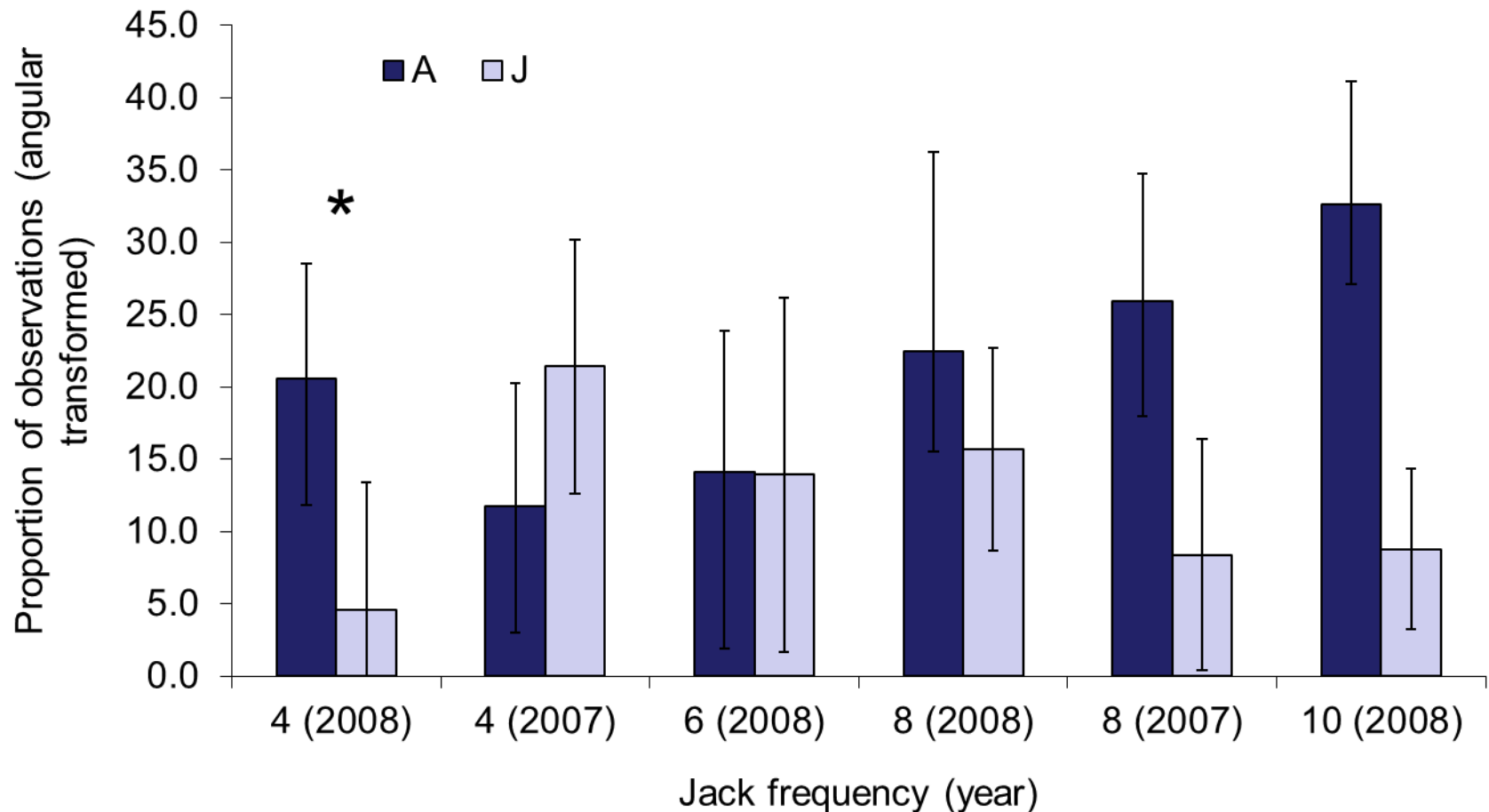
Hankin et al. 2009. Fig. 1

Offspring growth



- No effect of male type on survival
- Offspring of Jacks 0.5 to 31.2% larger than offspring of adult males ($P = 0.013$)

Observed spawning participation



Spawning observations (N = 62)

Date	Channel	# jacks	Observed spawnings	Pedigree analysis
9/13/07	A	8	9	Yes
9/06/07	C	6	3	Yes
9/06/07	D	5	2	Yes
9/13/07	B	4	10	Yes
9/04/08	C	10	11	No
9/04/08	D	8	14	No
9/11/08	A	6	6	No
9/11/08	B	4	10	No