Oceanic distribution of Chinook salmon inferred from age-specific arrival timing

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Take home message

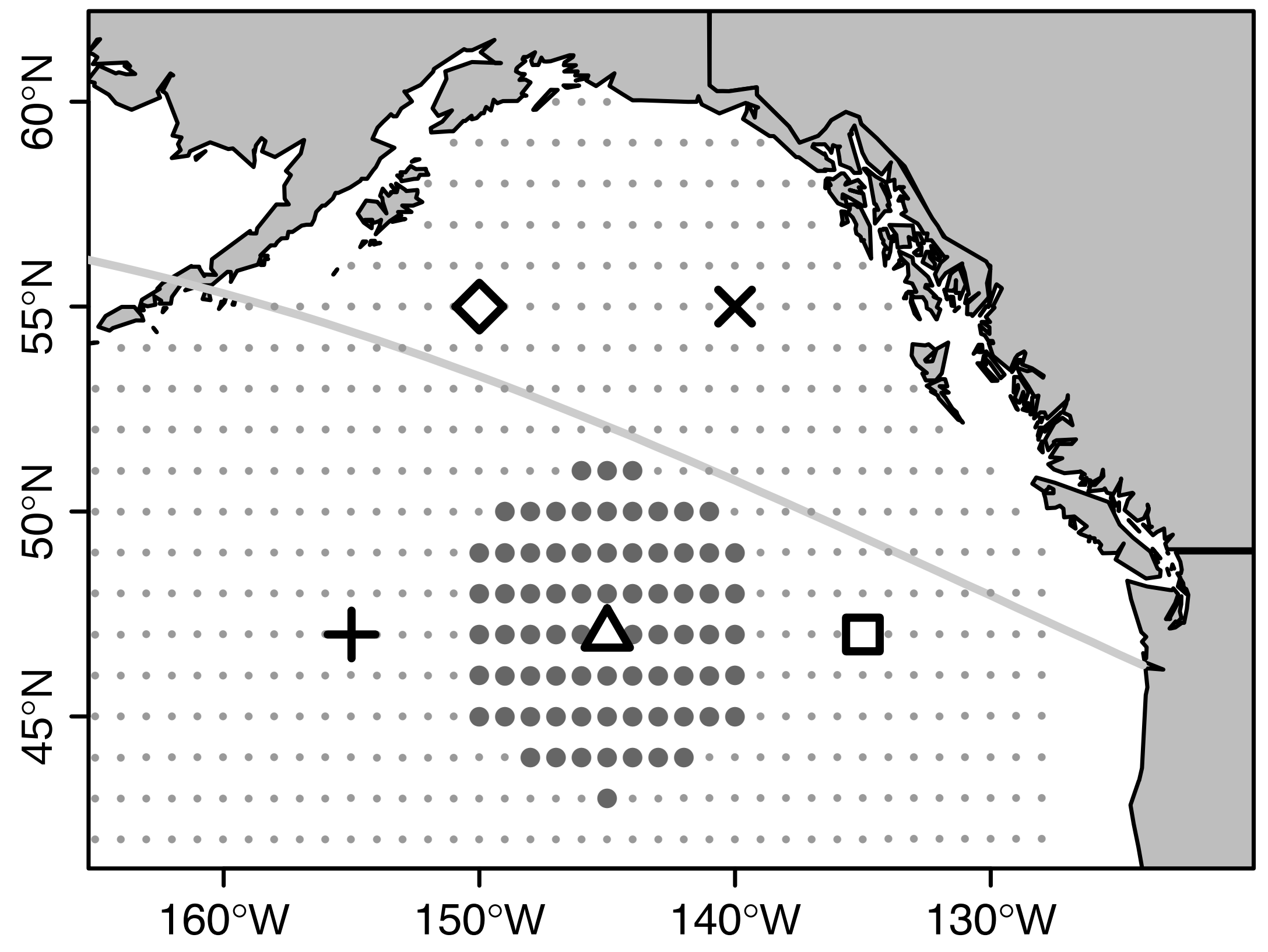
Utilizing arrival times from PIT tag data at Bonneville Dam of Columbia River spring–summer Chinook salmon *Oncorhynchus tshawytscha* as well as simulations of the geomagnetic-based homing migration with age-dependent swimming speed, we determined:

1) Populations displayed consistent ordering year-to-year, and within populations, ages displayed consistent ordering with 3-ocean first, 2-ocean fish next, and 1-ocean fish last.

2) Observed arrival time of 2- and 3-ocean fish could be explained with fish initiating migration from the same location and time in the NE Pacific Ocean.

3) Observed arrival time of 1-ocean fish could be explained with fish initiating migration from the same location and time as older fish or from a more consistent location in the northern Gulf of Alaska with some delay.

Methods



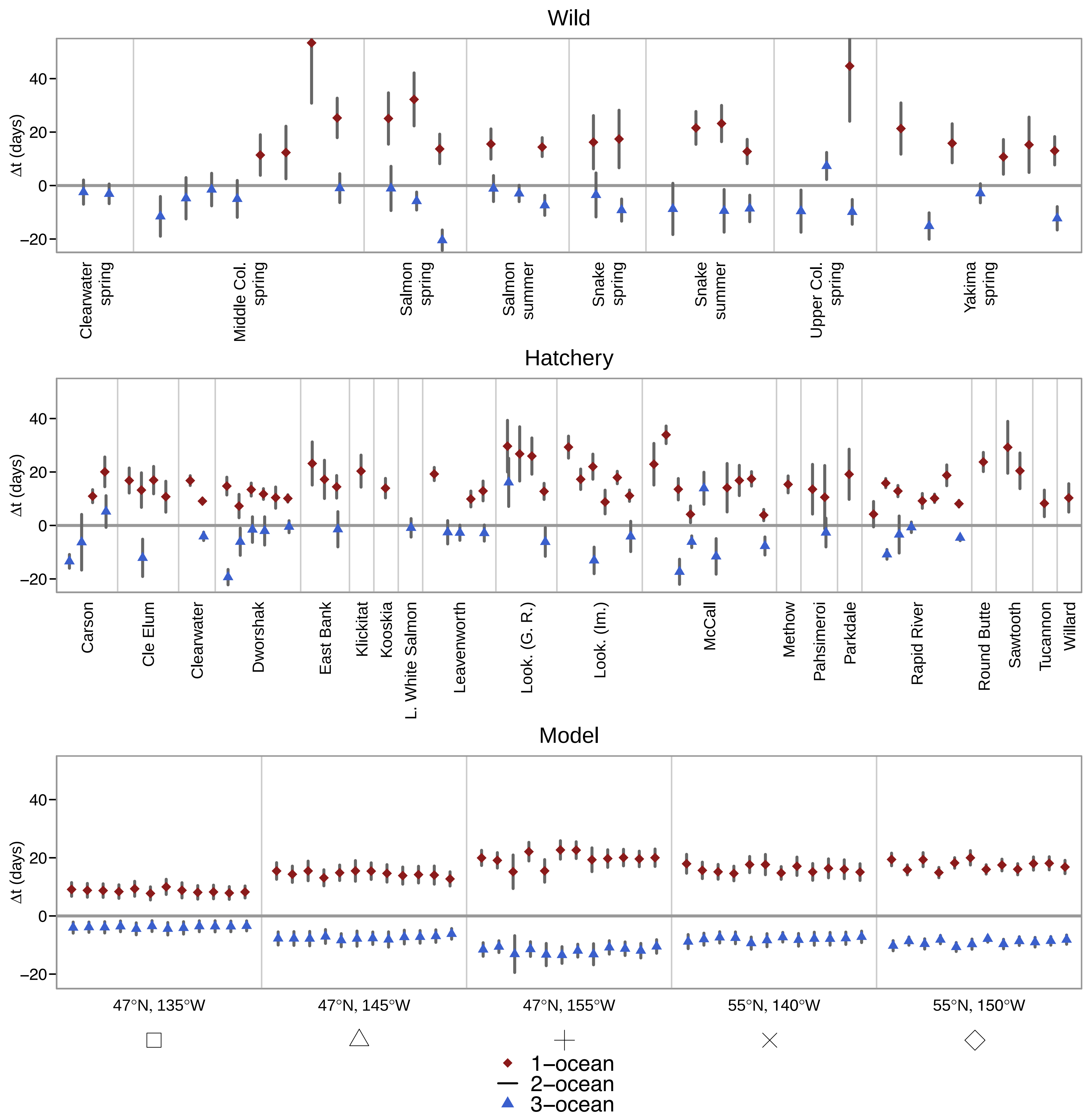
Data analysis

Using adult arrival distributions (2001–2011) of spring–summer Chinook salmon that were PIT-tagged as juveniles in the Columbia River basin, we compared consistency of population ordering among years using a randomization test and age-specific mean arrival time using unequal-variance *t*-tests.

Δ*t* = (mean arrival 1- or 3-ocean) – (mean arrival 2-ocean) for the same return year and population
positive Δ*t*: **later** relative mean arrival timing
negative Δ*t*: **earlier** relative mean arrival timing

Simulation model

In the homing migration model (Bracis and Anderson 2012), the difference between a reference geomagnetic cue, imprinted when juveniles enter the ocean, and the local geomagnetic cue guides the fish to the isoline matching the imprinted value and then along that isoline to the river mouth. We explored the effects of migration start date, location, and swim speed on age-specific arrival timing, comparing simulated arrival patterns to observed data.



Population- and year-specific difference in mean arrival timing. Points (ordered by return year) show Δ*t* with 95% confidence intervals for t-tests comparing 1-ocean and 3-ocean fish with 2-ocean fish.

3-ocean fish nearly always arrived before 2-ocean fish, and 1-ocean fish nearly always arrived after 2-ocean fish.

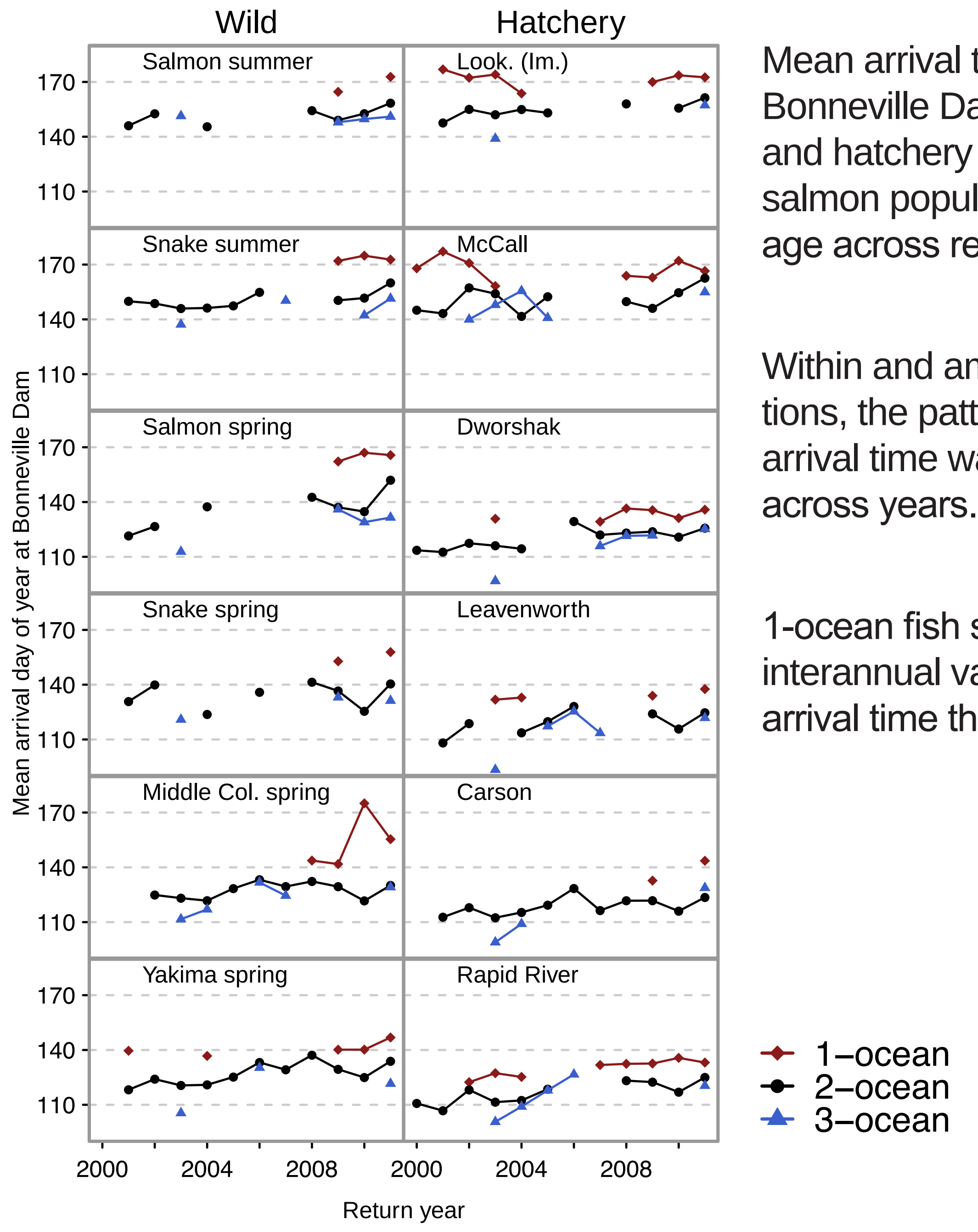
Δ*t* was generally larger for 1-ocean fish than for 3-ocean fish.

The simulation model, using age-dependent swim speeds and with all ages started from the same starting region, produced an arrival pattern similar to that observed.

Additional simulations examined the difference in mean arrival timing (Δ*t*) of modeled fish starting from all combinations of start locations with different migration initiation date lags (0, ± 10 d, and ± 20 d) comparing to the approximate range of observed Δ*t* values for 1-ocean fish (0–30 d) and 3-ocean fish (−20 to 0 d).

When all ages started in the same region, small differences in start date among ages (i.e., ± 10 d) still resulted in Δ*t* values within the observed range.

1-ocean fish starting from the northeastern-most region10–20 d after 2-ocean fish also produced the observed Δ*t* magnitudes (unless the 2-ocean fish started in the region closest to the river).



Mean arrival timing at Bonneville Dam for wild and hatchery Chinook salmon populations by age across return years.

Within and among populations, the pattern of mean arrival time was similar across years.

1-ocean fish showed less interannual variability in arrival time than older fish.

	Wild			Hatchery		
Age class	A	*n*	p̂	A	*n*	p̂
1-ocean	0.81	27	0.01	0.89	238	<0.01
2-ocean	0.90	468	<0.01	0.84	805	<0.01
3-ocean	0.87	53	<0.01	0.79	39	0.01
Across ages	0.87	1351	<0.01	0.85	3013	<0.01

$$\text{arrival order agreement } A = \frac{\text{number of agreements}}{\text{number of comparisons}}$$

The number of agreements is the sum (over all pairs of populations) of the number of years in which a pair of populations arrived in the same order. The estimated *p*-value (p̂) was obtained by performing a randomization test; *n* indicates the number of comparisons for which data were available.

Future directions

The homing migration model could be applied to other populations (e.g., Bristol Bay or Fraser River sockeye) with more complicated migration trajectories to evaluate possible behavior rules as well as ocean conditions associated with the pre-migration oceanic distribution. It could also utilize limited empirical data on salmon's geomagnetic sensing capabilities to evaluate the impact of differing capabilities on migration success.

Further information

Please contact Chloe Bracis at cbracis@uw.edu or visit http://students.washington.edu/cbracis.

Bracis, C. & Anderson, J.J. 2012. An investigation of the geomagnetic imprinting hypothesis for salmon. Fisheries Oceanography 21:170–181.
Bracis, C. & Anderson, J.J. 2013. Inferring the relative oceanic distribution of salmon from patterns in age-specific arrival timing. Transactions of the American Fisheries Society 142:556–567.

Acknowledgements

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