Shifts in Southern Resident Killer Whale Phenology in the Salish Sea

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Introduction

Phenology, or the timing of biological activities such as migration, growth, and reproduction, can have dramatic implications for fitness (citations). When out of step with resources, phenology can cause increased mortality (cite geese migration paper) or reduced reproductive success (caribou paper). The critical nature of these "matches" or "mismatches" was originally described for fish and zooplankton (citation), and have been received renewed scientific interest as phenological shifts have been increasingly observed in conjunction with recent climate change (Durant et al., 2007).

Despite its importance, phenology of many organisms, even those of conservation concern, remains poorly understood and is rarely quantified, especially for marine organisms. A recent meta-analysis found that shifts in marine phenology are at least as dramatic as those observed in terrestrial systems (e.g. XX days per decade) (Poloczanska et al., 2013). Though abundance of critical resources is more often a focus of natural resource management, the timing of resource peaks can be more important for consumers (Hipfner, 2008).

Southern resident killer whales (SRKWs, Orcinus orca)) are a federally endangered population, and have received widespread scientific and public attention in recent years as their numbers have declined(e.g., seattle times articles, Lusseau et al., 2009; Larson et al., 2018; Olson et al., 2018). SRKWs differ from many orca whales in that their primary prey are salmon (*Oncorhynchus* species). Insufficient prey availability is believed to be one of the primary threats to this population, along with vessel traffic and pollutants (Krahn et al., 2007; Lusseau et al., 2009; Hanson et al., 2010). SRKWs inhabit coastal waters of the western United States and Canada and their use of the Salish Sea varies seasonally across two broad areas. During the spring and summer, SRKWs can commonly be found in the upper Salish Sea (north of Admiralty Inlet, Figure 1), whereas during the winter they are more commonly seen in Puget Sound.

In recent decades, salmon abundance and phenology has shifted in the western United States (Weinheimer et al., 2017; Reed et al., 2011; Ford et al., 2006; Satterthwaite et al., 2014)(add Nelson for chinook hatchery release timing), though patterns vary by species and location. We would therefore expect SRKW phenology to have shifted during this time, if prey is a primary driver of their activity in the Salish Sea. SRKWs may be spending more time in Puget Sound (Olson et al., 2018). However, the details are unclear because monitoring effort has also increased during this time (Olson et al., 2018; Strebel et al., 2014).

Here, we seek to quantify seasonal variation in SRKW activity and the extent to which these seasonal patterns have shifted over the past four decades. Specifically, we ask:

1. Has the timing of SRKW activity (phenology) shifted in the Salish Sea?
2. If there have been phenological shifts in SRKW activity, do these shifts coincide with shifts in phenology or abundance of their prey (chinook, coho, chum salmon)?

Methods

Focal species

: Add a paragraph here detailing SRKW biology and introducing the three separate pods, as well as the two regions (define them: North= Upper Salish Sea, South = South Puget Sound)

Data

SRKW: To quantify SRKW seasonal phenology over time, we used the OrcaMaster Database for Whale Sighting Data (Whale Museum), comprised of data from five main sources, including public sightings networks (e.g., OrcaNetwork), commercial whale watch data, and scientific surveys (e.g., SPOT data from satellite tracking units) (Olson et al., 2018). We used data from 1978-2017, because prior to this time there was no dedicated effort to track SRKW presence in the region (Olson et al., 2018). We used these sighting data to quantify detection of SRKWs in the two sub-regions (Upper Salish Sea and south Puget Sound) and season (Winter– October through January; and Summer– May through September). We used these seasonal definitions because they are most aligned with mean SRKW seasonal activity patterns over time (Fig 1,Fig **??**). We also quantified number of whale days (i.e. days on which whales were observed) within a season and year for each region.

Salmon: WDFW adult salmon return data for coho, chum, chinook in XX streams OR WDFW recreational fishing data (in progress) for timing AND abundance

Need to add Fraser river timing and abundance from test fishery. Not sure if other Canadian data are reasonable

Analysis

SRKW:

We quantify pod-specific phenology for J, K, and L pods in the north versus south regions using occupancy models. Occupancy models (MacKenzie et al. 2002) can estimate jointly species presence or abundance and detection probability (the probability to detect at least one individual present at site). We parameterized the model with annual occupancy probabilities (i.e., we did not fit a dynamic model, but a multiseason model (Royle and Kery 2007). The distribution submodel distinguishes true presence or absence of pod,p, (z, a latent state) in marine area i in year t,(add equation here). We assumed zi,t to be a Bernoulli random variable. We modeled detection probability as a function of year and date, with detectability modeled as a semi-parametric, smooth function of date using flexible thin-plate spline regression modelling (Strebel et al., 2014).

We fit separate occupancy models within each region and season, for each pod, and estimated annual first-, last-, and peak detection dates with each model. We defined first-detection date as the first DOY within the season when detection probability exceeded 0.5; last-detection date was the latest DOY within the season when detection probability exceeded 0.5. (Using a threshold probability lowed than 0.5 did not qualitatively alter observed trends, Figure SX.)

Add analyses of subsets of data for which effort has not changed so dramatically: Lime Kiln observations for USS; West Seattle observations for PS. <u>Salmon</u>:

We used linear regression to identify trends over time in first, median, and last dates of salmon adult migration timing. Will add more as this approach develops!

Results

We found that SRKW phenology has shifted over the past four decades, though not necessarily in a linear fashion. Across the full time span, first-detection dates have gotten earlier by XX days per decade in Puget Sound and have not shifted in the Upper Salish Sea (Fig. **??** A,B). Last-detection dates have gotten later by XX days in Puget Sound and by XX days per decade in the Upper Salish Sea (Fig. **??** C,D). Add trends in whale days.

We found that salmon abundance and phenology as also shifted, though temporal patterns varied in space. Add more!

Discussion

The timing of SRKW activity has shifted.

1. SRKWs are spending more time in Puget Sound- first dates have gotten earlier, last dates have gotten later (this is a stronger trend)
2. SRKWs are spending less time in recent years in the upper Salish Sea. Though the trend across the full time series is earlier first-detection and later last-detection dates, in the last 5-10 years, first-detection dates have gotten later in the upper Salish Sea region
3.

The timing of adult salmon returns has shifted.

1. If using stream data: Hatchery fish are returning earlier, for the most part (Need to divide up by region) (Fig. 3)
2. If using rec data: discuss trends by region in timing and abundance

If using rec data, synthesis of timing versus abundance of SRKW prey in terms of how they coincide with SRKW shifts.

Observer effort has shifted over time.

1. Its great that so many people are outside looking for whales!
2. Recommend collecting absence data too. This would allow for more robust analyses of whale distributions. Challenge is increased time/money required for database maintenance with this extra data.

Conclusion

Needs/Questions

1. Intro: make a clearer case of the urgency faced by the SRKW pop and therefore the importance of this work
2. Intro: emphasize citizen science a bit more?
3. Intro: could remove/change the question about salmon, depending on how and what data/analyses are included.

Figures

Add the following:

1. A figure that is a 3-paneled figure with the following panels:
   (a) Map of Salish Sea showing 2 seasons and habitat use areas.
   (b) Observations in Puget Sound (fall/winter) (rough versions are Fig. 1 and **??**
   (c) Observations in the upper Salish sea (spring/summer)
2. A figure comparing SRKW to salmon abundance and phenology: could be SRKW vs salmon, or plot with effect sizes for all over time (i.e. change in days/proportion per decade)

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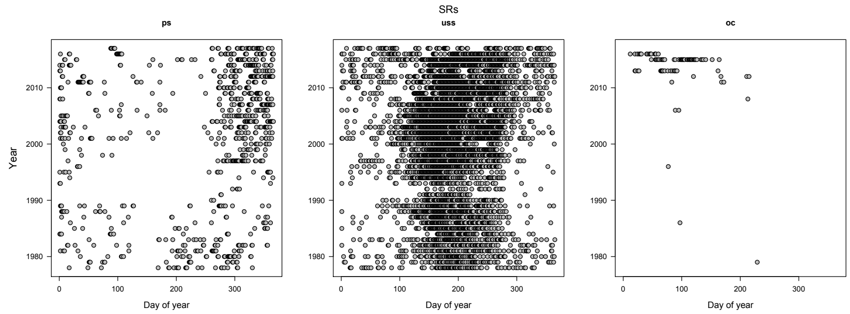

Figure 1: **Southern resident killer whale activity in the Upper Salish Sea and Puget Sound varies by season**. Need to add a map of where observations are, and make this look prettier...

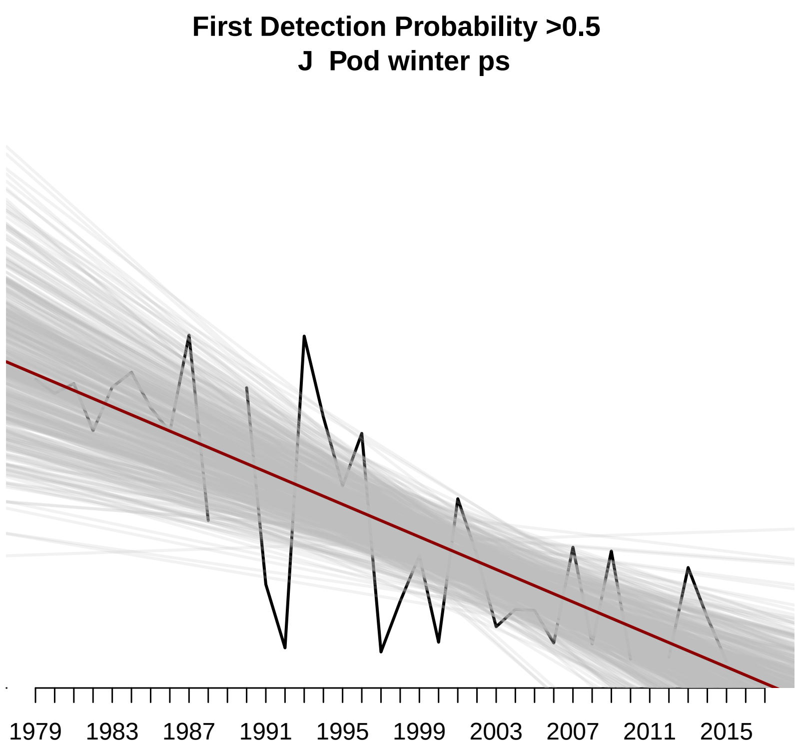

Figure 2: **Trends in first-, peak-, and last- observation dates for J, K, and L pod.** Make this a 9-paneled figure with first-, peak-, and last-detection for each pod

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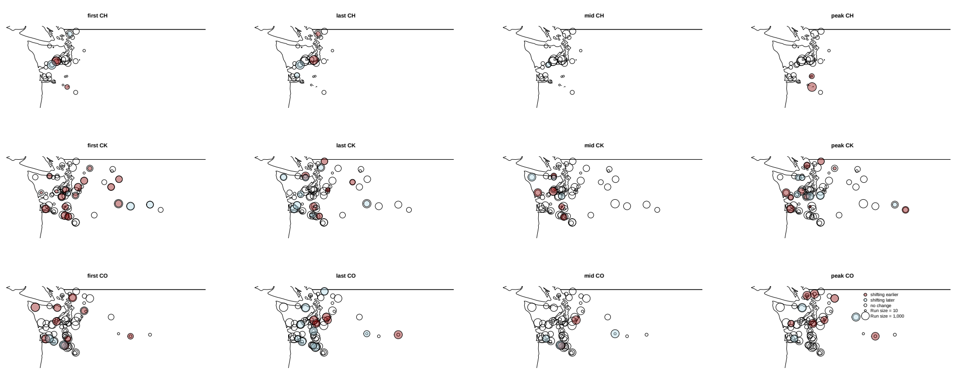

Figure 3: **Salmon return timing is shifting**, though patterns vary by stream and species.