Shifts in Orca Phenology and their Prey in the Salish Sea

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Background

1. Southern resident killer whales (SRKWs) are a threatened population, recieved much scientific and public attention.

2. SRKWs use of the Salish Sea varies seasonally across two broad areas: the upper Salish Sea (north of Admiralty Inlet, reference Map).

3. Efforts are underway to alter hatchery production to benefit orca whales, because one of the threats facing SRKWs is thought to be lack of prey. We know that SRKWs forage on chinook salmon as a primary food source (cite hanson papers), but there are lots of questions about what other species they use and how their prey varies seasonally.

4. SRKW activity is generally thought to be related to finding prey. In recent decades, salmon abundance and phenology has shifted in the Salish Sea (Weinheimer et al., 2017; Reed et al., 2011; Ford et al., 2006)(add Nelson for chinook hatchery release timing, others for abundance data), though rates 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.

5. SRKWs may be spending more time in Puget Sound (Olson et al., 2018). However, the details are unclear because monitoring effort has also increased duiring this time. Understanding how SRKW activity varies seasonally and how these seasonal patterns have shifted in recent decades will allow us to develop and test hypotheses about potential drivers of these shifts, which in turn will provide information that may be useful for management decision-making to conserve SRKWs.

6. Additionally: could make this more explicitly about changes in effort/presence-only database and citizen science.

Research Questions

Here, we ask:

1. Has the timing of SRKW activity (phenology) shifted in the upper Salish Sea and/or Puget Sound? (First observation date, Last observation date, number of days observed)

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

1. Data

   (a) To quantify orca 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 1976, there was no dedicated effort to track SRKW presence in the region (Olson et al., 2018). We used these sighting data to identify first observation day-of-year (DOY, the first date on which one or more pods of SRKWs were observed) and last observation DOY (the first date on which one or more pods of SRKWs were observed) for each sub-region (Upper Salish Sea and 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 2,Fig 3).

   (b) WDFW adult salmon return data for coho, chum, chinook in XX streams (Alternatively, may use RMIS data for coho, chum, chinook.)

2. Analysis

   (a) To identify trends over time in phenology for all SRKWs in the Upper Salish Sea and in Puget Sound, we used linear regression on first and last observation dates from 1978 through 2017. We also compared first and last observation dates across time periods (1978-1997 versus 1998-2018), using boxplots and t-tests (Fig 4 and 5), because relationships over time did not look linear and linear regression provided poor fit (Fig 7).

   (b) To estimate effects of increased effort (i.e., increased numbers of sightings over time) on trends in phenology, we simulated datasets of whale presence during two seasons equivalent to those in our dataset (summer, which was 1 May through 31 Sept, or 153 days, and fall, which was 1 October through 1 Feb, or 123 days). We used whale presence probabilities of 0.85 for the Upper Salish Sea and 0.6 for Puget Sound (the means in our dataset for each region) and kept it constant over 40 simulated years. We then created an observation dataset, in which effort (the number of observations), varied. During the low effort time period (years 1-20), the number of observations had a mean of 15 per year for Puget Sound and 104 per year in the Upper Salish Sea (matching the means for these reagions from 1978-1997 in the OrcaMaster database). During the high effort time period (years 21-40 in our simulated dataset), the number of annual observations had a mean of 39 for Puget Sound andand 133 for the Upper Salish Sea (matching those in the OrcaMAster database from 1998-2017). We then calculated first- and last- observations dates for each simulated year. We ran these simulation 100 times and calculated the difference between the low effort and high effort time periods. We compared these to the mean differences first- and last-observation daates across time periods in the OrcaMaster database, for each region, to understand whether observed changes may be due to changes in effort over time, rather than changes in orca activity (Fig ??).

   (c) To identify trends over time in phenology for each pod separately (J,K,L) in the Upper Salish Sea and in Puget Sound, we used linear regression on first-, last-, and peak detection dates estimated from pod-specific 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 $z_{i,t}$ to be a Bernoulli random variable... We modelled detection probability as a function of year and date, with detectability modelled as a semi-parametric, smooth function of date using flexible thin-plate spline regression modelling (Strebel et al., 2014).

(d) We used linear regression to identify trends over time in first, median, and last dates of salmon adult migration timing.

Results

Discussion

Conclusion

Figures

1. 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. 2 and 3
   (c) Observations in the upper salish sea (spring/summer)

2. 4- or 6-paneled figure with trends in first and last observation dates (and number of whale days?) of whales in upper Salish Sea (summer habitat) and south Puget Sound (winter habitat)

3. 6-paneled figured of Pod-specific trends in first and last observation dates puget sound and the upper salish sea (rough version is Fig. 8

References

Ford, M. J., H. Fuss, B. Boelts, E. LaHood, J. Hard, and J. Miller. 2006. Changes in run timing and natural smolt production in a naturally spawning coho salmon (oncorhynchus kisutch) population after 60 years of intensive hatchery supplementation. Canadian Journal of Fisheries and Aquatic Sciences 63:2343–2355.

Olson, J. K., J. Wood, R. W. Osborne, L. Barrett-Lennard, and S. Larson. 2018. Sightings of southern resident killer whales in the salish sea 1976–2014: the importance of a long-term opportunistic dataset. Endangered Species Research 37:105–118.

Reed, T. E., D. E. Schindler, M. J. Hague, D. A. Patterson, E. Meir, R. S. Waples, and S. G. Hinch. 2011. Time to evolve? potential evolutionary responses of fraser river sockeye salmon to climate change and effects on persistence. PLoS One 6:e20380.

Strebel, N., M. Kéry, M. Schaub, and H. Schmid. 2014. Studying phenology by flexible modelling of seasonal detectability peaks. Methods in Ecology and Evolution 5:483–490.

Weinheimer, J., J. H. Anderson, M. Downen, M. Zimmerman, and T. Johnson. 2017. Monitoring climate impacts: Survival and migration timing of summer chum salmon in salmon creek, washington. Transactions of the American Fisheries Society 146:983–995.
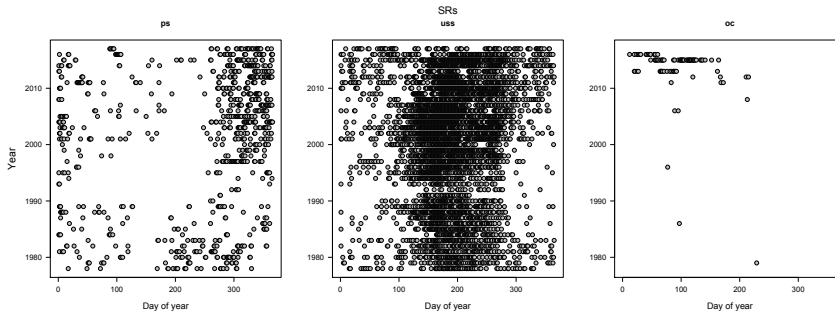
Figure 1: **Southern resident killer whale activity in the Upper Salish Sea and Puget Sound varies by season**.Need to add a map of where observations are, and make this look prettier...
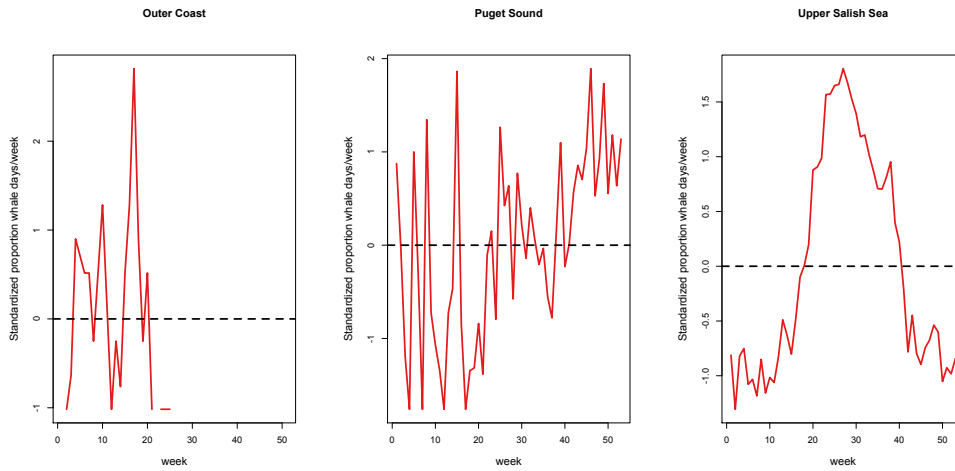

Figure 2: **Southern resident killer whale observations, in terms of proportion of days per week that whales were observed, in the Outer Coast, Puget Sound and Upper Salish Sea, varies by season**. Proportions are the mean across all years (1978-2017) and have been standardized by subtracting the mean and dividing by the standard deviation. Thus, the "0" line marks the mean proportion for that region. Weeks range from 1 (i.e., the first week in January) to 52 (i.e., the last week in December).
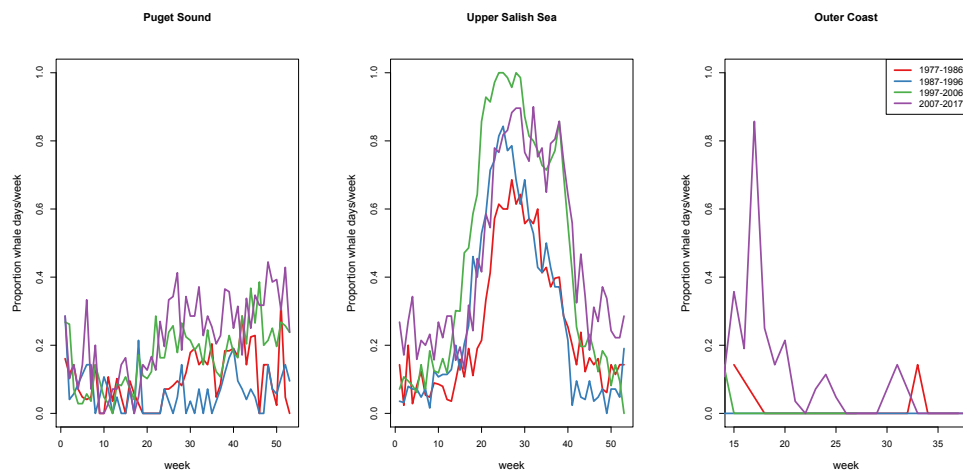
Figure 3: **Southern resident killer whale activity varies by season and region**. Lines show proportion of days per week (1 Jan= week 1) in which whales were observed in the region.
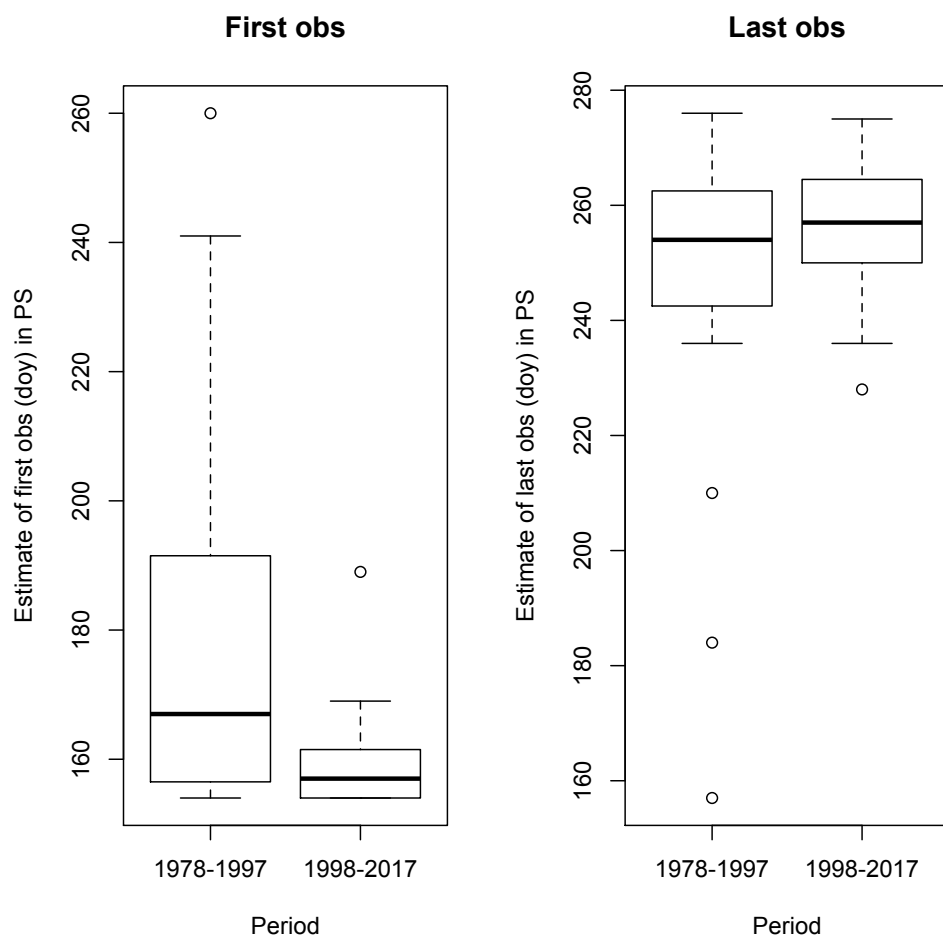
Figure 4: **Change in in first and last observation dates of SRKW in Puget Sound.**
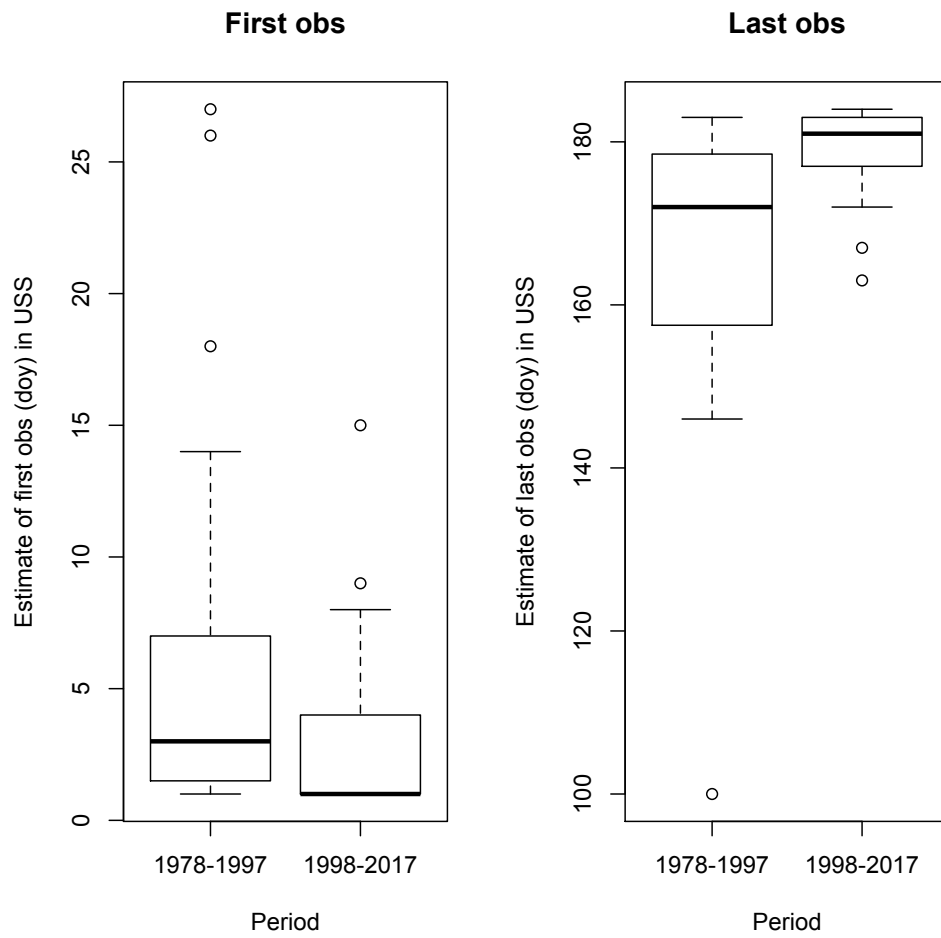
Figure 5: **Change in in first and last observation dates of SRKW in the Upper Salish Sea.**
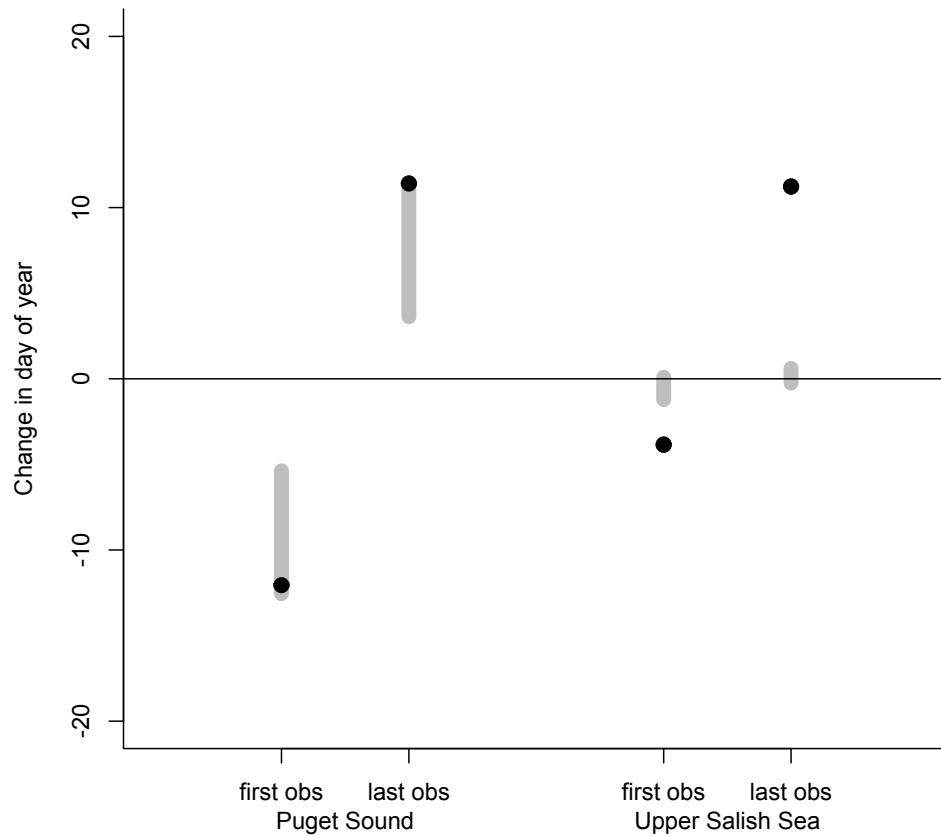
Figure 6: **Change in first and last observation dates in Puget Sound and the Upper Salish Sea.** Observed changes (black dots) are compared with expected changes due to shifts in effort alone (gray lines show 90 quantiles of from a simulated dataset resulting from shifts in effort, with the probability of SRKW presence was kept constant across time).
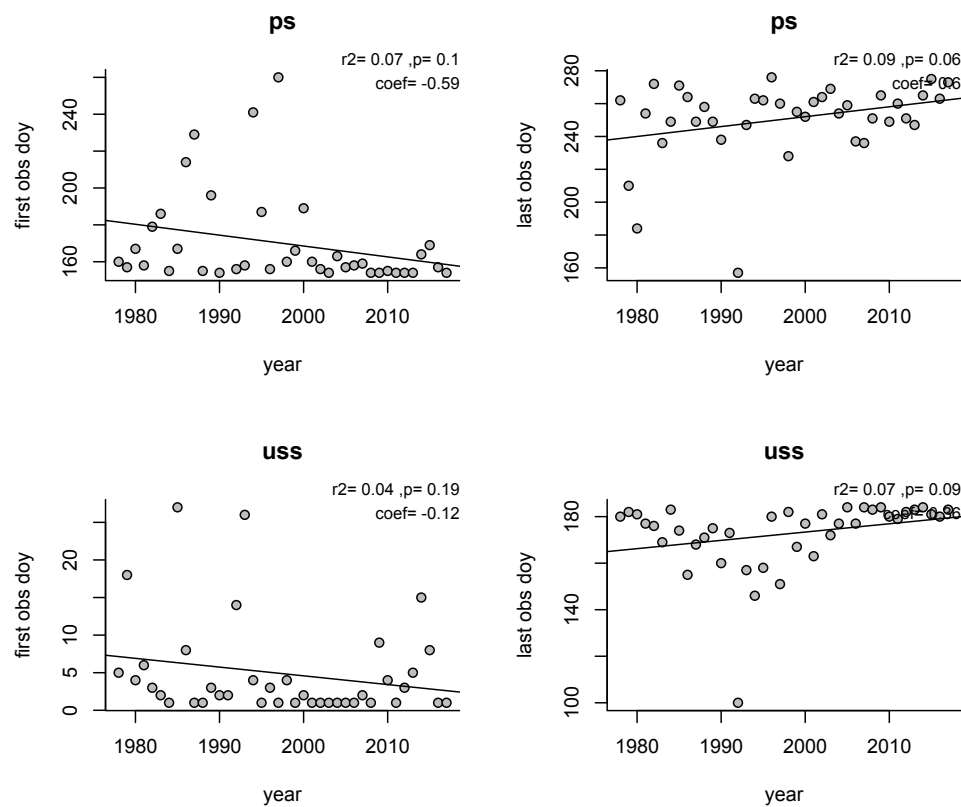
ps

r2= 0.07 ,p= 0.1
coef= -0.59

ps

r2= 0.09 ,p= 0.06
coef= 0.06

uss

r2= 0.04 ,p= 0.19
coef= -0.12

uss

r2= 0.07 ,p= 0.09
coef= 0.06

Figure 7: **Time series and linear regression of first and last observation dates of SRKW.**

First Detection Probability >0.5
J Pod winter ps

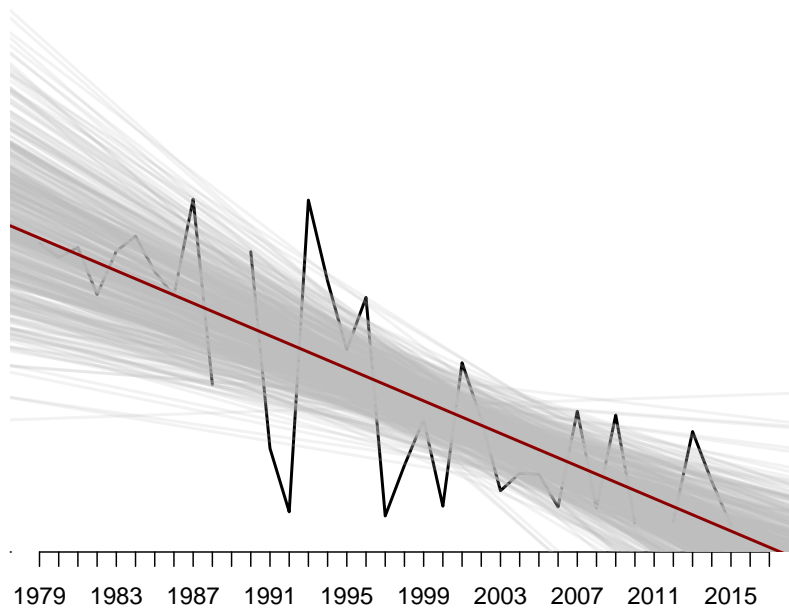1979   1983   1987   1991   1995   1999   2003   2007   2011   2015

Figure 8: **Trends in first- and last- observation dates for J, K, and L pod.** Make this a 6-paneled figure