**Discussion outline:**

\*Is this the first example of a post-release survival study for marine invertebrates?

***1 – Summarise the results***

* Under license conditions as specified for the commercial spot prawn fishery in BC, we found that spot prawns survive the physiological process of being captured and released relatively well (over 70% survival across all size/temperature ranges encompassed by the experiment).
* Survival declines with increasing air exposure and increasing air temperature and the effect of air exposure is more pronounced at higher temperatures – survival declines more quickly with time out of water when it is hotter.
* There may be some evidence of size-dependent effects such that smaller prawns (e.g., males) are more vulnerable to air exposure in the heat.
* Although we did not track survival beyond ~24 hours post-release, our assessment of reflex behaviours showed that the majority of surviving prawns were in good condition, indicative of likely longer term survival.

A large proportion of trap-captured spot prawns returned to the ocean near immediately survived the physiological process of being captured and released – we estimated survival probabilities greater than 70% across the range of carapace lengths and air temperatures encompassed by our field experiment. The 24-hour survival probability declined with increasing length of air exposure and the rate at which survival declined with increasing time out of water depended strongly on air temperature. In cool weather, we estimated a probability of survival just under 40% but this dropped quickly with increasing warmth and no prawns survived two hours of air exposure in >25oC weather. Although we did not track survival longer than 24-hours post release, our assessment of reflex behaviours suggests that the majority of surviving prawns were in good condition, indicating likely longer-term survival. Although discard mortality in fisheries is an increasingly acknowledged and investigated uncertainty (CITE), it is relatively less well understood for fished invertebrates and, as far as we are aware, this is the first assessment of post-release survival of spot prawns. The broad results of our experiment are generally consistent with previous studies on the discard mortality of other marine invertebrates, including the strong influences of air exposure and temperature on post-release survival. While we expected that spot prawns would fair less well out of water for long periods of time in hot weather, we were surprised by the relatively high survival of individuals released immediately and the high reflex scores for surviving prawns, regardless of air exposure treatment.

***2 – Discuss whether they are expected or unexpected***

* Contextualise results in what we understand about the physiological mechanisms:
  + Possible that injury decreases moulting frequency (Davis, 1981).
  + With increasing air exposure, oxygen becomes limiting factor and previous studies have looked into the shift from aerobic to anaerobic metabolism and associated biomarkers (hemolymph pH, lactic acid, ammonia concentration, desiccation rate). E.g., Vermeer, 1980.
  + Evidence that smaller individuals have higher desiccation rates.
  + Difference between animals adapted to some air exposure (e.g., crabs?).
  + Inability to ventilate the gills may lead to hypoxia, anaerobic metabolism, and accumulation of toxic metabolites.
* It is not surprising that survival probability declines at higher temperatures or with increasing air exposure but it is surprising how high baseline survival was for the ‘immediate release’ treatment.
* The size-based result is surprising and would likely take further investigation to be confident about but we can think of possible mechanisms for this result.
* The fact that the reflex scores were so high for prawns that survived (regardless of which treatment they were in) is fairly intuitive given that they do not have the same physiological vulnerabilities as other fished species that are returned to depth (e.g., rockfish). They do not have a swim bladder and they are known to make fairly large migrations at night to feed.
  + Cite Barr, 1970 re: DVM

Post-release mortality varies widely depending on capture method, environmental conditions, and physiological attributes of the discarded species (CITE) – all of which contributed to the range of survival we documented in this field experiment. To emulate the fishing style used in commercial and recreational spot prawn fisheries throughout the Pacific northwest, we focused our experiment on trap-caught spot prawns, differentiating this study from most existing research on the post release survival of crustaceans (CITE, CITE, CITE) which have found relatively lower survival rates usually below 50%. Studies on physiological biomarkers of released crustaceans found much higher survival for individuals captured by trap (95-100%) than those caught by trawl (0%, Lorenzon et al. 2013, Ridgway et al. 2006). This study and others note strong environmental effects with much lower survival in warmer conditions (CITE, CITE, CITE). Air temperature and length of air exposure are intuitively important determinants of post-release survival rates as they accelerate desiccation and resulting impaired oxygen exchange (CITE, CITE, CITE). It is not surprising that survival declines sharply with increasing air exposure and temperature but the relatively survival rate of immediately released prawns and other trap-caught shrimp (CITE) contrasts survival estimates for trawl-captured crustaceans (typically ~30-50%) and finfish (insert estimate from Wilson paper). [transition…]

***3 – Compare results to previous work***

* Compare to other fishery studies generally
  + There has been extensive focus towards discard mortality for Pacific salmon in Canada (Patterson et al. 2017). Often disaggregates ‘discard mortality’ into three sub-categories: onboard mortality, <24 hour post release mortality, and >24 h post-release mortality.
* Other invertebrate studies:
  + Oregon Dungeness crab estimates for discard mortality rates: 0.080 (females), 0.012 (hard shell males), 0.092 (soft shell males) (Yochum et al. 2017). Found that these estimates were lower than previous estimates.
  + High survival of benthic invertebrates: starfish, polychaete worm, whelk, hermit crab (>93%). Slightly lower survival for spider crab (~80%) and horse crab (50%) (Boussarie et al. 2020).
  + High mortality of Norway lobsters discarded through low salinity layers (Harris and Ulmestrand, 2004).
* Compare to Stoner paper.
* \*This section needs fleshing out and literature reading to support\*

***4 – Discuss problems & shortcomings***

* There are other sources of post-release mortality that we do not account for:
  + Predation from birds, fish, etc.
  + Longer term physiological damage (e.g., is there any evidence regarding eye damage?)
  + Whether or not prawns that are released make it back to suitable habitat.
  + We control for salinity and thus do not explore the influence of low salinity conditions on prawn survival
  + We do not explore density-dependent effects
  + We now have a starting estimate for post-release survival that can be integrated into population models and we can explore the sensitivity of specific model ouputs to this source of mortality. Suggest that further investigation/refinement through later experiments would be warranted if there is evidence that this source of mortality plays an important role
* There are additional sources of post-release mortality that we do not expect to apply in other contexts:
  + Prawns were released in traps and may have incurred additional damage/mortality from being in the traps.
  + Prawns that were ‘released’ were temporarily held in mesh bags ~20 m below the surface which does not perfectly mimic ideal release conditions.
* Some prawns were ‘lost’ from the experiment during the trial and we must consider the possibility that prawns were lost in a non-random manner that might bias our results
  + Prawns could be ‘lost’ through several alternative mechanisms: they could lose their noseband, they could be lost during the experiment treatment (i.e., escape the mesh bag), or they could be lost post-treatment during the post-release stage (i.e., escape the trap at some point between hauling and setting).
  + We lost fewer prawns due to losing their nosebands as the trials progressed (we got better at banding).
  + On average, we lost slightly more prawns from the longer treatment times.
    - This could be because more prawns died and dead prawns were more likely to be scavenged and fall through the trap mesh.
    - We evaluated whether this could systematically bias the results and do not find that it would substantially change the qualitative results of our analysis (see Supplement).
* We do not thoroughly consider or evaluate sub-lethal effects

***5 – Discuss alternative explanations***

* The interaction effect between temperature and length was unexpected and there are several possibilities for why (1) smaller prawns survive better in cooler temperatures (2) larger prawns survive better in warmer temperatures
  + Larger prawns might have a higher metabolic rate and in general die more quickly if that is the limiting factor (i.e., oxygen)
  + Larger prawns might not dessicate as quickly as smaller prawns when it is hot outside and thus it is possible that there is a different limiting factor at high temperatures.

***6 – Discuss the implications of the results in a fishery management context***

* The results of this experiment suggest that the size-based release measure implemented in the commercial fishery is reasonably effective at mitigating the physiological impacts of capture when implemented as outlined in the license conditions.
* This is important because:
  + An effective management measure can be considered as a tool moving forward – e.g., modifying the release size threshold.
  + There is evidence and increasing concern that given the intensity of the fishery, large numbers of undersized males are sometimes captured in the final weeks of the fishery before management closure decisions are implemented. Given that these males represent next year’s spawners, it is important to estimate post-release survival.
* This study is one of the first studies to investigate post-release survival of a marine invertebrate fishery in situ as opposed to in the lab.
* Although the license conditions for the commercial fishery are very specific, the rules for the recreational fishery are much less strict (no size limit, no specifications regarding release time) and this study shows that post-release handling is important with respect to ensuring survival.
  + Particularly relevant as the recreational spot prawn fishery becomes more and more popular.
  + Particularly relevant because, with exceptions, the recreational fishery occurs year round and thus, at certain times of year, catches a large number of egged females which must be returned. Although we were not able to include egged females in our experiment…

**TOPIC BASED NOTES:**

**Physiological effects**

* + Anaerobic glycolysis is not an efficient way to produce energy so it is suggested that prolonged air exposure leading to anaerobic metabolism contributes to ATP concentration declining and a related decrease in muscle pH. Shown for Norway lobsters captured in trawl nets (Albalat et al. 2009).
  + Air exposure leads to desiccation and associated impacts on hemolymph chemistry and, in spiny lobsters, these rates were faster in smaller lobsters (Vermeer, 1986).
    - Lactic acid levels increased, pH increased, ammonia concentrations increased.
    - Immersed lobsters survived and recovered normal hemolymph levels but not normal reflex behaviour. 75% of reimmersed lobters had delayed or absent tail flip responses.
  + Significant increases in ammonia, lactate, and glucose concentrations in harbour crab captured in trawl fishery (Giomi et al. 2008).
  + Evidence that ghost shrimp are tolerant of hypoxia and can regulate their oxygen consumption down.

**Fishing method effects**

* + Seasonality – higher mortality during the summer (Giomi et al. 2008, Lorenzon et al. 2013).
  + Capture method – much higher survival for trap caught vs. trawl caught mantis shrimp (Lorenzon et al. 2013). 95-100% survival by trap vs. 0% survival by trawl.

**Survival estimates from other studies & sublethal effects**

* + About half of discarded crustaceans alive after 30 min air exposure (Hill and Wassenberg, 1990). Prawn trawlers in Torres Strait.
    - 50% survival of mantis shrimp after 10 min exposure on deck after 30 min trawl.
    - Crabs survived at higher rates than shrimps.
  + Estimates of survival of Norway lobster captured in trawl fishery around around 30-50%. Depends on the sorting method. (Merillet et al. 2018).
    - Similar size to spot prawns (15-33 mm CL).
    - 37-51% survival after 14 days.
  + Rensel and Prentice, 1980 note quick recovery of moribund juvenile spot prawns when placed in cool water.
  + Evidence of effects that would make individuals more susceptible to predation (Haupt et al. 2006, Vermeer 1986)
  + Expected time for 50% mortality of western rock lobsters exposed to direct sunlight was 99, 158, and 233 mins with increasing temperatures compared to 387 minutes in shade (Brown and Caputi, 1983).
    - Percent mortality for shaded lobsters was under 10% after 120 mins exposure. Death monitored for two weeks post exposure. 72-76 mm carapace length.

**Environmental effects**

* + Low survival and condition of Norway lobsters released through low salinity layer (Harris and Ulmestrand, 2004).
  + High rates of scavenging by sharks, birds, dolphins (Hill and Wassenberg, 1990).
    - Estimated how long it took for discarded crustaceans to sink below 1 m. 9-10 seconds, 0% left floating.
    - Over 80% of bait set on a vertical drop line were still intact when recovered.

**Conclusions outline:**

1 – Summarise results/discussion (brief)

2 – Emphasize implications

3 – What are the most general claims that can be supported by the evidence?

4 – Provide future directions