

Using a Bayesian multi-state mark-recapture model to assess cost of first reproduction and influence of entanglement on recruitment in female North Atlantic rightwhales

Recruitment and age at first parturition are often estimated from sighting histories. Multi-state mark-recapture models have been used to provide estimates, albeit traditionally the state of an individual when sighted is assumed to be known with some certainty. Yet for many marine mammals certainty is not possible, because reproductive events can be missed. We developed a Bayesian multi-state mark-recapture model with state uncertainty in the observation process to account for uncertain breeding state assignment and imperfect detections. This model, based upon the multi-event framework, provides a flexible structure to estimate reproductive parameters, while accounting for the influence of sub-lethal stressors. By including individuals with state uncertainty, we are able to increase the sample size, thus improving the precision in estimating demographic parameters, which is important when dealing with small, declining populations. Using Stan we constructed and fit the model using 41 years of sighting histories for 199 known age female North Atlantic right whales. The aim was to assess 1) the age specific costs of first reproduction, and 2) how entanglement in fishing gear and birth cohort influence recruitment. Individuals were assigned to one of four observational states (pre-breeder, first-time breeder, unknown breeding state, or experienced breeder), with additional covariate information of age class (0-17+), entanglement score (minor, moderate, severe, and no entanglement), and cohort: 1) born prior to 2000, and 2) born in 2000 or after. Using this framework we estimated survival and transition (i.e. recruitment) probabilities. We found a higher cost of first reproduction for both younger and older first-time breeders with lower apparent survival, compared to individuals who commenced breeding 8-11 years of age. Individuals born after 2000 had a reduced chance of recruiting to breeder, and females who had a minor entanglement during recruitment had the lowest transition probability, regardless of when they were born. Our model allowed us to show for the first time that for North Atlantic right whales female recruitment to breeding is reduced in females born this century, and that even minor entanglements significantly impact recruitment to the breeding population.