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Developing a Bayesian state-space model for whale health and vital rates to quantify the combined effects of multiple stressors

Assessing and predicting the combined effects of multiple stressors on wildlife populations is a pressing management and conservation problem. However, for long-lived, wide-ranging species, it is not possible to measure the population-level consequences of multiple combinations of stressors directly. Mechanistic models of the functional cascades between stressor exposure and individual vital rates (survival and reproduction), mediated by changes in health, can be used instead to make predictions of these effects. Here, we use a long-term dataset of visually assessed health variables and life history from North Atlantic right whales (NARW) to develop one such approach. We cannot design experiments to quantify the effects of stressors on critically endangered species like NARW, but modelling can help management prioritize interventions to ensure population viability. Specifically, we reformulate a Bayesian state-space model for individual health and survival. A latent health state determines survival probability and is observed via four ordinal logistic regressions, generating the categorical health data: body condition, skin condition, cyamid load and rake marks. We extend the model to evaluate the effects of stressors that might affect survival directly (e.g., ship strikes and entanglements), or indirectly via health (e.g., sub-lethal entanglement). Moreover, we include a spatial structure, informed by the location of individuals' sightings, to account for the heterogeneous distribution of stressors across the species' range. In future, we plan to adjust the analytical approach so that it can be used to assess stressor effects on reproduction, in addition to survival. Ensuring the efficient convergence and mixing of the model requires extensive exploration of the trade-offs between complexity and data availability. Therefore, this effort offers a useful testbed as we strive to develop effective statistical methods to assess the combined effects of multiple stressors on individuals and populations.