

Statistical Tools for Fitting Models of the Population Consequences of Acoustic Disturbance to Data from Marine Mammal Populations (PCAD Tools II)

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LONG-TERM GOALS

To build an ecological modeling framework that facilitates understanding of the at-sea condition and health of various species of marine mammals. This project will develop statistical tools to allow mathematical models of the population consequences of acoustic disturbance to be fitted to data from marine mammal populations. We will work closely with Phase II of the ONR PCAD Working Group, and will provide statistical support to that group.

OBJECTIVES

Our scientific objectives are to build a statistical framework for understanding the at-sea health of (initially) three species of marine mammals: southern and northern elephant seals, and northern right whales. Should the Working Group decide that we should address additional species, e.g. bottlenose dolphins, we will take those up in turn.

For elephant seals our objective is to build a hierarchical Bayesian model that provides daily estimates of lipid status, as lipid status of the mother is directly linked to pup survival (McMahon et al. 2000). This model will use the drift dive behavior of elephant seals (Crocker et al. 1997) as the link to the underlying true, yet immeasurable, lipid state.

For right whales, our objective is to build a model that provides spatially and temporally explicit estimates of individual health, movement, and survival. The model builds upon some of the ideas from the elephant seal project, but as the photo-identification of individual right whales is the core of the data, the model also includes many ideas concerning mark/recapture from (Clark et al. 2005).

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APPROACH

The portion of the project in this fiscal year (2012) has been transferred from Duke University (Award N000141010516) to the University of St. Andrews. At St. Andrews, the work is led by Len Thomas, John Harwood, and Catriona Harris with the assistance of one research fellow, Rob Schick. For the three months in this fiscal year, work has focused on a) further refinement, development, and fitting of the right whale model to data, and b) conducting an analysis of different observation models in the state-space model for lipid gain in elephant seals.

For right whales, our work has included model fitting, and using different formulations of the model. For example, we have been conducting prior sensitivity analyses with the priors in the model that link discrete health observations with continuous latent health. In addition, we have been working with colleagues from the New England Aquarium in Boston, MA (NEAq) to analyze the effects of different entanglement data types on the health estimates of individuals.

On the elephant seals analysis, our work has focused on the possible use of the physics based equations linking lipid to drift rate (Biuw et al. 2003) in the observation model.

WORK COMPLETED

Much of our work this year has centered around fitting the model for health, movement and survival of right whales to data (Figure 1). We have explored the use of different model formulations, including changes in the following four areas: 1) changes in the number and type of entanglement classes used in the analysis; 2) changes in the strength and position of the curves that relate the discrete health observations to continuous health; 3) changes to how death is imputed; and 4) changing the strength of the movement priors.

One of the biggest changes to the model involved the imputation of the time of death for animals. Some animals were recovering after a sighting where the individual was in extremely poor condition. Only one such animal is known to have survived from this state (Pettis et al. 2004), so survival and health recovery following such an event was highly unlikely. We altered the death imputation code such that animals that have not been seen for some period of time (we have started with 4 years) are increasingly likely to have died. This has made the estimates of survival following times of poor health much more biologically realistic (see Results).

We have also been exploring ways to speed up the model fitting code, currently written in the statistical language R, by coding some parts in a low-level language like C.

We have produced estimates of health for individual right whales over the temporal extent of their sighting history.

Our manuscript on lipid gain/loss in elephant seals was submitted to a peer-reviewed journal, but was rejected with the two primary criticisms being that a) the observation model we used does not sufficiently capture all the factors that contribute to drift rate, and b) our scientific hypotheses were insufficiently focused. We have therefore been exploring the possibility of altering our existing linear observation model to a functional form similar to that of (Biuw et al. 2003). The first stages of this analysis have included using known measurements (lipid %, axial girth, length, depth, calculated sea water density) to derive drift rates using the equations from Biuw et al. (2003). We have then

compared these values to those measured by the tags. Currently we are in discussion with Martin Biuw about the best use of these equations within our modeling framework.

In late June, 2012, Schick moved from Duke University to the University of St. Andrews. The remaining months in FY 2012 from Award N000141010516 were transferred from Duke to St. Andrews.

Thomas, Harwood, and Schick traveled to NEAq in July to participate in the first Phase II meeting of the PCAD working group.

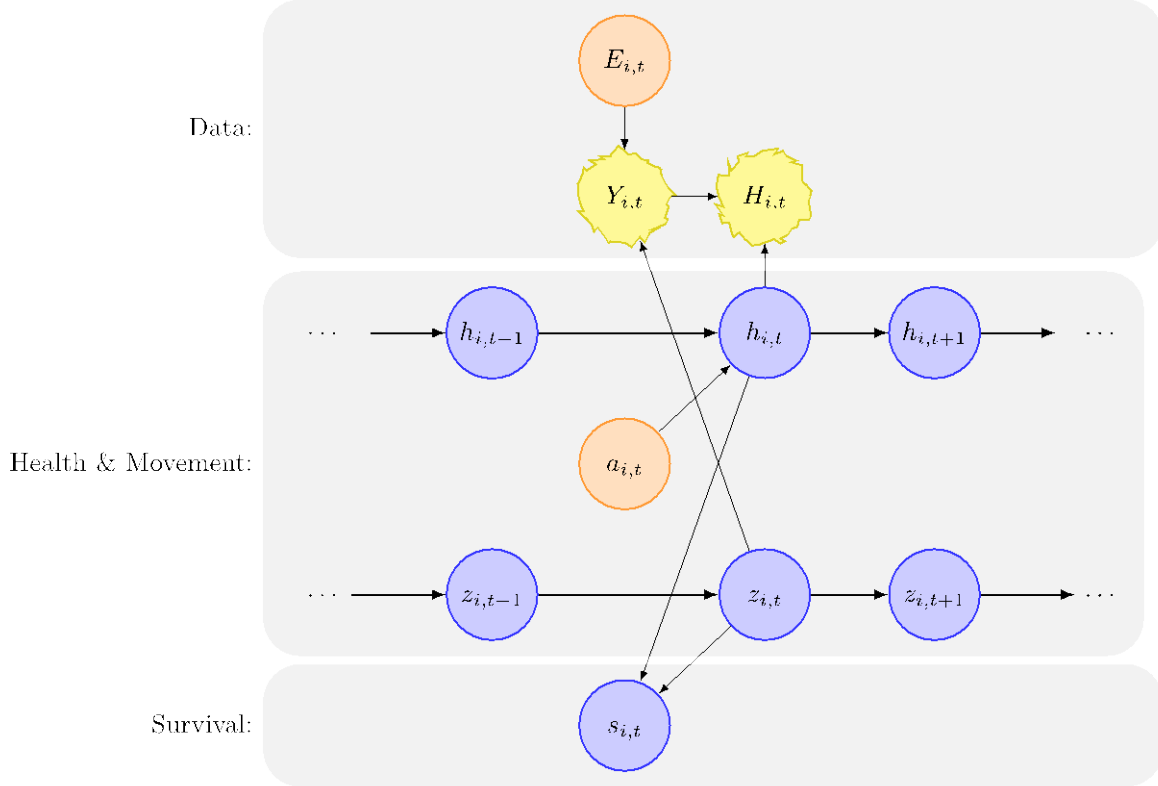


Figure 1. Graphical model depicting the dependency structure in the right whale model. In the observation, or data model, we have survey effort E , sightings Y , and health observations H . In the center panel we have processes for true latent health and true movement. Currently age a , and health h at $t-1$ contribute to health at t .

RESULTS

In both case studies, right whales and elephant seals, the estimates of a hidden process have provided a synthetic understanding of how animals fare over broad spatial and temporal scales. With elephant seals, the understanding has focused on aspects of foraging ecology, while in right whales we have quantified more precisely how the health of individuals and of the population change over time. This understanding in right whales can lead to specific management interventions.

The analysis of the observation model in elephant seals is ongoing, but early results indicate there may be mismatch between the derived values and the measured values (Figure 2). Some of this could be due to assumptions inherent in the physical equations. These include assumptions about density, residual air in the lungs, and the drag coefficient C_D . We have experimented with a variety of drag coefficients, yet none have yielded satisfactory matches between the observed and derived data.

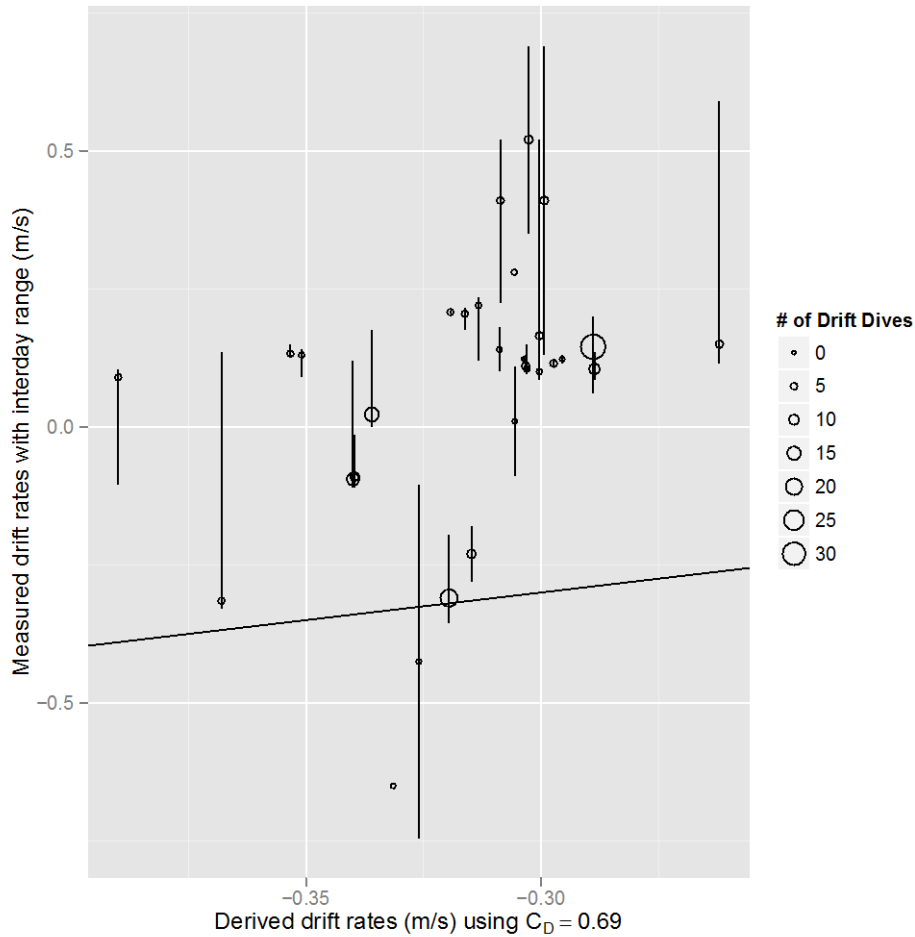


Figure 2. *A comparison of the values measured in situ by the tag (y-axis), and those calculated using Biuw's equation 6 (x-axis). One to one line is included for reference. Vertical lines correspond to the inter-day range of observed drift rates; circle represents the median value for the day. The C_D value of 0.69 is the mean value of two “optimal” drag coefficient values estimated by Biuw et al. (2003).*

For right whales, we now have a coherent view with uncertainty of how the health of individuals varies over time and space (Figure 3).

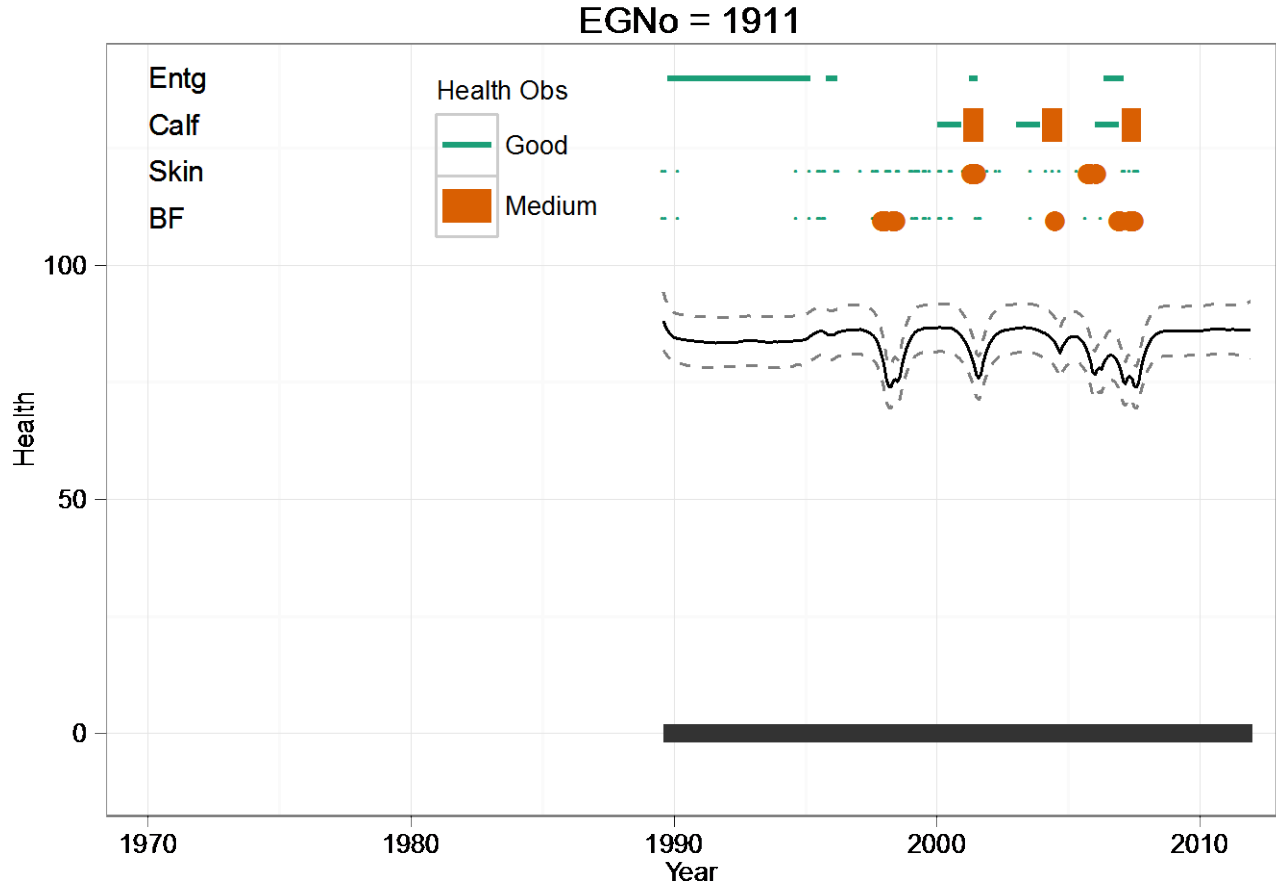


Figure 3. Health estimates for right whale # EGN0 1911, with uncertainty, represented as solid and dashed black lines, respectively. Data observations are shown above the black lines for body fat, and for skin condition. Observations where the animal is in poorer condition are shown with orange and blue dots of increasing size. Survival probability is shown by the grey rectangle at the bottom. This animal is currently estimated to be alive.

This synoptic view of individual health allows us insight into the dynamics of health across time. For example, NEAq researchers know that animals photographed and coded as ‘very thin’ are either known to have died, or have never been seen again (Pettis et al. 2004). Using this information, we can visualize the entire health trajectories for these animals instead of a single snapshot, and visualize their downward progression in health. For animals that are known to die the uncertainty around health is fairly narrow (Figure 4).

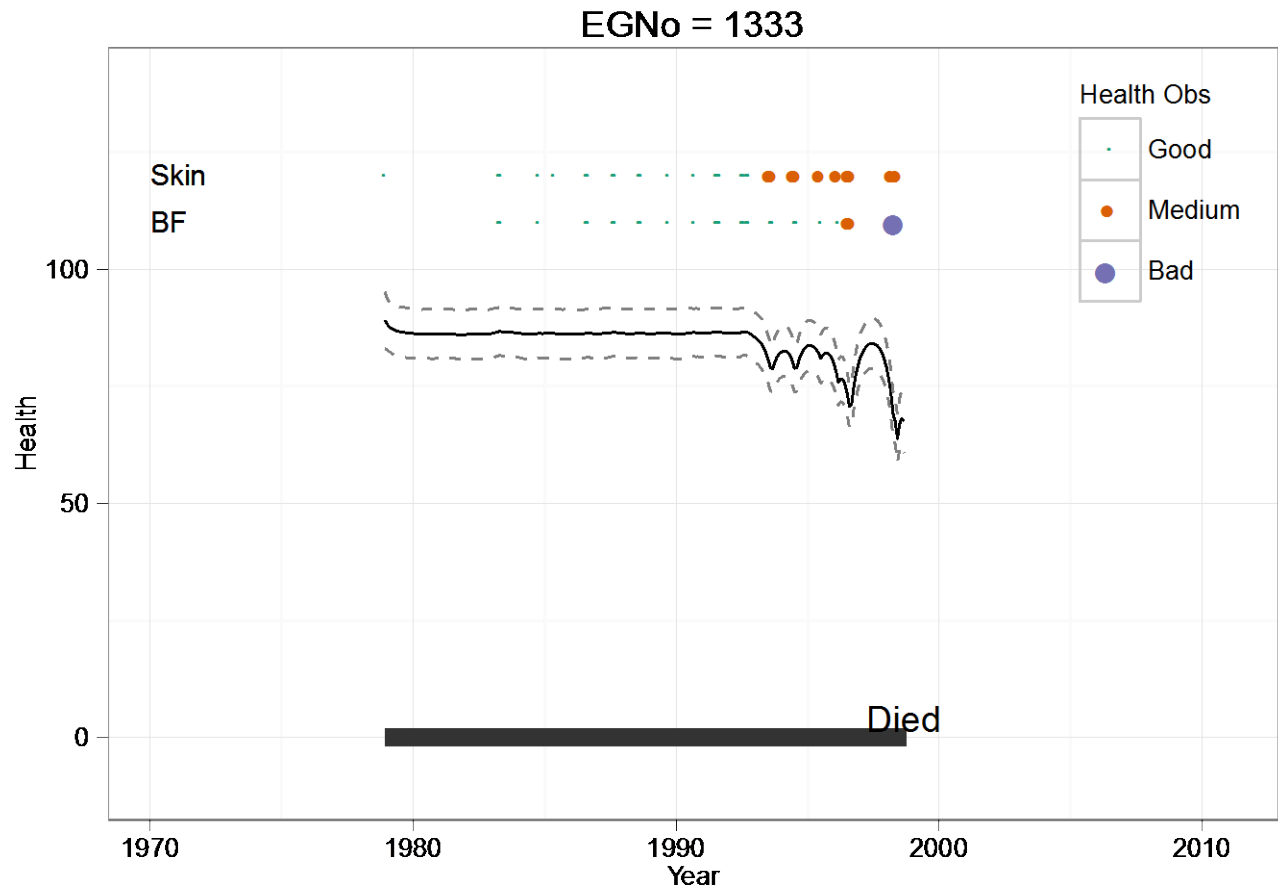


Figure 4. Health estimates for right whale # EGN0 1333, with uncertainty, represented as solid and dashed black lines, respectively. Data observations are shown above the black lines for body fat, skin condition, gestational status, and entanglement. Observations where the animal is in poorer condition are shown with orange and blue dots of increasing size. Survival probability is shown by the grey rectangle at the bottom. This animal is known dead.

In contrast, for animals that are seen in very poor body condition at the time of their last sighting, their health decays to 0 over time, but with much greater uncertainty (Figure 5). As compared to healthier animals, e.g. Figure 2, the animals that were coded ‘very thin’ typically have many more observations of poor health.

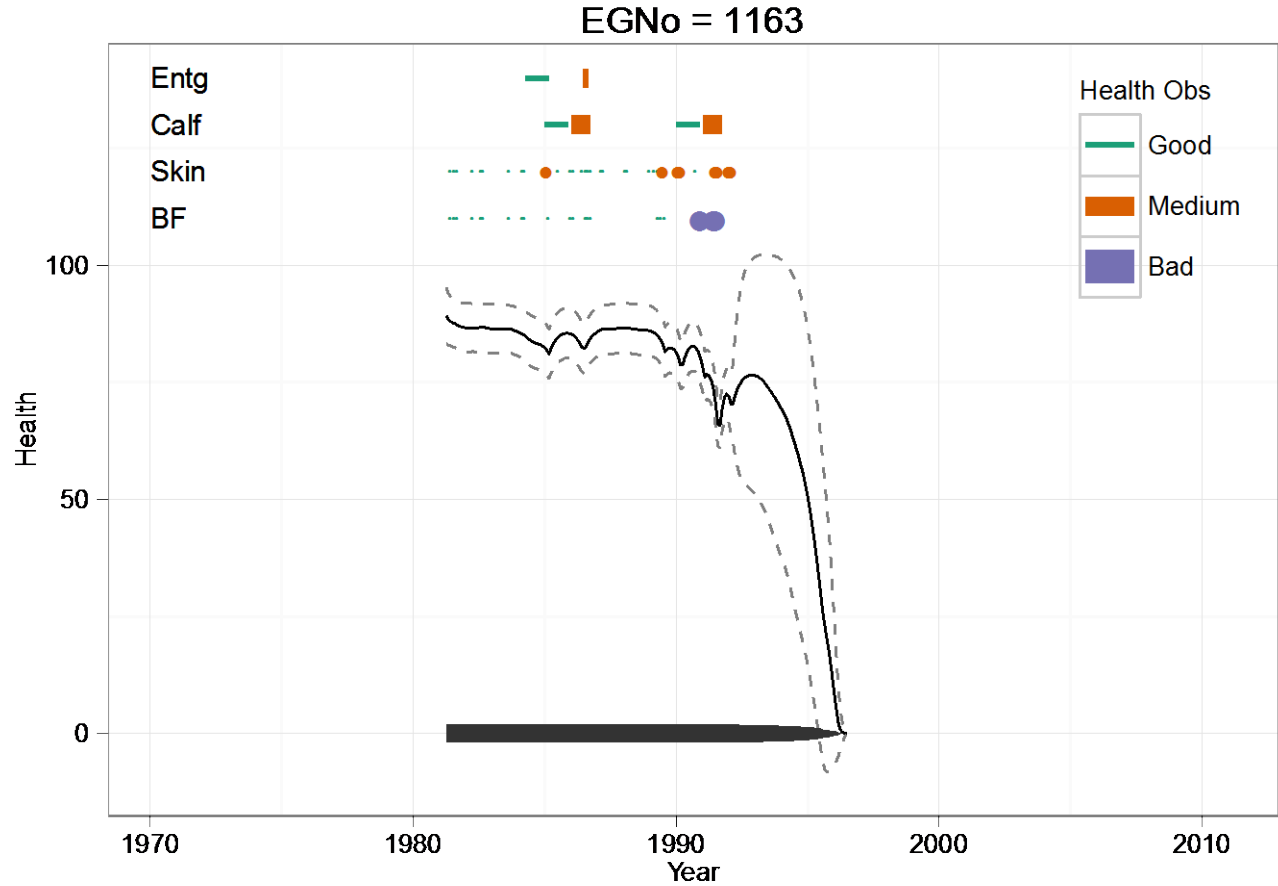


Figure 5. Health estimates for right whale # EGN0 1163, with uncertainty, represented as solid and dashed black lines, respectively. Data observations are shown above the black lines for body fat, skin condition, gestational status, and entanglement. Observations where the animal is in poorer condition are shown with orange and blue dots of increasing size. Survival probability is shown by the grey rectangle at the bottom. This animal is presumed dead.

As mentioned in the previous section, we altered how death is imputed in the model. Previously, we were observing recovery after a period of extreme poor health (Figure 6).

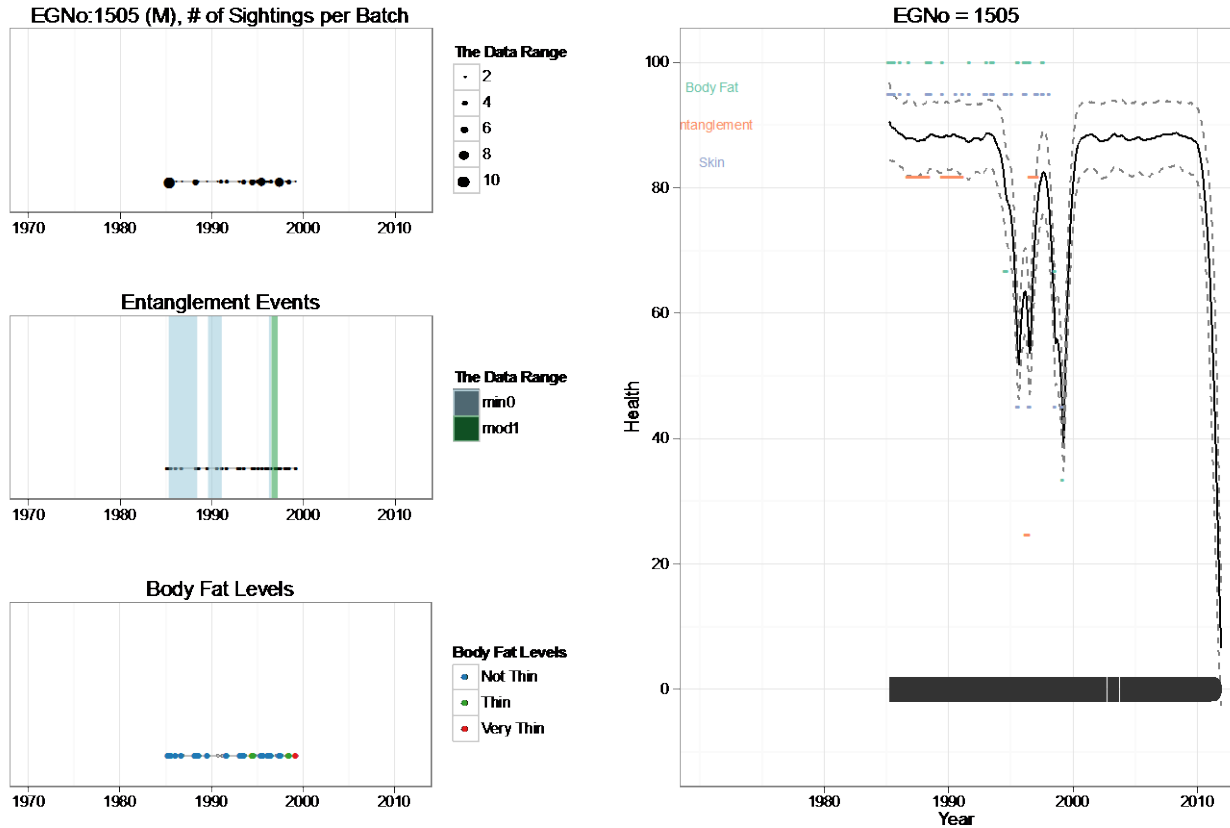


Figure 6. Health estimates for right whale # EGNo 1505, with uncertainty, represented as solid and dashed black lines, respectively. Results are from an older model run with a different structure for imputing death. Unlike the individuals in Figures 4 & 5, this animal also had a body fat score of very thin, but model estimates showed both a) rapid recovery in health, and b) continued survival.

Through consultation with the NEAq team, it became clear that this was improbable. Current health and survival estimates following observations of poor health are much more biologically realistic (Figure 5).

In our analysis of the right whale data, the main results have been the individual and population level assessments of health. While the individual results have provided additional information about how health changes over time (Figures 2 – 5), the aggregate population level information is the most compelling result (Figure 7).

This result shows that not only are we able to capture the major periods of population-wide poor health, i.e. the early and late 1990's (Caswell et al. 1999, Fujiwara and Caswell 2001, Kraus et al. 2005), but we have shown that population health has declined over the period of the analysis. Specifically, we have documented stable health of the population in the 1980's, decline in the 1990's, to a stable, but lower, health in the 2000's (Figure 7).

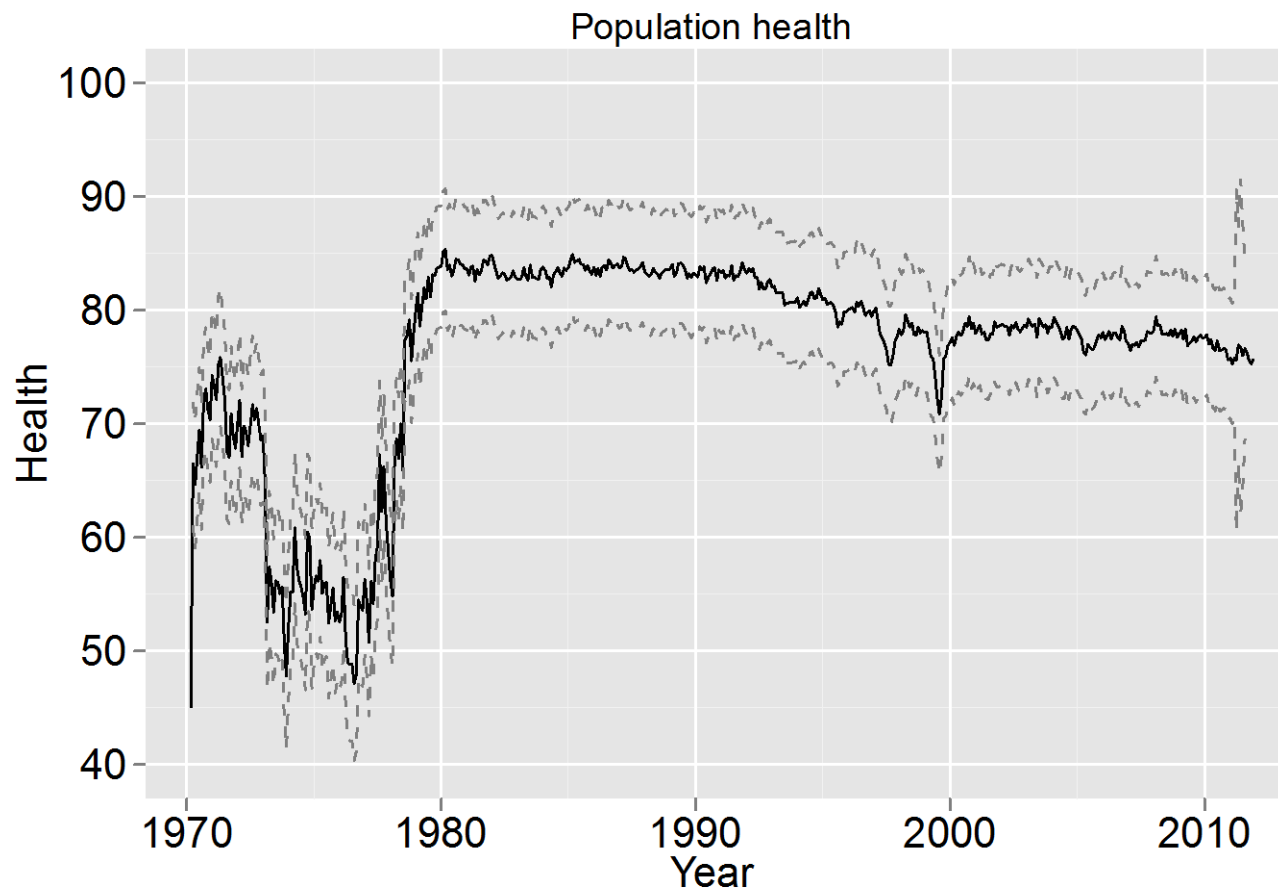


Figure 7. One estimate of the mean population health over the period of analysis. Results show stable health through much of the 1980's, declining health in the 1990's, and stable, but lower, health in the 2000's. The health estimates dip noticeably in the late 1990's – a known period of low vital rates.

IMPACT/APPLICATIONS

The modeling efforts here should have broad relevance in animal ecology. The elephant seal analysis provides insight into the specifics of physiological status of animals at fine spatial and temporal scale. Though the analysis takes advantage of a behavior that is unique to elephant seals, the ability to estimate condition from a buoyancy proxy is possible for a large variety of marine mammal species. Because we are able to link in situ measurements with biology and remotely sensed data, our approach should provide a useful scientific framework on which to build.

In addition to having relevance for other cetaceans, e.g. gray whales – (Bradford et al. 2012), the right whale analysis provides a framework for analyzing many different mammalian species – including humans. By using sporadic observations together with an underlying process model, we can infer how individuals are interacting with their environment, and how their health and condition is changing as a result.

RELATED PROJECTS

This project is closely related to two other ONR awards: N000141210389 to Scott Kraus (New England Aquarium), N000141010516 to Jim Clark (Duke University), and N000140910896 and N000141210274 to Erica Fleishman (UC-Davis).

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