REPORT OF THE WORKING GROUP

ON SURVIVAL ESTIMATION

FOR NORTH ATLANTIC RIGHT WHALES

Working group members:

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Introduction and objectives

On Monday, September 9th the Northeast Fisheries Science Center (NEFSC) convened a small working group in Woods Hole to discuss the issue of survival estimation in North Atlantic right whales (*Eubalaena glacialis*). The meeting was hosted by the Woods Hole Oceanographic Institution (WHOI).

The working group consisted of Richard Pace (NEFSC), Phil Clapham (NEFSC), Hal Caswell (WHOI), Masami Fujiwara (University of California, Santa Barbara), Solange Brault (University of Massachusetts, Boston), Paul Wade (National Marine Mammal Laboratory, Seattle) and Scott Kraus (New England Aquarium, Boston).

The North Atlantic right whale remains one of the most critically endangered of all the great whales. The remnant population numbers only about 300 individuals and is widely believed to be declining (Caswell *et al.* 1999, Fujiwara and Caswell 2001, IWC 2001) despite several decades of protection from whaling. Mortality from anthropogenic sources, notably entanglements in fishing gear and ship collisions, is probably the principal cause for this continued failure of the population to recover (IWC 2001). In addition, the population may suffer from general health problems, and has shown decreased reproduction in recent years (IWC 2001).

The primary objectives of the working group's meeting were:

- to review recent estimates of right whale survival;
- to discuss methodological or other issues that might bias these estimates; and
- to suggest approaches to future work.

Recent work

Recent work on survival estimation has included:

- stage-structured estimates by Caswell and Fujiwara;
- estimates by Richard Pace using various models, and analyses of heterogeneity, updated with recent aerial survey data;
- estimates by Wade and Clapham based upon cluster analysis to separate individuals into areas of primary occurrence; and
- examination by Kraus of sighting histories of individuals to address questions of heterogeneity.

Summaries of the work presented are given below.

Caswell/Fujiwara

Caswell and Fujiwara presented an update on their ongoing demographic analyses of the North Atlantic right whale. Their proximal goal in this project is to estimate, by maximum likelihood, stage-specific probabilities for sighting, survival and transition (between stages), as well as life expectancy, mean and median inter-birth intervals, lifetime reproductive output and population growth rate. In the course of this parameter estimation exercise, Caswell and Fujiwara evaluated with rigorous statistics the extent to which these parameters varied over time and how much they were affected by the North Atlantic Oscillation (NAO).

Caswell noted that their analyses incorporated the most dramatic source of biological heterogeneity, that due to sex and developmental stage. Males and females were treated separately, as were calves, juveniles, mature individuals (males and females) and, for females, mothers and immediately post-reproductive mothers. The last stage is a modification of the life cycle used in their previous analyses; it enforces an additional year lag between births, in accordance with the observational data from this population.

The results of the analyses suggested that both time trends and the NAO affected the survival of mothers and the reproductive rate of mature females. The NAO also appears to affect calf survival. The decline in survival of mothers has continued: it appeared in seven of the ten best models as measured by Akaike's Information Criterion (AIC, a test of the fit of a model to the data), including the two best models. This decline has driven a decline in population growth rate, life expectancy, and lifetime reproductive output, and population growth rate at the end of the study period was now below the replacement level.

Caswell noted that they are preparing a more complete analysis, incorporating the effects of demographic stochasticity and environmental stochasticity (including NAO fluctuations), as well as perturbation analysis.

Wade/Clapham

In the analysis conducted by Wade and Clapham (1999 and updated since), sighting data on individually identified right whales from 1980 to 1997 were analyzed using cluster analysis to form groups of whales with similar spatial distributions. The analysis produced four clusters or groups which are generally consistent with known patterns of distribution and connections among areas: (i) Massachusetts Bay/southeastern United States/Bay of Fundy; (ii) Scotian Shelf/Great South Channel; (iii) Bay of Fundy; and (iv) Bay of Fundy/Scotian Shelf. Survival rates were estimated using mark-recapture analysis, where sighting probability was allowed to vary by group as well as by year.

The results indicated that sighting probabilities vary significantly by area, and that these differences exert a substantial influence on survival estimates. In model comparisons using AIC, better fits to the data always resulted when sighting probability was permitted to vary by both group and year (versus either variable alone), no matter which survival model was used. Although non-calf survival declined in all except the Bay of Fundy cluster, the decline in at least two of the groups was potentially confounded by large changes in survey effort after 1989 in both the Great South Channel and Scotian Shelf and also by the abandonment by whales of the latter area after 1992. However, a marked decline in the Massachusetts Bay/southeastern United States/Bay of Fundy cluster (a group dominated by females) appeared to be real; that this decline was focused on females agrees with other recent demographic analyses, and is of considerable conservation concern.

Pace

The work by Pace evaluated resighting data linked to the North Atlantic Right Whale Catalogue (NARWC) for the purpose of estimating demographics of right whales using extended Cormack-Jolly-Seber (CJS) open population models for live recapture. First, various aspects of the resighting data were examined to investigate how their use in CJS models (and generalizations of such models such as Arnason-Schwarz) may be questionable. This analysis found that both whale and scientist behavior have changed over time in a way that may forever confound the 'recapture' and survival processes such that they cannot be considered comparable across the two decades concerned (the 1980s and 1990s).

Of note were the lengthy and variable recapture periods, shifts in geographic coverage among years and strong evidence for 'trap-happiness' among individuals. Despite the many problems, the National Marine Fisheries Service believes it is important to produce updated estimates of demographic parameters from this important data set. Consequently, annual recapture data were used to estimate survival rates of right whales. The resulting survival estimates are the only ones to incorporate data through the year 2000. This is significant since the more recent information includes data from the Great South Channel, which had not been surveyed for several years prior to 1998 when new aerial surveys began. Given the known affinity of certain individual right whales for this offshore habitat, there has been concern expressed regarding

whether earlier estimates of survival (Caswell *et al.* 1999, Wade and Clapham 1999, Fujiwara and Caswell 2001) were negatively biased through exclusion of these "offshore" individuals.

Use of models exactly equivalent to those in Caswell *et al.* (1999) was not possible because a predictor of capture effort that they used was not available. Instead, the analysis employed an individual catchability coefficient and a different measure of effort which was not independent of the resightings data, but always available as covariates to account for annual and individual capture heterogeneity.

Despite the methodological issues described above, the general conclusion of the work by Pace was much the same as that of others: that North Atlantic right whale survival declined through the 1990's relative to the 1980's. This was true even with incorporation of recent data from offshore areas.

Kraus

Kraus reported on his analyses of heterogeneity in sighting probabilities. He identified approximately 50 animals which are sighted in less than 50% of the years through the study period. An evaluation of these "rare" animals suggests that they may be problematic for models, since there did not appear to be any particular feature (sex, haplotype, habitat use pattern) that would allow prediction of when these whale would "disappear" or "re-appear". Older age in right whales may be correlated with lower sighting rates, but the data are confounded by changing effort over the study period and need further analysis.

Summary: status of the population

Having reviewed the updated work, the workshop participants agreed that, despite its small size, the right whale population is not performing as one might expect, with rates of population growth (decline) and reproduction that are markedly below those reported for right whales (*E. australis*) in the Southern Hemisphere.

Some participants remained concerned that the apparent trend in survival may be to some extent an artifact of heterogeneity in capture probability. It was suggested that it would not require very many individuals to exhibit major shifts in spatial distribution for a few years to impact apparent survival; this is particularly true for mature females, who appear to be disproportionately involved in the observed decline. Other participants disagreed equally strongly with this position, in the absence of evidence that this potential artifiact is more than just potential.

There was some discussion regarding the apparent correlation between survival and the NAO. The mechanism by which survival could be affected in not clear; however, Caswell hypothesized that animals that were already stressed from entanglement or other problems might have a lower probability of survival if NAO-related nutritional stress was also in effect at the time.

Nonetheless, despite these uncertainties participants agreed that the population is struggling and cannot from any perspective be termed healthy.

Approaches to future work

Participants described several studies that were ongoing or planned in relation to survival estimation. Caswell noted that he and Fujiwara were planning to examine the heterogeneity issue using simulated data sets, and would also attempt to include geographic variation and differential site fidelity in future models.

Pace is continuing to work on an individual-based model; he is also attempting to calculate capture probabilities for specific locations and integrate these into the estimation process. In addition, he plans to explore aspects of heterogeneity

in whale distribution and in sampling, and to test the influence of these on survival estimation through the use of simulated data.

Wade and Clapham noted that they would revise the cluster analysis study to include sighting updated data through 2000. Wade also proposed an approach to survival estimation that would involve spatially explicitly modeling of capture probability; this is outlined in Appendix I below.

Finally, Brault said that she was planning to explore the application of Population Viability Analysis to the North Atlantic right whale population.

Literature cited

Caswell, H., Brault, S. and Fujiwara, M. 1999. Declining survival probability threatens the North Atlantic right whale. *Proc. Natl. Acad. Sci. USA* 96: 3308-3313.

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Wade, P.R. and Clapham, P.J. 1999. The influence of sighting probabilities on survival estimates North Atlantic right whales. Paper SC/O99/RW2 presented to the IWC Workshop on Status and Trends of North Atlantic Right Whales. Available from the International Whaling Commission, Cambridge, UK.

Appendix I

A proposal for a spatially explicit capture probability model

Paul Wade

Wade and Clapham (1999) attempted to account for spatial heterogeneity in sighting probability by grouping individuals, recognizing that different individuals had different patterns for using different habitats/areas. Another approach to accounting for this heterogeneity in capture probability would be to directly model different capture probabilities in different areas, in combination with an individual-based covariate to account for different habitat use by different individuals. Thus, rather than assume (or test) a different capture probability for different groups of right whales that use different areas, assume a different capture probability in different areas that applies to any whale that is there, and then make an individual's capture probability a function of that as well as of its preference for how long it stays in each different area.

This will involve moving to a spatially explicit model for capture probability. As an example, consider two different areas, the Bay of Fundy (BOF) and the Great South Channel (GSC). Construct a capture probability model that allows for a different parameter that defines capture probability in each of those two areas. Then calculate an individual covariate based on the number of times an individual is seen in one of those areas, and make capture probability a function of that individual covariate.

Total capture probability in a given year would then be the sum of the probability of capture in each area, minus the probability of being captured in both areas in a year. For just two areas,

$$PTOT = PBOF + PGSC - (PBOF * PGSC)$$

Thus, the maximum number of capture probability parameters would be five times the number of years of data, which is not too different than the cluster/grouped analysis of Wade and Clapham (1999), that had a different capture probability for each of four groups in each year.

It is not entirely clear if this framework might fit into existing software for spatially explicit models. The biggest problem is that right whales are often seen in more than one location in a year, for which some of the spatially explicit models do not allow.