Incorporating Uncertainty into Management Models for Marine Mammals

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Good management models and good models for understanding biology differ in basic philosophy. Management models must facilitate management decisions despite large amounts of uncertainty about the managed populations. Such models must be based on parameters that can be readily estimated, must explicitly account for uncertainty and should be simple to understand and implement. In contrast, biological models are designed to elucidate the workings of biology and should not be constrained by management concerns. Past marine mammal management was based on a simple biological model that, although it may have adequately represented population dynamics, failed as a management tool because the parameter that triggered management action, maximum net productivity level, was extremely difficult to estimate for the majority of populations (Taylor et al. in press). Uncertainty in parameter estimation resulted in few conservation actions. The recently adopted management scheme translates management objectives into quantitative objectives called performance criteria. This allows the management scheme to be adjusted to meet objectives using simulation models (Wade 1997) and puts management decisions on a quantitative footing such that those disagreeing with the management outcome must openly state that they disagree with the performance criteria.

The marine mammal example shows how a rarely implemented law can be turned into a functioning and pro-active law through appropriate consideration of uncertainty. The new management regime grew out of proposals from NMFS, the Marine Mammal Commission, fishing groups and environmental organizations. It sought to do three things: (1) explicitly consider uncertainty in management, (2) base management on parameters that could be estimated, and (3) provide incentives to gather better data. The management goals of the Act are to maintain populations 1) above optimum sustainable yield, and 2) as functioning elements of their ecosystem. These were interpreted as performance criteria: 1) populations starting at 50% of K (MNPL) should remain at that level or above over the next 20 years with a 95% probability, 2) populations at 30% of K should reach MNPL in 100 years with a 95% probability, and 3) stocks should be defined so as to maintain the species' range. A mortality limit, called the Potential Biological Removal (PBR), is calculated as:

$$PBR = N_{MIN} \frac{1}{2} R_{MAX} F_R \qquad (1)$$

where, N_{MIN} = minimum population estimate, R_{MAX} = maximum population growth rate, and F_R = recovery factor.

The idea of the model is basic: humans should not remove more than the population needs to maintain at least half of its current carrying capacity (K) (or if K has been constant, historical numbers). The model explicitly incorporates two types of data uncertainty: imprecision and bias. To get an intuitive grasp of the PBR management scheme, consider an analogy of shooting at a target. Instead of a bullseye, the target is a square with a horizontal line bisecting the midpoint. For any given shot at the target, the goal is to always (i.e., with high probability) place your round above the line. This symbolizes maintaining populations above MNPL. Imagine that you want to make certain when you shoot that you hit above this line 95% of the time. Now consider two guns: a pilgrim's musket and a sniper's rifle. The rifle shoots with great precision and is equivalent to an abundance estimate with a very low coefficient of variation (CV). Even an expert marksman, however, would be considerably less precise with the musket; repeated attempts with the musket results in a more diffuse pattern than with the rifle. In order to insure a high chance of hitting the target above the line, the marksman would deliberately aim the musket higher than the rifle. Using N_{MIN} in the PBR equation effectively raises the aiming point to adjust for poorer precision in the abundance estimates. How high above the line the marksman needed to aim was decided by simulating the response of the hypothetical population to PBR-type management. The simulations both estimated abundance and removed the estimated PBR from model populations. Finding the proper level needed to adjust for poor precision is termed tuning. Repeated simulations using different lower percentiles of the abundance distribution for N_{MIN} were used to find the level of precision that met management objectives. This level would allow the marksman to placed his/her round above the line 95% of the time. Wade (1997) found the appropriate level for N_{MIN} to be the lower 20th percentile of the distribution of an abundance estimate.

The simulations illustrated that using the "best" estimate manages less well known populations (with lower precision abundance estimates) less conservatively. Using a lower percentile of the abundance, in contrast, manages less well known populations more conservatively. Thus, simply incorporating the uncertainty due to the precision of the abundance estimate met two management goals: increasing the margin of safety commensurate with the level of our ignorance of the population, providing an incentive to gather more precise data.

The second type of uncertainty is bias, which was incorporated through the recovery factor parameter (F_R). Returning to the marksman analogy, bias would be indicated if shots aimed at a target consistently missed in one direction. The correction is to tune the sights. If the sights are improperly adjusted, the marksman may aim above the line but consistently hit below it. There are many ways that bias could lead to unfavorably overestimating PBR; therefore, a second set of simulations considered bias in the estimated parameters. One scenario considered was overestimating the abundance by a factor of two. Such an overestimate could come from the relatively unlikely event of animals being attracted to the survey vessel or, more likely, from animals being included in the abundance estimate that were really part of another population. The possibility of such errors led to the setting of default values for the recovery factor (F_R) such that 95% of the simulated populations equilibrated within OSP despite such errors. If the possible factors that cause bias are eliminated, this parameter can be raised to a value of one. However, doing so dramatically reduces the safety margin for managing the species (Taylor 1997).

The final parameter in eq. 1 is R_{MAX}. Here again we chose to use conservative default values when data are lacking. Using data from recovering populations, conservative default values were chosen as 0.04 for whales and dolphins and 0.12 for seals and sea lions. Of course, data from the species or population of concern are used whenever available. Details of the simulations and rationale for default values are given in Wade (1997).

Uncertainty about how the law will be implemented by government agencies was also considered. PBR's are calculated for each stock by federal government scientists and are presented in stock assessment reports. These reports are reviewed by three regional Scientific Review Groups, a body of non-federal scientists (representing perspectives of state agencies, academia, fisheries and environmental groups) who make recommendations on research priorities and the adequacy of the data used. Stocks for which estimated fishery-caused mortality exceeds PBR are termed "strategic". Regulations are not automatically imposed on fisheries when kills exceed the PBR. Instead, data are scrutinized for the potential that biases can be reduced by improving abundance estimates or stock definitions. If the data are sound and fisheries contribute significantly to mortalities in strategic stocks, a Take Reduction Team is formed. The team of fishers, environmentalists, state and federal government representatives and scientists is charged with the task of recommending means to reduce the kills (take) to levels at or below PBR within 14 months subsequent to the finalization of the stock assessment reports.

Results of current management model

After the first year of implementation (1994), stock assessment reports were written for 153 stocks in U.S. waters, and PBRs were published for 89 stocks (Barlow et al. 1995; Blaylock et al. 1995; Small and DeMaster 1995). Kills exceeded PBR for 24 stocks of marine mammals. Although some of these, such as harbor porpoise in the Gulf of Maine, were known to be at risk before the management scheme was instituted, many were species that had received no attention in the past. Chief among these are species of whales that spend long times beneath the surface, including sperm whales (*Physeter macrocephalus*) and numerous species of beaked whales (Family *Ziphiidae*). Some of the greatest advances in knowledge since the new management regime came into place are for the relatively rare and unstudied species, like the beaked whales. New assessment techniquesthat are more suitable for these rare species have been created (Barlow and Sexton 1996).

The stock assessment reports reveal both stocks that are at risk and gaps in our knowledge required for proper management. Comprehensive surveys of the Pacific coast were completed in 1996 and are scheduled for the Atlantic coast in 1998. Because the law mandates monitoring, surveys are planned to continue on a rotational schedule. Testing of the scheme has also made clear the importance of understanding population structure and genetic sampling (which are becoming an integral part of survey design). Knowing the spatial distribution of kills allows formulation of stock boundary hypotheses needed to interpret genetic data (Taylor and Dizon 1996, Taylor 1997, Taylor et al. in press). Take Reduction Teams have been formed and research is underway to develop techniques to reduce the number of marine mammals killed in fisheries to as near zero as practicable.

Despite the initial appearance that for many species and areas this management scheme seems to be working well, there are some concerns. The most neglected parameter is the estimate of kills. Estimates are especially poor for fisheries with large numbers of very small boats, often operated by one person. Assuring adequate coverage would require a much higher level of funding than is currently allocated to this problem.

Another area of concern is the definition of stocks. Although a single definition was used in the PBR guidelines published to standardize management (Barlow et al., 1995, Wade and Angliss 1997), different regions did not agree with this definition and created their own definitions. The success of this management scheme depends in large part on proper definition of stocks or use of F_R to account for potential biases. If stocks are defined in large units, such as the entire Pacific coast, it is likely that localized fisheries will never exceed PBR and therefore any management actions needed to preserve the integrity of the range would not occur. Nevertheless, many scientists feel it is beyond the prerogative of science to draw lines on a map when data are few to nonexistent. Refusing to draw stock boundaries does not, however, leave the stock as “undefined” with no kills allowed. Rather, refusal defines the management unit as the range of the species and puts the burden of proving that population structure exists on scientists before any management actions will be taken. Obtaining measures of population structure for marine animals is difficult because their aquatic nature limits access for research. Requiring proof of structure means at the least lengthy delays until management units are adequately defined. Indeed, requiring such proof may make the new management scheme as ineffective as the old scheme for some species because a required parameter is essentially impossible to estimate.

Indirect and direct human-caused mortality pose the greatest risks for marine species and we have directed our management efforts accordingly. General lessons from our marine experience are: 1) models must be based on parameters that are easily estimated, 2) model performance is guided by performance criteria, which are a quantitative form of management objectives, 3) uncertainty should be directly incorporated so that not only can management proceed despite uncertainty but that management is more conservative the greater the uncertainty, and 4) management models should be rigorously tested using simulations.

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