CONCLUSIONS

The widely used mortality rate estimated for the 1987-1988 epizootic of bottlenose dolphins along the Atlantic coast of the U.S. appeared to be an overestimate. Using the same stranding data as the previous analysis, a simple computation yielded the die-off mortality rate of <0.47, which was less than the previously reported value (0.53). Although the analysis was based on the same set of assumptions as the previous study, these assumptions were neither testable nor persuasive. Further, recent studies indicated there was more than one stock of bottlenose dolphins along the coast, violating one of the main assumptions of the analysis. Consequently, the argument about the validity of these estimated mortality rates during the epizootic became meaningless. The process of estimating mortality during a die-off from stranding data, however, was shown to be useful as a methodology.

To compute mortality of a die-off from stranding data, estimation of vital rates of the species before the die-off is critical. The rate of recovery of a population from a mass die-off depends largely on anthropogenic mortality rates, birth rates, and natural mortality rates. Consequently, these parameters should be estimated before a mass die-off occurs in a population. Effort for collecting stranding data also should be measured because the recovery rate of carcasses generally increases during a die-off due to increased public awareness.

Regardless of the mortality rate during the epizootic of 1987-1988, management and conservation decisions are necessary for bottlenose dolphins along the coast. The most recent management decision for bottlenose dolphins along coast defines seven management units (Waring et al. 2002). Other studies have indicated this should be the minimum number of management units along the coast. The mortality due to human interactions, such as by-catch from fishing operations, may be unacceptably high for some management units (Waring et al. 2002). If small genetically distinct stocks are combined together to form a large management unit, a computed PBR for the unit may be large enough to extirpate one or more of stocks within the unit. To estimate the abundance of bottlenose dolphin populations, capture-mark-recapture methods with photographic captures may be appropriate because of the existing photographic identification studies in many locations.

To successfully apply a CMR method to estimate the minimum abundance of a management unit, however, the existing sampling protocol for photographic identification studies needs to be refined. A sampling protocol for making inferences on abundance should include the randomization of sampling within a management unit so that all areas have the equal probability of being sampled. Further, a quantitative method should be used for estimating the proportion of identifiable individuals in each management unit.

Because the size of each management unit probably is small and the sighting probabilities are low, the maximum likelihood estimates may not provide precise estimates. The proposed Bayesian method provides an alternative approach. The proposed method enables a researcher or manager to use the existing photographic identification data for obtaining information on capture probabilities and abundance. The information, then, is updated via new data.

As Arnason (1998) pointed out, all available information should be used for designing and planning a CMR study. I have shown, through a simulation analysis and the analyses of real data, that incorporating prior information could enhance the precision of a posterior distribution of abundance via a Bayesian analysis. Even for opportunistically collected photographic sighting data in this study, considerable amount of information was available for making inferences on sighting probabilities and abundance. The proposed Bayesian method is one way to incorporate the information into an analysis via a formal mathematical framework. The widely used maximum likelihood estimators, such as from MARK, are not capable of updating one's knowledge about capture probabilities or abundance. Bayesian methods should provide an alternative approach to the widely used frequentist methods, whose validity has been questioned by many statisticians.

Although Bayesian methods are useful in ecological sciences, the use of Bayesian methods has been criticized. I briefly justify the use of Bayesian methods in this study and ecological studies in general. More complete philosophical and theoretical discussion of Bayesian and non-Bayesian statistics can be found elsewhere (Berger 1985, Edwards 1992, Robert 1994, Royal 1997, Goodman 2002, Goodman 2003).

A strong criticism of the Bayesian philosophy in ecological science is found in Dennis (1986). Dennis (1996) condemned the use of Bayesian methods in ecology:

> *"…I would argue that the Bayesian philosophy of science is scientific relativism.*
> *"To scientific relativists, truth is subjective. Scientific theories are socially 'warranted' constructs that do not necessarily make progress toward uncovering universal truths…."*

He argued that Bayesian analyses were based on subjective beliefs of a researcher. In his paper, however, he implicitly assumed that all Bayesian analyses were based on subjective prior distributions. In many situations, however, prior distributions can be constructed from available data. These data may come from a similar species from the same area, the same species from other areas, the same population but from past studies, or a combination of these data. Hence, the belief of the investigator does not necessarily constitute the prior distribution. The state of current knowledge about the parameter, which is described by the prior distribution, is updated via new data, a statistical model (i.e., likelihood function), and Bayes theorem. Bayesian analyses offer a formal mathematical method for incorporating existing knowledge about parameters into a current analysis. In this perspective, Bayesian methods are another set of tools for making inferences on unknown parameters, conditional on the model, data, and the prior information, which may be independent of the belief of a researcher.

Results of a scientific study often are not clear-cut, especially in ecological and conservation sciences, where a large variability exists in the system. Decisions have to be made at the conclusion of a study regarding interpretations of the results. A scientist would not make a decision independent of his/her knowledge about the system. Such a decision would be unproductive and ignores the progress of science. The Bayesian approach to a study requires that knowledge of the system be quantified; more specifically the knowledge needs to be expressed in a probability distribution. The probability distribution then is updated as more data are collected. I find this process to be a productive scientific process.

Several researchers have shown that Bayesian methods are valuable in conservation biology (Ludwig 1996, Taylor et al. 1996, Wade 2000) and assessment and management of populations (Best and Underhill 1990, Thompson 1992, Raftery et al. 1995, Punt and Butterworth 1997, Kinas and Bethlem 1998, Punt et al. 2000). As an ecologist, not as a professional statistician, I do not claim a complete knowledge of Bayesian statistics nor do I successfully defend Bayesian statistics from all criticisms. Rather, I think the Bayesian approach is a viable alternative (or at least addition) to the generally accepted hypothesis testing approach. I think my research has demonstrated a useful application of a Bayesian method in an ecological study.