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Ten thousand and increasing: Is the western Arctic population of bowhead whale endangered?

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ABSTRACT

Based on a series of 11 abundance estimates over 23 years, the western Arctic population of bowhead whale (WABW) has recovered substantially since it was listed under the US Endangered Species Act. We evaluate extinction risk for WABW to determine if this population should be considered for reclassification under the ESA. Given the uncertainty associated with distinguishing process error and observation error, we consider three scenarios reflecting different assumptions for process error. We applied the quantitative criteria for recovery and delisting using the approach proposed by [Gerber, L.R., DeMaster, D.P., 1999. An approach to endangered species act classification of North Pacific humpback whales. Conservation Biology, 13, 1203–1214] for large whales. To further examine the monitoring process and make recommendations for future data needs, we then re-ran the model using progressively smaller sub-samples of the census data. As longer time series of data were considered, the fraction of outcomes consistent with a "delisting" decision increased. For the 10 and 11-census year subsets, data unequivocally support a decision to delist this population for the 3 scenarios. Furthermore, the IUCN criteria for endangered and vulnerable are not met for this population of bowhead whale under any of our scenarios. Results from the population projections and application of the risk classification criteria are consistent with a determination that the risk of extinction for this population is insignificant in the foreseeable future.

1. Introduction

Given the broadly perceived lack of objectivity in making risk averse conservation decisions, population viability analyses (PVA) offers an approach to making classification decisions less arbitrary and more grounded in scientific information by allowing explicit estimation of the likelihood that a population will persist for a particular time period. However, previous analyses of US Endangered Species Act Recovery plans have led some biologists to conclude that most plans do not include biologically defensible listing guidelines (Wilcove et al., 1993). Without clearly defined metrics for recovery, responsible agencies may be unable to gauge the successes and failures of recovery efforts (Gerber and Hatch, 2002; Pyare and Berger, 2003). Incorporating analyses of extinction risk into formal risk classification criteria such as those provided by the IUCN provides one approach to address this issue.

Large whales represent an interesting case study for developing quantitative approaches to risk classification. Contrary to conventional wisdom, a majority of populations of large whales (where data exist on trends in abundance or status) that were depleted by commercial fisheries 50–150 years ago are recovering (Best, 1993). However, the same cannot be said for all of the extant populations of bowhead whales (*Balaena*

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mysticetus) that inhabit Arctic waters (Mitchell and Reeves, 1982). Several of these populations show little or no sign of recovery (e.g., the Okhotsk Sea population of a few hundreds of animals and the eastern North Atlantic population of a few tens of animals), while the western Arctic population (WABW, also referred to as the Bering-Chukchi-Beaufort Seas population) has monotonically increased since the late 1970s (IWC, 2004) and currently includes over 10,000 individuals. The only other area where bowhead whales exist is the eastern Canadian Arctic. The status of bowhead whales in this area is under review by the IWC and is therefore currently unknown (IWC, 2006).

The dynamics of the WABW population have likely been impacted by a well-managed harvest by Native subsistence hunters primarily in Alaska, but also in Russia. Nonetheless, this population has shown robust growth and recovery over the last 20 years. The Alaska Eskimo Whaling Commission (AEWC) has co-managed this population with the US government since the early 1980s under a management protocol developed by the International Whaling Commission. In addition, the AEWC and Russia have a bi-lateral agreement to manage WABW bowheads (Shelden and Rugh, 1995).

The purpose of this paper is to apply the risk of extinction criteria reported in Gerber and DeMaster (1999) and Gerber et al. (1999) to the population of WABW. We used time series of abundance estimates reported by Zeh and Punt (2005) to evaluate the likelihood that this population, which is currently increasing at approximately 3% per year, will fall below the threshold for a non-negligible risk of extinction (i.e., a population level that falls below a minimum of 500 animals in the next 35 years – Gerber and DeMaster, 1999; Gerber et al., 1999). This particular time period (i.e., 35 years), while relatively short compared to the published literature on population viability analyses (DeMaster et al., 2004), is consistent with the timescales deemed appropriate for management of large whales (Gerber and DeMaster, 1999). To put our findings in the context of the more traditional time period referenced in risk of extinction evaluations in the published literature, we also evaluated the likelihood of the risk of extinction in 100 years.

Our rationale for applying the Gerber and DeMaster criteria to this case study is to allow for comparisons across populations where data availability and quality varies considerably. Further, a similar analysis reported by Gerber et al. (1999) for the eastern North Pacific population of gray whale indicated that roughly 10 or more abundance estimates for a population with the life history of a mysticete whale were required to make a robust evaluation regarding the likelihood that a population would fall below 500 animals within the next 35 years. With the most recent abundance estimate for this population in 2001 reported by George et al. (2004), there are 11 estimates of abundance from 1978 to 2001 for WABW (Fig. 1), thus providing an interesting opportunity to explore the generality of this approach to risk classification for another endangered population of large whales.

Risk of extinction is only one factor generally considered in developing recommendations concerning the appropriate listing status under the US Endangered Species Act (i.e., endangered, threatened, not listed). Four other factors (i.e., overexploitation, lack of regulations, disease/predation, and

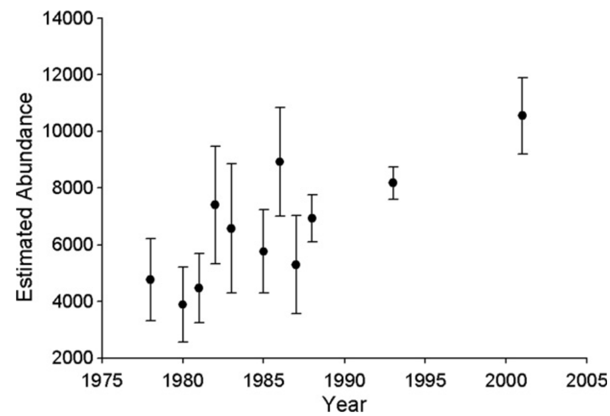

Fig. 1 – Abundance estimates and standard deviation for the western Arctic bowhead whale stock (Zeh and Punt, 2005). Survey data indicate an estimated annual rate of increase from 1978 to 2001 of 3.4% (95% CI 1.7% to 5%, George et al., 2004).

habitat destruction) must also be considered, but are beyond the scope of this paper. Thus, we suggest that our results be considered in the context of those reported by Shelden et al. (2001) and the IWC (2004) in making a determination regarding the merits of initiating a status review of the WABW population for the purpose of potentially reclassifying this population under the ESA.

2. Methods

2.1. *Estimating population growth using the diffusion approximation model*

We used the Dennis et al. (1991) diffusion approximation method to estimate the infinitesimal mean (μ) and variance (σ^2) of the growth rate, which then allowed us to evaluate probabilities for the future behavior of stochastic populations. Variance in estimates of growth rate reflects environmental stochasticity, which is typically assumed to be a lognormal variate. Together these parameters allowed us to estimate a probability distribution that describes the likely range of future population sizes. To estimate the population growth rate for the western Arctic population of bowhead whale, we applied this simple diffusion approximation model (Dennis et al., 1991) to survey data on abundance collected by the North Slope Borough and NMFS between the years of 1978 and 2001 (George et al., 2002; Brandon and Wade, 2004; Zeh and Punt, 2005; Fig. 1). This is an exponential model:

$$N_{t+1} = \lambda_t N_t$$

where *N* is the population abundance for year *t* and λ is the growth rate for year *t*.

The Dennis model assumes that (1) total abundance is estimated at each survey, (2) interannual variation in the estimates of abundance are determined primarily by process error (environmental stochasticity) rather than sampling error, (3) the population experienced no severe catastrophes during the study period, and (4) density dependent influences on the population growth rate are negligible. For the WABW, there is sufficient evidence to justify assumptions 1, 3 and 4, but data are not yet available to evaluate assumption 2 (Shelden et al., 2001). However, Zeh and Punt (2005) provide an estimate of process error specifically for WABW, which we consider as an alternate scenario in our model.

A number of extensions have been developed that allow partitioning of sampling and process error (Staples et al., 2004; Holmes, 2004). Unfortunately, the data available for bowhead whales do not meet the assumptions of these more sophisticated methods. These approaches require that data come from uniform sampling intervals with no missing points and further requires more years of data than the Dennis model because of the additional parameter to be estimated. In the absence of enough data to apply these methods, Staples et al. (2004) recommend that an estimate of the trend (μ) may be the best metric available for assessing risk. Thus, in addition to applying the Dennis et al. approach as described above, and considering the process error estimate of Zeh and Punt (2005), we also analyzed the situation in which all variation is observation error (with no process error), so risk estimates are based entirely on μ.

In summary, our three scenarios include: (1) "all process error", where interannual variation in the estimates of abundance is determined by process error (rather than sampling error), (2) "no process error", variation is determined by sampling error (rather than process error), and finally, (3) "intermediate process error", where we consider the estimate of 0.270 for process error for WABW from Zeh and Punt (2005). This value is derived based on interannual variation in the proportion of the population that is within 4 km of observation points, and thus may represent an overestimate of true process error. Attributing the between-year variation in abundance estimates entirely to process error may lead to an overestimate of extinction risk, and assuming all error is observation error would lead to an underestimate of risk. Thus our three scenarios are likely to bracket the real population dynamics of WABW.

2.2. Criteria to evaluate risk of extinction in the foreseeable future

We applied our analysis of risk of extinction to evaluate the appropriateness of the current ESA classification of the WABW population as endangered and to contribute to the establishment of quantitative criteria for recovery and downlisting to threatened. Several methods for risk classification exist, and several were applied to WABW by Shelden et al. (2001). We chose to use the approach developed by Gerber and DeMaster (1999) because this approach was developed particularly for applying results of risk of extinction analyses to populations of large whales. Thus far, the approach has been applied to populations of North Pacific humpback whales using demographic data (Gerber and DeMaster, 1999), abundance data for the eastern North Pacific population of gray whale (Gerber et al., 1999), census data for the WABW using data from 1978 to 1993 (Shelden et al., 2001) and to evaluate the sensitivity of extinction under varying stochastic scenarios for the Steller sea lion (Gerber and VanBlaricom, 2001). Conceptually, the approach relies on estimates of μ and σ^2 to determine a probability distribution for the rate of growth, λ, and the lower 5th percentile of this distribution, $\lambda_{(.05)}$. The value of $\lambda_{(.05)}$ is then compared to the values for λ which correspond to the deterministic rate of growth for which the observed population size in year y would decline to a critical population threshold in specified time periods (described below).

The method developed by Gerber and DeMaster (1999) allows us to use the growth rate estimates from the Dennis model and incorporate sampling error inherent in the fluctuating population. The Dennis model represents a simple method to estimate extinction risk based on abundance data and widely used in conservation biology. This approach is based on a probability-driven model of population demographics, which establishes threshold levels for threatened and endangered status by projecting a growth rate back from a specified quasi-extinction threshold level (N_q). An N_q value of 500 is used as the lowest limit a whale stock can reach and still recover (Ralls et al., 1996; Gerber and DeMaster, 1999). We define the endangered threshold (N_{end}) as the population size at which the population has a 95% chance of remaining above N_q over a 10-year period. The threatened threshold (N_{th}) is the population size with a 95% chance of remaining above N_q for 35 years. These criteria are then used to evaluate the risk of extinction of the WABW population. We estimate the 5th percentile of the λ distribution as the growth rate (corresponding to our stated 95% criterion) to encompass likely variation and produce conservative estimates. If the population model indicated a greater than 5% chance that the population would fall below the quasi-extinction level in the next 10 years, listing as endangered would be warranted. Similarly, a 5% chance of such a decline occurring over 35 years would be consistent with listing as threatened. A recommendation to delist (i.e., remove a population from the List of Endangered and Threatened Wildlife) would be consistent with a finding that it was unlikely the WABW stock would fall below 500 animals in the foreseeable future (i.e., 35 years).

To further examine the monitoring process and make recommendations for future data needs, we re-ran the model using progressively smaller sub-samples of the full census data (Gerber et al., 1999). All consecutive combinations of data were used and each subset was applied to the Dennis model and analyzed in the context of extinction risk criteria reported by Gerber and DeMaster (1999). We applied the previously described techniques to find the 5th percentile λ from all subsets of data ranging from 4 to 11 data points, as well as data from alternating years. For any given subset of abundance estimates, all sequential combinations of data were used. Distributions of possible population growth rates resulting from each sample were subjected to the risk classification protocol described above.

Because of the life history characteristics of this species (e.g., delayed maturation, extreme longevity, George et al., 2004; high survival, Zeh et al., 2002), we also examined the probability that this population will fall below the 500 animal threshold within the next 100 years. Results from this second analysis are then applied to determining the population's status based on the IUCN criteria (World Conservation Union, 1996).

3. Results

Using the entire time series of data (11 counts over 23 yrs), it appears unlikely that the WABW population will fall below a threshold of 500 animals in the next 35 years. This is not an unexpected result, given the current population size and the consistent increasing trend in abundance of this stock (Fig. 1). The analysis of the subsets of census data ranging from a minimum of four data points to the maximum of 11 data points produced a range of estimates of λ_{end} and λ_{th} of 0.74–0.79 and 0.92–0.93 (Table 1). That is, the WABW population would have to be declining at approximately 25% per year to decline to a population level of 500 in 10 years and a decline rate of approximately 8% per year to decline to a population level of 500 in 35 years. Given the observed increase in abundance in the WABW population over the past 23 years, declines of this magnitude appear to be extremely unlikely.

Overall, the median times to extinction were 237, 249 and >500 years for the all process error, intermediate process error and no process error scenarios, respectively (Fig. 2). For the population to be classified under the IUCN criteria as endangered (a different classification of risk of extinction than used under the ESA), the probability of extinction must be least 20% within 20 years or 5 generations, whichever is longer. For the population to be considered as vulnerable, this probability must be at least 10% in 100 years. Our results indicate that the IUCN criteria for endangered and vulnerable are not met for bowhead whales (Fig. 2). For bowhead whales,

Table 1 – Fifth percentile λ values for each census and the associated threshold levels for endangered and threatened under the criteria of Gerber and DeMaster (1999) for each scenario (all process error, intermediate process error, and no process error)

Time period (yrs)	λ_{end}	λ_{th}	$\lambda_{(.05)}$ all process	Classification (all process)	$\lambda_{.05}$ Intermediate process	Classification (intermediate process)	$\lambda_{.05}$ No process	Classification (no process)
1978–1982	0.77	0.93	0.874	Threatened	0.900	Threatened	1.093	Delist
1980–1983	0.77	0.93	0.956	Delist	0.950	Delist	1.192	Delist
1981–1985	0.78	0.93	0.813	Threatened	0.866	Threatened	1.051	Delist
1982–1986	0.75	0.92	0.820	Threatened	0.852	Threatened	1.034	Delist
1983–1987	0.79	0.93	0.677	Endangered	0.770	Endangered	0.935	Delist
1985–1988	0.77	0.93	0.756	Endangered	0.848	Threatened	1.063	Delist
1986–1993	0.76	0.92	0.759	Endangered	0.882	Threatened	1.017	Delist
1987–2001	0.74	0.92	1.000	Delist	1.001	Delist	1.102	Delist
1978–1983	0.77	0.93	0.861	Threatened	0.886	Threatened	1.049	Delist
1980–1985	0.78	0.93	0.888	Threatened	0.905	Threatened	1.070	Delist
1981–1986	0.75	0.92	0.916	Threatened	0.960	Delist	1.136	Delist
1982–1987	0.79	0.93	0.735	Endangered	0.782	Endangered	0.925	Delist
1983–1988	0.77	0.93	0.781	Threatened	0.845	Threatened	1.000	Delist
1985–1993	0.76	0.92	0.893	Threatened	0.943	Delist	1.071	Delist
1986–2001	0.74	0.92	0.854	Threatened	0.968	Delist	1.057	Delist
1978–1985	0.78	0.93	0.858	Threatened	0.879	Threatened	1.007	Delist
1980–1986	0.75	0.92	0.961	Delist	0.980	Delist	1.138	Delist
1981–1987	0.79	0.93	0.821	Threatened	0.878	Threatened	1.020	Delist
1982–1988	0.77	0.93	0.807	Threatened	0.844	Threatened	0.980	Delist
1983–1993	0.76	0.92	0.904	Threatened	0.929	Delist	1.037	Delist
1985–2001	0.74	0.92	0.896	Threatened	0.997	Delist	1.083	Delist
1978–1986	0.75	0.92	0.922	Delist	0.938	Delist	1.063	Delist
1980–1987	0.79	0.93	0.867	Threatened	0.906	Threatened	1.037	Delist
1981–1988	0.77	0.93	0.881	Threatened	0.922	Threatened	1.056	Delist
1982–1993	0.76	0.92	0.906	Threatened	0.923	Delist	1.023	Delist
1983–2001	0.74	0.92	0.974	Delist	0.986	Delist	1.062	Delist
1978–1987	0.79	0.93	0.863	Threatened	0.888	Threatened	0.996	Delist
1980–1988	0.77	0.93	0.914	Threatened	0.943	Delist	1.068	Delist
1981–1993	0.76	0.92	0.956	Delist	0.967	Delist	1.065	Delist
1982–2001	0.74	0.92	0.973	Delist	0.980	Delist	1.052	Delist
1978–1988	0.77	0.93	0.900	Threatened	0.919	Threatened	1.024	Delist
1980–1993	0.76	0.92	0.961	Delist	0.978	Delist	1.071	Delist
1981–2001	0.74	0.92	0.997	Delist	1.006	Delist	1.077	Delist
1978–1993	0.76	0.92	0.949	Delist	0.959	Delist	1.041	Delist
1980–2001	0.74	0.92	1.006	Delist	1.012	Delist	1.080	Delist
1978–2001	0.74	0.92	0.971	Delist	0.997	Delist	1.059	Delist

$N_q = 500$, and λ_{end} represents the population growth rate at which the population would reach 500 animals in 10 years. λ_{th} is the population growth rate at which the population would reach 500 in 35 years.

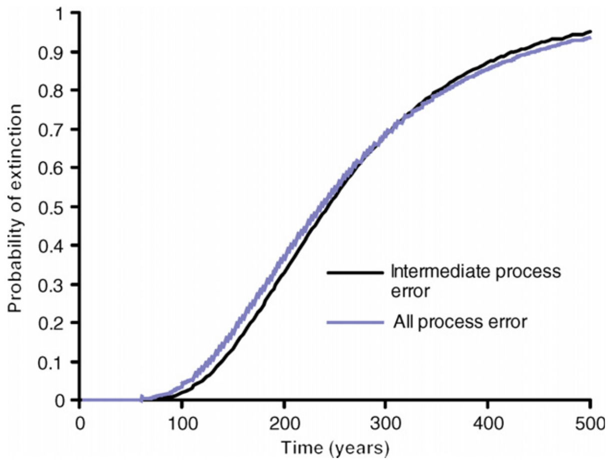

Fig. 2 – Cumulative probability of extinction for Western Arctic population of bowhead whale, using the entire 11 years of survey data for 3 different scenarios. The "no process error" scenario falls on the *x*-axis (i.e., there is no chance of extinction in 500 years for a population increasing at 3.5% per year with no process error).

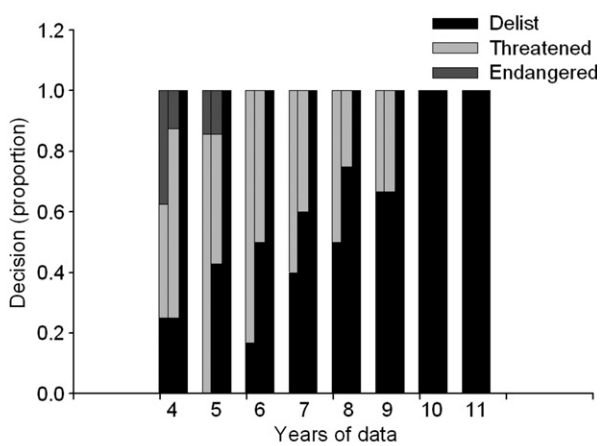

Fig. 3 – Fraction of classification decisions for all eight data subsets. Order of bars is, "all process error", "intermediate process error" and "no process error". Results indicate a higher variation in listing recommendations in smaller subsets with an unequivocal decision to delist in subsets containing 10 and 11 years of survey data over the 23-year period. For the "no process error" scenario, all subsets yield a "delisting" outcome.

the probability of extinction in 100 years is 3%, 2% and 0% for the all process error, intermediate process error and no process error scenarios, respectively.

When subsets of the full census data were considered, smaller subsets ranging from 4 to 9 years of data resulted in variable listing recommendations (endangered, threatened, delisted). Assuming no process error, all subsets yield a "delisting" outcome (Fig. 3). For the other two scenarios, as longer time series of data were considered, the fraction of outcomes leading to "delisting" increased. For the 10 and 11-year subsets, data unequivocally support a decision to delist this population under all scenarios.

Results from the population projections and application of the risk of extinction criteria of Gerber and DeMaster (1999) are consistent with a determination that the risk of extinction for this population in the foreseeable future is insignificant. Our results from the three different scenarios regarding the relative contribution of process error indicate that conclusions drawn are robust to the degree to which process error and sampling error contribute to uncertainty in the census data.

4. Discussion

The results of our analysis of risk of extinction are consistent with the findings reported by Shelden et al. (2001) using a similar type of PVA analysis and census data through 1993. That is, ignoring observation error, and consequently attributing the between-year variation in abundance estimates entirely to process error, leads to a negatively biased estimate for $\lambda_{(.05)}$. Because we know that the bowhead whale abundance estimates contain sampling error, using the Dennis et al. (1991) model will overestimate process error, yielding an overestimate of extinction risk (Shelden et al., 2003).

Our results are also consistent with those of the Scientific Committee of the International Whaling Commission, who has published extensively on the issue of devising "strike limit algorithms" (SLA) that do not seriously increase the risk of extinction due to subsistence whaling. The details of four specific SLAs applied to the WABW population are reported in IWC (2002). The SLAs that were actually adopted for management purposes are described in Givens (2003) and Dereksdóttir and Magnússon (2003). In most cases, the simulation trials were run for a time period of 100 years using similar demographic parameters to those reported in Brandon and Wade (2004). In all cases, populations did not go extinct. These findings indicate that even with annual removal levels on the order of 0.5–2% per year, the WABW population is unlikely to go extinct over the next 100 years, given that the assumptions in the modeled populations are met.

Results from our analysis are consistent with a decision to delist the western Arctic population of bowhead whale. In addition, our results from the application of IUCN criteria to current abundance estimates indicate that the WABW is not in danger of extinction in the next 100 years. It has been demonstrated that longer lengths of time-series data provide population projections with less variability when applied to PVA models (Gerber et al., 1999). For example, in the case of the eastern North Pacific gray whale, 11 years of data were needed to unequivocally provide a recommendation to delist. For the bowhead population currently in review, we have demonstrated that only 10 years of data were needed to provide a consistent recommendation to delist this population from the ESA. Considering that the delisting of the Eastern North Pacific gray whale was partly based on similar statistical analyses, we propose that our results for the western Arctic bowhead whale be used to support a decision by the US National Marine Fisheries Service to initiate a status review for this population.

It has been recognized that population-specific management is necessary to ensure the recovery of species listed as endangered and to avoid extirpation of individual populations.

Because of this, the US government currently manages large whales under the ESA at the population level, rather than the species level. Only one population of the 20–25 populations of large whales (depending on the definition of population) originally listed as endangered has been removed from the List of Endangered and Threatened Wildlife (i.e., the Eastern North Pacific gray whale). This appears to be inconsistent with the general observation that a majority of populations of large whales, where data on trends in abundance exist, have likely been recovering for over two decades (with several notable exceptions, including all three of the four populations of northern right whale (*Eubalaena glacialis* and *E. japonica*), at least two of the other four populations of bowhead whale, and the western North Pacific stock of gray whale). This lack of progress in reviewing the status of populations of large whales that are recovering, and reclassifying them, as appropriate, is to a large extent related to uncertainty regarding population structure. For example, the putative population of western North Atlantic humpback whale, which includes over 10,000 animals and has been increasing in abundance for over a decade (Barlow and Clapham, 1997), was considered a logical candidate for a status review under the ESA by NMFS (DeMaster, personal communication). However, based on extensive information from photo-identification studies, it was determined that this breeding population might be composed of several distinct feeding populations. Therefore, the issue of what constitutes a distinct population segment for western North Atlantic humpback whales remains to be resolved and hence consideration of the appropriate ESA classification has been put on hold.

Uncertainty in designating population structure is not the only factor contributing to the delay in the initiation of status reviews of populations of large whales. To some extent, this lack of progress stems from the lack of objective recovery criteria, as well as the iconic status of whales in the eyes of the US public. In addition, it should be noted that the process of downlisting and delisting populations of endangered and threatened whales is very complicated and requires considerable time and resources of several government agencies. Finally, based on the experience of the NOAA Fisheries Service in delisting the eastern North Pacific population of gray whale, such actions will very likely be opposed by many of the environmental groups. For example, Taylor (2003) suggests that uncertainty about the future environment of bowheads (e.g., related to global warming and the loss of sea ice in the Arctic) should be considered in reclassification decisions for bowhead whales. In addition, the Alaskan Native Organization that currently utilizes bowhead whales for subsistence purposes (i.e., the Alaska Eskimo Whaling Commission) may also resist downlisting or delisting this population because this may diminish its protection of bowheads under the ESA from offshore development of oil and gas resources. (Craig George, personal communication, Wildlife Department, North Slope Borough, Barrow, Alaska.)

In this analysis we have not incorporated recent concerns regarding the possibility of there being multiple stocks of bowhead whales in the western Arctic (IWC, 2004). Presumably, the IWC Scientific Committee will address this issue over the next few years. Therefore, the results of these findings will have to be considered as part of the next status review of this species by the NOAA Fisheries Service, and are beyond the scope of this paper.

The ongoing recovery of the bowhead whale is likely attributable to the relatively low anthropogenic mortality since commercial whaling ended in the early 20th Century (George et al., 2004). However, offshore oil development, increasing ship traffic, sea ice retreat, and commercial fishing may influence this population in the future. As noted above, these factors and others will have to be considered by the US National Marine Fisheries Service should the Agency agree to initiate a status review of this population for the purpose of evaluating whether the current ESA classification is appropriate. Objective, quantitative criteria are helpful in making this classification process as transparent as possible. At the same time, very difficult policy decisions will have to be made prior to the quantification of the five factors used to determine the status of a species under the ESA. Of particular relevance to the problem of ESA classification is a policy determination by the government agencies involved as to what is meant by "foreseeable future". In this analysis, we assumed that using a quasi-extinction level of 500 animals combined with a time period of 35 years provides a reasonable balance of being appropriately precautionary and practical at least for evaluating the risk of extinction of large whales in the foreseeable future. Ongoing research will help develop more sophisticated tools that incorporate uncertainty and policy parameters. Until such tools are available, we believe that relatively simply modeling approaches like the one used in this analysis present a reasonable way to proceed regarding the evaluation of risk of extinction for a variety of species.

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