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LESSONS FROM MONITORING TRENDS IN ABUNDANCE OF MARINE MAMMALS

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Abstract

We assessed scientists' ability to detect declines of marine mammal stocks based on recent levels of survey effort, when the actual decline is precipitous. We defined a precipitous decline as a 50% decrease in abundance in 15 yr, at which point a stock could be legally classified as "depleted" under the U.S. Marine Mammal Protection Act. We assessed stocks for three categories of cetaceans: large whales ($n = 23$, most of which are listed as endangered), beaked whales ($n = 11$, potentially vulnerable to anthropogenic noise), and small whales/dolphins/porpoises ($n = 69$, bycatch in fisheries and important abundant predators), for two categories of pinnipeds with substantially different survey precision: counted on land ($n = 13$) and surveyed on ice ($n = 5$), and for a category containing polar bear and sea otter stocks ($n = 6$). The percentage of precipitous declines that would *not* be detected as declines was 72% for large whales, 90% for beaked whales, and 78% for dolphins/porpoises, 5% for pinnipeds on land, 100% for pinnipeds on ice, and 55% for polar bears/sea otters (based on a one-tailed t-test, $\alpha = 0.05$), given the frequency and precision of recent monitoring effort. We recommend alternatives to improve performance.

Key words: decision analysis, marine mammals, monitoring, trends, trends in abundance, statistical power.

In 1994 the U.S. Marine Mammal Protection Act (MMPA) was amended to implement a new management approach designed to identify excessive human-caused mortality in U.S. waters (often referred to as the PBR scheme, for Potential Biological Removal) (Taylor *et al.* 2000). Scientists designing this approach recognized that trends in abundance would not be effective to identify at-risk stocks because the statistical power to resolve trends in abundance was very low with the data series that were available at that time. The new management approach was therefore based on estimates of direct, human-caused mortalities as well as information on stock abundance and structure. The implicit assumption behind the new management approach was that direct mortality, such as bycatch in fisheries, was the main threat to marine mammal populations.

However, several marine mammal stocks experienced severe declines that were not, so far as we know, a result of direct, human-caused kills. The noteworthy examples are the western stock of Steller sea lion (Loughlin *et al.* 1984, Merrick *et al.* 1992, Sease *et al.* 2001), several stocks of harbor seals in Alaska (Pitcher 1990, Ver Hoef and Frost 2003), the southwestern stock of sea otter in western Alaska (Doroff *et al.* 2003), and Hawaiian monk seals (Antonelis *et al.* 2006). Because the PBR system was not designed to identify stocks declining due to factors other than direct kill, we wondered whether this new approach, involving new and more-or-less regular population surveys instituted since 1994, has improved scientists' ability to detect trends in marine mammal stocks, particularly those resulting from causes such as depletion of prey base, ecosystem changes, predation, habitat degradation, or disease. Of course, it is also important to identify trends in cases where there is direct but unobserved mortality, as could be the case for fisheries without observers.

Our analysis addresses two questions: How likely are we to detect precipitous declines in abundance of marine mammals under U.S. management and does the answer to this question differ among different categories of marine mammals? We base our analyses on recent levels of survey effort and on the precision of abundance estimates from those surveys. We chose to define "precipitous decline" as a decline of 50% over a 15-yr monitoring period because such a decline would result in a stock being classified as "depleted" under the MMPA and either "vulnerable" or "endangered" under the IUCN Red List Guidelines, depending on whether the cause of the decline was known and reversible. If declines of less than 50% in 15 yr were occurring, our ability to detect those declines would be less than what is reported here.

This analysis was designed to demonstrate the consequences of employing standard practices of detecting declines in abundance and to represent a sufficiently representative group of stocks. We use the standard criteria for significance ($\alpha = 0.05$). Many scientists and managers remain unaware that this value is not an objective scientific value but rather a policy choice (Taylor and Gerrodette 1993). In a simplified way, using this criterion means that we expect to falsely conclude that a precipitous decline is occurring 5% of the time, which we call an overprotection error. Consider a case where our statistical power to detect such a decline is only 10%, that is, 90% of the time we would falsely conclude that there was no precipitous decline (an underprotection error). In this case, using the standard significance criterion ($\alpha = 0.05$) represents an implicit policy choice that we are eighteen times more willing to make an under- than an overprotection error (90/5).

The practice of examining trends in abundance using hypothesis testing has been questioned (Johnson 1999). Trends in abundance can be estimated directly and used in formal decision analysis (Taylor *et al.* 1996). However, both approaches (hypothesis testing and parameter estimation) require policy decisions to interpret what level of decline warrants management action and what degree of evidence is required that such a decline is occurring. Because there has been no policy decision made on what balance is desired between underprotection and overprotection errors, we chose to demonstrate the consequences of the current default for deciding significance ($\alpha = 0.05$). We later discuss alternatives to this approach.

METHODS

Our approach required two steps: extraction of data from both primary literature and the MMPA Stock Assessment Reports (SARs), and calculation of statistical power based on the extracted data. Two kinds of information were needed for the power calculation: precision of abundance estimates and survey interval. Data on precision of abundance estimates were extracted from three SARs (Angliss and Lodge 2003, Waring *et al.* 2003, Carretta *et al.* 2004), the primary literature, and in some cases from SAR authors (Appendix, Sources column). Many narratives for individual stocks gave sparse information on survey intervals. In cases of uncertainty in survey interval, we assumed more frequent surveys; thus, our results are likely optimistic. Some stocks covered in the SARs had insufficient information to use in this exercise. Those not included here with rationale for exclusion include Eastern North Pacific Transient Stock of killer whales—proportion identified not known and frequency of effort across range variable and not recorded; Eastern North Pacific Offshore Stock of killer whales—proportion of mixed abundance estimate with previously mentioned stock unknown, West Indian manatees—coefficient of variation (CV) unknown and effort across range unknown, all Hawaiian stocks—survey interval unknown as first survey was completed in 2002 (Barlow 2006), various stocks found primarily in non-U.S. waters and for which the SAR CV was likely to be unrepresentative—gray seals, hooded seals, harp seals, and Guadalupe fur seals. Data used in this analysis are presented in the Appendix. To make our study as representative as possible, we included estimates that are in reports and that only appear in the SARs and remain unpublished. We have indicated the level of review in the table and strongly discourage citing this paper as a source for these unpublished data.

For cetaceans, precision of estimation was summarized as the CV reported in the SARs for abundance estimates. For pinnipeds that haul out on land, abundance estimates were usually not given; rather, these populations are monitored by direct counts of adults or pups. The counts are typically reported each year as a single number, with no estimate of variance or error in extrapolation to the total population size. To estimate precision for pinniped monitoring, we computed CVs from the unexplained variance about a linear regression line on log counts. Although we feel this simple regression estimate for CVs is sufficient for our purposes in detecting precipitous declines, we caution readers that precision is likely overestimated because of unaccounted-for factors such as heterogeneity in portion of the population counted or heterogeneity in count timing (see Barker and Sauer 1992 for a more sophisticated method using time-series data).

For sea otter stocks in Alaska, CVs and abundances were given for parts of the range within a stock. We calculated overall CVs by dividing the square root of the sum of the variances by the total abundance.

In this analysis we define statistical power as the rate of correctly detecting that a population is declining when in fact it is declining precipitously, using a simple regression analysis. We used the typical significance criterion ($\alpha = 0.05$). We used this typical criterion because this value is perceived as a scientifically accepted standard and therefore accepted without argument in management decisions. We also show examples of power calculations using alternate values for significance criteria for beaked and bowhead whales. Power calculations were completed via the TRENDS program available at http://swfsc.noaa.gov/prd.aspx (Gerrodette 1987, 1991). Constant features were set as follows: duration of study was 15 yr, rate of decline per year was 5% (which results in the defined precipitous decline), one-tailed test, CV proportional to 1/sqrt (abundance), and intervals between sampling occasions were set to be equal, based on survey frequencies (for cases with survey intervals of more than 1 yr, sampling occurs less than once at each time step).

To evaluate our ability to detect declines, we pooled results into several categories with different management mandates or concerns: large whales, beaked whales, other small cetaceans, land-hauling pinnipeds, ice-hauling pinnipeds, and sea otters/polar bears. Most species of large whales are listed as endangered under the Endangered Species Act, and therefore monitoring trends in abundance is particularly important not only to be alert to declines but also to be able to detect recovery for potential reclassification of listed species. Large whales are typically easy to detect because they are large and have conspicuous blows that can be seen for many miles. We also include minke whales in this category with the other baleen whales, but they are neither large nor conspicuous. In contrast, beaked whales are inconspicuous and spend the vast majority of their time diving to great depths. However, beaked whales are of high conservation interest because of recent strandings associated with use of military sonar and seismic surveys (Anonymous 2001, Jepson *et al.* 2003). Because the magnitude of this problem remains unknown, it would be helpful if current surveys could detect declines in beaked whale abundance. The next category we investigated is all other cetaceans, including small whales with no conspicuous blow (like pilot whales), killer whales, dolphins, and porpoises. These species are numerically the most abundant cetaceans in most marine habitats and are likely important predators in the context of ecosystem management. Pinnipeds are of particular interest for two reasons: the most precise abundance estimates are for land-hauling pinnipeds, which could serve as indicator species, and ice-hauling species are of conservation interest because their habitat is changing rapidly (Tynan and DeMaster 1997, Ferguson *et al.* 2005). Polar bears, which face similar risks but breed on land, are treated separately with sea otters because they do not fit well into any of the above.

We first estimated the statistical power for detecting the precipitous decline, which is the probability of correctly rejecting the null hypothesis that the stock is increasing or remaining constant in size. The distribution of estimates of power sheds light on whether certain groups of stocks have consistently high precision while others have consistently low precision. To estimate the percent of stocks for which we expect to detect precipitous declines, we summed the calculations for power within a category (*i.e.*, we assumed power approximated probability of detection). This sum is the expected (average) number of stocks that would be detected as declining. Given five stocks declining at the precipitous rate described above, four with a power of 0.25 and one with a power of 0.20 to detect a decline, most often a significant decline would be detected for one of them and there would be a smaller chance of detecting the decline of a second stock ($4 \times 0.25 + 0.20 = 1.20$). The percent detected would be the ratio $(1.20/5)100 = 24$, and hence, the percent not detected would be 76.

Our analysis is optimistic in three technical aspects: (1) in cases of uncertainty about survey interval we used optimistic values (all large-ship surveys were assumed to occur at 4-yr intervals), (2) stocks excluded from the analysis because of insufficient information in the SARs are likely to have lower power than those with reported precision and survey interval, and (3) the test is only for detecting that a population is declining and not the magnitude of the decline. There are other reasons that our analyses are likely optimistic. Funding for surveys has remained level over many years. Because cruise costs increase, actual cruise effort has to decrease with time given level funding. Furthermore, surveys have never been conducted for some stocks due to insufficient funding.

RESULTS

There is considerable variability in the distribution of estimates of power among stocks within a category (Fig. 1), but power is consistently low for all beaked whales and pinnipeds that haul out on ice. The stocks with the highest statistical power were exceptional in one of the following ways: (1) counts could be made from land or using aerial photography when pinnipeds were hauled out on land, (2) photographic identification was used on small, easily accessed populations (humpback whales off California, North Atlantic right whales, southern resident killer whales), or (3) counts could be done from land and were done annually (some sea otter stocks). Although precision levels differed somewhat among the categories (see Appendix), the likelihood of *not* detecting a precipitous decline is quite high (Fig. 2) for all categories except pinnipeds that haul out on land.

DISCUSSION

Given current monitoring levels, our ability to detect precipitous declines in abundance remains low for most stocks of marine mammals in U.S. waters using standard

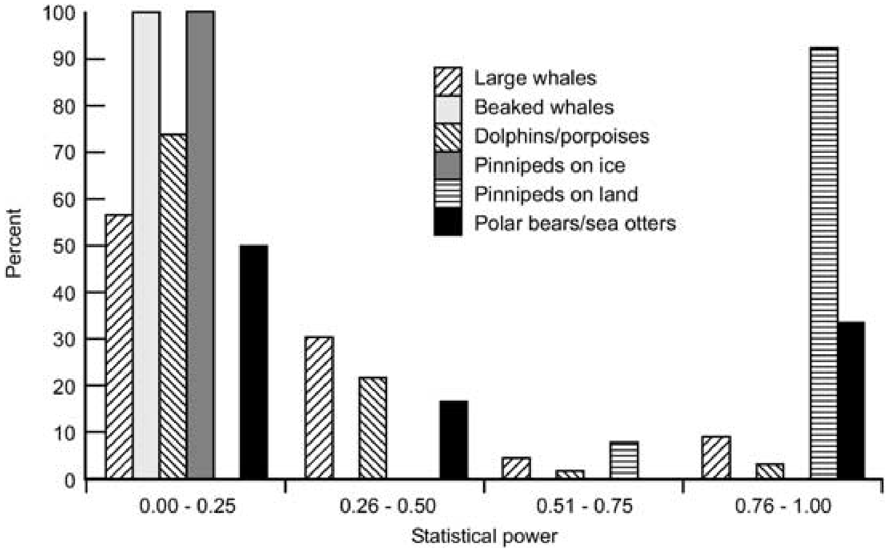

Figure 1. Percent of stocks within four ranges of statistical power. Statistical power is the probability of correctly rejecting the null hypothesis that a population is not declining (*i.e.*, one-tailed t-test, $\alpha = 0.05$) when the stock is experiencing a precipitous decline (50% over 15 yr). Results are summarized for six categories of marine mammals: large whales, beaked whales, dolphins and porpoises, pinnipeds on ice, pinnipeds on land, and polar bears and sea otters.

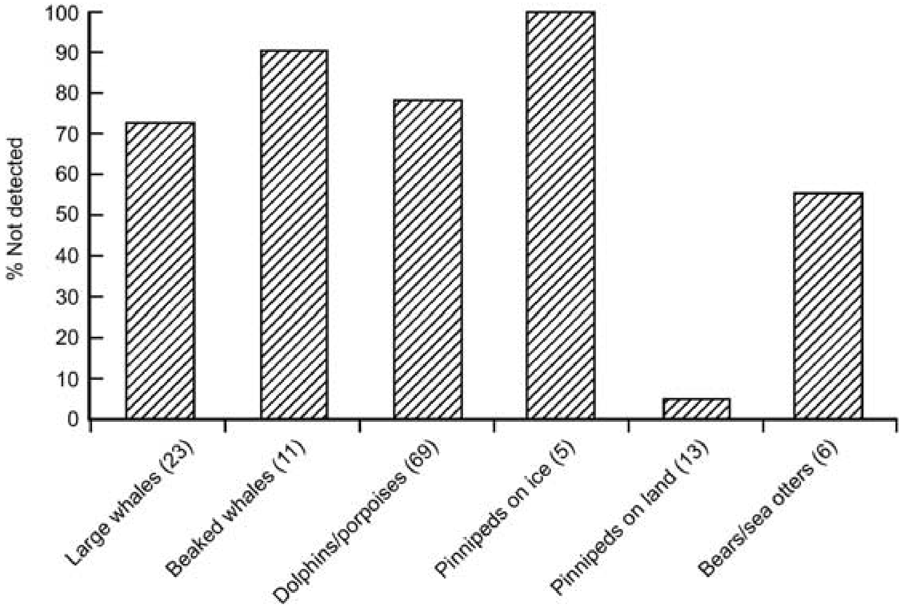

Figure 2. Percent of stocks for which a precipitous decline would not be detected as a decline for different categories of cetaceans, pinnipeds, and the category of polar bears and sea otters. Numbers in parentheses indicate the number of stocks examined.

analyses (hypothesis testing using $\alpha = 0.05$). Thus, we would be unlikely to detect a decline in abundance for cetacean or ice seal stocks similar to the decline in abundance that was associated with the listing of the western stock of Steller sea lion as endangered under the U.S. Endangered Species Act. In fact, of the stocks receiving attention because of observed declines (the western stock of Steller sea lion, several stocks of harbor seals in Alaska, the southwestern stock of sea otter in western Alaska, and Hawaiian monk seals), only the sea otters had relatively low power of detection (Appendix). The detection of sea otter declines occurred because the magnitude of the decline is greater than the 50% decline for which we estimated power. The low precision for most marine mammals, including most large whales, also means that detecting recovery of endangered species for consideration in delisting decisions is similarly problematic.

Although this paper deals with stocks in U.S. waters, many of the factors that lead to low precision in marine mammal abundance estimates are likely to be global problems. For example, beaked whales are always difficult to see when they are on the surface, spend most of their time below the surface, and are found at low densities over large areas (Barlow *et al.* 2006). For cetaceans with highly pelagic distributions, detecting declines is likely more problematic than depicted here as many of the world's oceans, particularly the Indian Ocean and the South Atlantic, have very little survey effort.

For many species, increased monitoring effort is necessary to detect declines of serious conservation concern. For example, 23 of the 127 stocks examined have no information for either CV or survey interval, usually meaning that there is no acceptable abundance estimate. Thus, there is no analytical fix for 18% of all marine mammal stocks, and more resources must be devoted to monitoring if we can hope to effectively manage these stocks. This severe lack of information is not equal among our categories; there was no abundance or trend information for any stocks found on ice (pinnipeds or polar bear), for 36% of beaked whale stocks, and for a surprising 26% of large whale stocks. The level of risk is also not equal among categories: Ice-dependent species are at greater risk due to the likely effects of global climate change, and beaked whales are at greater risk due to human-caused acoustic-related mortality as seen in mass stranding associated with naval exercises (Cox *et al.* 2006). Beaked whales and ice-dependent species face both high potential risks and low levels of available information.

The most common methods to increase our ability to detect precipitous declines are to increase survey frequency and/or change decision criteria. Consider a case of high precision, the western arctic stock of bowhead whales (CV = 0.13), and a case of low precision, the Cuvier's beaked whale stock in the western North Atlantic (CV = 0.34). If we wanted to detect a precipitous decline 80% of the time, we could do annual surveys for bowhead whales (Fig. 3). To save expense, surveys could be less frequent, but the decision criterion for significance would have to be changed to $\alpha = 0.1$ for 4-yr intervals or $\alpha = 0.2$ for 6-yr intervals. In the latter case, underprotection and overprotection errors are equal at about 20%. For the western North Atlantic stock of Cuvier's beaked whale (which has the highest precision of any beaked whale), the only option to attain an 80% probability of detection is to have annual surveys *and* use a significance criterion of $\alpha = 0.3$. In this case the over- to underprotection ratio is 1.5 (0.3/0.2).

Alternatively, Bayesian methods could be used to directly estimate the growth rate together with uncertainty as was done for a population of harbor seals in Alaska (Ver Hoef and Frost 2003). Using this different methodology does not obviate the need to

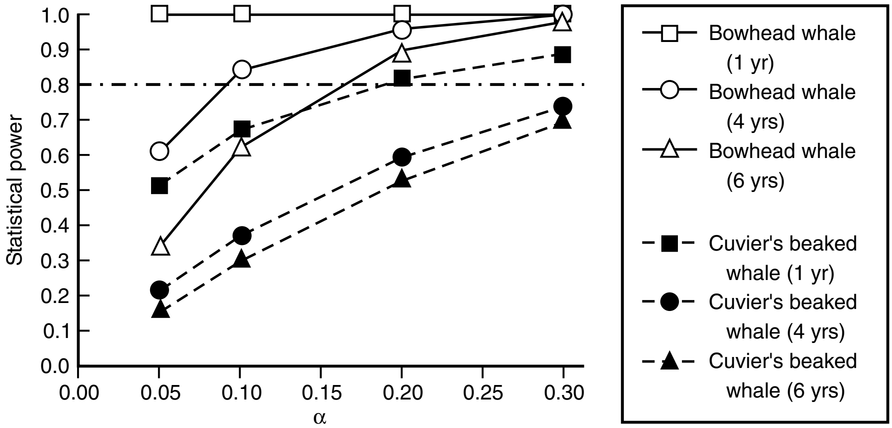

Figure 3. Statistical power to detect a precipitous decline with different significance criteria (α) for a high precision species (bowhead whales—CV = 0.13 shown with clear symbols and connected by solid lines) and a low precision species (Cuvier's beaked whale—CV = 0.34 shown with solid symbols and dashed lines). Three different survey intervals are shown: 1 yr (squares), 4 yr (circles), and 6 yr (triangles). The horizontal dashed line represents a hypothetical goal of being able to detect 80% of such precipitous declines. Values above that line represent combinations of survey intervals and decision criteria (α) that meet this goal.

choose the magnitude of decline and the level of evidence needed to trigger a management action. Bayesian methods allow different kinds of information, including prior knowledge, to be included in the analysis of trends (Goodman 2004, Thompson *et al.* 2005), and they have the advantage of producing probability distributions that can be used directly in formal decision analysis (Wade 2000). Furthermore, in a Bayesian analysis, the costs of different kinds of errors can be included directly in explicit loss functions. This method was used for endangered species listing criteria for spectacled eiders (Taylor *et al.* 1996).

There are many ways by which temporal data can be analyzed for trends (Thomas *et al.* 2004). The detection of trends is improved by the use of models, which include covariates that effectively remove some of the "noise" that may otherwise obscure trends (Forney *et al.* 1991, Fewster *et al.* 2000, Ver Hoef and Frost 2003). Careful attention to design of monitoring programs—which kinds of data to collect, where and how often to collect them—can increase detection of trends (Urquhart and Kincaid 1999).

Another method to increase power to detect trends is to design a survey specifically to detect trends in abundance (as opposed to a survey to estimate absolute abundance). A trend-site survey design would seek to maximize precision by reducing the area surveyed and increasing the effort in the chosen area. There are two ways by which reduction in survey area could be accomplished: surveying part of the range of the stock or identifying stocks at a smaller spatial scale than currently identified in the SARs. The first way requires the strong assumption that the proportion of the total population in the surveyed area is constant across time. Although movement data may help to assure that this assumption is met, this strategy is risky because changes in conditions resulting in distributional shifts may occur with a declining trend. The second way is to identify demographically independent populations and survey the smaller area that they occupy. Although the MMPA mandates management at the level of stocks, which have been interpreted to be demographically independent populations (Payne 2004, Taylor 2005), many of the stocks listed within the SARs are extremely large and likely encompass several demographically independent populations. For example, all the ice seal species are listed as single stocks that cover a very large area. None of the ice seals have abundance estimates for this large area but most have estimates for smaller areas. Identifying multiple stocks may make monitoring feasible. Coastal and offshore bottlenose dolphins off California are a successful example where the small coastal stock, clearly demographically independent using both photographic identification (Defran and Weller 1999) and genetic data (Lowther 2006), can be monitored separately. Aerial surveys achieved a statistical power of 0.67 with a survey interval of 4 yr by flying a narrow strip of coastal waters where these animals are found (Carretta *et al.* 1998). Should this stock be chosen as an indicator stock for coastal cetacean health, survey frequency could be increased to enhance power.

However, the effectiveness of redistributing the effort in this way assumes that the spatial distribution of population density is understood and remains constant within the chosen area. Trend site surveys have worked well for harbor seals in Alaska because genetics and telemetry have shown that seals are loyal to their birth sites even in the face of large declines in some areas (O'Corry-Crowe *et al.* 2003). However, for cetaceans the potential for movement, and our ignorance about linkages between distribution and habitats, complicates area choice. Despite the potential for cetaceans to move quickly over large distances, genetic, morphological, and tagging data indicate strong population structure for most species, including highly coastal species such as harbor porpoise (Chivers *et al.* 2002), migratory species such as humpback whales (Palsbøll *et al.* 1995, Palsbøll *et al.* 1997), and several populations of pelagic dolphins and porpoises (Escorza-Treviño and Dizon 2000, Escorza-Treviño *et al.* 2005).

Reduction in area is unlikely to increase precision for pelagic cetaceans because of the uncertainties in meeting the assumption that the same proportion of the stock is surveyed each time. Reducing the area surveyed to improve power would require much better knowledge of population structure and of the links between pelagic species distribution and characteristics of their habitat (Ferguson *et al.* 2006*a*, *b*). Many stocks shift their distributions seasonally and with different environmental conditions (Danil 2004). Data on habitat variables associated with their distribution can be used to improve our ability to detect trends (Forney 2000), but additional research is needed to broaden the range of stocks considered and to better characterize population structure. Unfortunately, all pelagic stocks are characterized by a statistical power of less than 0.25 in the current sample of surveys. Changing the decision criterion, as mentioned earlier, would be a more reliable solution to improve decline detection for these species than adopting partial range coverage.

Our last suggestion is to detect potential declines within an ecosystem context by selecting species as indicator species. Careful consideration of how to choose indicator species, and indeed what factors we desire to be indicated, must precede this strategy. Indicator species should be chosen in a hierarchical fashion: first, which species are known to be linked to ecosystem health or are known to have abundances correlated with a suite of other species, and second, of those species, which can we monitor with the highest precision.

Fundamentally, we cannot reliably detect even precipitous declines in most whale, dolphin, porpoise, and ice-hauling pinniped populations with present levels of investment in surveys and current survey technology and design. Improvement of performance in detecting declines depends on increasing survey extent and frequency, developing different methods to detect declines, or making explicit decisions on the magnitude of decline warranting farther action and the level of evidence needed that decline is occurring, or some combination of the above. The first two require a substantial increase in funding. Should such funding levels be unlikely, then the most efficient way to increase our ability to detect declines is to alter decision criteria.

Current trends in management are to move from single species management to an ecosystem approach to management. Our results suggest that uncertainty, even for single species management, remains high. Ecosystem models will have higher overall uncertainty driven by large uncertainties resulting both from imprecision and from ignorance about how different components of the ecosystem are linked. Thus, a good management decision rule should not require large numbers of precise estimates in order to trigger warranted management actions.

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APPENDIX

This appendix contains coefficients of variation in abundance estimates (CV), survey intervals, statistical power to detect a 50% decline in 15 yr for stocks of marine mammals found in U.S. waters used in this paper. The sources of data for each stock are given in bold if the CVs were from peer-reviewed papers, in italics if the CVs were from readily available documents or reports that present complete methods, or in plain font if the CVs were not readily available from a public source or if the source did not present complete methods. Readers are cautioned not to extract CV information when sources are neither in bold or italics as these are considered unreviewed data. Multiple sources mean either that the CV in the SAR was derived from multiple abundance estimates (for cetaceans) or that the CV was derived from a time series (for pinnipeds); therefore, the CV in the table will not appear in any single reference. Ice seals are noted with an asterisk. Statistical power to detect a decline (power 15 yr) was calculated using the CV and survey interval data except as noted below. For some stocks "na" (not available) appears in the CV and/or survey interval column. When it appears in both columns, that is, there are no abundance data, we assume the probability of detecting a decline is 0.0. There are two cases where there is no CV but a survey interval. In both cases, southern resident killer whales, where all individuals are known and identified each year and North Atlantic right whales where a large fraction is identified each year, we assumed that the probability of detecting a loss of half the individuals over 15 yr was 1.0. Abbreviations are as follows: WNA = Western North Atlantic; cont. = continental; Mex. = Mexico; OR = Oregon; WA = Washington; CA = California; CNP = Central North Pacific; SEAK = Southeast Alaska.

Species	Stock	CV	Survey interval	Power 15 yr[a]	Source
	Dolphins and Porpoises				
Atlantic spotted dolphin	N. Gulf of Mex. Outer Cont. Shelf/Oceanic	0.27	4	0.26	1, 2
Atlantic spotted dolphin	WNA	0.87	4	0.11	3,4
Atlantic white-sided dolphin	WNA	0.38	4	0.19	4, 5, *6*, 7
Beluga whale	Beaufort Sea	0.23	4	0.32	8
Beluga whale	Bristol Bay	0.20	4	0.37	9
Beluga whale	Cook Inlet	0.09	1	1.00	10
Beluga whale	E. Bering Sea	0.24	4	0.30	11
Beluga whale	E. Chukchi Sea	0.20	4	0.37	9
Bottlenose dolphin	CA/OR/WA Offshore	0.66	4	0.13	*12*
Bottlenose dolphin	CA Coastal	0.12	4	0.67	13
Bottlenose dolphin	E. Gulf of Mex. Coastal	0.12	10	0.32	14
Bottlenose dolphin	Gulf of Mex. Bay, Sound, Estuarine	0.57	10	0.12	14
Bottlenose dolphin	Gulf of Mex. Cont. Shelf/Slope	0.26	4	0.28	1
Bottlenose dolphin	N. Gulf of Mex. Coastal	0.26	3	0.35	1
Bottlenose dolphin	N. Gulf of Mex. Oceanic	0.41	3	0.21	2
Bottlenose dolphin	W. Gulf of Mex. Coastal	0.21	10	0.20	*15*
Bottlenose dolphin	WNA Coastal	0.46	3	0.19	14
Bottlenose dolphin	WNA Offshore	0.25	4	0.29	3, 4
Clymene dolphin	N. Gulf of Mex. Oceanic	0.65	4	0.13	2
Clymene dolphin	WNA	0.93	4	0.11	3
Common dolphin	WNA	0.32	4	0.22	4
Common dolphin, short-beaked	CA/OR/WA	0.25	4	0.29	*12*
Common dolphin, long-beaked	CA	0.72	4	0.12	*12*
Dall's porpoise	CA/OR/WA	0.33	4	0.21	*12*, *16*
Dall's porpoise	Alaska	0.10	5	0.38	17
Dwarf sperm whale	N. Gulf of Mex. Oceanic	0.29	4	0.24	2
Dwarf sperm whale	WNA	0.57	4	0.14	3, 4

Species	Stock	CV	Survey interval	Power 15 yr^{a}	Source
False killer whale	N. Gulf of Mex. Oceanic	0.71	4	0.12	**2**
Fraser's dolphin	N. Gulf of Mex. Oceanic	0.70	4	0.12	**2**
Fraser's dolphin	WNA	na	na	0.00	18
Harbor porpoise	Bering Sea	0.22	6	0.21	**19**
Harbor porpoise	Gulf of Alaska	0.21	5	0.20	**19**
Harbor porpoise	Gulf of Maine/Bay of Fundy	0.22	4	0.33	**5**, 6, *20*
Harbor porpoise	Monterey Bay	0.42	3	0.20	*21*
Harbor porpoise	Morro Bay	0.41	3	0.21	*21*
Harbor porpoise	N. CA/S. OR	0.39	3	0.22	22
Harbor porpoise	OR/WA Coast	0.38	5	0.14	22
Harbor porpoise	San Francisco Russian River	0.39	3	0.22	*21*
Harbor porpoise	SEAK	0.24	7	0.22	**19**
Harbor porpoise	Washington Inland Waters	0.40	5	0.14	23
Killer whale	E. N. Pacific Northern Resident	na	na	0.00	24
Killer whale	E. N. Pacific S. Resident	0.00	1	1.00	**25**
Killer whale	N. Gulf of Mex. Oceanic	0.49	4	0.15	**2**
Killer whale	WNA	na	na	0.00	18
Melon-headed whale	N. Gulf of Mex. Oceanic	0.55	4	0.14	**2**
Melon-headed whale	WNA	na	na	0.00	18
Northern right whale dolphin	CA/OR/WA	0.26	4	0.28	*12*
Pacific white-sided dolphin	CA/OR/WA	0.50	4	0.15	*12*
Pacific white-sided dolphin	CNP	0.90	6	0.12	**26**
Pantropical spotted dolphin	N. Gulf of Mex. Oceanic	0.16	4	0.49	**2**
Pantropical spotted dolphin	WNA	0.56	4	0.14	**3**, 4
Pilot whale, short-finned	CA/OR/WA	1.02	4	0.12	*12*
Pilot whale, short-finned[18]	N. Gulf of Mex. Oceanic	0.48	4	0.16	**2**
Pilot whale, long- and short- finned	WNA	0.30	4	0.24	4
Pygmy killer whale	N. Gulf of Mex. Oceanic	0.60	4	0.13	**2**
Pygmy killer whale	WNA	na	na	0.00	18
Pygmy sperm whale	CA/OR/WA	1.06	4	0.10	*12*
Pygmy sperm whale	N. Gulf of Mex. Oceanic	0.29	4	0.24	**2**
Pygmy sperm whale	WNA	0.49	4	0.15	**3**, 4
Risso's dolphin	CA/OR/WA	0.28	4	0.25	*12*
Risso's dolphin	N. Gulf of Mex. Oceanic	0.32	4	0.22	**2**
Risso's dolphin	WNA	0.29	4	0.24	**3**, 4
Rough-toothed dolphin	N. Gulf of Mex. Outer Cont. Shelf/Oceanic	0.41	4	0.18	**1, 2**
Spinner dolphin	N. Gulf of Mex. Oceanic	0.71	4	0.12	**2**
Spinner dolphin	WNA	na	na	0.00	18
Striped dolphin	CA/OR/WA	0.53	4	0.14	*12*
Striped dolphin	N. Gulf of Mex. Oceanic	0.43	4	0.17	**2**
Striped dolphin	WNA	0.40	4	0.18	**3**, 4
White-beaked dolphin	WNA	na	na	0.00	18

Species	Stock	CV	Survey interval	Power 15 yr[a]	Source
	Large Whales				
Blue whale	Eastern North Pacific	0.23	4	0.32	*12*[b]
Blue whale	WNA	na	na	0.00	18
Bowhead whale	W. Arctic	0.13	4	0.61	**27**
Bryde's whale	N. Gulf of Mex. Oceanic	0.61	4	0.13	**2**
Fin whale	CA/OR/WA	0.31	4	0.23	*12*
Fin whale	NE Pacific	na	na	0.00	24
Fin whale	WNA	0.21	4	0.35	4, **5**
Gray whale	E. N. Pacific	0.10	5	0.38	28
Humpback whale	CNP entire stock	0.10	6	0.43	29
Humpback whale	E. N. Pacific	0.11	1	1.00	*12*
Humpback whale	Gulf of Maine	0.29	5	0.16	**30**
Humpback whale	W. N. Pacific	0.08	6	0.53	29
Minke whale	Alaska	na	na	0.00	24
Minke whale	CA/OR/WA	0.73	4	0.12	*12*
Minke whale	Canadian east coast	0.16	5	0.25	4, **31**
N. Pacific right whale	E. N. Pacific	na	na	0.00	24
North Atlantic right whale	WNA	na	2	1.00	18, **32**
Sei whale	CA/OR/WA	0.61	4	0.13	*12*
Sei whale	Nova Scotia	na	na	0.00	18
Sperm whale	CA/OR/WA	0.41	4	0.18	*12*[c]
Sperm whale	N. Atlantic	0.36	4	0.20	**3**, 4
Sperm whale	N. Gulf of Mex.	0.23	4	0.32	**2**
Sperm whale	N. Pacific	na	na	0.00	24
	Beaked Whales				
Baird's beaked whale	Alaska	na	na	0.00	24
Baird's beaked whale	CA/OR/WA	0.92	4	0.11	*12*
Blainville's beaked whale	N. Gulf of Mex. Oceanic	0.41	4	0.18	**2**
Cuvier's beaked whale	Alaska	na	na	0.00	24
Cuvier's beaked whale	CA/OR/WA	1.06	4	0.10	*12*
Cuvier's beaked whale	N. Gulf of Mex. Oceanic	0.47	4	0.16	**2**
Cuvier's beaked whale/ Mesoplodon beaked whales	WNA	0.34	4	0.21	*12*
Gervais' beaked whale	N. Gulf of Mex. Oceanic	0.41	4	0.18	**2**
Mesoplodon beaked whales	CA/OR/WA	0.68	4	0.13	*12*
Northern bottlenose whale	WNA	na	na	0.00	18
Stejneger's beaked whale	Alaska	na	na	0.00	24
	Pinnipeds				
Bearded seal*	Alaska	na	na	0.00	24
CA sea lion	Pacific	0.29	1	0.76	*33*, **34**
Harbor seal	Bering Sea	0.06	10	0.59	35
Harbor seal	California Pacific	0.11	1	1.00	*36*
Harbor seal	Gulf of Alaska	0.02	2	1.00	37, 38, *39*
Harbor seal	OR/WA Coast	0.12	1	1.00	**40**, *41*, **42**
Harbor seal	SEAK	0.03	1	1.00	43
Harbor seal	WA inland waters	0.15	1	1.00	**40**
Harbor seal	WNA	0.10	1	1.00	44

Species	Stock	CV	Survey interval	Power 15 yr[a]	Source
Hawaiian monk seal	Hawaii	na	1	1.00	48
Northern elephant seal	Pacific	0.08	1	1.00	*45*, *46*, **47**, *48*
Northern fur seal	Eastern Pacific	0.05	2	1.00	*49*
Ribbon seal*	Alaska	na	na	0.00	24
Ringed seal*	Alaska	na	na	0.00	24
Spotted seal*	Alaska	na	na	0.00	24
Steller sea lion	Eastern U.S. Stock	0.06	2	1.00	*50*, **51**, *52*, *53*, *54*, *55*
Steller sea lion	Western U.S. Stock		2	1.00	*53*, *54*, *55*, **56**
Walrus*	Alaska	na	na	0.00	18
	Polar bears/Sea otters				
Polar bear	Alaska	na	na	0.00	18
Sea otter	SEAK	0.37	10	0.14	*57*, *58*
Sea otter	Southcentral AK	0.16	10	0.25	*58*, 59
Sea otter	Southwest AK	0.13	10	0.30	59, **60**
Sea otter	WA	na	1	1.00	61
Southern sea otter	CA	na	1	1.00	61

[a] All nonzero values are statistical power. Zero values are inferred probability of detection of decline given that there is no monitoring of abundance for these stocks.

[b] For recently peer-reviewed estimate see Calambokidis and Barlow, 2004.

[c] For a recently peer reviewed estimate see Barlow and Taylor, 2005.

Sources:

1. (Fulling *et al.* 2003), **2**. (Mullin and Fulling 2004), **3**. (Mullin and Fulling 2003), 4. (Palka[d]), **5**. (Palka 1995), *6*. (Palka 1996), *7*. (Palka *et al.* 1997), **8**. (Harwood *et al.* 1996), 9. (personal communication as referenced in Angliss and Lodge 2003[e]), 10. (NMFS unpublished data as referenced in Angliss and Lodge 2003[f]), 11. (DeMaster 1997), *12*. (Barlow 2003), **13**. (Carretta *et al.* 1998), 14. (NMFS unpublished data as cited in Waring *et al.* 2003), *15*. (Blaylock and Hoggard 1994), *16*. (Calambokidis *et al.* 1997a), 17. (Hobbs and Lerczak 1993), 18. (Waring *et al.* 2003), **19**. (Hobbs and Waite, in press), *20*. (Palka 2000), *21*. (Carretta 2003), 22. (Laake *et al.* 1998), 23. (Laake *et al.* 1997), 24. (Angliss and Lodge 2003), **25**. (Ford *et al.* 2000), **26**. (Buckland *et al.* 1993), **27**. (George *et al.* 2004). 28. (Hobbs and Rugh 1999), 29. (Calambokidis *et al.* 1997b), **30**. (Clapham *et al.* 2002), **31**. (Kingsley and Reeves 1998), **32**. (Kraus *et al.* 2001), *33*. (Lowry *et al.* 1992), **34**. (Lowry 1999), 35. (Withrow and Loughlin 1996), *36*. (Lowry and Carretta 2003), 37. (Withrow and Loughlin 1995), 38. (Withrow and Loughlin 1997), *39*. (Frost *et al.* 1997), **40**. (Jeffries *et al.* 2003), *41*. (Brown 1997), **42**. (Huber *et al.* 2001), 43. (Loughlin 1994), **44**. (Gilbert *et al.* 2005), *45*. (Lowry 2002), *46*. (Lowry *et al.* 1987), **47**. (Lowry *et al.* 1996), *48*. (Carretta *et al.* 2000), *49*. (Antonelis *et al.* 1994), *50*. (Merrick *et al.* 1992), **51**. (Calkins *et al.* 1999), *52*. (Sease *et al.* 1999), *53*. (Strick *et al.* 1997), *54*. (Sease *et al.* 2001), *55*. (Sease and Loughlin 1999), **56**. (Loughlin *et al.* 1984), *57*. (Agler *et al.* 1999), *58*. (Doroff and Gorbics 1998), 59. (USFWS/USFS unpublished data as in Angliss and Lodge 2003), **60**. (Doroff *et al.* 2003), 61. (Carretta *et al.* 2004).

[d] Personal communication from D. Palka, Northeast Fisheries Science Center, Woods Hole, MA, July 2006.

[e] Personal communication from R. Hobbs, National Marine Mammal Laboratory, 7600 Sandpoint Way, N.E. Seattle, WA.

[f] Available from R. Hobbs, National Marine Mammal Laboratory, 7600 Sandpoint Way, N.E. Seattle, WA.