Bycatch of Marine Mammals in U.S. and Global Fisheries

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Abstract: *Fisheries bycatch poses a significant threat to many populations of marine mammals, but there are few published estimates of the magnitude of these catches. We estimated marine mammal bycatch in U.S. fisheries from 1990 to 1999 with data taken from the stock assessment reports required by the U.S. Marine Mammal Protection Act. The mean annual bycatch of marine mammals during this period was 6215 ± 448 (SE). Bycatch of cetaceans and pinnipeds occurred in similar numbers. Most cetacean (84%) and pinniped (98%) bycatch occurred in gill-net fisheries. Marine mammal bycatch declined significantly over the decade, primarily because of a reduction in the bycatch of cetaceans. Total marine mammal bycatch was significantly lower after the implementation of take reduction measures in the latter half of the decade. We derived a crude first estimate of marine mammal bycatch in the world's fisheries by expanding U.S. bycatch with data on fleet composition from the Food and Agriculture Organization. The global bycatch of marine mammals is in the hundreds of thousands. Bycatch is likely to have significant demographic effects on many populations of marine mammals. Better data are urgently needed to fully understand the impact of these interactions.*

Key Words: cetacean, fisheries, pinniped

Captura Incidental de Mamíferos en Pesquerías de E.U.A. y Globales

Resumen: *La captura incidental de pesquerías es una amenaza significativa para muchas poblaciones de mamíferos marinos, pero existen pocas estimaciones publicadas de la magnitud de esas capturas. Estimamos la captura incidental de mamíferos marinos en pesquerías de E.U.A. de 1990 a 1999 con datos obtenidos de los reportes de evaluación de existencias requeridos por el Acta de Protección a Mamíferos Marinos de E.U.A. el promedio de captura incidental anual de mamíferos marinos durante este período fue 6215 ± 448 (DS). La captura incidental de cetáceos y pinnípedos ocurrió en números similares. La mayor parte de la captura incidental de cetáceos (84%) y pinnípedos (98%) ocurrió en pesquerías que utilizan redes agalleras. La captura incidental de mamíferos marinos declinó significativamente a lo largo de la década, debido principalmente a una reducción en la captura incidental de cetáceos. La captura incidental total de mamíferos marinos fue significativamente menor después de la implementación de las medidas de reducción en la captura en la segunda mitad de la década. Derivamos una primera estimación cruda de la captura incidental de mamíferos marinos en las pesquerías mundiales expandiendo la captura en E.U.A. con datos sobre la composición de las flotas de la Organización Mundial de Alimentación y Agricultura. La captura incidental global de mamíferos marinos se ubica en los cientos de miles. Es probable que la captura incidental tenga efectos demográficos sobre muchas poblaciones de mamíferos marinos. Urgentemente, se requieren mejores datos para entender el impacto de estas interacciones integralmente.*

Palabras Clave: cetáceo, pesquerías, pinnípedo

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Introduction

Interactions between marine mammals and commercial fisheries have occurred for centuries but are increasing in frequency and intensity, a trend that is likely to continue into the foreseeable future (DeMaster et al. 2001). This trend is due to continued human population growth, increasing industrialization of fisheries, and their expansion into new areas, such as the high seas. The increasing demand for marine protein has resulted in a cycle of intensive harvesting and serial depletion of fish stocks. Consequently, fisheries have dramatically altered the structure and function of marine ecosystems (Jackson et al. 2001; Pauly et al. 2002; Myers & Worm 2003). The depletion of fish stocks often results in an intensification and displacement of fishing effort, which increases the likelihood of interactions with marine mammals.

Interactions between marine mammals and fisheries take several forms. Some are operational, in which marine mammals come into physical contact with fishing gear (Beverton 1985). In others, marine mammals and fisheries interact through trophic pathways. Resolution of these two forms of interactions typically requires different management approaches (Northridge & Hofman 1999).

Operational interactions can result in the mortality or serious injury of marine mammals that are "captured" but discarded, a process known as bycatch (Alverson et al. 1994). In some areas of the world, marine mammals are captured unintentionally but retained for consumption or sale. Hall (1996) distinguished such retained unintentional captures from discarded bycatch and referred to them as nontarget catch. Both bycatch and nontarget catch may have important demographic consequences for marine mammal populations (IWC 2001). The nature of operational interactions can change over time. In some fisheries marine mammals are first taken as bycatch, then are retained as nontarget catch because of their value as food or bait, and finally become the target of the fishery itself (Read et al. 1988; Leatherwood & Reeves 1989; Dolar et al. 1994). In the United States, however, the Marine Mammal Protection Act prohibits the use and sale of marine mammals captured in commercial fisheries. Similar legislation prohibits use and sale of marine mammals in many other industrialized nations. We restricted our analysis to bycatch as defined by Alverson et al. (1994) and Hall (1996).

Bycatch can have important consequences for the demography of affected populations (Reeves et al. 2003) and endanger the existence of some species (e.g., D'Agrosa et al. 2000). There is a growing recognition of the conservation significance of these interactions. In January 2002, for example, a group of experts concluded that "[i]ncidental capture in fishing operations is the major threat to whales, dolphins and porpoises worldwide. Several species and many populations will be lost in the next few decades if nothing is done" (Read & Rosenberg 2002). As we look to the future, fisheries bycatch poses the single greatest threat to many populations of marine mammals in the United States and elsewhere.

Despite recognition of the importance of this problem in some areas (e.g., NOAA 2003*b*), our knowledge of the global extent, nature, and impacts of direct interactions between marine mammals and fisheries is fragmentary. We know little about current levels of bycatch in most of the world's fisheries, although experience suggests bycatch is likely to be widespread, if not universal. In addition, we have almost no information on the history of such interactions before the early 1970s (Reeves et al. 2003). It is likely that direct interactions with fishing operations caused significant adverse impacts on many populations of marine mammals before scientists could take notice (Jackson et al. 2001).

Direct fisheries interactions are not unique to marine mammals, and bycatch is an important conservation problem for many other marine organisms. Several species of albatrosses and sea turtles face extinction from unsustainable bycatch in fisheries (NRC 1990; Tasker et al. 2000). Other long-lived, but less charismatic, species are also in serious decline because of bycatch. For example, many long-lived elasmobranchs have suffered precipitous declines from bycatch in fisheries (Casey & Myers 1998; Baum et al. 2003). Fisheries bycatch of these species is seldom monitored or regulated, so impacts on their populations may go unnoticed until the species disappear.

We estimated cetacean and pinniped bycatch in fisheries of the United States in the last decade. We did not consider the bycatch of sirenians or sea otters, although these marine mammals are also taken in fisheries. In 1994 the United States implemented a management scheme designed to assess and mitigate marine mammal bycatch in commercial fisheries (Wade 1998; Read & Wade 2000; Young 2001). Under this scheme fisheries are categorized according to their likelihood of taking marine mammals during their operations. Vessels in fisheries deemed to have frequent or occasional interactions with marine mammals are required to register and take observers, if requested to do so. Fishers are required to report the bycatch of marine mammals but seldom do, and in practice the only reliable data come from observer programs (Northridge 1996). To assess marine mammal bycatch, therefore, independent observers are placed aboard a sample of commercial fishing vessels to estimate bycatch rates. This observed bycatch rate is then applied to some measure of total fishing effort to estimate total bycatch for each fishery. This scheme allowed us to estimate total marine mammal bycatch in the United States. We extrapolated from these data to derive a first estimate of marine mammal bycatch in the world's fisheries.

Methods

Bycatch in U.S. Fisheries

We obtained estimates of bycatch for 125 stocks of marine mammals in U.S. waters from published stock assessment reports (NOAA 2002). These assessments are updated every 3 years or more frequently, depending on the status of the stock. Information on bycatch is provided in the section of each report entitled *Annual Human Caused Mortality and Serious Injury*. This information is typically stratified by year and fishery. We compiled information on bycatch for each stock from 1990 to 1999 and combined bycatch into three categories of fisheries: gill nets, trawls, and other (e.g., longlines, purse seines, traps). We also stratified these data by the three geographical regions in which they were collected: Atlantic (including the Gulf of Mexico), Pacific (including Hawaii), and Alaska.

In some cases, particularly when it is difficult to identify individuals to the species level at sea during surveys, two or more species from a genus are lumped together in the stock assessment reports (e.g., some species of *Mesoplodon*, *Globicephala*, *Stenella*, and *Kogia*). In these cases, we followed the Stock Assessment Reports and included bycatch data from the genus.

Most estimates of bycatch in the reports are derived from observer programs. Sometimes, however, these estimates are augmented with supplemental information from other sources such as reports of stranded, entangled animals or data from fishery logbooks. In addition, the reports include information on mortality and serious injuries that are likely to lead to mortality. We included both categories in our analysis. Throughout our compilation we followed the format of the stock assessment reports and used the total estimated mortality and serious injury reported for each stock. Because of the variation in reporting procedures, it was not possible to estimate a total variance for each marine mammal taxonomic group, fishery type, or region. Thus the measures of variance we present (standard errors) underestimate the true level of uncertainty in the estimates of total bycatch.

We assessed whether bycatch changed over the decade by conducting linear regressions of bycatch against year for cetaceans, pinnipeds, and all marine mammals. Using analysis of variance, we also compared mean bycatch in two periods (1990–1994 and 1995–1999). We chose these periods because most attempts to reduce marine mammal bycatch in U.S. fisheries began after 1994, when the U.S. Marine Mammal Protection Act was amended to deal with this issue (Bache 2001; Young 2001). Finally, we compared the time series of marine mammal bycatch with landings of target species from selected gear types obtained from the National Oceanic and Atmospheric Administration (NOAA) Commercial Fisheries Landings database (NOAA 2003*a*).

Toward an Estimate of Global Bycatch

To extrapolate from the U.S. data set to global marine mammal bycatch, we used the ratio of U.S. fishing vessels to the total number of vessels in the world's fleet. We stratified the U.S. marine mammal bycatch by fishery type (gill net, trawl, and other) and used ratios of the number of U.S. vessels to global vessels in each fishery category to expand the U.S. bycatch estimates to global totals. We obtained data on the number of fishing vessels from a database of global fishing fleets maintained by the Food and Agriculture Organization (FIGIS 2003). These data were available only to 1995 and, for reasons described below, we used data only from 1990 to 1994.

Results

Bycatch in U.S. Fisheries

The mean annual bycatch of marine mammals in U.S. fisheries between 1990 and 1999 was 6215 (SE 448) (Table 1). Bycatch of cetaceans (3029 ± 316) and pinnipeds (3187 ± 341) occurred in similar numbers. Dolphins and porpoises constituted most of the cetacean bycatch. The mean annual bycatch of large whales was only 20.1 (SE 2.9). The majority of cetacean (84%) and pinniped (98%) bycatch was reported from gill-net fisheries.

Marine mammal bycatch declined significantly over the decade ($p = 0.002$, $r^2 = 0.714$). A significant negative trend was apparent in the bycatch of cetaceans ($p = 0.011$, $r^2 = 0.576$) but not in pinnipeds ($p = 0.244$,

Table 1. Estimates of marine mammal bycatch in U.S. fisheries stratified by taxon and fishery type.

Taxon and fishery type	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*	*1998*	*1999*
Cetaceans										
gill net	4902	3154	2373	2489	2928	2261	2624	2095	1481	1051
trawl	195	297	232	133	199	195	999	436	116	332
other	3	9	256	60	388	475	114	11	70	408
Pinnipeds										
gill net	1921	3312	5626	3573	3540	3136	2472	2873	2323	2344
trawl	19	36	34	10	29	3	15	17	14	11
other	151	149	148	10	29	30	6	20	15	0

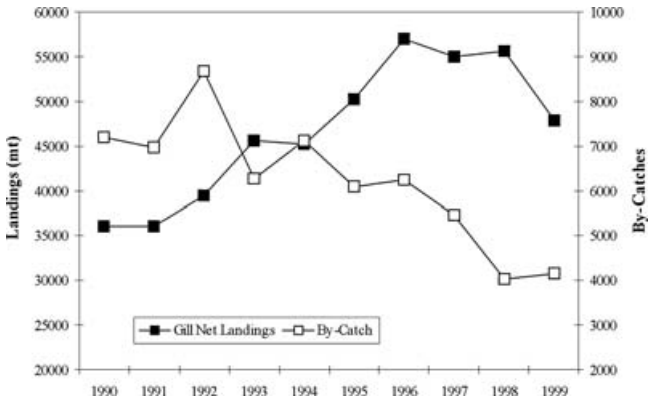

Figure 1. Bycatch of marine mammals in all U.S. fisheries from 1990 to 1999, with gill-net fisheries landings (NOAA 2003a) from the same period.

$r^2 = 0.165$). Annual marine mammal bycatch was significantly lower ($F = 11.21$, $p = 0.010$) in 1995–1999 (5189 ± 471) than in 1990–1994 (7241 ± 392). Bycatches of both cetaceans and pinnipeds were lower in 1995–1999 than in 1990–1994, but not significantly ($F = 2.99$, $p = 0.122$ and $F = 2.954$, $p = 0.124$, respectively). Because the true variance of each annual estimate is unknown and, therefore, not included here, our analyses were prone to Type I error. The declines were most likely not the result of a reduction in fishing effort, because landings from gill-net fisheries in the United States rose throughout this period (Fig. 1).

Some of these general trends can be explained by examining the bycatch of particular species. For example, the Gulf of Maine population of harbor porpoises (*Phocoena phocoena*) was subject to the largest known bycatch of any marine mammal in the United States during the early 1990s. This bycatch declined dramatically from 2900 (CV = 0.32) in 1990 (57% of cetacean bycatch) to 332 (CV = 0.46) in 1999 (19% of cetacean bycatch). Several mitigation measures, including time-area closures and the use of acoustic alarms, were used in the late 1990s to reduce this bycatch (NOAA 2002). At the same time fishing effort in the New England sink gill-net fishery declined dramatically because of measures designed to conserve overfished stocks of groundfish.

In a similar vein, the large bycatch of pinnipeds recorded in the Pacific region during the early 1990s (Table 2) was composed mostly of California sea lions (*Zalophus californianus*) and harbor seals (*Phoca vitulina*) taken in a coastal gill-net fishery. In 1992, for example, 3418 (CV = 0.28) sea lions and 1204 (CV = 0.47) harbor seals were taken in this fishery. A series of conservation measures was introduced in 1994 to address the bycatch of marine mammals, and these measures dramatically reduced the bycatch of Pacific pinnipeds during the last half of the decade (Table 2).

Toward an Estimate of Global Bycatch

Bycatch reduction measures were used during the late 1990s in several U.S. fisheries, but similar measures rarely have been used in other parts of the world. Therefore, we used U.S. data from 1990 to 1994 to generate estimates of the annual global bycatch of marine mammals. The U.S. fleet comprised 1.1%, 5.9%, and 4.2% of the global registry of gill-net, trawl, and other vessels, respectively, in the Food and Agriculture Organization (FAO) database between 1990 and 1994 (Table 3). Using these ratios to extrapolate to global bycatch during this period yielded an annual estimate of 653,365 marine mammals, comprising 307,753 cetaceans and 345,611 pinnipeds. The preponderance of gill-net vessels in the global fleet, coupled with the known high bycatch rates of marine mammals in gill-net fisheries in the United States, suggests that most of the world's cetacean and pinniped bycatch occurs in gill-net fisheries.

Discussion

Our estimates of marine mammal bycatch in U.S. fisheries were negatively biased. Potential bycatch in many fisheries, particularly those in remote regions such as Alaska, has yet to be properly assessed because observer programs have not been implemented in these areas. Existing

Table 2. Estimates of marine mammal bycatch in U.S. fisheries, stratified by taxon and region.

	Atlantic			*Pacific*			*Alaska*		
Year	*cetaceans*	*pinnipeds*	*total*	*cetaceans*	*pinnipeds*	*total*	*cetaceans*	*pinnipeds*	*total*
1990	4574	602	5176	451	1363	1814	76	126	202
1991	2696	231	2927	705	3143	3848	60	123	183
1992	2192	373	2565	639	5340	5979	31	95	126
1993	2142	716	2858	521	2740	3261	20	137	157
1994	3153	2210	5363	342	1332	1674	21	31	52
1995	2419	2018	4437	489	1118	1607	23	33	56
1996	3214	1049	4263	506	1432	1938	18	12	30
1997	2208	998	3206	313	1897	2210	22	15	37
1998	1523	499	2022	124	1840	1964	21	13	34
1999	1649	1682	3331	133	662	795	9	11	20

Table 3. Estimates of bycatch of marine mammals in the world's fisheries (number of vessels used to expand U.S. estimates to global totals).

Fishery type and year	*No. of U.S. vessels*	*Total no. of vessels*	*Global cetacean bycatch*	*Global pinniped bycatch*	*Global marine mammal bycatch*
Gill net					
1990	2,140	203,598	466,392	182,763	649,154
1991	2,140	217,585	320,633	336,748	657,381
1992	2,160	218,272	239,766	568,518	808,283
1993	2,500	219,461	218,513	313,654	532,167
1994	2,500	220,500	258,250	312,228	570,478
Trawl					
1990	7,446	129,403	3,389	330	3,719
1991	7,440	130,128	5,198	630	5,828
1992	8,150	132,957	3,790	555	4,344
1993	8,290	137,720	2,213	166	2,379
1994	8,030	137,479	3,407	496	3,904
Other					
1990	3,220	77,640	72	3,645	3,717
1991	3,180	79,045	222	3,708	3,930
1992	3,230	80,606	6,382	3,698	10,079
1993	3,495	80,366	1,377	235	1,612
1994	3,430	80,991	9,164	685	9,849

information for such fisheries relies on anecdotal reports or logbook accounts, which do not reflect the true magnitude of marine mammal bycatch. Few U.S. fishers report marine mammal bycatch voluntarily, although they are required to do so by the Marine Mammal Protection Act. For example, in 1990 fishers reported a bycatch of 74 harbor porpoises in the Gulf of Maine, whereas the total bycatch extrapolated from an observer program was 2900 (CV = 0.32) (Bisack & DiNardo 1992; Weber 2002:159). It is widely accepted that accurate estimation of bycatch rates in any fishery requires an independent observer scheme (Northridge 1996).

In some cases, even well-planned monitoring programs may underestimate marine mammal bycatch. For example, in some fisheries (such as the New England lobster fishery) entanglement of large whales is a rare event, although a large quantity of gear is fished. Any monitoring program designed to detect such rare events would be enormously costly and inefficient. Many small entangled marine mammals (such as porpoises and seals) may drop out of fishing gear while it is being retrieved, unseen by fishers or observers (Bisack 1997). Aspects of the behavior of some marine mammals may also lead to negatively biased estimates. For example, many large whales carry off gear after becoming entangled, so on-board observation programs underestimate the true bycatch rate of whales. This conclusion is supported by analysis of scars borne by humpback and right whales along the U.S. Atlantic coast (Knowlton et al. 2003; Robbins & Mattila 2004). These analyses indicate that from 50% to more than 70% of animals in some populations (Gulf of Maine humpbacks and North Atlantic right whales, respectively) have been entangled at least once in their lives and that between 10% and 30% of individuals in these populations become entangled each year. These rates are considerably greater than the rates documented in the stock assessment reports. Thus, although not all entanglements are life threatening (many whales eventually shed fishing gear), the frequency with which entanglements are reported in observer programs greatly underestimates the real situation.

Despite these caveats, it has been possible, for the first time, to generate an estimate of total marine mammal bycatch in U.S. fisheries and extrapolate a rough first estimate of global bycatch. In the United States most observed bycatch occurs in gill-net fisheries, despite the existence of fleets of large, industrial fishing vessels using other types of gear. At present it is unclear to what extent this observation can be extended to the fleets of other nations, but we suggest that initial efforts to document bycatch should focus on gill-net fisheries. This does not imply that significant bycatch does not occur in other gear types such as some pelagic trawl fisheries, but we conclude that marine mammal bycatch is more likely to occur in gill-net fisheries. There is one important exception to the dominance of gill nets as a source of bycatch mortality. Baleen whales are taken frequently in gill nets but, in contrast to other marine mammals, are also taken in other types of fisheries, especially those that use vertical lines to mark traps, pots, or other demersal gear. The true magnitude of bycatch in different gear types is unknown, but, at least in U.S. fisheries, both gill net and trap fisheries are responsible for the bycatch of baleen whales.

Conservation measures have been effective in reducing marine mammal bycatch in U.S. fisheries, resulting in a 40% decrease between 1990 and 1999. This decline was attributable primarily to a reduction in the recorded bycatch of cetaceans, which decreased by almost two-thirds (Table 1). At least some of this reduction in cetacean bycatch was due to conservation

measures implemented through "take reduction plans" (Bache 2001; Young 2001). This success demonstrates that it is possible to reduce bycatch while maintaining viable fisheries (see also Hall 1996). We caution, however, that some of this reduction most likely came from reduced fishing effort brought about by the collapse of important fish stocks, particularly in New England. It will be important to monitor bycatch rates of harbor porpoises and other marine mammals in the gill-net fisheries of this region as these fish stocks recover to determine whether the conservation measures in place will be effective at higher levels of fishing effort.

We acknowledge that the estimates we present here are crude and likely to be biased, but it is clear that the global bycatch of marine mammals is very large. There are good reasons to believe that the bycatch of marine mammals in U.S. fisheries are not representative of those in other parts of the world; potential biases exist in both directions. As discussed below, in general we believe our approach overestimates global pinniped bycatch and underestimates global cetacean bycatch.

Our estimates of global pinniped bycatch are likely to be positively biased. Pinniped bycatch is likely to be minimal or nonexistent in many tropical countries because seals and sea lions are rare or absent in many low-latitude regions. A future analysis could refine these estimates by estimating bycatch country by country, excluding nations where pinnipeds are rare or absent. Such an approach would severely test the resolution of current FAO data holdings on fishing effort. As these holdings are further refined, the value of this approach will increase.

We believe our estimates of global cetacean bycatch are negatively biased, primarily because the registry of fishing vessels in the FAO database is incomplete. This information is contributed voluntarily to the FAO by member countries, but many states fail to report altogether or do not report the composition of their fleet by vessel type (M. Perotti, personal communication). Thus our extrapolation to global cetacean bycatch based on the number of vessels may be biased downward. Given the incomplete nature of the FAO database, we believe it is likely the total bycatch of cetaceans may be even greater than the figures we present here.

In addition, the nature of fisheries in the developing world is very different from that in the United States. Artisanal gill-net fisheries are very common in the developing world, but less so in the United States. For example, Zhou and Wang (1994) estimated that 3.5 million gill nets were in use in China in the early 1990s. Many of these small-scale gill-net fisheries most likely capture dolphins and porpoises. The intensity with which such fishing gear is used in southeastern Asia and elsewhere is likely to have a severe impact on regional populations of small cetaceans. To date there has been little assessment of such impacts. Several other gear types take small cetaceans in the developing world but have no counterpart in the United States.

Despite these limitations, our simple extrapolations provide a useful first estimate of global marine mammal bycatch. The global bycatch of marine mammals is likely to number in the hundreds of thousands each year. This is consistent with what we know of some large, documented bycatch of marine mammals (e.g., Vinther 1999; IWC 2002; MMC 2002).

Our estimates could be improved considerably if better data were made available by fishing nations on the composition of the fleet and on relative measures of effort in different fleet sectors. Such information might also assist management organizations such as the FAO and regional fisheries bodies in directing conservation efforts to areas where marine mammal bycatch is likely to be large but where no research infrastructure exists to assess their size or impact. For example, we can predict that a region or country with large marine mammal populations and an active fleet of coastal gill-net vessels is likely to experience significant marine mammal bycatch, even in the absence of other direct information.

Our understanding of marine mammal bycatch is hindered by the almost complete lack of reporting on a global scale. Few countries have any effective reporting system for bycatch of any species. And, there is no centralized global data repository that holds information on marine mammal bycatch. Some data on cetacean bycatch are reported annually to the Scientific Committee of the International Whaling Commission (IWC), but these reports are limited primarily to member states of the IWC and acknowledged as far from complete. A central repository of bycatch data would greatly assist in comparing and contrasting bycatch rates among different fishery types and assessing potential mitigation strategies.

With a global marine mammal bycatch of several hundred thousand animals per year, fisheries pose a major conservation threat to many populations and some species of marine mammals. More than half the initiatives recommended in the recent conservation action plan for the world's cetaceans (Reeves et al. 2003) deal with bycatch. Bycatch is recognized as the primary threat to several endangered species of marine mammals (Reeves et al. 2003), including the vaquita (*Phocoena sinus*) and Hector's dolphin (*Cephalorhynchus hectori*), and contributes to the dire conservation status of the Mediterranean monk seal (*Monachus monachus*) and the North Atlantic right whale (*Eubalena glacialis*). It is likely that many other important conservation problems exist but have not been identified. It is important to improve on the simple methods and incomplete data described here so that we can better assess the demographic impacts of bycatch on marine mammal populations.

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