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A review of marine mammal, sea turtle and seabird bycatch in USA fisheries and the role of policy in shaping management

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ABSTRACT

This paper reviews the available information (observer programs, estimates, statutes, regulations) for bycatch of marine mammals, sea turtles, and seabirds in fisheries of the United States. Goals of the review were to evaluate the state of knowledge of bycatch and the role of existing protective legislation in shaping bycatch management for different taxa. Pressing issues are identified, as well as knowledge gaps and policy limitations that hinder multi-species bycatch reduction. The USA has made important progress toward reducing bycatch in its fisheries, but the efficacy of its management has been limited somewhat by a focus on taxon- and fishery-specific regulation and the lack of consistent mandate across taxa for taking a cumulative perspective on bycatch. Applying consistent criteria across taxa for setting bycatch limits (e.g., extending the approach used for marine mammals to sea turtles and seabirds) would be the first step in a multi-species approach to bycatch reduction. A population-based multi-species multi-gear approach to bycatch would help identify priority areas where resources are needed most and can be used most effectively.

1. Introduction

Incidental capture of non-target species in fishing gear, or 'bycatch', is a common artifact of marine fisheries worldwide, often with severe consequences for marine fish and wildlife populations and habitats [1–4]. Bycatch also can have a detrimental impact on fishing industries and fishermen due to bait loss, valuable time spent removing non-target animals from gear, the resulting damage to gear, and diminished catch of target species (e.g., [5,6]). Each nation is responsible for management of marine resources, including species taken as bycatch, within its exclusive economic zone (EEZ[1]) (United Nations Convention on the Law of the Sea, 1982), and the 1995 Food and Agricultural Organization (FAO) Code of Conduct for Responsible Fisheries calls on countries to "minimize waste, catch of non-target species, both fish and non-fish species, and impacts on associated or dependent species."

Some countries and international management bodies have adopted bycatch reduction measures to protect particular species or taxa of conservation concern or to regulate a particular fishery (e.g., 7–11]). However, species- or fishery-specific management approaches may be inefficient and only partially effective and may lead to unintended consequences for other species or fisheries. Unfortunately, policies constructed to protect a particular taxon do not easily translate into a roadmap for multi-species management and some do not even facilitate multi-fisheries management to protect the taxon in question. This stems from the fact that many species interact with multiple fisheries and fishing gears, and many fisheries take multiple species as bycatch. Addressing

Abbreviations: CA/OR, California/Oregon; CDFG, California Department of Fish and Game; CFR, Code of Federal Regulations; EEZ, exclusive economic zone; ESA, Endangered Species Act; FAO, Food and Agricultural Organization of the United Nations; ITL, incidental take level/limit; LOF, List of Fisheries; MBTA, Migratory Bird Treaty Act; MMPA, Marine Mammal Protection Act; MSA, Magnuson-Stevens (Fishery Conservation and Management) Act; NEFOP, Northeast Fisheries Observer Program; NMFS, National Marine Fisheries Service; NOAA, National Oceanic and Atmospheric Administration; PBR, potential biological removal; SAR, stock assessment report; SE/GOM, Southeast Atlantic/Gulf of Mexico; TED, turtle excluder device; TRP, take reduction plan; TRT, take reduction team; USA, United States of America; USC, United States Code; USFWS, United States Fish and Wildlife Service

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[1] See abbreviations.

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bycatch with a multi-gear approach would allow for cumulative effects of multiple fisheries on particular species to be evaluated, for the population consequences of bycatch to be assessed, and for the most problematic fisheries to be identified and prioritized for management. Similarly, a multi-species perspective is essential for effectively implementing solutions that benefit multiple taxa in a fishery [12,13] and avoiding mitigation measures that merely shift problems from one species group to another [14].

This review considers the consequences and efficacy of taxon-specific policy frameworks for bycatch management in the United States (USA). The USA is of particular interest because of its large fishing region, the diversity of its fisheries and taxa with which they interact, and its commitment to bycatch reduction over the past decade. Including territorial waters, the USA has the largest EEZ (>11 million km^2) of any country in the world and includes at least eight large marine ecosystems (FAO Fisheries and Aquaculture Country Profile, United States of America, http://www.fao.org/fishery/countrysector/FI-CP_US/en, accessed 8 April 2008). The USA's annual tonnage of fisheries landings over the past decade—roughly 5.2% of total reported global landings—consistently places the USA among the top 3 countries in the world (FAO Global Capture Production Statistics, 1996–2005). Given the magnitude of USA fishing fleet operations and landings, as well as the diversity of marine habitats and associated biodiversity within the USA's EEZ, bycatch is a prominent management concern for USA fisheries. Since the early 1990s, the USA has collected bycatch data and implemented a number of bycatch reduction policies. The combination of a diverse policy framework and available bycatch data make the USA an ideal case study to explore the role of policy in comprehensively and successfully reducing fisheries bycatch.

The agency charged with managing fisheries activities in the USA—the National Oceanic and Atmospheric Administration Fisheries Service (NOAA Fisheries, or National Marine Fisheries Service, NMFS)—developed a National Bycatch Plan ('Plan'; [15]), updated with a National Bycatch Strategy ('Strategy') in 2003 (Federal Register 68: 11501–11518; [16,17]), to guide research and management on bycatch. Some aspects of the Plan and Strategy include the continuation and development of onboard observer programs, ongoing experiments and implementation of bycatch mitigation techniques, legislative frameworks, and the allocation of considerable funding for marine scientific research and conservation efforts. A National Bycatch Report is currently being compiled with projected release sometime in 2008. This report will summarize bycatch estimates and outline actions to improve bycatch data collection and estimation.

Although the Plan has stimulated data collection and regulations, these data sources have not been integrated into a national summary of the comprehensive impact of fisheries bycatch looking across species and gear types. To explore the importance of taking a multi-taxa, multi-fishery perspective, cumulative bycatch estimates are reviewed for marine mammals, sea turtles, and seabirds in USA fisheries, and the role of existing protective legislation in shaping bycatch management is evaluated. First, the major statutes that guide management of bycatch in USA fisheries are briefly overviewed. Second, fishery-specific bycatch estimates are summarized for all three taxonomic groups based on data from observer programs, and management actions are highlighted that have been implemented to reduce bycatch in some fisheries. In doing so, the aim was to identify the most pressing bycatch issues in USA fisheries and important knowledge gaps. The review concludes with a discussion of how current policies have facilitated or hindered the evaluation of bycatch estimates within a species population context and a multi-fishery or multi-species framework. By using the USA as a case study, this review is intended to highlight successes and limitations of existing legislative and management mandates and to promote more ecologically efficient and economically effective bycatch reduction policies.

The scope of this review is restricted to bycatch of marine mammals, sea turtles, and seabirds, and primarily to extant federally managed fisheries operating at least partially within the USA EEZ. Distant water fisheries are not considered (e.g., those fishing exclusively outside of the USA's EEZ such as the purse seine fishery for highly migratory species in the eastern tropical Pacific; see Refs. [18,19]). Bycatch was generally not reviewed for fisheries of individual USA states, though a few well-known cases are discussed. Finally, with respect to marine mammals, this review focuses principally on small odontocetes and pinnipeds, which made up >99% of marine mammal bycatch during the 1990s [20]. As such, mortality of baleen whales caused by gear-entanglement in Atlantic trap/pot and gillnet fisheries is not discussed. This important and complex issue has been thoroughly discussed elsewhere (Atlantic Large Whale Take Reduction Plan [Federal Register 72:57104–57194, 5 October 2007], Refs. [21–25]).

2. Bycatch policy for marine mammals, sea turtles, and seabirds in the USA

There are four key federal statutes (Table 1) that address fisheries bycatch of our study taxa and have led to a number of taxon-specific regulations. These regulations have had differing degrees of success as measured by their ability to address bycatch across gear, species and taxa. The Marine Mammal Protection Act (MMPA) and the Migratory Bird Treaty Act (MBTA) are only relevant to marine mammals and birds, respectively, and both taxa are excluded from bycatch minimization mandates of the Magnuson-Stevens Fishery Conservation and Management Act (MSA), which has some application to sea turtles. The Endangered Species Act (ESA) is relevant to all Threatened and Endangered species, with management conducted on a species by species basis. These statutes have led to taxa-specific regulation, each with different recipes for addressing bycatch of the taxa within their respective purview.

2.1. Marine mammals

Marine mammals are the only taxon whose management with respect to bycatch is guided by a federal statute enacted expressly for the purpose of this taxon's protection. The MMPA prohibits "take" (to hunt, harass, capture, or kill) of all marine mammals in USA waters and by USA citizens on the high seas. Since its enactment in 1972, the MMPA has included an exemption from the take prohibition for marine mammals taken incidental to commercial fishing. Following amendments in 1994, the MMPA provides specific provisions for reducing incidental take of marine mammals by USA commercial fishery operations. NOAA Fisheries and the US Fish and Wildlife Service (USFWS) (for walrus, sea otter, manatee, and polar bear) are required implement monitoring programs (accomplished through use of scientific observers) to estimate the human-caused mortality and serious injury (hereafter 'mortality') of marine mammals from interactions with commercial fisheries, and to estimate the potential biological removal (PBR) for each marine mammal stock. PBR is a conservative threshold of sustainable additive mortality, based on estimates of stock abundance and potential population growth rates and incorporating uncertainty in estimates of abundance, mortality and stock status [26–28]. All commercial fisheries (state and federal) are classified into one of three categories (I, II, III) that indicate their relative frequency of serious injuries and mortalities to marine mammals, with Category I fisheries having the most

Table 1
Protective statutes and protected taxa that are relevant to this paper

Statute	Year enacted (amended)[a]	Official US Code	Species addressed	Regulatory agency
Migratory Bird Treaty Act (MBTA)	1918	16 USC Ch. 7 16 USC Sec. 701	Bird species of the USA	USFWS
Marine Mammal Protection Act (MMPA)	1972 (1994)	16 USC Ch. 31 16 USC Sec. 1361	Pinnipeds, cetaceans, polar bear, sea otter, manatee	NOAA Fisheries (cetaceans and pinnipeds) USFWS (polar bear, sea otter, manatee, walrus)
Endangered Species Act (ESA)	1973	16 USC Ch. 35 16 USC Sec. 1531	Species listed as Threatened or Endangered under the Act	NOAA Fisheries (marine mammals listed above, sea turtles in water) USFWS (marine mammals listed above, seabirds, sea turtles on nesting beaches)
Magnuson-Stevens Fishery Conservation and Management Act (MSA)	1976 (1996, 2006)	16 USC Ch. 38 16 USC Sec. 1801	All marine animals except mammals and birds	NOAA Fisheries

[a] All of these Acts have been amended several times. Only those most relevant to this paper are listed here.

frequent interactions. This classification is published annually in the List of Fisheries (LOF; most recent is for 2008, [29]). If the level of human-caused mortality across all fisheries for a marine mammal stock exceeds PBR, it is designated as a Strategic Stock. Declining stocks and marine mammal species listed as Threatened or Endangered under the ESA also receive this designation. The MMPA directs NOAA Fisheries to establish Take Reduction Teams (TRTs) to develop TRPs to reduce the mortality of Strategic Stocks below PBR within 6 months after implementation. In addition, the measures must reduce mortality within 5 years to 'insignificant levels approaching a zero rate' (MMPA Sec. 118 b and f; Federal Register 69:43338–43345).

Marine mammals that are listed under the ESA are subject to additional measures. The ESA prohibits "take" (to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect) of listed species in the USA or by USA citizens on the high seas, and it requires NOAA Fisheries or the USFWS to develop and implement recovery plans for listed species. As under the MMPA, incidental take of a protected species may be authorized under the ESA for certain activities, following a formal process outlined under Section 7 (for federal activities) or Section 10 (for non-federal activities) of the ESA. The incidental take authorization process requires evaluation by NOAA Fisheries or the USFWS to determine whether the proposed activity will reduce the likelihood of species recovery. Activities found to jeopardize species recovery do not receive an incidental take authorization. However, this determination is sometimes based on a non-quantitative evaluation process as it is subject to the best available information, which may not lend itself to quantitative analysis. Thus, the determination is ultimately left to the judgment of NOAA Fisheries or USFWS. This contrasts with the quantitative and relatively rigid regulatory framework by which marine mammal bycatch is managed under the MMPA.

2.2. Sea turtles

Sea turtle bycatch falls under the aegis of two pieces of legislation—the ESA and the MSA. All six sea turtle species that occur in USA waters (green *Chelonia mydas*, loggerhead *Caretta caretta*, olive ridley *Lepidochelys olivacea*, Kemp's ridley *Lepidochelys kempii*, leatherback *Dermochelys coriacea*, and hawksbill *Eretmochelys imbricata*) are listed as either Threatened or Endangered under the ESA and are therefore afforded federal protection under this statute in all USA waters. However, as with all listed species, there is an incidental take authorization process which entails evaluation by NOAA Fisheries to determine whether the proposed activity (i.e., fishing) will reduce the likelihood of species recovery.

The MSA guides management of USA fisheries in its EEZ (3–200 nautical miles from shore). The MSA specifies that bycatch-related mortality of non-target fish should be minimized, and sea turtles are implicitly included in the definition of "fish" under the MSA. In addition, the MSA authorizes (but does not require) NOAA Fisheries to place scientific observers on vessels for conservation and management of federal fisheries. However, authority of NOAA Fisheries under the MSA does not extend to state fisheries, where many incidental takes of sea turtles occur (see 'State of knowledge: Sea turtles' below).

2.3. Seabirds

Two statutes mandate minimization of seabird bycatch. First, seabird species listed under the ESA as Threatened or Endangered are afforded protection as described for the other taxa and activities that result in take can be authorized pending a Section 7 or Section 10 process by the USFWS. Second, the MBTA makes it a felony to knowingly "pursue, hunt, take, capture, [or] kill" any migratory bird, "by any means or in any manner". However, the spatial reach of the MBTA beyond land remains unclear. Formerly, the MBTA applied to the 22-km limit (12 nautical mile) of the USA Territorial Sea but since 2001 has only applied to state waters (A. Manville, USFWS, pers. comm.). A legal opinion drafted by the Solicitor of the US Department of Interior in 2001, would extend enforcement of the MBTA to all USA citizens or USA flagged vessels fishing in any USA waters or on the High Seas [30], but this opinion is still under review. Courts have repeatedly found that direct accidental deaths to migratory birds (as opposed to indirect mortality, e.g., via habitat destruction) by otherwise lawful activities are actionable under the MBTA in cases where bird mortalities were reasonably foreseeable and preventable (e.g., USA v Corbin Farm Services (444 F. Supp. 510) [E.D. Cal. 1978],

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USA v FMC Corp. (572 F.2d 902 [2d Cir. 1978], USA v Moon Lake Electrical Assoc. (45 F. Supp. 2d 1070 [D. Colo. 1999]). However, the USFWS (which has jurisdiction over migratory birds) has never enforced the Act in cases of incidental mortality of seabirds in marine fisheries operations, despite legal pressure from conservation organizations (e.g., [31,32]).

The final version of the Administration's MSA reauthorization bill (September 2005), which reflected the official position of NOAA Fisheries (K. Rivera, pers. comm.), proposed amending the definition of 'bycatch' to include seabirds. This would have provided a new mandate to reduce seabird bycatch in federal fisheries. However, the final Congressional bill reauthorized in 2006 did not include seabirds in the bycatch definition, so the MSA does not explicitly mandate seabird bycatch reduction. The 2006 reauthorization of the MSA did, however, establish a new bycatch reduction program (Sec. 316) that acknowledges the importance of seabird bycatch and establishes a new legislative framework to address the problem. Generally, it promotes development of bycatch reduction technology and authorizes incentives and cooperative bycatch reduction programs between federal agencies and industry. Moreover, NOAA Fisheries has invoked the MSA to reduce seabird bycatch under its mandate to conserve and manage the marine environment (Sec. 3(5); for example, see Federal Register 69:1930–1951, 13 January 2004).

In addition to limited statutory protection, management of seabird bycatch in longline operations is guided by the USA National Plan of Action for Reducing Incidental Catch of Seabirds in Longline Fisheries (NPOA-Seabirds [33]). This voluntary roadmap was developed in collaboration by NOAA Fisheries and the USFWS at the request of the International Plan of Action for Seabirds (IPOA-Seabirds), which was developed under the framework of the 1995 FAO Fisheries Code of Conduct. NOAA Fisheries appointed a National Seabird Coordinator in 2001 to implement the NPOA.

Presidential Executive Order 13186 (Federal Register 66:3853–3856, 17 January 2001) instructed agencies whose actions negatively impact migratory birds to, within 2 years, develop and implement a Memorandum of Understanding (MoU) with the USFWS to promote conservation of migratory birds. However, NOAA Fisheries has not yet submitted an MoU to the USFWS.

3. State of knowledge for bycatch in the USA: estimates, management progress, and knowledge gaps

Budget constraints and taxon-specific policies have resulted in incomplete and unequal evaluation and mitigation of bycatch for different air-breathing marine taxa. Observer programs with adequate vessel coverage provide the most reliable data from which to estimate bycatch in fisheries [17,34,35]. However, many fisheries are not monitored for marine mammal, sea turtle, or seabird bycatch, or have received observer coverage only recently [17,36]. Of the observer programs in existence, many are inadequately funded and thus provide insufficient coverage to reliably inform bycatch management. The USA National Bycatch Strategy calls for estimating bycatch with coefficients of variation between 20% and 30%, yet many bycatch estimates are far less precise and are also biased due to the problem of estimating parameters for rare events from small samples [37–39]. For example, funding constraints limited observer days in Northeast and Mid-Atlantic bottom trawl and gillnet fisheries in 2007 to 802 fishing days, when the level required to estimate cetacean bycatch with 30% CV was 57,000 [40]. Babcock et al. [37] recommended as rule of thumb that at least 20–50% observer coverage was required in most fisheries to achieve precise bycatch estimates of these taxa, yet many programs have coverage <1–5% [36,37,41]. On the other hand, some fisheries have up to 100% observer coverage (e.g., shallow-set Hawaii longline fishery for swordfish, Alaskan groundfish vessels >125 ft long; west coast hake trawls).

Table 2
Summary of extant USA commercial fisheries of the Pacific Ocean known to have bycatch of marine mammals, sea turtles, or seabirds and that did (●) or did not (○) have 'developing' or 'mature' observer programs as of 2004 [29]

Gear	Fisheries	Mammals		Turtles		Birds	
		Byc	Mit	Byc	Mit	Byc	Mit
Gillnet	CA/OR driftnet	● (I)	√	●	√	●	
	CA set gillnet[a]	○ (I)	√	●		●	√
	CA small-mesh drift	○ (II)					
	AK drift/set[a]	○ (II/III)				○	
	WA drift/set[a]	○ (II/III)				○	
	Main HI nearshore	○ (III)					
Longline	HI pelagic (deep set)	● (I)		●		●	√
	HI pelagic (shallow)	● (I)		●	√	●	√
	CA pelagic (deep set)[b]	○ (II)		○		○	√
	AK groundfish[c]	● (II/III)				●	√
	AK halibut	○ (III)				○	√
Trawl	West Coast hake[d]	● (III)					
	AK groundfish[c]	● (II/III)				●	
Other	CA, AK purse seine	○ (II)					

Only those that have reported bycatch estimates for at least one species group, or that are otherwise discussed in text are included here. Many other fisheries interact with these taxa to some degree (e.g., for marine mammals, see Ref. [29]). For marine mammals, the fishery's MMPA classification [29] is also shown in parentheses. Check marks (√) indicate whether mitigation measures are in place specifically to reduce bycatch of the particular species group. CA = California; OR = Oregon; AK = Alaska; WA = Washington. HI = Hawaii.

[a] Predominantly State fisheries.

[b] Since 2004, there has been one tuna-targeting (deep set) longline vessel operating out of California and fishing outside of the USA EEZ with 100% observer coverage (J. Carretta and K. Forney, pers. comm.).

[c] AK groundfish fishery (excluding vessels fishing for halibut) is a multi-gear fishery, including various trawl, longline, and pot/trap fisheries, all of which are Category II or III and receive observer coverage (in part to monitor halibut bycatch).

[d] Includes at-sea and shore-based midwater hake trawls, but only for the smaller at-sea component are bycatch estimates available (Fig. 1B).

Observer coverage is established by NOAA Fisheries on a fishery-specific basis through regulations under the authority of the MMPA, ESA, or MSA. Because the MMPA is the only legislation that mandates cumulative bycatch assessments across gear types, evaluation of marine mammal bycatch is generally more comprehensive than for other taxa. Category I and II fisheries must accommodate observers if requested by NOAA Fisheries to do so, and five of the seven Category I fisheries (see Ref. [29]) have 'developing' or 'mature' observer programs, which enable calculation of bycatch variance estimates [17]. The two fisheries that do not are special cases.[2] In contrast, some of the most problematic fisheries for other taxa—such as the Atlantic and Gulf of Mexico shrimp trawl for sea turtles, or northwest Pacific gillnet fisheries for seabirds—have not been consistently or comprehensively observed (Tables 2 and 3).

[2] Lobster pot fishery in Gulf of Maine is Category I due to interactions with Endangered North Atlantic right whales (*Eubalaena glacialis*) but is not observed, partly because of large number of small vessels (>13,000, [29]) with extremely low per capita interaction rates that make an observer program impractical. The California halibut set gillnet fishery is Category I due to historic takes of harbor porpoises (*Phocoena phocoena*), California sea lions (*Zalophus californianus*), and harbor seals (*Phoca vitulina*), but fishery closures and declining participation in the fishery have reduced marine mammal interactions to historically low levels, and even so, the fishery received some observer coverage in 2006 and 2007 (Jim Carretta, pers. comm.).

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Table 3
Summary of extant USA commercial fisheries of the Atlantic Ocean and Gulf of Mexico known to have bycatch of marine mammals, sea turtles, or seabirds and that did (●) or did not (○) have 'developing' or 'mature' observer programs as of 2004 [29]

Gear	Fisheries	Mammals		Turtles		Birds	
		Byc	Mit	Byc	Mit	Byc	Mit
Gillnet	Northeast sink	● (I)	√			●	
	Mid-Atlantic coastal	● (I)	√	●	√	●	
	Mid-Atlantic inshore[a]	○ (II)		○	√		
	Mid-Atlantic pound[a,b]	○ (II/III)		○	√		
	SE shark driftnet	● (II)	√	●			
Longline	Atlantic/Gulf of Mexico pelagic	● (I)	(√)[c]	●	√	●	
	SE demersal shark	● (III)		●			
Trawl	NE midwater and bottom	● (II)	(√)[c]			●	
	Mid-Atlantic bottom	● (II)	(√)[c]	●	√[d]		
	Mid-Atlantic midwater	○ (II)	(√)[c]				
	Mid-Atlantic scallop trawl	(III)		○			
	Mid-Atlantic scallop dredge[e]	(III)		●	√		
	SE/Gulf of Mexico shrimp trawl	○ (III)		○	√		
Other[f]	NE/Mid-Atlantic lobster trap/pot	○ (I)					
	SE/Gulf of Mexico gillnets	○ (II)					
	Mid-Atlantic/GOM purse seine	○ (II)					

Only those that have reported bycatch estimates for at least one species group, or that are otherwise mentioned in text are included here. Many other fisheries may interact with these taxa to some degree (e.g., for marine mammals, see ref. [29]). For marine mammals, the fishery's MMPA classification [29] is also shown in parentheses. Check marks (√) indicate whether mitigation measures are in place specifically to reduce bycatch of the particular species group.

[a] Predominantly State fisheries.

[b] Not a gillnet fishery, but another type of passive net fishery.

[c] No mitigation yet in place, but Take Reduction Teams have been formed under the MMPA.

[d] TEDs required in the summer flounder component of Mid-Atlantic bottom trawl fisheries.

[e] Not a trawl fishery, but another type of towed-net fishery.

[f] Other unobserved Category II fisheries use various pound/stop net, haul/seine, trap/pot gear (see Ref. [29]).

Below is a detailed summary of available bycatch estimates within each taxon, for Pacific and Atlantic Oceans (including the Gulf of Mexico). Fisheries with potentially problematic bycatch are highlighted, regulatory measures that have been used to reduce bycatch in some of these fisheries are discussed, and potentially important knowledge gaps are identified. These summaries are not necessarily exhaustive because they are based entirely on summary reports and publications that include fishery-wide bycatch estimates. Moreover, since not all fisheries are observed, fully cumulative bycatch estimates are not possible for most affected taxa. New bycatch estimates were not calculated for this summary (only pre-existing estimates from available reports were used) and the statistical validity of estimates used here was not checked. Since many individuals caught as bycatch are retrieved alive (in some fisheries), the number of mortalities (defined as 'mortality and serious injury' in the case of marine mammals) have been reported when possible. Where this was not possible, attempts were made to at least be consistent in terms of the bycatch metrics that were summarized for particular taxa, e.g., total bycatch (lethal plus non-lethal) vs. only lethal bycatch. In some cases, the available information types were inconsistent across years, and data availability (number of years with data) almost always varied across fisheries for a given taxon. Thus, while summary tables and figures reflect available information, they are not always directly comparable with each other. These caveats are noted within the tables and figures and it is recommended that they be interpreted cautiously.

3.1. *Marine mammals*

From 1990 to 1999, annual cetacean and pinniped mortality in the USA was estimated at 3029 (±316 SE) and 3187 (±341 SE), respectively, with the vast majority (84% and 98%) occurring in gillnet fisheries for both taxonomic groups [20]. In the Pacific Ocean, marine mammal bycatch monitoring has focused on 4 groups of fisheries: the Hawaiian pelagic longline fishery, the California/Oregon (CA/OR)-based driftnet fishery, the California halibut set gillnet fishery, and salmon gillnet fisheries in Alaska. The latter two are state fisheries. Additionally, marine mammal bycatch estimates are available for the complex of Alaska groundfish fisheries and west coast at-sea hake trawl fishery, which are low relative to the fisheries described above (Fig. 1A–B, [42,43]).

In the Hawaii longline fishery (shallow-set targeting swordfish and deep-set targeting tunas), an average of 30 cetaceans from seven species (six odontocetes and one mysticete-humpback whale *Megatera novaeangliae*) were killed or seriously injured annually between 1995 and 2005 (Fig. 1C). Of primary concern in this fishery is high take of false killer whales *Pseudorca crassidens* (14 per year on average during the same time period [44]), which are designated as a Strategic Stock because these removals exceed PBR, but for which no TRT has been formed or other legal management action taken. During a 2001–2004 ban on shallow-set longlining in Hawaii to reduce sea turtle bycatch (Federal Register 67:40232–40238), pelagic longliners targeting swordfish operated out of California, before this fishery was closed (Federal Register 69:11540–11545, March 11, 2004). There were similar concerns about marine mammal bycatch in this fishery as in the Hawaii-based operations; no marine mammal takes were observed in 2001–2002 [45] but two dolphin mortalities were later observed (one Risso's dolphin *Grampus griseus* and one unidentified species) (K. Forney, pers. comm.).

In the CA/OR drift net fishery, an average of 456 cetaceans (17 odontocete species and 1 mysticete—the minke whale *Balaenoptera acutorostrata*) and 160 pinnipeds (Stellar sea lion *Eumetopias jubatus*, California sea lion *Zalophus californianus*, harbor seal *Phoca vitulina*, northern elephant seal *Mirounga angustirostris*) were killed or seriously injured annually between 1990 and 1996 (Fig. 1D). These dropped to annual averages of 105 cetaceans (8 odontocetes and 3 mysticetes—fin whale *Balaenoptera physalus*, minke whale, and gray whale *Eschrichtius robustus*) and 77 pinnipeds per year (California sea lion and northern elephant seal) from 1997 to 2006, as a result of regulatory action in 1997 to reduce cetacean bycatch via use of acoustic deterrents (pingers) and a minimum depth of fishing requirement (Pacific Offshore TRP; Federal Register 62:51805–51814, 3 October 1997, also see Ref. [46]). Large time-area closures effective since 2001 to reduce bycatch of Pacific leatherback turtles have probably also reduced marine mammal bycatch (Federal Register 66:44549–44552, August 24, 2001).

In the set gillnet fishery for California halibut *Paralichthys californicus*, high bycatch of harbor porpoises *Phocoena phocoena*, pinnipeds, and Endangered southern sea otters *Enhydra lutris* occurred until recently. During the early to mid-1970s, annual harbor porpoise mortality was probably well under 100 animals per year [47]. However, mortality increased through the late 1970s and 80 s, with rough annual estimates of ~200–300 animals taken along the entire central California coast between 1980 and 1987 (Fig. 1E). These takes led to probable population declines of harbor porpoise [48]. Increasingly restrictive fishing closure regulations by the California Department of Fish and Game

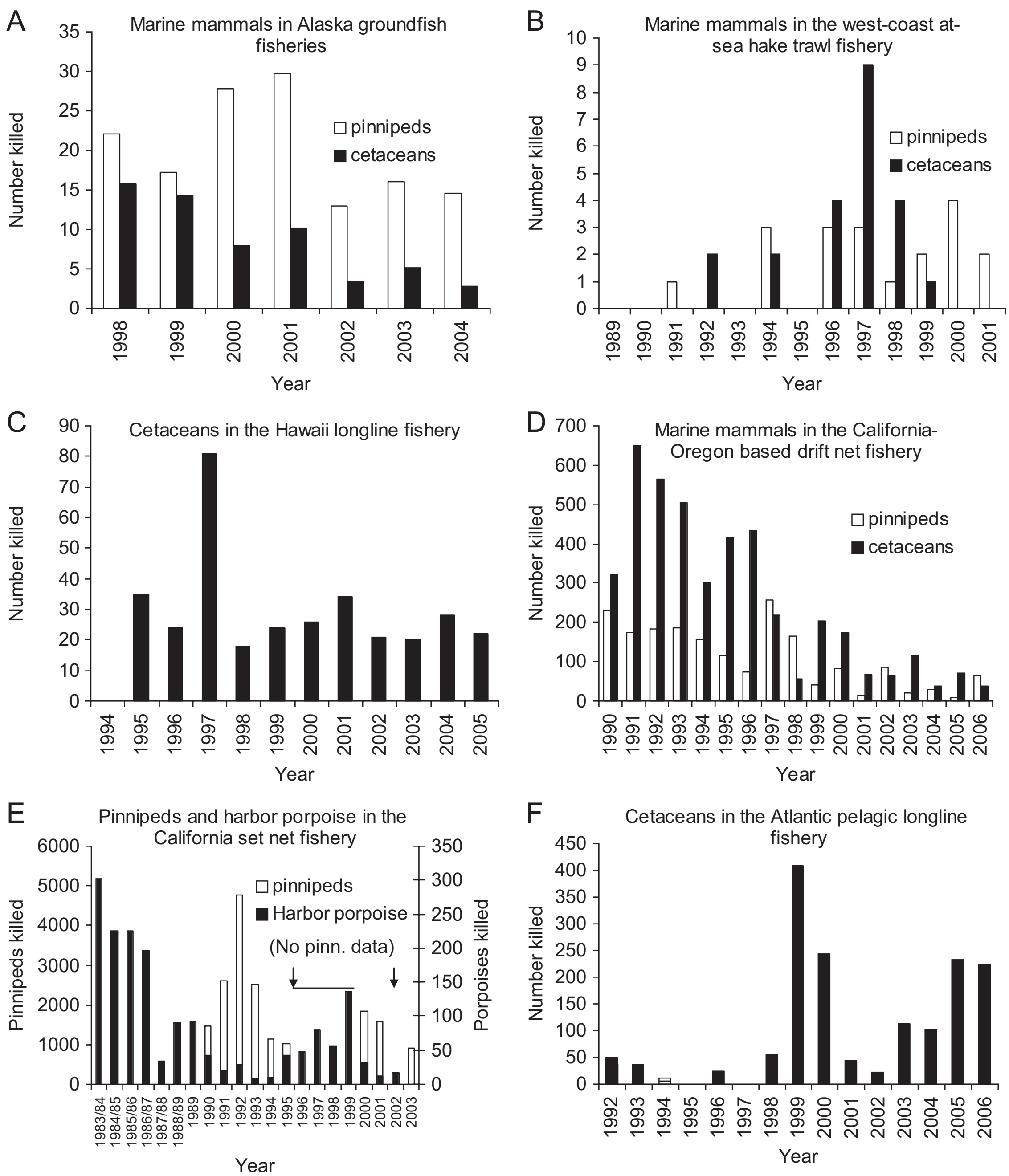

Fig. 1. Available estimates of incidental mortality and serious injury of marine mammals USA commercial fisheries. (A) Pinniped and cetacean mortality in the Alaskan groundfish fisheries, 1998–2004 [43], (B) and in the west-coast at-sea hake trawl fishery, 1989–2001 [42]. (C) Cetacean mortality in the Hawaii longline fishery, 1994–2005 [44]. (D) Pinniped and cetacean mortality in the California–Oregon-based drift net fishery, 1990–2006 [51,62,65,81,130,150]. (E) Pinniped (1990–1995, 2000–2001, 2003) and harbor porpoise (1983–2003) mortality in the set net fishery for California halibut and angel shark [53,62,80,81,151,152]. Harbor porpoise estimates are for Monterey and Morro Bay stocks combined (split from a single Central California stock in 2002). (F) Cetacean mortality in the Atlantic/Gulf of Mexico/Caribbean pelagic longline fleet, 1992–2006 [85,153–159].

(CDFG) throughout the 1980s and early 1990s, aimed primarily at reducing seabird and sea otter bycatch [31,49–53] reduced harbor porpoise mortality statewide to values typically below 50 throughout the 1990s but with peak estimates of 80 and 136 in 1997 and 1999, respectively (Fig. 1E). Further restrictions that effectively closed most of this fishery were applied between 2000 and 2002, after which harbor porpoise bycatch was presumably reduced to near zero [54]. Annual pinniped mortality (California sea lions, harbor seals, elephant seals) ranged from 1016 to 4777 (mean = 2257) during 1990–1995 and from 904 to 1842 during 2000–2003 (Fig. 1E), which represent the only years with published estimates of pinniped bycatch. Sea otter mortality was estimated at 80 per year between June 1982 and 1984 [55], 64 in 1990, and 7–14 per year between 1995 and 1998 [53].[3]

A potentially important bycatch knowledge gap occurs in Alaska. Estimates for Alaskan gillnets (drift and set) are difficult to obtain because of low or non-existent observer coverage in this

[3] Forney et al. [53] used two sets of assumptions (A and B) to obtain seabird and marine mammal bycatch estimates for 1990–1994, and six sets of assumptions (A–F) to estimate bycatch for 1995–1998. For 1990–1994, estimates reported here are from B, which Forney et al. [53] argued was the better method during these years. For 1995–1998, estimates are reported from C, which were considered the preferred method in 2001 US marine mammal stock assessments.

Table 4
Available estimates of marine mammal mortality and serious injury in Alaskan gillnet fisheries

Fishery	Year	Pinniped Est.	Cetacean Est.	Ref.
Prince William sound, set net	1990	0	0	[56]
Prince William sound, drift net	1990	36[a]	8[a]	[56]
South Unimak, drift net	1990	0	28[b]	[56]
Prince William sound, drift net	1991	40.2[c]	42.8[c]	[57]
Cook Inlet, set net	1999, 2000	0	0	[58]
Cook Inlet, drift net	1999	0	0	[58]
"	2000	0	31.2[d]	[58]
Kodiak Island, set net	2002	0	32.2[d]	[59]
"	2005	0	39.4[d]	[59]

[a] Estimated mortality: 8 harbor porpoise (95% CI: 0–23) and 36 harbor seal (0–74).
[b] Estimated mortality: 28 Dall's porpoise *Phocoenoides dalli* (95% CI: 0–81).
[c] Estimated mortality: 28.7 Steller sea lion *Eumetopias jubatus*, 11.5 harbor seal, 32.1 harbor porpoise, 10.7 unidentified porpoise.
[d] All animals caught were harbor porpoises.

Table 5
Available estimates of marine mammal mortality and serious injury in various Atlantic fisheries

Fishery	Year	Est.	Ref.
Harbor porpoise (Phocoena phocoena)			
New England sink net	1990	2900	[160]
	1991	2000	[160]
	1992	1200	[160]
	1993	1400	[160]
	1994	2100	[160]
	1995	1400	[160]
	1996	1185	[161]
NE+Mid-Atlantic sink net	1998	778	[67]
	2004	790	[68]
	2005	1100	[69]
Bottlenose dolphin (Tursiops truncatus)			
Mid-Atlantic gillnet	1996	233	[72]
	1997	274	[72]
	1998	229	[72]
	1999	228	[72]
	2000	202	[72]
Other cetaceans			
Atlantic pair trawl	1991	20	[73]
	1992	114	[73]
	1993	126	[73]
New England sink net	1996	185	[161]
Southeast shark drift net	1999	12.4	[110]
	2000	2	[110]
	2001	4	[110]
	2002	7.7	[110]
	2003	1	[162]
	2004–07	0	[163–165]
NE+Mid-Atlantic sink net	2004	7	[68]
	2005	100	[69]
Southeast shark demersal longline	2003	37–100	[74]
	2004–06	0	[74,75]
Pinnipeds			
New England sink net	1996	994	[161]
NE+Mid-Atlantic sink net	2004	1726	[68]
	2005	1391	[69]

complex of fisheries. Out of the 11 coastal Alaskan gillnet salmon fisheries currently listed as Category II [29] only five have ever been observed (and never concurrently) by the Alaska Marine Mammal Observer Program and none for more than 2 years [36,56–59]. Limited data (Table 4) suggest that Gulf of Alaska stock of harbor porpoises are the most frequently caught species. Although estimated mortality in any one fishery has never exceeded 30–40 porpoises (well below PBR), these bycatch estimates are only a fraction of the number likely taken annually in all Alaskan gillnet fisheries combined. Moreover, this fishery complex is just one exemplary case of poor observer coverage yielding unreliable bycatch estimates. For example, in the Cook Inlet set and drift net fisheries in 1999, observer coverage for different segments of these fleets was estimated to be only between 0.16% and 3.6% [58]. Based on observed bycatch of only two entangled animals (1 in a set net, 1 in a drift net), both released uninjured, harbor porpoise entanglement was estimated to be 750 but estimated mortality was zero. Coefficients of variation across fleet segments were high (between 90% and 199%). Consider that if the entangled animal in the set net had been recovered dead, the mortality estimate would have been 628 instead of zero, well above the largest PBR (347 animals) that has been estimated for the Gulf of Alaska stock [60]. In every well-studied gillnet fishery known to interact with porpoises (*Phocoena* spp.), bycatch has been a major threat to this genus in the absence of protective regulatory measures [61]. Thus, additional observer coverage is clearly required in Alaska salmon gillnet fisheries to better document bycatch of harbor porpoises there.

Other Pacific Category II fisheries that receive little or no observer coverage represent additional knowledge gaps. These include salmon gillnet fisheries in the Pacific Northwest (e.g., Puget Sound, Washington), the California small-mesh drift net fishery for yellowtail, barracuda and seabass [62], and various purse seine fisheries based in California and Alaska [29]. Purse seine fisheries dominate total fish catch (by weight) in most regions of the USA (Pacific, Atlantic, and the Gulf of Mexico), and though they are considered to generally have low collateral impact in most measured respects [63], marine mammal bycatch is a potential concern in tuna purse seines around the world (e.g., [18,64]). California purse seine fisheries for tunas, small pelagics, and squid have received limited observer coverage ($<2\%$) since 2004 [36,65]. In 2005, an estimated 87 short-beaked common dolphins (*Delphinus delphis*) were killed in squid purse seines and an estimated 5196 other marine mammals were taken but released alive across all observed California purse seine fisheries [65]. Species included mostly California sea lions, plus harbor seals, sea otters, and an estimated five gray whales. The 2007 stock assessment for Hawaiian monk seals (*Monachus schauinslandi*) suggests that Category III state-managed nearshore fisheries (especially gillnets) of the main Hawaiian Islands could be problematic for this species, but no mortality estimates have been undertaken.

In the Atlantic Ocean, marine mammal bycatch occurs in a diversity of fisheries (Fig. 1F, Table 5) and is most important in various gillnet and trawl fisheries of New England and the Mid-Atlantic coast, and in the pelagic longline fishery of the Atlantic, Gulf of Mexico, and Caribbean (hereafter, just 'Atlantic pelagic longline') [20,66]. Long-term ($\geqslant$5 years) bycatch estimates have been summarized only for the pelagic longline fishery (Fig. 1F), the southeastern drift net fishery for sharks, and for harbor porpoises and bottlenose dolphins taken in New England and Mid-Atlantic gillnets, respectively (Table 5).

In the Atlantic pelagic longline fishery, annual mortality ranged from zero to 408 animals (mean = 104) between 1992 and 2006, consisting mostly of pilot whales (short-finned *Globicephala melaena* and long-finned *G. melas*), Risso's dolphins, and to a lesser extent bottlenose dolphins *Tursiops truncatus*. A Pelagic Longline TRT was formed in 2005 (Federal Register 70:36120–36121), due to excessive takes of pilot whales, and a draft TRP was recently published by NOAA Fisheries (Federal Register 73:35623–35631, 24 June 2008). If finalized, this would

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place an upper limit on longline lengths and would establish a special research area with increased observer coverage and research efforts to reduce fishery–cetacean interactions.

Most marine mammal bycatch in the Atlantic occurs in New England sink gillnet fisheries and is dominated by harbor porpoises and pinnipeds. In the early to mid-1990s, prior to required mitigation, harbor porpoise mortality in the New England sink net fishery varied from a high of 2900 in 1990 (57% of all cetacean bycatch in the USA [20]) to a low of 1185 in 1996 (mean = 1740; Table 5). Regulatory measures established under the Harbor Porpoise TRP to reduce harbor porpoise bycatch (e.g., acoustic deterrents and time-area closures; Federal Register 63:66464–66490, 2 December 1998) appeared successful, as harbor porpoise mortality in gillnet fisheries of New England and the Mid-Atlantic combined was estimated at 778 in 1998 [67], 790 in 2004 [68], and 1100 in 2005 [69] (Table 5). These values represented 99% and 92% of all cetacean bycatch in these fisheries in 2004 and 2005. However, harbor porpoise mortalities have recently increased [70], possibly due to low compliance with regulations by fishermen, and/or because of habituation by porpoises to acoustic deterrents [9,71]. This led to reconvening of the Harbor Porpoise TRT in December 2007. Pinniped bycatch in New England and Mid-Atlantic gillnet fisheries was 994 (New England only), 1726, and 1391 in 1996, 2004, and 2005, respectively, and consisted mainly of gray seals *Halichoerus grypus*, harbor seals, harp seals *Pagophilus groenlandicus*, and hooded seals *Cystophora cristata*.

Summarized estimates outside of the SARs are highly fragmentary for other Atlantic fisheries. In Mid-Atlantic fisheries, bottlenose dolphins are commonly killed in coastal gillnets [72], with annual mortality estimated between 202 and 274 from 1996 to 2000 (Table 5). Recent regulatory measures to reduce bottlenose dolphin bycatch include restrictions on net-mesh size and time-area closures (Bottlenose Dolphin TRP; Federal Register 71:24776–24797, 26 April 2006). Estimates of bottlenose dolphin bycatch in southeastern Atlantic or Gulf of Mexico gillnet fisheries (Category II fisheries, [29]) do not exist, however. Bycatch mortality in Atlantic pair trawl fisheries varied from 20 to 126 (mostly bottlenose and common dolphins) between 1991 and 1993, when this fishery had just started and was concentrated mostly in the mid-Atlantic [73]. Bycatch estimates from other Atlantic trawl fisheries have not been published apart from SARs, but values are relatively high; based on the 2007 SARs [70], annual estimated mortality across various trawl fisheries included 74 pilot whales, 146 common dolphins, and 326 Atlantic white-sided dolphins between 2001 and 2005. A TRT has been formed for these fisheries (Federal Register 71: 54273–54274, 14 September 2006) but no TRP has yet been developed. A negligible amount of marine mammal bycatch occurs in the southeast shark driftnet fishery (Table 5). Bycatch in the southeast demersal shark longline fishery appears low in most years as well (zero recorded bycatch from 2004 to 2006), although an estimated 37–100 bottlenose dolphins were killed in this fishery in 2003 [74,75] (Table 5).

Other Atlantic Category II fisheries that receive little or no observer coverage represent additional knowledge gaps. These include menhaden purse seine fisheries in the Mid-Atlantic and Gulf of Mexico, and various trap/pot fisheries, haul and beach seines, and stop/pound nets, most of which are known to take bottlenose dolphins on occasion [29].

3.2. Sea turtles

In USA fisheries of the Pacific Ocean, primary concerns are for leatherbacks and loggerheads, due to their critical conservation status [76–78]. In the CA/OR drift net fishery, an average of 14 leatherbacks (1990–1996) and up to 11 (but usually zero) loggerheads were killed on average annually (Fig. 2A, B) before regulations were implemented in 1997 and 2001 to reduce bycatch of cetaceans and sea turtles, respectively (Federal Register 62:51805–51814, 3 October 1997; Federal Register 66:44549–44552, August 24, 2001). Mitigation for sea turtles included time-area closures, namely a large zone referred to as the ‘Pacific leatherback conservation area’, and a smaller Pacific loggerhead conservation area in waters off southern California (Federal Register 68:69962–69967, December 16, 2003). No leatherback takes have been recorded in this fishery since sea turtle mitigation regulations have been put in place. Carretta and Enriquez [65] estimated 5 loggerhead turtles were taken (1 killed) in this fishery in 2006. We are not aware of loggerhead bycatch estimates for the period 2003–2006.

In the Hawaii longline fishery (mostly in shallow sets targeting swordfish), an annual average of 115 leatherbacks (mortality rate = 0.33) and 393 loggerheads (mortality rate = 0.40) were taken between 1994 and 2000 [79] (Fig. 2A, B). Combining mortality estimates from the CA/OR driftnet and the Hawaiian longline fishery, an average of approximately 52 leatherbacks and 161 loggerheads were killed annually in Pacific USA fisheries in the mid-1990s. Approximately 142 olive ridleys (mortality rate = 0.51) and 44 green turtles (mortality rate = 0.46) were captured on average annually in the Hawaii longline fishery during the same time period (Fig. 2C). Following a series of regulations to reduce sea turtle bycatch in this fishery, incidental takes of sea turtles were dramatically reduced to an average of 5 leatherbacks and 13 loggerheads per year between 2001 and 2007 (Fig. 2A–C). These regulations included a complete closure of the Hawaii shallow-set longline fishery from April 2001–April 2004 (Federal Register 67:40232–40238) and permanent closure of the California-based shallow-set longline fishery (Federal Register 69:11540–11545, March 11, 2004), followed by mandatory gear modifications (e.g., use of circle hooks), effort limits and sea turtle bycatch quotas, and 100% observer coverage when the Hawaii-based fishery re-opened (Federal Register 69:17329–17354, 2 April 2004). Nonetheless, the fishery was closed for the remainder of the season in March 2006 due to excessive interactions (>16) with loggerheads (Federal Register 71:14416–14418).

Small numbers (0–8) of leatherbacks, loggerheads, and green turtles have also been killed each year in the California set gillnet fishery [51,80,81], but temporal and spatial observer coverage of this fishery has been sporadic, so adequate evaluation of sea turtle bycatch in this fishery is difficult. The geographic distributions of sea turtles in the Pacific Ocean generally do not overlap with fisheries of the Pacific Northwest coast or Alaska, although leatherback foraging areas do exist off the coasts of Oregon and Washington [82] but we are not aware of any recorded leatherback takes in this area.

In the Atlantic Ocean and Gulf of Mexico fisheries, primary concern is for loggerheads. The southeastern USA comprises one of the largest aggregate nesting rookeries for loggerhead sea turtles in the world, and the USA continental shelf provides critical ontogenetic habitats for this population [83]. Thus, because a large number of individuals are present throughout areas of high fishing activity, loggerheads interact with a greater number of fishing fleets and gear types in the USA Atlantic than other sea turtle species. Unfortunately, because most fisheries in this region are inadequately assessed, bycatch data are highly fragmentary and incomplete, thus making it difficult to obtain cumulative bycatch estimates.

In the USA Atlantic pelagic longline fleet—the best assessed fleet in the Atlantic for turtle bycatch (~3–8% observer coverage since 1992 [84,85])—an estimated 727 loggerheads have been hooked each year between 1992 and 2006 (Fig. 2D). The mortality

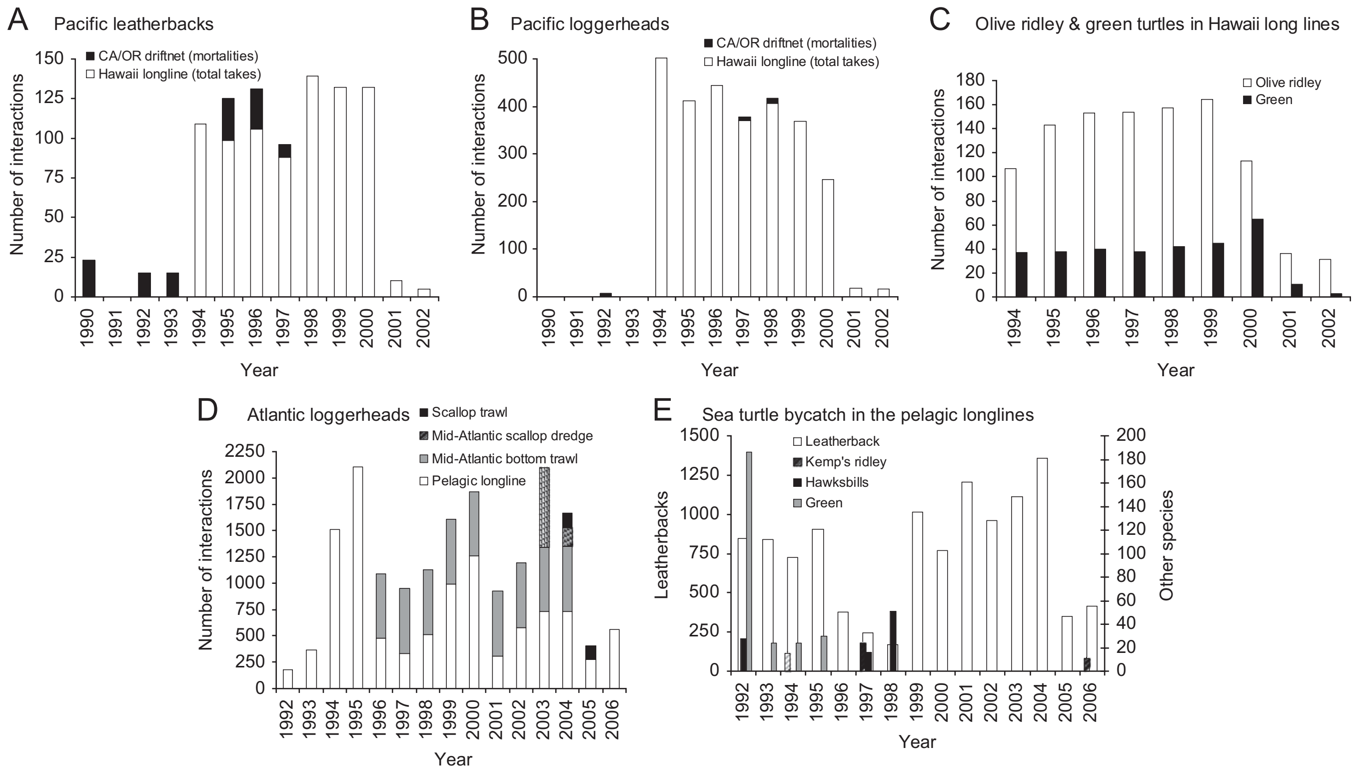

Fig. 2. Available estimates of sea turtle bycatch USA commercial fisheries. California–Oregon drift net fishery estimates are for mortality. All others are for total take (fatal and non-fatal interactions combined), with mortality rates given in the text. Bycatch of (A) Pacific leatherbacks and (B) Pacific loggerheads in the California–Oregon-based driftnet fishery, 1990–2002, and Hawaiian-based pelagic longline fishery, 1994–2002 [38,51,79,130]. (C) Olive ridley and green turtle bycatch in the Hawaiian-based longline fishery, 1994–2002 (see refs in B). (D) Atlantic loggerhead bycatch in the Atlantic/Gulf of Mexico/Caribbean pelagic longline fishery from 1992 to 2006, Mid-Atlantic scallop dredge fishery, 2003–2004 [106–108], Mid-Atlantic bottom trawl, 1996–2004 (the 9-yr average estimate shown for those years [105]), and scallop trawl (the 2-yr average estimate shown for those years [108]). (E) Bycatch of Atlantic leatherbacks, Kemp's ridleys, hawksbills, and green turtles in the Atlantic and Gulf of Mexico pelagic longline fishery, 1992–2006 [85,153–159].

rate is relatively low, however—only 38 deaths were estimated to occur on average each year, corresponding to a mortality rate of 0.052. An estimated 753 Atlantic leatherbacks were caught annually (estimated mortality rate = 0.027) on average during the same years (Fig. 2E). Bycatch of Kemp's ridley, hawksbill, and green turtles occurs in small numbers in the pelagic longline fleet (Fig. 2E). A variety of regulations exist to reduce sea turtle bycatch in this fishery (50 Code of Federal Regulations (CFR) 223.206), including time-area closures, mandatory use of circle hooks rather than J-hooks, and bait requirements (Federal Register 69:40734–40758, 6 July 2004). Circle hooks have been shown to be effective at reducing sea turtle bycatch [86–88]. As a result, sea turtle bycatch in the Atlantic pelagic longline fishery appears to have decreased since 2004 (Fig. 2D, E). However, the effectiveness of these regulatory measures is difficult to assess, given their recent implementation and variable bycatch estimates, which make it difficult to evaluate changes in bycatch through time.

Without question, the majority of sea turtle bycatch occurs in the southeastern Atlantic and Gulf of Mexico (SE/GOM) shrimp trawl fleet, which consists of >18,000 vessels [29]. However, until October 2006, fishermen in this fleet were not required to accommodate scientific observers; now they are if requested (Federal Register 71:56039–56047, 26 September 2006). NOAA Fisheries also recently established a new regulation (Federal Register 72:43176–43186, 3 August 2007) to annually review sea turtle interactions across fisheries, identify those that require monitoring, and require fishermen to accommodate observers if requested. This should lead to mandatory observer coverage in those fisheries (including state fisheries) that pose the greatest potential risk to sea turtle populations, and shrimp trawls are acknowledged as a high priority gear for NOAA Fisheries (Federal Register 71:65473–65474, 8 November 2006). However, for the time-being no empirically based estimates of sea turtle bycatch in the shrimp trawl fishery or a comprehensive statistically based sampling plan yet exist. Epperly et al. [89] suggested that roughly 62,300 loggerheads may have been killed each year, along with 2300 leatherbacks, 20,000 Kemp's ridley turtles, and 1400 green turtles, prior to new regulations that increased the opening size of TEDs (Federal Register 68:8456–8471, 21 February 2003). Even with the new TED size regulations, Epperly et al. [89] anticipated sea turtle mortality on the order of 25,000 individuals per year (mostly Kemp's ridley). However, these estimates have a high degree of uncertainty. Nevertheless, considering that sea turtle mortality in this fishery may exceed that of all other USA fisheries combined (by an order of magnitude or more) and that western Atlantic loggerheads have shown recent signs of decline [90,91], this fishery is one of the most important bycatch knowledge gaps and insufficiently addressed bycatch issues in the USA. Examples of successful bycatch reduction (for turtles, finfish, and other taxa) in trawl vessels exist worldwide, but many obstacles exist in the SE/GOM shrimp trawl industry—owing largely to its size and logistics—that will make successful bycatch monitoring and management difficult [92].

Bycatch of loggerheads and Kemp's ridley turtles (and to a much lesser extent, green and hawksbill turtles) in summer flounder trawls [93,94], which are a component of the multi-species multi-gear Mid-Atlantic bottom trawl fisheries, also has concerned managers, but there are no bycatch estimates for this

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fleet either, apart from the 1991–1992 fishing season in North Carolina, where an estimated 89–181 sea turtles were killed (loggerheads, Kemp's ridley, and hawksbills) [94].

In spite of huge knowledge gaps concerning Atlantic trawl fisheries, there is a long and complex regulatory history surrounding the use of turtle excluder devices (TEDs) to reduce sea turtle bycatch in USA shrimp and summer flounder trawls [9,95–97]. TEDs can be highly effective at reducing bycatch, and their use on shrimp and flounder trawlers has been required since 1987 (Federal Register 52:24244–24262) and 1996 (Federal Register 61:1846–1848), respectively. However, the development of fully effective TEDs has taken nearly two decades [98,99]. Moreover, TED effectiveness in the shrimp trawl fleet has been further limited by low use-compliance [9,97], likely facilitated by a lack of observer coverage and the unwillingness of some states (e.g., Louisiana) to enforce federal TED regulations [100]. As such, TEDs have reduced trawling-related strandings of sea turtles by perhaps only 20–40% [97,101], in comparison to the potential 97% reduction in trawl bycatch reported by [102]. Indeed, where issues of non-compliance are addressed (e.g., Australian prawn fisheries), TED effectiveness in reducing sea turtle bycatch is >90–95% [9,103,104].

Murray [105] estimated an average take of 616 loggerheads per year in the Mid-Atlantic bottom trawl fleet for fishes (which includes summer flounder trawls plus many others) from 1996 to 2004. With a mortality rate of 0.43, this fleet may therefore kill seven times more loggerheads annually than the pelagic longline fleet. Murray [105] also observed very low levels of leatherback and Kemp's ridley bycatch in the same study. Only recently has bycatch been monitored and estimated for the scallop dredge and scallop trawl fisheries. Loggerhead bycatch estimates in the dredge fishery ranged from 749 in 2003 (0.77 mortality = 577 deaths), to zero in 2005 [106–108]. Murray [108] also estimated an average annual estimate of 132 loggerheads caught in scallop trawls in 2004 and 2005, but the observed mortality rate was zero. The wide ranges of bycatch and mortality rate estimates in these fisheries are further examples of inadequate observer coverage levels resulting from under-funded management programs. Chain mats are now required to reduce sea turtle interactions during setting and retrieval of scallop dredges (Federal Register 71:50361–50373, 25 August 2006), and NOAA Fisheries is currently considering regulation to expand use of TEDs to a variety of Atlantic trawl fisheries besides just those for shrimp and summer flounder (Federal Register 72:7387–7389, 15 February 2007).

In the southeast demersal longline fishery for sharks, loggerhead bycatch was estimated in the low hundreds from 2003 to 2006 with substantial mortality—from a few dozen to approximately 150 each year [74,75]. An insignificant amount of loggerhead bycatch occurs in the southeast directed driftnet fishery for sharks as well, on the order of a few individuals per year [109,110]. Leatherback bycatch in these southeastern shark fisheries also appears to be low. During observer surveys from 2003 through 2006, an estimated 11–31 leatherbacks died in 2005, but none were captured in the other 3 years [74,75,110].

Finally, loggerhead, Kemp's ridley, and green turtles are also captured in Mid-Atlantic coastal and inshore gillnets ([111]; Federal Register 69:65127–65142, 10 November 2004) and inshore pound nets [112,113]. No bycatch estimates have been published for these fisheries, but various regulatory measures have been taken to reduce sea turtle bycatch in some of them (e.g., North Carolina and Virginia pound net fisheries—Federal Register 67:56931–56934, 6 September 2002; Federal Register 71:36024–36033, 23 June 2006; and mid-Atlantic coastal gillnet fisheries—Federal Register 67:71895–71900, 3 December 2002; Federal Register 71:24776–24797, 26 April 2006).

3.3. Seabirds

In USA Pacific fisheries, studies have focused predominantly on albatross bycatch in Hawaiian pelagic longlines for swordfish and tunas, and in Alaskan groundfish fisheries (excluding the halibut fishery), which consist mostly of demersal longline gear, but also trawl and pot gears. Higher numbers of albatross were caught annually in Hawaiian than in monitored Alaskan fisheries in the 1990s, before regulatory measures to reduce bycatch were established (in 2002 and 1997, respectively). In Hawaii, an average of 874 Laysan albatrosses *Phoebastria immutabilis* were captured or killed each year between 1991 and 2001, while 538 were taken annually between 1993 and 1996 in Alaskan fisheries [114,115] (Fig. 3A). Black-footed albatross *P. nigripes* bycatch in Hawaiian fisheries was estimated to average 1440 annually from 1991 to 2001, compared to an average of 269 from 1993 to 1996 in Alaskan fisheries. A small number of Endangered short-tailed albatrosses (avg. 1 per year) were taken in Alaska during the same time period [115]. Total seabird bycatch in Alaskan groundfish fisheries averaged about 14,000 annually from 1993 to 2004 (Fig. 3B), made up mostly (>8000) of northern fulmars *Fulmaris glacialis*, and occurring mostly (91%) in demersal longline gear. Seabird bycatch in both Hawaiian and Alaskan longline fisheries have decreased dramatically in the past ~5–10 years (Fig. 3A, B) following initial regulatory bycatch reduction measures (Federal Register 62:23176–23184, April 29, 1997; Federal Register 67:34408–34413, May 14, 2002), which today include use of streamer lines, weighted line, thawed and dyed bait, side-setting, line shooters, and offal discharging on the opposite side of line-setting ([116]; Alaska, 50 CFR 679.24; Hawaii, 50 CFR 665.35; California, 50 CFR 660.712).

An estimated 8.4% of the bycatch in Alaskan groundfish fisheries from 1993 to 2004 occurred in trawl gear [115]. Seabird mortality in trawl gear is a previously overlooked but emerging issue of concern around the world, and current observer program protocols may greatly underestimate seabird bycatch in trawl gear because many birds killed by warp and third wire cables do not make it into the codend of the trawl net and are thus not observed [117–120]. Thus seabird bycatch estimates in Alaskan trawl gear are likely lower than reality [121].

Alaskan longline fisheries for halibut represent an important seabird bycatch knowledge gap [122–124]. This fishery has a comparable number of vessels to the number of demersal longline vessels for other groundfishes [29], and although mitigation measures are required to reduce seabird bycatch on halibut-fishing vessels (Federal Register 63:11161–11167, 6 March 1998), the fishery as a whole is generally not observed so bycatch estimates and compliance with mitigation regulations are unknown. McElderry et al. [125] and Ames et al. [123] conducted feasibility studies that found video monitoring to provide an accurate and cost-effective way of observing bycatch in Alaskan longline and trawl vessels fishing for halibut and other groundfishes.

Bycatch of diving seabirds in Pacific coastal gillnet fisheries (mostly in State waters) is also an issue of serious concern [30] and a major knowledge gap. Alaska salmon drift nets also are poorly observed but also appear to kill thousands of seabirds annually [56–59] perhaps contributing to population declines of marbled murrelets *Brachyramphus marmoratus* [126,127] and Kittlitz's murrelets *B. brevirostris*, the latter of which became a candidate for listing under the ESA in 2004. In Puget Sound (Washington) net fisheries for salmon, possibly thousands of birds are killed annually, mostly murres and auklets, but bycatch in these fisheries has not been adequately quantified or addressed [128,129]. Bycatch of loons, grebes, cormorants, and various alcids (predominantly common murres *Uria aalge*) occurs in the set net

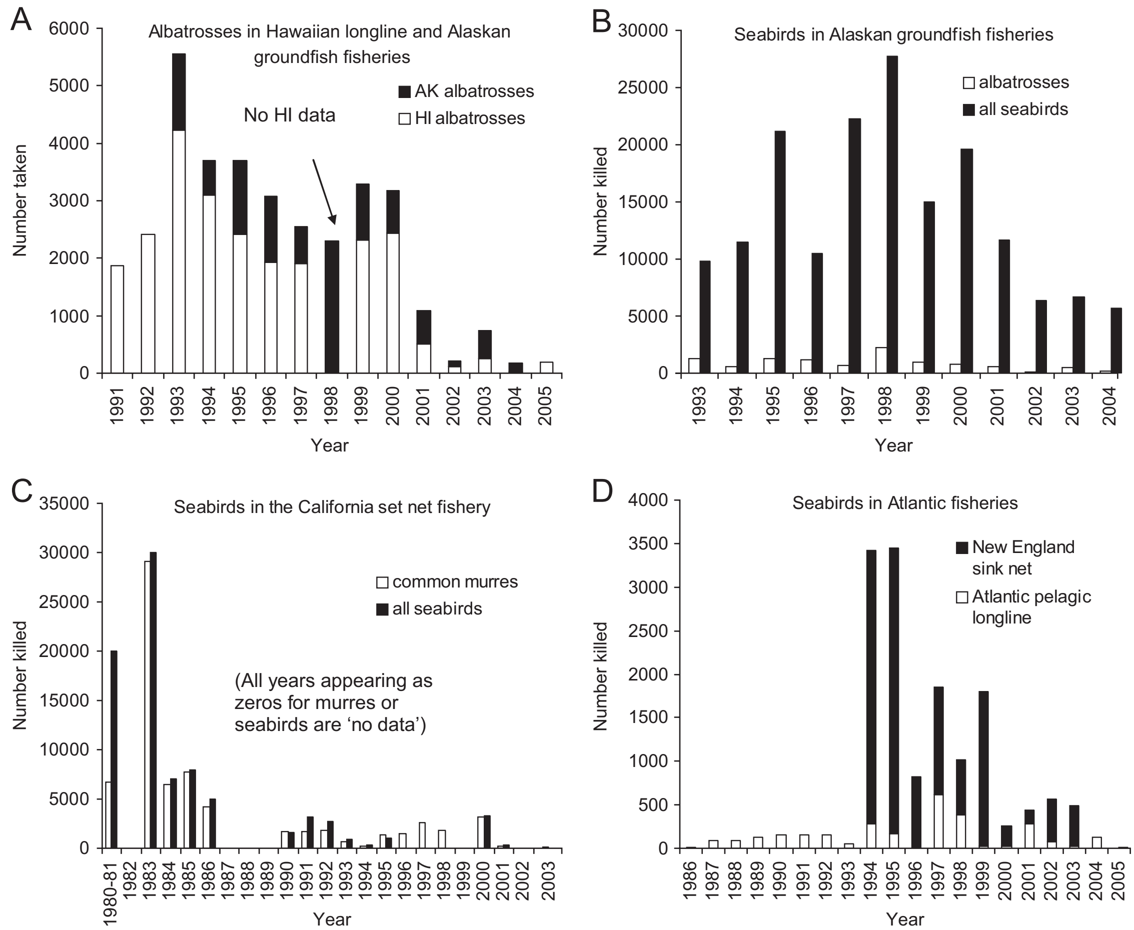

Fig. 3. Available estimates of seabird bycatch in commercial USA fisheries. (A) Albatross bycatch (total takes) in Hawaiian pelagic longlines, 1991–2005, and Alaskan groundfish fisheries (including longline, trawl, and pot, but excluding longline fishing for halibut), 1993–2004 [114,115,166]. (B) Mortality of all seabirds in Alaskan groundfish fisheries, including longline, trawl, and pot, but excluding longline for halibut, 1993–2004 [115]. (C) Mortality of common murres and of all seabirds combined in the set net fishery for California halibut, from 1980 to 2003 [49–51,53,80,130]. Only a pooled 2-yr estimate was available for 1980–1981. (D) Mortality of all seabirds in New England sink gillnet fisheries, 1994–2003, and the Atlantic/Gulf of Mexico/Caribbean pelagic longline fishery, 1986–2005 [131,132].

fishery for California halibut [51]. An estimated 70–75 thousand murres were killed in this fishery between 1979 and 1987 [50]. Annual seabird mortality from 1983 through 1986 ranged from 5000 to 30,000, 85% to 97% of which consisted of murres (Fig. 3C). A series of regulatory changes to the fishery by the CDFG, beginning in the early 1980s and continuing through 2002 [31,49,52,54], helped reduce seabird mortality tremendously. Annual murre bycatch from 1990 through 2001 varied from an estimated 251–3143 individuals [53,80] (Fig. 3C). Total annual seabird bycatch during the same period (no data from 1996 to 1999) varied from 308 to 3259 [51,80]. Following permanent closure in 2002 of the central California component of the fishery in depths <60 fathoms, only 1 common murre and 60 other seabirds were estimated to be killed in the fishery in 2003 [81]. Seabirds are caught in very small numbers in the CA/OR driftnet fishery, i.e., 0–23 per year from 1990 to 1995 [51,130].

Seabird bycatch in Atlantic USA fisheries occurs mostly in gillnet fisheries but is generally thought to have little impact on seabird populations [131,132], and no seabird bycatch mitigation measures are required in Atlantic fisheries. However, we lack cumulative bycatch estimates throughout the range of affected species—some of which may overlap with many international fisheries (e.g., Greater shearwater *Puffinus gravis* [133]; Cory's shearwaters *Calonectris diomedia* [134])—so potential impacts are unknown. Hata [132] estimated an average of 143 birds (mostly gulls and shearwaters) killed each year in the Atlantic pelagic longline fishery (Fig. 3D). Based on Northeast Fisheries Observer Program (NEFOP) data, Soczek [131] estimated an annual average of 1224 seabirds captured (mortality >99%) in New England sink nets between 1994 and 2003 (Fig. 3D). Eighty-nine percent of the birds caught in sink nets were shearwaters, with other species groups including gulls, loons, northern gannets *Morus basannus*, fulmars, and alcids. Soczek [131] also found very low levels (no quantitative estimate) of bird bycatch in New England bottom trawls, mid-water trawls and scallop dredges. Lanza and Griffin [135] observed similar patterns based on NEFOP data from 1989 to 1993: throughout the fisheries observed, 77% of observed bycatch was made up of shearwaters and 99% came from sink net fisheries. Forsell [136] estimated 2387 seabirds were killed in Mid-Atlantic sink net fisheries in 1998; most of these were common *Gavia immer* and red-throated loons *G. stellata*.

3.4. Summary

Although there are differences across taxa, the tally of existing bycatch estimates yields two clear patterns; (a) truly cumulative bycatch estimates are lacking for all taxa, but particularly for sea turtles and seabirds and (b) in most places where it occurs, observer coverage levels are insufficient to accurately characterize these rare bycatch events across fleets. Given the enormous gap

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between recommended and available observer coverage in many fisheries, it is clear that creative approaches will be required to effectively manage fisheries to reduce bycatch. On-board observer programs will benefit from additional funding but also will need to be augmented by a combination of lower-cost data collection techniques (e.g., video monitoring) and indirect assessment approaches, some examples of which are cited in the next section. Numerous bycatch knowledge gaps have been listed in this section, but based on the above summary, the following few fisheries may be particularly noteworthy in having little or no observer coverage and potentially having significant consequences for wildlife populations. Salmon gillnet fisheries of the Pacific Northwest (Washington and Alaska) may kill large numbers of marine mammals and seabirds; halibut longline operations in Alaska may affect seabird populations; and shrimp trawls along the southeast Atlantic coast and in the Gulf of Mexico kill large numbers of sea turtles with unmeasured population consequences.

4. Placing bycatch in a population context: science, policy, and incidental take limits

Having estimated incidental mortality for a particular species in a fishery, the next question for managers to ask is whether this mortality estimate is something to be concerned about from a population perspective. However, taxon-specific policy frameworks have not only resulted in unequal quantification of bycatch for different species groups in different fisheries; they also have led to unequal success at assessing the population-level consequences of bycatch for these different taxa. The ramifications of these inequalities for setting sensible incidental take thresholds in various fisheries are discussed here.

There are two important obstacles to answering whether bycatch is having a population-level effect—one is scientific, the other is political. Regarding the scientific obstacle, perpetual challenges of studying long-lived wide-ranging marine animals make the determination of how much incidental mortality is sustainable for a population difficult. For most species considered in this review, there are no good estimates (or any estimates) of population size, which precludes direct estimation of the proportion of a population that is removed annually by bycatch. Since estimates of demographic vital rates are also missing for most air-breathing marine vertebrate populations, it would be difficult to evaluate the biological significance of a certain added mortality rate even if such a value were known.

In spite of these scientific challenges, successfully managing fisheries to minimize bycatch and meet target-species yield goals demands that population impacts of bycatch be assessed. National policy frameworks can help this pursuit or can act as the political obstacle to population-relevant bycatch reduction efforts. For marine mammals in the USA, policy has provided important guidance. Population impacts of bycatch are assessed using a framework based on PBR that is explicitly outlined under the MMPA. While obtaining valid estimates of PBR and marine mammal bycatch remains challenging, the process is clear: estimate population stock size, determine cumulative bycatch across all fisheries, assess whether bycatch exceeds a certain population-viability threshold, account for uncertainty in estimates using a precautionary principle, and develop and implement a plan to reduce bycatch in the highest-impact fisheries [8,27,28].

No congruent roadmap exists to address sea turtle or seabird bycatch. Bycatch for these taxa is addressed largely on a fishery by fishery basis, or in some cases is not addressed at all. Unlike the MMPA, the ESA does not specify an explicit process for *how to determine* what incidental take levels (ITLs) are acceptable. Cumulative bycatch estimates for a population across fisheries are seldom undertaken, and the setting of ITLs may not be adequately informed by demographic principles. Consequently, ITLs for sea turtles and seabirds (i.e., short-tailed albatross) in many fisheries could be interpreted as arbitrarily defined, grounded only weakly in population demography or by any other specific mandated process. While the ESA specifies that ITLs must not jeopardize species recovery, scientific information is simply not available to objectively determine what take levels will jeopardize populations, so established ITLs are likely not defensible in many cases.

In an example regarding sea turtles, NOAA Fisheries has set annual ITLs in ~25 different fisheries (see Ref. [137]). In contrast with the PBR scheme for marine mammals: (1) these ITLs are for individual fisheries, not for cumulative take across all fisheries; thus some fisheries have an allowable lethal take as low as 1, while the SE/GOM shrimp trawl fleet has an allowable lethal sea turtle take of 9390 [138], and many fisheries have not had ITLs set at all; (2) these ITLs (individually or taken together in sum) represent an unestimated proportion of sea turtle population sizes and have unknown potential demographic impact (rather, ITLs for individual fisheries have historically been set simply according to anticipated take values); and (3) there is no federally coordinated guiding framework for prioritizing regulatory action in the fisheries with the highest proportion of sea turtle bycatch. For example, in November 2007 the North Carolina Division of Marine Fisheries forced an early closure of the Pamlico Sound large-mesh ($\geqslant$5 in) gillnet fishery (Proclamation M-19-2007, 13 November 2007) because it exceeded the ITL for green turtles (46 lethal takes or 168 total takes [137]). But there is virtually no knowledge of whether this take is demographically important, and the SE/GOM shrimp trawl fishery was authorized to take 18,757 (514 lethally) green turtles [138]. Other time-area fishery closures, such as those of the shallow-set Hawaiian longline fleet and the CA/OR driftnet fishery—to protect Pacific leatherbacks and loggerheads—have similarly been implemented without understanding the full demographic impacts of measured takes. Meanwhile, many fisheries have exceeded much higher ITLs with no resulting management action [137].

In the case of short-tailed albatross, ITLs have been set through Section 7 Biological Opinions in four different fisheries—three in Alaska and one in Hawaii (K. Dietrich, pers. comm.) Zador et al. [139] constructed an empirically based population model to evaluate incidental mortality levels that might affect recovery of this endangered species. They found that ITLs for short-tailed albatross in Alaskan trawl fisheries could be exceeded by a factor of 10 with little impact on USFWS recovery goals for this species. This example and those for sea turtles above reflect the discord between current ITLs for many fisheries and the demographic information that should underpin those limits. They also highlight the lack of inter-jurisdictional cooperation that may exist for managing protected species that overlap management zones, in absence of a statutory mandate to cooperate on shared management concerns.

Under the ESA, NOAA Fisheries and USFWS have broad regulatory authority to recover ESA-listed populations. Developing a regulatory framework under the ESA that is analogous to that used under the MMPA would greatly improve management to reduce bycatch of threatened and endangered marine taxa, namely sea turtles and seabirds. Certainly, obstacles to studying long-lived wide-ranging marine species would make implementation of such a scheme difficult. Marine mammal stock assessments are challenged by difficulties in estimating bycatch mortality, population size and potential population growth [28]. These issues may be even more difficult when studying sea turtles, which have more complex life histories and wider geographic ranges than most marine mammals, and whose populations typically sustain bycatch mortality from fisheries of multiple countries with unequal consequences [140,141]. Evaluating effects of different international fisheries is a major challenge for wide-ranging seabird populations as well [116,142]. Given that many marine wildlife populations are taken as bycatch in many countries' fleets, efforts to conduct transboundary research, management, and policy-making should be strongly promoted. Examples of such efforts include the Agreement on the International Dolphin Conservation Program (for dolphins caught in purse seine nets by international fleets in the Eastern Tropical Pacific) and the Marine Turtle Research Program that focuses on conservation of Pacific leatherbacks and green turtles in partnership with other Pacific nations. Nevertheless, even a cumulative bycatch assessment for sea turtles and seabirds across USA fisheries would help prioritize research and management action within the USA. In this regard, NOAA Fisheries has taken a step in the right direction with its recent regulatory decision to conduct an annual review of sea turtle bycatch across fisheries for purposes of prioritizing monitoring needs (Federal Register 72:43176–43186, 3 August 2007).

Sea turtle nesting beaches and seabird breeding colonies facilitate collection of life history data, and given a mandate to direct bycatch research toward estimating population sizes and key demographic rate parameters, creative solutions for assessing population-level effects of bycatch would likely arise. The PBR management model for marine mammals is itself an example of this [26–28], as are numerous PBR-like and quasi-population viability approaches that have been developed to understand human impacts on demography of sea turtles and seabirds [139,143–146]. In a couple of recent cases, such efforts have been used by NOAA Fisheries to evaluate incidental take limits of sea turtles in individual fisheries [147,148], but these efforts did not consider cumulative impacts on populations from multiple fisheries. A better understanding of demographic impacts of cumulative bycatch mortality would greatly improve the efficiency of management responses to bycatch problems for threatened marine species, while reducing the chance of making decisions that could unintentionally threaten fishermen's livelihoods.

5. Conclusions

The USA has clearly made important progress toward reducing bycatch of marine mammals, sea turtles, and seabirds in its commercial fisheries, but that progress and efficacy has been limited in part by policy-related factors, namely the focus on taxon-specific policies and the lack of consistent mandate across taxa for taking a cumulative bycatch perspective.

Taxon-specific bycatch policy in the USA has resulted in inefficiencies bycatch reduction action. In spite of the fact that many bycatch issues overlap spatially, taxon-specific legislation in the USA has generally led to bycatch being addressed at the federal level for one taxonomic group in one fishery at a time, resulting in more expensive and potentially less effective management than if overlapping problems were addressed together. Albatross and sea turtle bycatch within the same longline fisheries in Hawaii have separate research and management histories, as do sea turtles and marine mammals in CA/OR drift net fisheries, and mammals and turtles in Atlantic trawl, gillnet, and pelagic longline fisheries.

Given resource constraints, it makes sense to seek added value for every management effort and to prioritize efforts that have the greatest overall benefit when evaluated in a multi-gear multi-species context. In a positive example at the state-management level, restrictions by the CDFG on fishing depth in the shallow set net fishery in California to benefit seabirds and southern sea otters also benefited other marine mammals (most notably harbor porpoises). Coordinated pressure from environmental action groups and the public on behalf of seabirds and sea otters were instrumental in bringing about a multi-taxa perspective to this management problem in the 1980s and 1990s [31,52]. In a unique example of multi-taxa bycatch management at the federal level (with respect to taxa discussed in this paper), NOAA Fisheries established a single set of regulations for Mid-Atlantic gillnet fisheries in 2006 to jointly address bycatch of bottlenose dolphins under the MMPA and to modify measures previously established under the ESA to reduce sea turtle bycatch (Federal Register 71:24776–24797, 26 April 2006). In doing so, NOAA Fisheries improved consistency among multiple state and federal regulations (which may help reduce confusion and increase compliance) and set a precedent for taking a multi-taxa approach to the rule-setting process.

For non-mammalian taxa, there has been a failure to assess cumulative bycatch mortality relative to population sizes across multiple fisheries, to assess the sustainability of this mortality based on population demography, and to prioritize management of fisheries that do the most harm to one or more populations. The PBR-based framework for evaluating mammal bycatch has proven to be a useful model for addressing these issues [28] and could be adopted for other protected taxa. Such an approach applied to Threatened and Endangered sea turtles and seabird species (under authority of the ESA) would help in setting demographically justified ITLs for these taxa and in focusing limited resources to address the biggest problems. Given limited resources to conduct bycatch management, this would help optimize effort to achieve species recovery while also relieving management pressure from fisheries that have relatively little impact on protected populations. Applying consistent criteria across taxa (e.g., implementing a PBR approach for sea turtles and seabirds) would be the first step in a multi-species approach to bycatch reduction.

While there appears to be significant room for improvement of bycatch reduction in USA fisheries, there will remain institutional and budgetary constraints to optimizing bycatch management. As one legal example, NOAA Fisheries does not currently have statutory authority to place observers on vessels for the express purpose of monitoring seabird species that are not listed under the ESA. However, NOAA Fisheries and the USFWS do have various authorities under the MBTA, ESA, MSA, and MMPA that would enable them to develop comprehensive strategies to restrict or limit any fishing practices that cause excessive take of seabirds, sea turtles, or marine mammals within a particular fishery. Meanwhile, information on all taxa such as non-threatened seabirds could be collected opportunistically during monitoring efforts initiated on behalf of other populations, although this would require appropriate resources invested in training observers to record and identify species from multiple taxonomic groups.

Regarding budgetary obstacles, sufficient funding to provide recommended observer coverage in all priority fisheries is unlikely to become available. The use of technology to cost-effectively increase observer coverage (e.g., [123,125]) and placing greater responsibility on industry to pay for observer costs may help (e.g., [92,149]), but the problem of limited management resources also requires that use of those resources be optimized. Regulatory authorities should work to implement multi-species and multi-gear strategies, given constraints in terms of coordinating efforts across taxa and fisheries. This will require cooperation between management jurisdictions, which in some cases must occur between agencies (e.g., state and federal, USFWS and NOAA Fisheries). Additional international cooperation also will be required to comprehensively address bycatch of species taken in multiple international fleets. Holistic evaluation of the bycatch problem within a population context will help identify priority areas where resources are needed most and can be used most effectively.

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