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Wasted fishery resources: discarded by-catch in the USA

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Abstract

Fishery by-catch, especially discarded by-catch, is a serious problem in the world's oceans. Not only are the stocks of discarded species affected, but entire trophic webs and habitats may be disrupted at the ecosystem level. This paper reviews discarding in the marine fisheries of the USA; however, the type, diversity and regulatory mechanisms of the fisheries are similar to developed fisheries and management programmes throughout the world. We have compiled current estimates of discarded by-catch for each major marine fishery in the USA using estimates from existing literature, both published and unpublished. We did not re-estimate discards or discard rates from raw data, nor did we include data on protected species (turtles, mammals and birds) and so this study covers discarded by-catch of finfish and fishable invertebrates. For some fisheries, additional calculations were required to transform number data into weight data, and typically length and weight composition data were used. Specific data for each fishery are referenced in Harrington *et al.* (*Wasted Resources: Bycatch and discards in US Fisheries*, Oceana, Washington, DC, 2005). Overall, our compiled estimates are that 1.06 million tonnes of fish were discarded and 3.7 million tonnes of fish were landed in USA marine fisheries in 2002. This amounts to a nationwide discard to landings ratio of 0.28, amongst the highest in the world. Regionally, the southeast had the largest discard to landings ratio (0.59), followed closely by the highly migratory species fisheries (0.52) and the northeast fisheries (0.49). The Alaskan and west coast fisheries had the lowest ratios (0.12 and 0.15 respectively). Shrimp fisheries in the southeast were the major contributors to the high discard rate in that region, with discard ratios of 4.56 (Gulf of Mexico) and 2.95 (South Atlantic). By-catch and discarding is a major component of the impact of fisheries on marine ecosystems. There have been substantial efforts to reduce by-catch in some fisheries, but broadly based programmes covering all fisheries are needed within the USA and around the world. In response to international agreements to improve fishery management, by-catch and discard reduction must become a regular part of fishery management planning.

Keywords by-catch, discard, overfishing, USA fisheries, waste

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Introduction

The unintentional capture of non-target species of fish, mammals, turtles, birds and invertebrates is a well-recognized feature of fisheries around the world. Usually termed by-catch, some of the captured organisms may be retained for sale or use, while others are discarded back into the sea because of either low value or regulatory requirements. Survival rates for discarded by-catch are highly variable (Chopin and Arimoto 1995; reviewed in Alverson *et al.* 1994; Davis 2002), as are the impacts of by-catch on marine ecosystems (Hall *et al.* 2000), but it is widely accepted that the ecological impacts of by-catch are substantial (Kelleher 2005).

By-catch, particularly discarded by-catch, is a serious conservation problem because valuable living resources are wasted, populations of endangered and rare species are threatened, stocks that are already heavily exploited are further impacted and ecosystem changes in the overall structure of trophic webs and habitats may result (Alverson and Hughes 1996; Crowder and Murawski 1998; Morgan and Chuenpagdee 2003).

Discarding also results in substantial waste of potential food resources. As global marine fisheries catches have begun to decline (Watson and Pauly 2001) and competition for increasingly depleted stocks has intensified, the ecological, social and economic arguments to decrease by-catch have received greater attention from policy makers, industry and the general public (Pitcher and Chuenpagdee 1994; Alverson and Hughes 1996; FAO 2005; UN 2005).

The conservation problems associated with by-catch have been well recognized by the scientific community (Alverson *et al.* 1994; Alverson and Hughes 1996; Hall 1996; Crowder and Murawski 1998; Kaiser and de Groot 2000; ICES 2004; Kelleher 2005) and are reflected in policy instruments (UN 1995; NOAA Fisheries 1996; NMFS 2004b,c). The UN Food and Agriculture Organization Code of Conduct for Responsible Fisheries (FAO 1995) states that, as a general principle, '[s]tates and users of aquatic ecosystems should minimize waste, catch of non-target species, both fish and non-fish species, and impacts on associated or dependent species' (FAO 1995). While the Code of Conduct is voluntary, this same principle is carried forward in international treaties such as the UN Treaty on Straddling Fish Stocks and Highly Migratory Fish Stocks (UN 1995).

In the USA, the Magnuson–Stevens Fisheries Conservation and Management Act of 1996 has, as one of the national standards for management of marine fisheries, required that, '[c]onservation and management measures shall, to the extent practicable, (A) minimize bycatch and (B) to the extent bycatch cannot be avoided, minimize the mortality of such bycatch' (NOAA Fisheries 1996).

In response to these requirements, there has been a substantial effort to reduce by-catch internationally and in the USA (NMFS 2004b). In general, there are three possible means of by-catch reduction: modifying fishing methods including gear, timing or location of fishing or other aspects of the methodology, such as the introduction of by-catch reduction devices in shrimp fisheries in New England, the South Atlantic Bight and the Gulf of Mexico (Nance *et al.* 1997; NMFS 1998; Epperly *et al.* 2002; Morgan and Chuenpagdee 2003); changing fishing gear or fishing methods entirely, such as the change from drift gill net fishing to trolling for tunas or from trawls to traps for groundfish such as lingcod (scientific names for all species mentioned in this study given in Table 1) (Morgan and Chuenpagdee 2003); and reducing fishing effort and therefore the amount of fishing gear in use overall, as has occurred in the New England and Alaska groundfish fisheries.

Any one of these methods alone does not necessarily guarantee the reduction of by-catch, but one or more must be a component of any conservation programme to reduce the loss of resources due to by-catch. In addition, there are other means of converting discarded by-catch to landed catch, such as development of new markets and processing techniques and changing regulatory limits and requirements to land all catch.

In this study, we focused on the discarded portion of the by-catch from most USA fisheries. Although

Table 1 Common and scientific names of species referred to in the text and Table 2.

Common name	Scientific name
American lobster	*Homarus americanus*
Atlantic cod	*Gadus morhua*
Atlantic croaker	*Micropogonias undulatus*
Atlantic herring	*Clupea harengus*
Atlantic mackerel	*Scomber scombrus*
Atlantic menhaden	*Brevoortia tyrannus*
Atlantic scallop	*Placopecten magellanicus*
Black sea bass	*Centropristis striata*
Blue crab	*Callinectes sapidus*
Bluefish	*Pomatomus saltatrix*
Butterfish	*Peprilus triacanthus*
Dungeness crab	*Cancer magister*
Great barracuda	*Sphyraena barracuda*
Gulf of Mexico menhaden	*Brevoortia patronus*
Jonah crab	*Cancer borealis*
Lingcod	*Ophiodon elongatus*
Monkfish	*Lophius americanus*
Northern anchovy	*Engraulis mordax*
Ocean quahog	*Artica islandica*
Pacific halibut	*Hippoglossus stenolepis*
Pacific sardine	*Sardinops sagax*
Pacific whiting	*Merluccius productus*
Red crab	*Chaceon quinquedens*
Red drum	*Sciaenops ocellatus*
Sablefish	*Anaplopoma fimbria*
Scup	*Stenotomus chrysops*
Spanish mackerel	*Scomberomorus maculatus*
Spiny dogfish	*Squalus acanthius*
Striped bass	*Morone saxatilis*
Summer flounder	*Paralichthys dentatus*
Surf clam	*Spisula solidissima*
Swordfish	*Xiphias gladius*
Tanner crab	*Chionoecetes bairdi*
Tilefish	*Lopholatilus chamaeleonticeps*
Walleye (Alaskan) Pollock	*Theragra chalcogramma*
Weathervane scallop	*Placopecten magellanicus*
Winter skate	*Raja ocellata*

the USA has made extensive efforts to monitor and, in some cases, minimize by-catch in domestic and international fisheries, much of the information on by-catch is unpublished or unavailable in the primary scientific literature. Because of this and the lack of a regularized reporting mechanism, an overview of the level of discarding in USA fisheries has not been available until now. For this paper, we reviewed all the federally managed marine fisheries in the USA and compiled the available information on discards for each fishery to provide a comprehensive picture of discarded by-catch in federally managed commercial fisheries.

In general, we have not included the near shore or the Caribbean regions (NMFS 1999) in the study. Fisheries in these regions may have significant discarding issues including many state-managed fisheries for species such as American lobster, blue crab, Dungeness crab, inshore herring fisheries, bait shrimp fisheries and many others. As there are extremely limited data publicly available about these fisheries, we were unable to include them in the study. We included some discard estimates for recreational fisheries, but data on recreational fisheries are also very limited. In most cases, we only included information on commercially targeted species discards. In some cases, we have only been able to include information on by-catch, as the proportion of that by-catch that was discarded is not estimable using the available data.

Our intention is to provide a reference point for management and monitoring of by-catch as well as the basis for a regularized reporting system for by-catch and discards to accompany annual reports on landings and status of fisheries. By-catch is clearly an important component of fisheries' impacts on marine ecosystems and should be closely monitored and carefully managed.

Methodology

Our goal was to produce estimates of discarded by-catch for each species in each fishery in the USA. We defined fisheries by region and target species using similar designations as those given in the NOAA Fisheries report, 'Our Living Oceans, 1999'. We used estimates of discarded biomass or ratio of discards to landings for each USA fishery available in published and unpublished literature along with landing data to arrive at estimates of by-catch. We did not re-estimate discard rates or levels from raw data and, therefore, could not estimate uncertainty in each estimate. Clarifications and additional insights were provided by many scientists directly involved in by-catch monitoring and fishery stock-assessment programmes. We then extrapolated the total amount of discarded fish for each gear type or area of each fishery using the ratio of discards to landings and the reported level of landings, and summed the gear type and area estimates to calculate the level of discarded by-catch for each fishery as a whole.

In some cases, we only had estimates reported in terms of numbers of fish caught and discarded, and we inferred weights to produce comparable analyses

among fisheries. In these cases, we used length and weight composition data for each species to convert data on the number of fish discarded to weight of discards. In the few cases where length and weight composition data were not available, we used length and weight composition data from similar species in the same fishery. Length frequency and weight data were obtained from stock-assessment documents, regional research data or the United States National Marine Fisheries Service's (NMFS) commercial and recreational fisheries online databases (NMFS 2004a,c). As a last resort, in a few cases we used generic summaries such as those found in FishBase (2004) to obtain species' growth parameters for the calculation of length at age and/or length–weight relationships for the conversion of numbers of fish discarded to the weight of fish discarded. In each case where we had by-catch estimates in numbers instead of weight, we were able to obtain some independent data on the length or weight of the animals discarded to check if our estimates of the discard ratios were reasonable and appropriate. All data used for this compilation are publicly available (detailed sources are provided in Harrington *et al.* 2005).

We could not quantify uncertainty in the total discard estimates or the ratios of discarded by-catch to fish landings estimates because we did not have access to raw data and uncertainty was rarely quantified in the source documents we used. However, where possible, we indicate cases where we clearly identified factors that were likely to result in overly conservative (low) or extreme (high) discard estimates. Kelleher (2005) reported the standard deviation among fisheries in various parts of the world. However, this does not provide any information concerning the uncertainty of the estimate for a given fishery so we do not include such calculations here.

Major sources of uncertainty included sampling issues such as small sample size, biased samples from logbook or observer programmes, heterogeneity in space and time or within a gear type or fishery, lack of length–weight relationships (needed to convert numbers of animals to weight), occasional lack of species-specific discard information, non-reporting of certain species (especially invertebrates) and the use of ratio estimators for most by-catch estimates. Furthermore, in some cases, the discard to landings ratio from the previous year (2000, for example) was multiplied by the landings for the recent year (2002 or 2003) to obtain a more recent estimate of discards. This further complicates the picture of uncertainty in the estimates.

In addition, the uncertainty related to the behaviour of fishers when observers are not present and to the inability to estimate changes in uncertainty when the behaviour of fishers is rapidly changing is considerable. The problem is probably most acute in the shrimp fisheries. There the use of turtle excludes devices (TED)s and bycatch reduction devices (BRD)s is undergoing rapid change; there are overlapping jurisdictions with many different sized boats and uncertainty about how many boats are using TEDs and BEDs effectively. In this case, it is very difficult to estimate the uncertainty, because not only of sample size, but also the difficulty of obtaining reliable estimates of by-catch rates.

The discard data presented in this study have been extrapolated from the most recent data publicly available for each fishery from around the country, and combined into one estimated biomass of dead discards for each fishery. The discard estimates include data from almost all sectors of the commercial fishery, and some data from the recreational, tribal, and subsistence fisheries. We have compiled the most recent data for all major gear types. Generally, our estimates are for 2002, the year for which the most recent landings and effort data were available in the NMFS online database during the course of this study. However, for 8 fisheries (Atlantic sea herring, surf clam and ocean quahog, Atlantic and Gulf menhaden, Pacific coastal pelagics, Pacific whiting, Atlantic highly migratory species gillnet and bottom longline fishery, Western Pacific bottomfish and seamount groundfish and the Western Pacific pelagics), data from 2003 were available. Data for the Atlantic highly migratory species pelagic longline fishery are only current until 2001. Details of the data sources for each fishery are referenced in Harrington *et al.* (2005). In many cases, estimates presented here are clearly underestimates of the actual level of discarding because substantial portions of a given fishery are unobserved or reporting is minimal. In addition, many discarded species which are not commercially valuable are not recorded at all. In a few cases, discarding may be over-estimated due to poor data quality.

For almost all the fisheries we considered, the majority of by-catch was apparently discarded. Thus, our focus was on discarded by-catch, and we noted exceptions as appropriate. Also, while by-catch of protected species such as mammals,

turtles and birds is a major conservation issue, our focus was on by-catch of fish and fishable invertebrates. The west coast salmon, Alaskan salmon, bluefish, tilefish, red crab and red drum fisheries were not included in this study, as the discard data were minimal for these fisheries.

Discarded by-catch estimates for the 27 major fisheries in the USA

Overall, we estimated that 1.06 million tonnes of fish are discarded for 3.7 million tonnes of targeted landings annually (Table 2). This amounted to discards equalling 28% of the target landings or 22% of the total nominal catch.

In addition, we separated total discards by gear type and target species type (Figs 1 and 2). The shrimp trawl and bottom trawl fisheries are responsible for 72% of the total discards by gear type (Fig. 1), and the crustacean and demersal fisheries are responsible for 86.3% of the discards by target species type (Fig. 2).

Regional differences in discard rates are important because of the regional nature of fisheries management in the USA. Fig. 3 gives the ratio of discards to landings by region. In terms of the ratio of discards to landings, the southeast highly migratory species, and northeast fisheries discard more than other regions by nearly a factor of two.

We then examined those fisheries with the highest estimates of discard to landings ratios, mainly trawl fisheries (Fig. 1), most of which target bottom-dwelling species (Fig. 2). Clearly, shrimp fisheries still discarded some of the largest quantities of fish, despite great efforts to reduce by-catch through gear modification (NMFS 1998). Note that all these fisheries are under complex regulatory plans and some of this discard was due to management requirements, not just fishing practices.

Discussion

This analysis shows that the estimated discarded tonnage of fish for all federally managed USA fisheries combined was 28% of the landed tonnage or 1.06 million metric tons. This number is higher than FAO's estimate that 8% of the world's landed catch is discarded (Kelleher 2005), but is comparable to the FAO estimate of by-catch for the USA (927 599 tonnes or 21.7% of the total nominal catch).

We cannot make a statistical comparison of our estimates vs. Kelleher's because appropriate estimates of uncertainty are unavailable for either study. However, a comparison can be made between the total discards or discard rates of select group of USA fisheries as reported by Kelleher (2005) and our corresponding estimates. The discard estimates of 480 000 and 70 000 tonnes in the Gulf of Mexico and South Atlantic shrimp fisheries respectively (Kelleher 2005), are comparable to our estimates of 473 000 and 35 000 tonnes of discards in the same fisheries. In addition, in the Gulf of Mexico reef fish fishery, Kelleher reports a discard rate of 44%, very close to our estimated rate of 41%. On the west coast, Kelleher's estimate of 140 000 tonnes of discards in the Bering Sea Aleutian Islands/Gulf of Alaska groundfish fisheries compares to our estimate of 207 000 tonnes of discards for those fisheries combined. Finally, Kelleher estimated that the Alaskan crab pot fishery produces 40 000 tonnes of discard annually, we report just over half of that, 22 000 tonnes. In each case, the numbers we present are based on the most recent data available (2002). The year(s) or data sources for Kelleher's estimates are unclear, so it is impossible to make an exact comparison. Our estimate for each fishery is based on observer data as well as individual scientific studies and logbooks.

Our estimate may be higher than the global fisheries by-catch estimate because in many world fisheries, there is a substantial amount of landed by-catch in addition to discards (Zeller and Pauly 2005). In addition, according to the FAO report on by-catch (Kelleher 2005), small-scale fisheries tend to have lower by-catch rates than industrialized fisheries, particularly trawl fisheries for shrimp and groundfish. As the USA fishery consists of a high number of these higher by-catch fisheries, the USA may have higher discard rates than the rest of the world. According to the FAO, the world's discard rates are decreasing for some fisheries, and we believe this is true in the USA as well.

We compared our results with a recent overview report on by-catch by NMFS (2004b). All the fisheries we considered to have the worst discard ranking by weight had at least moderate, if not high, vulnerability ratings according to NMFS (2004b). However, three fisheries that NMFS considered to have excessive fish by-catch, the South Atlantic and Gulf of Mexico snapper and grouper fisheries and the Atlantic highly migratory species

Table 2 Overall landings and discards in 27 USA fisheries in 2002/2003.

Fishery	Landings (1000 tonnes)	Discards (1000 tonnes)	Discard to landings ratio[a]	Major discarded species groups	Notes and major limitations
Northeast region					
Northeast groundfish[b]	54.5	97.7	1.790	Spiny dogfish, skates, butterfish, monkfish, hake	
Squid, mackerel, butterfish	41.7	51.4	1.230	Spiny dogfish	By-catch disposition is not known for the mackerel fishery
Monkfish	20.6	17.3	0.840	Spiny dogfish, winter skate, Jonah crab	
Summer flounder, scup, black sea bass	18.8	11.4	0.610	Skates, butterfish, groundfish, flatfish	Amount of non-target species discards is not known: major underestimate
Atlantic scallop[b]	211.5	55.6	0.260	Skates, monkfish, flatfish, crabs	Includes 8000 metric tons of landed by-catch
Spiny dogfish	2.2	0.2	0.080	Skates, cod	Does not include longline data; as of 2003, this is no longer a directed fishery
Surf clam, ocean quahog	46.1	3.8	0.080	Skates, monkfish, flatfish, crabs	No non-target species discard data available: major underestimate
Atlantic herring[b]	100.7	3.6	0.040	Spiny dogfish	Includes 1700 metric tons of landed by-catch
Regional total[c]	496.0	241.1	0.490		
Southeast region					
Gulf of Mexico shrimp[b]	103.7	472.6	4.560	Snappers, mackerel, Atlantic croaker, crabs, porgies	By-catch disposition is not known
South Atlantic shrimp[b]	11.9	35.2	2.950	Crabs, Atlantic croaker, menhaden	By-catch disposition is not known
Gulf of Mexico reef fish	17.4	7.2	0.410	Skates, toadfish, barracudas, sharks	Recreational non-target species discards are unknown: minor underestimate
South Atlantic snapper-grouper	5.6	1.3	0.230	Skates, sharks	Minimal observer data, does not include recreational non-target species discards or commercial trap discards: moderate underestimate
Gulf of Mexico coastal migratory pelagics	12.5	1.8	0.150	Swordfish, tunas, sharks	Non-target species discards are unknown in both the commercial and recreational fisheries: major underestimate
South Atlantic dolphinfish-wahoo	5.6	0.2	0.030	Swordfish, tunas, sharks	Recreational discards do not include non-target species: minor underestimate
Atlantic and Gulf of Mexico menhaden[b]	725.5	4.6	0.010	Spanish mackerel, striped bass, rays, bluefish, sharks	By-catch disposition is not known
Regional total	882.1	522.9	0.590		
West Coast region					
West coast groundfish	25.0	23.3	0.880	Flatfish, skates, halibut, whiting, sharks	Recreational discards do not include non-target species: minor underestimate
Pacific halibut[b]	26.1	20.9	0.800	Rockfish, spiny dogfish, skates, sharks, sablefish	

Table 2 *Continued.*

Fishery	Landings (1000 tonnes)	Discards (1000 tonnes)	Discard to landings ratio[a]	Major discarded species groups	Notes and major limitations
Pacific coastal pelagics[b]	123.1	2.6	0.020	Flatfish, skates, halibut, scorpionfish, salmon, sharks	No discard data available for the mackerel, anchovy, or CA sardine fisheries. OR and WA data are incomplete: major underestimate
Pacific whiting[b]	142.0	0.6	0.004	Rockfish, salmon	By-catch disposition is not known
Regional total	316.2	47.4	0.150		
Alaskan region					
BSAI King and Tanner crab	21.6	22.4	1.030	Pacific cod, Pacific halibut, pollock, rockfish, sculpins, skates	
Weathervane scallop	1.8	1.0	0.560	Sea stars, skates, flatfish	
Gulf of Alaska groundfish[b]	142.8	47.3	0.330	Halibut, crabs, salmon	
BSAI groundfish[b]	1793.1	160.1	0.090	Skates, sculpin, halibut, crabs, salmon	
Regional total	1959.3	230.8	0.120		
Western Pacific region					
Western Pacific bottomfish[b]	0.3	0.1	0.220	Squirrelfishes, sharks, rockfish, goatfish	Estimate does not include Guam, American Samoa and the Commonwealth of the Northern Mariana Islands: major underestimate
Western Pacific pelagics	52.6	10.4	0.200	Sharks, marlins, swordfish	Estimates for Guam and the Commonwealth of the Northern Mariana Islands are incomplete: moderate underestimate
Regional total	52.9	10.4	0.200		
Highly migratory species (HMS) fisheries					
Pelagic longline	5.7	3.8	0.670	Sharks, swordfish	
Bottom longline and drift/set gillnets	4.7	1.5	0.330	Sharks	
HMS total	10.4	5.4	0.520		
National total	3717.0	1058.2	0.280		

[a]Discard to landings ratios were calculated using weight data only; where possible, weights were estimated for all discards that were in numbers of animals.
[b]The disposition of a significant portion or all the by-catch in these fisheries is unknown and may be landed, not discarded.
[c]Totals may not be equal to the sum of each fishery in each region due to rounding.

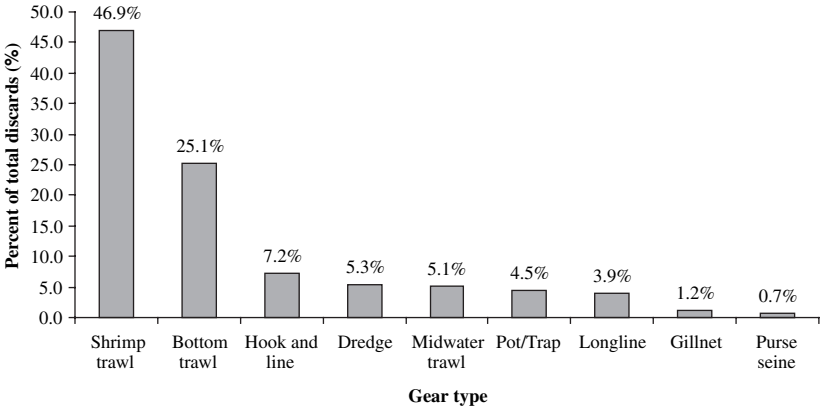

Figure 1 Percent of total USA discards (1.06 million tonnes) by gear type in 2002/2002. Discard estimates from published and unpublished sources were summed by gear type and divided by total discards. Standard errors could not be calculated.

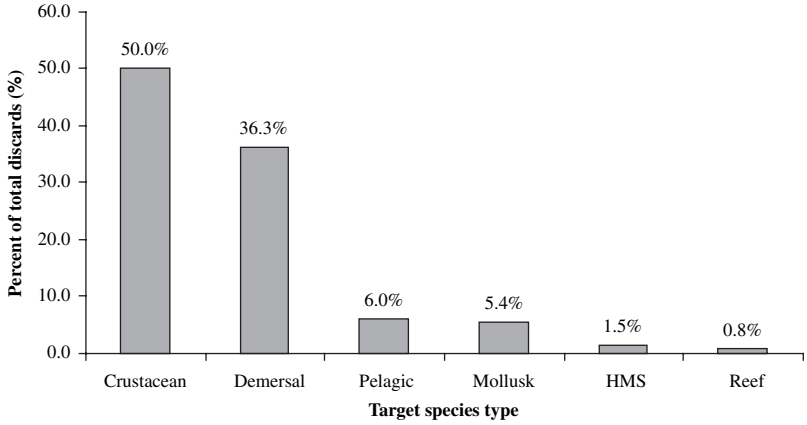

Figure 2 Percent of total USA discards (1.06 million tonnes) by target species type in 2002/2003 (HMS represents highly migratory species). Discard estimates from published and unpublished literature were summed by target species type and divided by total discards. Standard errors could not be calculated.

fisheries, did not rank high on our list. This is because these are relatively low-volume fisheries when considered nationally and are unlikely to have a high weight of discards relative to the total fisheries by-catch. In addition, given the major recreational share of the catch in these fisheries, the ratio of discards to landings is poorly estimated and likely to be an underestimate.

While our data corresponded to NMFS' vulnerability ratings in most situations, there were some fisheries with very limited data for estimating by-catch. The analyses we carried out should be updated on a regular basis to maintain an accurate picture of discards in USA fisheries.

Efforts to implement by-catch reduction strategies for USA fisheries have been substantial and partially successful in many cases (Morgan and Chuenpagdee 2003). However, our analysis shows that discarding and by-catch is still a major problem, likely to have considerable impacts on several marine ecosystems around the country. While by-catch monitoring and reduction programmes have made important advances, these programmes are far from comprehensive across USA fisheries. A nationwide programme sharing expertise and experiences may be a more effective strategy.

In many fisheries, the ratio of discards to landed catch was higher than 28%, with resultant greater waste and ecosystem level impacts (Hall *et al.* 2000; Kaiser and de Groot 2000). Unfortunately, high by-catch rates can be found in fisheries that are currently struggling to rebuild, such as the

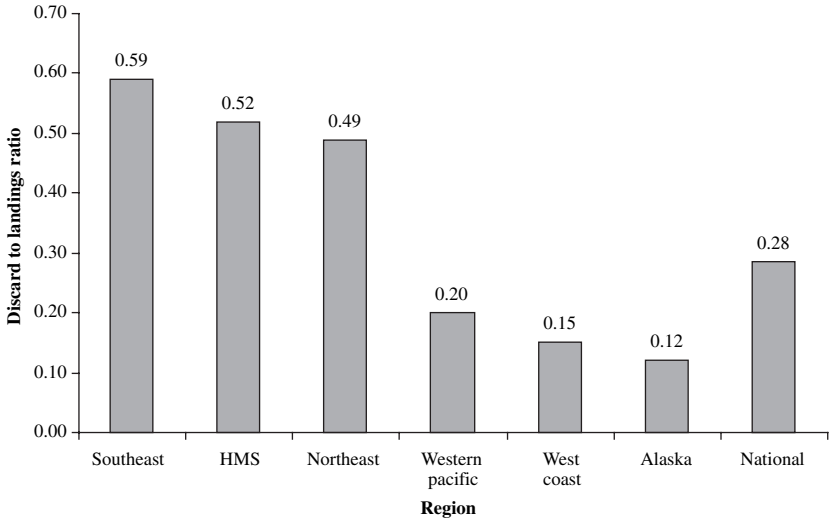

Figure 3 Weighted average regional discard to landings ratios in 2002/2003 (HMS means highly migratory species). The discard to landings ratio for each fishery was weighted by landings and averaged for each region of the USA. Discards, landings and ratio estimates were obtained from published and unpublished sources. Standard errors could not be calculated.

New England groundfish and Pacific coast groundfish fisheries (Murawski *et al.* 1997). By-catch in these fisheries is especially detrimental to stock recovery because juveniles of the target species are often a major component of the discarded by-catch. If juvenile mortality is increased, rebuilding of overfished fisheries will be delayed (Crowder and Murawski 1998; Diamond *et al.* 1999). On the contrary, by-catch of non-commercial species can be problematic because populations can be greatly reduced (Baum *et al.* 2003a,b) with little or no awareness on the part of managers or the public. In addition, destruction of habitat-forming species such as corals and sponges may have significant, long-term ecosystem impacts (NRC 2002). While we were unable to estimate by-catch rates for such species, this should be a component of future monitoring efforts.

The most pressing and effective means of addressing problems of by-catch, as well as overfishing and ecosystem impacts, is eliminating over-capitalization and overfishing (Pauly *et al.* 2002). Of course, in some fisheries the by-catch itself can be a major component of fishing and therefore an important part of the overfishing problem. Reducing fishing effort and the amount of fishing gear in the water can immediately reduce by-catch. Over-capitalization encourages wasteful fishing practices such as a 'race for fish' or the use of regulations specifically designed to reduce vessel efficiency including gear restrictions and trip limits that may encourage by-catch or at least not provide appropriate incentives for by-catch reduction (Crowder and Murawski 1998).

The most successful programmes include clear financial incentives for fishermen to minimize by-catch by reducing costs or increasing value (Branch *et al.* 2005; Gilman *et al.* 2005). Change to more selective fishing gear continues to be an essential element of by-catch reduction programmes. More selective gear can mean higher-value landings for fishermen at potentially lower costs (Clucas and James 1997; Crowder and Murawski 1998). Examples of gear changes that improve catch value and reduce by-catch in certain circumstances are the conversion of trawl fisheries to traps, switching from dragging to groundfish longlining in selected areas (NMFS 2003), the mandated use of larger mesh throughout the net or in panels for release of certain sizes or species (Kelleher 2005) or the use of sorting grates to improve efficiency while reducing by-catch (Alverson 1997).

As demonstrated by Hall and Mainprize (2005), different gear modifications can have strikingly different impacts on catch rates for both by-catch and target species. However, impressive reductions in by-catch (e.g. a reported reduction of 99% of demersal fish by-catch in prawn directed trawls)

brought about by gear modification points to the effectiveness of this method of reducing by-catch. It is important to note that the use of more selective gear cannot be brought about by regulation alone; there must be specific incentives to continually improve the selectivity of the gear and disincentives for unsustainable levels of by-catch. Enforceability of gear requirements is often very difficult, so care must be taken when structuring the regulations to improve compliance.

Positive steps to protect seabirds, turtles and other charismatic animals may not be ensuring that other heavily impacted species are protected. For instance, efforts to reduce catch of seabirds on pelagic longlines (Hall *et al.* 2000) have not also prevented sharks from being caught as by-catch on longlines in the Pacific (Ward and Myers 2005). By-catch reduction devices implemented in the Gulf of Mexico shrimp trawl fishery have also not ameliorated threats to coastal shark and ray species (Shepherd and Myers 2005).

Continuous efforts at improving fishing methodology as well as regulatory controls are needed particularly for fisheries with relatively high by-catch rates. For example, by-catch reduction devices have been implemented in the Gulf and South Atlantic shrimp fisheries, but in spite of these improvements, discards are still high in terms of weight and ratio of discards to landings. Using a different method to calculate by-catch, Alverson *et al.* (1994) estimated that the Gulf of Mexico shrimp trawl fishery had a discard ratio (kg discarded: kg landed) of 10.3 and the South Atlantic shrimp trawl fishery had a discard ratio of 8. Here we estimate that the Gulf of Mexico's ratio has decreased to 4.6 and the South Atlantic's ratio has decreased to 3.0. These are still among the highest discard ratios recorded for all fisheries, but, even accounting for differences in methods of calculating by-catch, it appears that by-catch has been greatly reduced over the last decade. In another example, mesh size has increased in the mid-Atlantic squid fisheries but there is still a substantial by-catch of forage species such as butterfish (NEFSC, 2004). Clearly, management programmes need to be adaptive and make continuous improvements rather than consist of fixed regulations that are not performance based. In addition, when gear modifications are made, efforts must be undertaken to ensure that these methods are, indeed, decreasing by-catch mortality (Crowder and Murawski 1998).

Regulations are needed to provide incentives to reduce by-catch and disincentives to continue fishing practices with high by-catch rates. For example, trip limits are often implemented to slow the harvest and reduce the race for fish. However, trip limits result in by-catch and discarding of catch over the limit or of less valuable species. Alternatively, closed or protected areas can reduce by-catch and improve fishermen's ability to target specific species of fish and reduce other ecosystem level impacts (Murawski *et al.* 2000). The creation of fishing cooperatives operating within clear conservation limits, such as those established in some Alaskan fisheries, can result in major reductions in by-catch (Kelleher 2005). This is because the incentive is to reduce excess capital and fishing effort along with the development of fishing practices for cooperative members that reduce the risks of violating the conservation limits. Individual quota systems can have similar incentive benefits if they are carefully monitored with observer programmes, and checks are in place to ensure there is no unreported discarding and high grading.

New fisheries need to be strictly controlled to ensure that new by-catch problems do not develop. It is much harder to change fishing practices once fisheries become established than to require best practices from the outset of any new venture. In addition, actions should be taken by managers and scientists to improve estimates of by-catch and discards and lessen uncertainty surrounding estimates of by-catch. The expansion of observer programmes to cover more fisheries would be an improvement, especially in the southeastern and western Pacific regions of the USA.

For the recreational component of most fisheries, only target species discard data are available. If the collection of non-target species catch data were made a primary objective, it would strengthen our ability to estimate discards. For many fisheries, the recreational catch is far greater than the commercial catch, and the exclusion of the non-target species discard data associated with these fisheries has a large impact on the overall estimate of discards.

Across all USA fisheries, a large amount of living marine resources are caught and discarded. The overall magnitude of discarding is surprising as are the details for each fishery when considered in context of major domestic policy efforts such as the Sustainable Fisheries Act of 1996 and international efforts such as the FAO Code of Conduct for

Responsible Fisheries, developed to prevent further degradation of marine ecosystems. This study should serve as a basis for improving information on by-catch and discarding, regular reporting of by-catch, focusing efforts on by-catch reduction in those fisheries with the largest problems and encouraging the steps necessary to create national programmes to minimize by-catch in fisheries.

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