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Shifting gears: assessing collateral impacts of fishing methods in US waters

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Problems with fisheries are usually associated with overfishing; in other words, with the deployment of "too many" fishing gears. However, overfishing is not the only problem. Collateral impacts of fishing methods on incidental take (bycatch) and on habitats are also cause for concern. Assessing collateral impacts, through integrating the knowledge of a wide range of fisheries stakeholders, is an important element of ecosystem management, especially when consensual results are obtained. This can be demonstrated using the "damage schedule approach" to elicit judgments from fishers, scientists, and managers on the severity of fishing gear impacts on marine ecosystems. The consistent ranking of fishing gears obtained from various respondents can serve as a basis for formulating fisheries policies that will minimize ecosystem impacts. Such policies include a shift to less damaging gears and establishing closed areas to limit collateral impacts.

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There is strong scientific consensus that overfishing – the deployment of excessive levels of fishing effort – is one of the most pressing problems for fisheries around the world (Pauly *et al*. 2002; Myers and Worm 2003). While attempts to address this problem continue at a single-species level, an ecosystem-based approach to fisheries management is necessary to understand the overall impacts of fishing (Dayton *et al*. 1995; Pitcher and Pauly 1998). In addition to changing the trophic structure of marine ecosystems (eg fishing down food webs, as described by Pauly *et al*. 1998), there is growing evidence that collateral impacts, such as bycatch and habitat damage, have occurred in many fisheries (Watling and Norse 1998; AMCC 2001; POC 2003).

The term "bycatch," as used here, refers to incidental catch of fish, other vertebrates, and invertebrates not targeted by the fishing gear, and subsequently discarded alive, injured, or dead (Figure 1). The term includes "economic bycatch" (species discarded because they are of little or no economic value), "regulatory bycatch" (marketable species discarded because of management regulations, such as size limits, allocations, and seasons) and "collateral mortality" (species killed in encounters with fishing gear, though not necessarily brought on board the vessel). Habitat damage includes damage to living seafloor structures (eg corals, sponges, seagrasses) as well as alterations to the geologic structures (eg boulders, cobbles, gravel, sand, mud) that serve as nursery areas, refuges, and homes for fish and organisms living in, on, or near the seafloor.

A number of measures have been implemented in the US to address the collateral impacts of fishing. For example, a mandatory observer program places government representatives on board fishing vessels to collect data and observe practices in several fisheries, including, among many others, the Alaska cod (*Gadus macrocephalus*) bottom trawl fishery, which has 30% observer coverage (AMCC 2000) and the California swordfish (*Xiphias gladius*) drift net fishery, which has 14% observer coverage (Rasmussen and Holts 2001). In some cases, gears are modified to reduce bycatch, as with the turtle excluder devices (TEDs) inserted into shrimp trawls to reduce catch of turtles, and the streamer lines used on longline boats to reduce catch of seabirds. The banning of bottom trawls throughout the 1.5 million mi^2 of the Western Pacific Fishery Management Council (Anon 2002) and the closing of the groundfish fishery on Georges Bank in New England (Collie *et al*. 1997) have also reduced habitat damage, although this was not explicitly the reason these measures were put in place.

However, much more could be done to systematically and consistently address the collateral impacts of major fishing gears operated in US waters. One novel approach, called the "damage schedule", merges existing information about collateral impacts of ten commercial fishing gears with the pertinent knowledge and judgments of fishers, managers, and scientists to compare levels of impacts

In a nutshell:

- Bycatch and habitat damage are major problems in fisheries
- Scientists' and fishers' knowledge and judgment can be integrated to assess the relative severity of ecological impacts of fishing gears
- Bycatch and habitat damage caused by mobile bottom fishing gears are generally considered more severe than those caused by pelagic gears
- Appropriate policy responses, in the context of ecosystem-based fishery management, include shifting to gears that cause less ecological damage and the establishment of protected areas

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Figure 1. *Bycatch of fish and invertebrates can outweigh target species (in this case, Gulf of California shrimp) by 5, 10, 20, or more times.*

caused by these gears. This study addresses provisions in the US Magnuson-Stevens Fishery Conservation and Management Act, reauthorized and amended in 1996 by the Sustainable Fisheries Act, that specifically call for a reduction in bycatch "to the extent practicable" and to minimize the mortality of bycatch (Section 301). More attention to habitat protection, including designation of essential fish habitat and consideration of actions to conserve such habitat (Section 110) were emphasized in the Sustainable Fisheries Act. These tasks fall under the mandate of the eight regional fishery management councils (FMC), whose main responsibility includes the preparation of fishery management plans that take into consideration social, economic, biological, and environmental factors associated with fisheries. Recent attention has focused on the development of environmental impact reports by the councils to address essential fish habitat considerations and bycatch reduction.

Here, we summarize the regional use of fishing gears and current knowledge about gear-specific bycatch and habitat impacts. We describe the process employed to assess and compare impacts of ten selected fishing gear classes commonly used in the US: dredges, bottom gillnets, midwater gillnets, hook and line, bottom longlines, pelagic longlines, pots and traps, purse seines, bottom trawls, and midwater trawls (Figure 2). We conclude with the severity ranking of these impacts and suggest possible policy responses.

Regional use of fishing gears

Table 1 shows the distribution of landings by different fishing gears for seven of the eight FMC regions in 2001 (no data are available from the Caribbean FMC). Only the top four gears with the highest landings, in metric tons (mt), are presented; the rest are summed as "other gears". The landings vary greatly from region to region, with the highest amount in the North Pacific (Alaska) and the lowest in the Western Pacific (Hawaii and US Pacific territories). Landings from purse seine fisheries are highest in all regions except the North Pacific, Western Pacific, and New England FMC regions.

Roughly 33% of the 286 000 mt of total landings in the New England FMC region comes from bottom trawls, followed by midwater trawls, pots and traps, and dredges. In the Mid-Atlantic FMC region, purse seines targeting Atlantic menhaden (*Brevoortia tyrannus*) contribute 72% of catches, while dredges, pots and traps, and bottom trawls contribute the other 28% of total landings. Sea scallops (*Placopecten magellanicus*) are the dominant catch for bottom trawls and dredges, while blue crabs (*Callinectes sapidus*) are the dominant catch for pots and traps. Purse seine landings of Atlantic menhaden contribute 29% of total landings in the South Atlantic FMC, although landings from other gears, such as pots and traps and bottom trawls, are also high. Similar gears are used in the Gulf of Mexico FMC, but the fisheries are dominated by the purse seine Gulf menhaden (*Brevoortia patronus*) fishery.

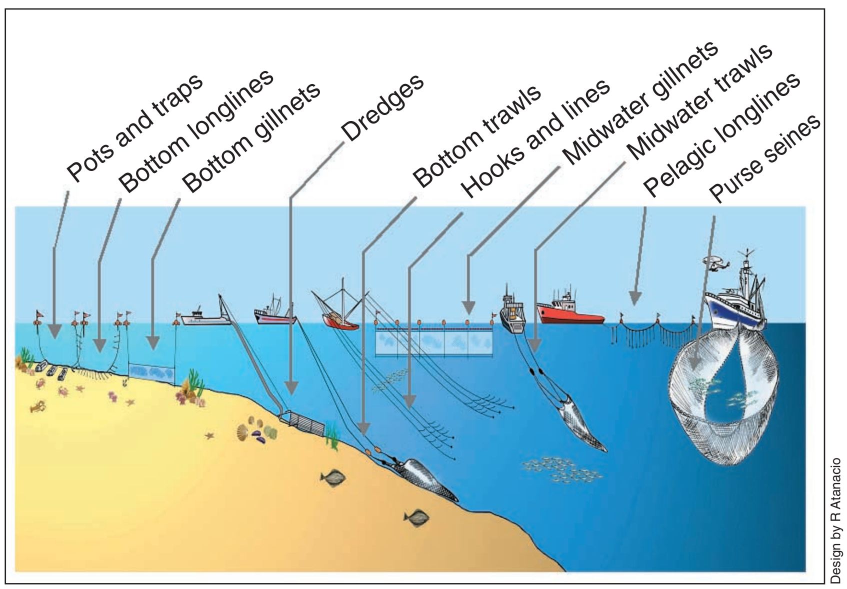

Figure 2. *Schematic representation of the ten classes of fishing gears analyzed.*

Table 1. Percentage landings (by weight) of the top four fishing gears in each Fishery Management Council region

	FMC						
Gear	New England	Mid-Atlantic	South Atlantic	Gulf of Mexico	North Pacific	Pacific	Western Pacific
Dredges	7	14	-	-	-	-	-
Gillnet – bottom	-	-	-	-	-	-	1
Gillnet – midwater	-	-	-	-	7	-	-
Hooks and lines	-	-	5	-	-	-	32
Longline – bottom	-	-	-	-	-	-	-
Longline – pelagic	-	-	-	-	-	-	63
Pots and traps	15	8	23	4	-	4	-
Purse seine	-	60	29	73	16	48	3
Trawl – bottom	33	6	20	13	5	11	-
Trawl – midwater	26	-	-	3	63	20	-
Other gears*	19	12	23	7	9	17	1
Total landings (thousand t)	286	379	85	730	1530	389	9

*Percentage for other gears sums percentages for gears other than the top four

Landings from gears that are not in the top four are indicated by hyphens. Data are from 2001. Landings data are from NMFS, Pacific data from PacFIN, North Pacific data from Alaska Department of Fish and Game; Western Pacific data from Hawaii Division of Aquatic Resources. Data are unavailable for the Caribbean FMC. Data for Western Pacific Region includes Hawaii only.

Fisheries in the North Pacific FMC region are the largest in the US, with total state landings of 1 530 000 mt. Midwater trawls, particularly for Bering Sea walleye pollock (*Theragra chalcogramma*), dominate fisheries in this region and comprise 63% of landings. In the Pacific FMC, purse seine fisheries predominantly targeting squid (*Loligo opalescens*) constitute almost half of the total landings, with another 20% from midwater trawls mainly targeting hake (*Merluccius productus*). Catches in the Western Pacific FMC region are the smallest, and are dominated by pelagic longline fisheries for bigeye tuna (*Thunnus obesus*).

■ Current understanding of collateral impacts

We found over 170 documents reporting, in quantitative terms, on the bycatch and habitat impacts of the ten fishing gears included in the study (Morgan and Chuenpagdee 2003). Most studies of habitat damage focused on dredges and bottom trawls, and to a lesser extent on pots and traps and gillnets. Bycatch information exists for all gear types. References to ghostfishing, where lost gear continues to cause damage to the seafloor or to unintentionally catch organisms, were found for pots and traps, bottom and midwater gillnets, and bottom and midwater trawls.

This information was the basis for discussion at a one-day expert workshop of 13 fishers, managers, and scientists on how the ten fishing gears are deployed in US waters and their probable impacts. Workshop participants compared and rated the gears in terms of impacts to physical and biological habitats and across five bycatch groups, including shellfish and crabs, finfish, sharks, marine mammals, and seabirds and sea turtles. These experts were asked to consider average impacts, combining knowledge of gear usage throughout all US fisheries (this was done by assessing the impact of a single application of a given gear, rather than the cumulative effect of all applications of this gear). Consensus ratings of these impacts on a scale of 1 to 5, where 1= very low impact and 5 = very high impact, are shown in Figure 3.

These ratings show that the highest level of habitat impacts are caused by bottom gears such as dredges and bottom trawls. High levels of shellfish and crab bycatch occur in dredge, pot, and trap fisheries. Several gears cause a high level of finfish bycatch, in particular bottom trawls, gillnets, and bottom longlines, while midwater gillnets and pelagic longlines result in a high shark bycatch. High marine mammal bycatch occurs in gillnet fisheries. Finally, bycatch of seabirds and sea turtles are highest in fisheries using midwater gillnets and pelagic longlines.

■ Paired comparison survey

The ratings of bycatch and habitat damage associated with different fishing gears obtained at the workshop provided the basis for another, larger group of fishers, managers, and scientists to compare the ecological severity of the gear impacts. Following the "damage schedule" approach developed by Chuenpagdee *et al*. (2001a, b), we presented these impact ratings as a series of pair-wise scenarios (or binary choices) in a questionnaire format, and asked the respondents to choose one impact scenario that they considered more ecologically severe. The use of paired comparisons to elicit respondents' judgments about complex issues, such as presented here, mirrors the thought processes people use to make decisions on a daily basis (Opaluch *et al*. 1993).

The basic model for the paired comparison method involves all possible pair combinations for the objects, with total number of pairs (N) equals n (n-1) / 2, where n

Gear class	Habitat: Physical	Habitat: Biological	Bycatch: Shellfish & crabs	Bycatch: Finfish	Bycatch: Sharks	Bycatch: Marine mammals	Bycatch: Sea birds & turtles
Dredge	5	5	4	2	1	1	1
Gillnet – bottom	3	2	1	4	3	4	3
Gillnet – midwater	1	1	1	4	4	5	5
Hook and line	1	1	1	2	3	1	2
Longline – bottom	2	2	1	4	3	1	2
Longline – pelagic	1	1	1	3	4	3	5
Pots & traps	3	2	4	2	1	3	1
Purse seine	1	1	1	2	2	3	2
Trawl – bottom	5	5	3	5	2	2	2
Trawl – midwater	1	1	1	3	2	2	2

1 Very low 2 Low 3 Medium 4 High 5 Very high

Figure 3. *Ratings of habitat and bycatch impacts for each gear class, as determined by participants of a workshop held in March 2002 in Seattle, WA (Morgan and Chuenpagdee 2003).*

is the number of objects (David 1988). When pairs are presented to a sample of respondents, it is assumed that each object has the same possibility of being selected because all are paired an equal number of times. For example, when paired comparison involves four objects (n), the total number of pairs for comparison (N) equals 6, and each object is paired three times. This method has been applied to assess potential sites for noxious facilities (Opaluch *et al.* 1993), comparative values of public and private goods (Peterson and Brown 1998), preference for fisheries ecosystems (Chuenpagdee and Vasconcellos 2000), and importance of marine reserves (Chuenpagdee *et al.* 2002).

Figure 4 shows one pair of impact scenarios, where scenario A represents impacts from midwater trawls and scenario B those from bottom longlines, as indicated in Figure 3. However, these two scenarios were presented without any association to the gears causing the impacts, to remove personal bias that respondents might have about certain gear types. Collateral impacts caused by purse seine, hook and line, and midwater trawls, as rated by the workshop participants (Figure 3), were very similar. The impacts of midwater trawls were thus used to represent those of the other two gears.

Surveys were mailed out to randomly selected potential participants chosen from three groups of people knowledgeable about fisheries in the US. These included voting members of the eight FMCs, predominantly representing the fishing industry (Okey 2003), scientists and experts serving on the National Research Council's Ocean Studies Board and its committees (www.nationalacademies.org), and fishery specialists of marine-related conservation organizations. Of the 111 members of the eight FMCs, a randomly selected subset of 56 received the questionnaire and 24 responded. The Ocean Studies Board consists of 104 scientists, of which 39 were randomly selected and 22 responded. To represent the marine conservation communities, a list of organizations meeting the following criteria was compiled: (a) must have a website with a mission statement relevant to marine conservation; (b) scope must be at least regional or national; and (c) must have a fishery specialist serving as a program officer. These criteria yielded 42 organizations and their regional offices, of which 36 were randomly selected; 24 responded. In total, 70 people responded to the survey, for an overall response rate of 53%. Table 2 presents the respondents by occupation and geographic area. About 64% of respondents had knowledge and expertise specific to a particular FMC region, while the rest were considered knowledgeable about the US fisheries and fishing gears in general. Of the respondents, 58% indicated that they had experience on board a commercial fishing vessel.

Table 2. Number of respondents by occupation and geographic area of specialization

Region	Occupation: Fishers/Fisheries related	Fishery managers	Academic*	Biologist/ scientists	Others	Total
New England	1	1	-	1	2	**5**
Mid-Atlantic	1	3	-	1	1	**6**
South Atlantic	2	2	-	1	2	**7**
Caribbean	1	-	-	1	-	**2**
Gulf of Mexico	1	-	-	3	1	**5**
Western Pacific	3	1	-	2	2	**8**
Pacific	-	5	-	4	-	**9**
North Pacific	-	-	2	1	-	**3**
National **	-	-	9	14	2	**25**
Total	9	12	11	28	10	**70**

*Self identified as "university professors"; includes (mainly) natural and social scientists
**Includes respondents whose expertise and knowledge were not specific to a particular region

Relative severity of collateral impacts

Responses from the paired comparison survey were analyzed using Dunn-Rankin's variance stable rank sum method (Dunn-Rankin 1983), where impact scores indicated by selected choices were calculated. These scores were then normalized to a scale of 0 (least severe) to 100 (most severe), yielding as a final result an interval scale of relative severity of collateral impacts.

Data analysis was performed based on aggregation of impact scores of individual respondents in each group (Table 3). Numerical ranks were assigned to these scores such that "1" referred to most severe and "8" referred to least severe. Kendall's Tau rank correlation coefficient analysis was employed to test significant difference between rankings obtained from the three respondent groups. As shown in Table 4, all correlations were significant at $\alpha = 0.01$, suggesting strong agreement in the ranking of collateral impacts by all respondents. Further analysis showed that mean correlation coefficient increased rapidly with number of respondents, and reached significance level well below our total number of respondents, suggesting strong convergence between individuals previously known to represent diverse interests (Figure 5). Based on these analyses, we averaged impact scores from the three respondent groups to obtain one relative scale, which was then used to formulate three categories of possible policy responses (Figure 6).

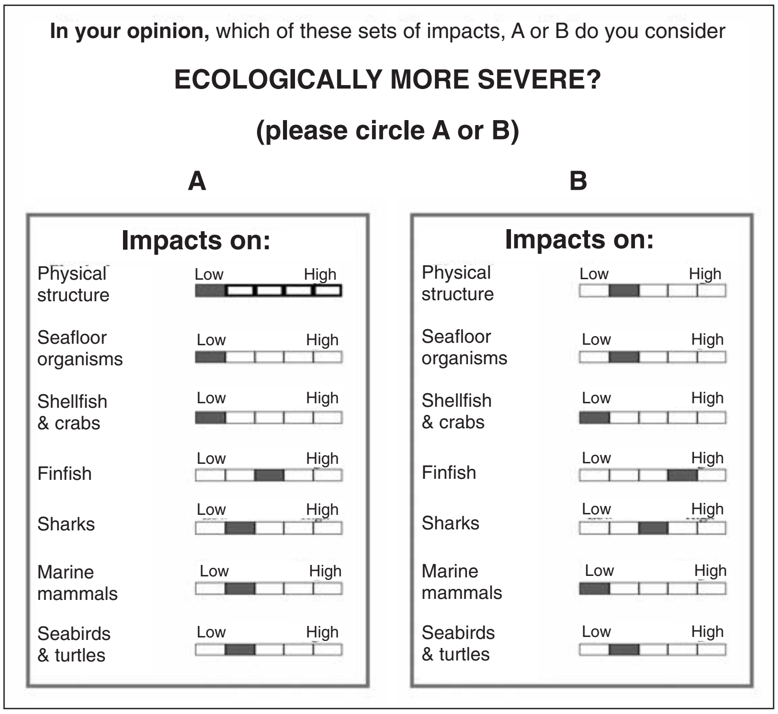

Figure 4. *A paired comparison as presented in the questionnaire on gear impact sent to three respondent groups.*

Our analysis of the judgments of these three expert groups show that collateral impacts caused by gears such as bottom trawls, bottom gillnets, dredges, and midwater gillnets are considered high. These gears should therefore be managed using very stringent policies such as a complete prohibition of use in ecologically sensitive areas. The level of bycatch and habitat impacts associated with pots, traps, and pelagic and bottom longlines are moderate, suggesting policies that are rigorous, but less urgent than for the previous set of gears. Management should include mandatory modifications of gears such as use of bird-scaring lines in longline fisheries. Finally, management of gears causing relatively low impacts, such as midwater trawls, purse seines, and hook and line, requires relatively less stringent policies and would merit lower priority. Regardless of the gear, where impacts occur to threatened or endangered species or sensitive habitats, their management should be considered high priority. The severity ranking of fishing gears suggests policies that encourage shifting from high-impact gears to low-impact gears.

It is important to note that we examined only the collateral impacts of fishing gears. Virtually any gear can be used in ways that overfish target species. For example, it has been suggested that the extinction of Atlantic gray whales (*Eschrichtius robustus*) was hastened or caused by overexploitation by harpooning, a type of gear that has virtually no collateral impacts (Lindquist 2000; Reeves *et al.* 2002). Precautionary measures must therefore be implemented to avoid overexploitation, even when using "clean" gears. Moreover, the severity ranking developed in this study is based on current knowledge of habitat and bycatch impacts of fishing gears. As understanding of these gears and their operation increases, we might recognize that some gears cause lower or higher impacts than originally thought. As suggested by Loverich (2001), recent studies show substantial seafloor disturbance and bycatch of benthic species such as red king crabs (*Paralithoides camthschaticus*) and snow crabs (*Chionoecetes opilio*) from so-called mid-water trawling by the Bering Sea pollock trawl fishery. Further, the systematic use of "chaffing gear" – rugged cov-

Table 3. Relative impact scores and corresponding rankings of collateral impacts as indicated by three respondent groups

	Fishery Management Councils		NRC Ocean Studies Board		Conservation organizations	
Gear Class	Score	Rank	Score	Rank	Score	Rank
Dredges	63	3	69	3	68	3
Gillnet – bottom	74	2	72	2	72	2
Gillnet – midwater	55	4	66	4	67	4
Longline – bottom	36	6	29	7	24	7
Longline – pelagic	29	7	41	5	36	5
Pots and traps	42	5	37	6	36	5
Trawl – bottom	90	1	89	1	95	1
Trawl – midwater*	6	8	6	8	2	8
Respondents	24		22		24	

*Impact scores for hooks and lines and purse seine are similar to those of midwater trawls; see text for the impacts of midwater trawls operating very close to seabottom

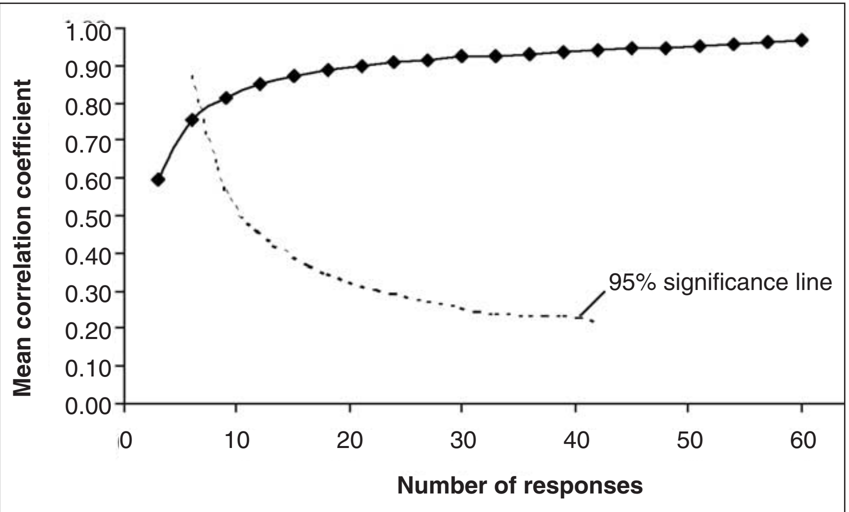

Figure 5. *Relationship between the number of respondents and the correlation of the gear impact severity rankings. A rapid initial increase suggests that high correlation (consensus about gear impacts ranking) can be obtained with a small number of respondents. The 95% significance line is based on Table 38 in Rohlf and Sokal (1981).*

ers for the lower belly of the nets, to prevent ripping when dragged on the sea bottom – implies that this "mid-water" gear has habitat impacts more similar to bottom trawls. This fishery should therefore be managed as if it were a bottom-trawl fishery.

Finally, our analysis did not account for the magnitude of operations by these gears in a particular fishery. Again, midwater trawling for Bering Sea pollock is one of the largest fisheries in the US and the world. While the per-unit impacts of midwater trawls are low compared to other gears, the size of this fishery will tend to magnify even small impacts. Overall, management policies should err on the side of caution, putting healthy ocean ecosystems and resources first.

Ranking gears can also be region- and fishery-specific. For any region, a set of fishery-specific gears can be graded without having to reconstruct a new scale. A small group of knowledgeable persons can provide consensus ratings of collateral impacts associated with these gears, using a workshop setting as done in this study. These impact ratings of fishing gears can then be matched with the ten gears in Figure 3. For example, if the impact ratings of a certain gear in a particular fishery are medium for physical and biological habitats, medium for shellfish and crab bycatch, high for finfish bycatch, and low for shark, marine mammal, seabird, and sea turtle bycatch, their impact ratings will fall within the medium impact category, and thus should be managed with moderately stringent policies.

Consistent and proactive policies based on gear impacts

The severity ranking of the ten commonly used gears in the US provides a basis for the formulation of fisheries policies that are in accord with current knowledge and judgments by knowledgeable participants in fisheries management processes. Fishery policies should encourage a shifting of gears from the higher to lower impact categories whenever alternatives exist and incentives may be given to fishers who voluntarily shift gears. A good example was seen in the spot prawn (*Pandalus platyceros*) fishery in California, where rockfish bycatch was greatly reduced when bottom trawls were replaced by traps (Reilly and Geibel 2002). Reduction of bottom trawl use has not only helped recovering rockfish stocks, but also lessens damage to benthic habitat on which spot prawn, rockfish, and many other marine species rely. Clearly, changing gear type pays off in the long run, as fishers can maintain high economic returns.

Given that gears can be modified and fishing practices can be changed, it is likely that they will move up and down the severity scale over time. Adjustment of impact categories based on gear performance is another incentive for many fishers who are already active in developing better fishing techniques. Adoption of the back-down method in the Eastern Tropical Pacific yellowfin tuna (*Thunnus albacares*) purse seine fishery, which allows dolphins to escape over the top of the net (Hall 1996), the use of streamer lines in Alaska's sablefish (*Anoplopoma fimbria*) longline fishery to reduce bycatch of albatrosses and other seabirds (American Bird Conservancy 2001), and the introduction of raised footrope trawls to reduce bycatch in small-mesh whiting (*Merluccius productus*) trawl fisheries in Massachusetts (Glass 2000) are all good examples. These innovations are both inexpensive and can increase catch, as shown in the use of streamer lines in Norwegian groundfish longline fisheries, because more fish are caught when seabirds do not take the bait (Lokkeborg 2001).

In cases where collateral impacts cannot be addressed by alternative fishing gears and prac-

Table 4. Correlation between the gear impact severity rankings of three repondents groups

	Fishery Management Councils	NRC Ocean Studies Board	Conservation organizations
Fishery Management Councils	1.000	–	–
NRC Ocean Studies Board	0.817	1.000	–
Conservation organizations	0.873	0.971	1.000
Average coefficient	0.887		

*All Kendall's Tau rank correlation coefficients are significant at the 0.01 level tices, implementing closed areas will protect healthy ocean ecosystems and species (Collie *et al.* 1997; NRC 2002). Together, this suite of management activities will lead to substantial progress in maintaining marine biodiversity and sustainable fisheries.

While the complete prohibition of destructive gears in ecologically sensitive areas might be justified, it may be difficult to achieve in practice. Indeed, as large-scale seabed habitat mapping has only recently begun to take off, it may be some time before scientists can identify the location and extent of sensitive areas. In the meantime, emphasis should be given to educating both the fishing industry and the public about the importance of the ecosystem impacts of fishing and the need for ecologically friendly practices.

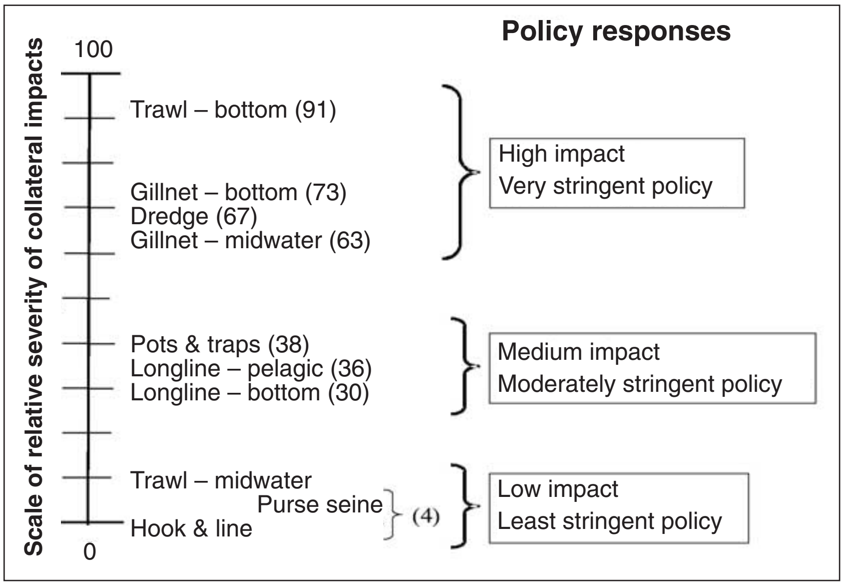

Figure 6. *Scale of relative severity of collateral impacts of ten fishing gears, and possible policy responses.*

Conclusion

One of the key principles of ecosystem-based fisheries management is the need to protect ecosystems and populations by applying the precautionary principle, which includes halting destructive fishing methods. The measures described above are important steps towards this goal. Ranking gears, as shown here, offers consistency, transparency, and inclusiveness, which are key elements of effective fishery policies.

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