Reanalyses of Gulf of Mexico fisheries data: Landings can be misleading in assessments of fisheries and fisheries ecosystems

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We used two high profile articles as cases to demonstrate that use of fishery landings data can lead to faulty interpretations about the condition of fishery ecosystems. One case uses the mean trophic level index and its changes, and the other uses estimates of fishery collapses. In earlier analyses by other authors, marine ecosystems in the Gulf of Mexico (GOM) and U.S. Atlantic Ocean south of Chesapeake Bay were deemed to be severely overfished and the food webs badly deteriorated using these criteria. In our reanalyses, the low mean trophic level index for the GOM actually resulted from large catches of two groups of low trophic level species, menhaden and shrimp, and the mean trophic level was slowly increasing rather than decreasing. Commercial targeting and high landings of shrimps and menhaden, especially in the GOM, drove the index as previously calculated. Reanalyses of fishery collapses incorporating criteria that included targeting, variability in fishing effort, and market forces discovered many false cases of collapse based simply upon a decline of catches to 10% of previous maximum levels. Consequently, we suggest that the low mean trophic level index calculated in the earlier article for the GOM did not reflect the overall condition of the fishery ecosystem, and that the 10% rule for collapse should not be interpreted out of context in the GOM or elsewhere. In both cases, problems lay in the assumption that commercial landings data alone adequately reflect the fish populations and communities.

landings data | mean trophic level index

The fisheries and ecological literature demonstrates the unintended ecological consequences of fishing and has prompted numerous pleas for a more holistic ecosystem approach to marine fisheries management (1–3). This movement in support of ecosystem-based management has been paralleled by efforts to identify indicators of ecosystem status (4). Among the most high profile indicators of marine ecosystem status is the mean trophic level index (MTLI) (5). This index represents a weighted average of the trophic level of fisheries landings. Pauly *et al*. (5) initiated the analyses and demonstrated downward trends in the mean trophic level of fisheries landings for a variety of marine ecosystems. Their initial findings have been repeated in subsequent analyses from additional locations (6–8).

One noteworthy example of a declining mean trophic level comes from analysis of landings data from fisheries in the Gulf of Mexico (GOM) and in the U.S. Atlantic Ocean south of Chesapeake Bay (6). The authors (6) concluded that these regions were severely overfished and exhibited badly degraded food webs, as evidenced by a low initial trophic index and subsequent declines in the index over time. However, fisheries landings in these regions historically would be expected to have a low index because the fisheries have been and are dominated currently by menhaden and several shrimp species that feed at low trophic levels (menhaden $\approx$2.2; shrimp $\approx$2.6). We evaluate the idea that the low indices derived from landings data are driven not by fishery-induced changes in the food web, but by large landings of commercially targeted species of high-value, but low trophic-level. Gulf menhaden *Brevoortia patronus* support the second largest U.S. fishery by weight; penaeid shrimps support the fifth largest by value ($300–400 million per year).

To test the above idea, we compared the trophic level index based upon (*i*) landings with and without commercially targeted low trophic level species in the calculation, and (*ii*) long-term, fishery-independent surveys that are not subject to any effects of selective and variable targeting of low trophic level species. Our calculations used a different set of landings data than did Pauly *et al*. (5); we used the National Marine Fishery Service (NMFS) data rather than that from the Food and Agriculture Organization (FAO). Our expectations were that trophic indices based upon landings data without menhaden and shrimps would not indicate that the GOM fisheries ecosystem is as badly degraded as reported (6).

We also investigated GOM landings data in reference to predictions of near-future collapses of fish populations analyzed in a high-profile article by Worm *et al*. (9). In this article, collapses were defined as a reduction in landings of a species to 10% of any previous annual catch level. Using the same criteria, we quantified the occurrences of false positives but added additional criteria to identify those species where collapses actually have occurred. Finally, we examined red snapper landings from the GOM in the context of changing regulations and user conflicts.

Results and Discussion

Mean Trophic Level Index. Targeting by the fisheries has a significant effect on the mean trophic level index calculated from landings data. When all landings data are considered, we estimated a low initial index value ($\approx$2.4; Fig. 1) similar to results in Pauly and Palomares (6). The low index occurred whether or not we used landings from the GOM alone or from the combined GOM and U.S. Atlantic south of the Chesapeake Bay (defined as "USA only"). The indices for the GOM or USA only differ by $<$3% in any year (Fig. 1). When menhaden and shrimp were excluded from the landings, the indices calculated for each region (GOM or USA only) had an initial value (intercept $\approx$2.8) only slightly less that other regions where the index has been calculated ($\approx$3.0) (7, 8, 10). Initial index values (intercepts) differed between indices calculated with or without menhaden and shrimp included (ANCOVA; intercepts $P < 0.001$).

None of the time series of MTLI exhibited negative trends

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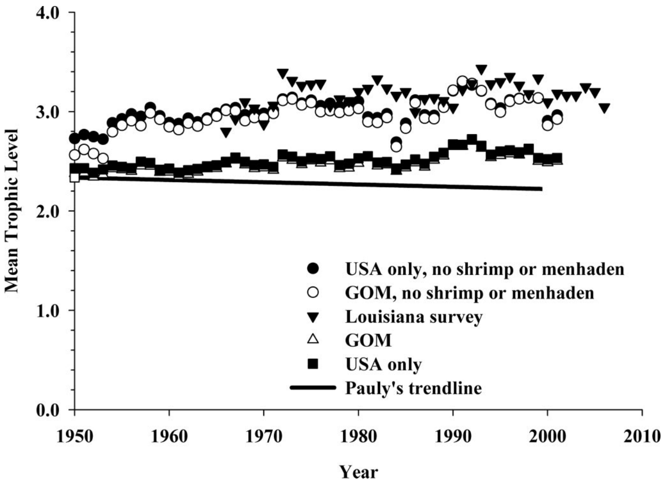

Fig. 1. Annual mean trophic level index from 1950 to 2006. USA only is the northern Gulf of Mexico and the Atlantic south of Chesapeake Bay. GOM is the Gulf of Mexico only. Overlap can be seen when comparing GOM with USA only, and when comparing all indices without shrimp and menhaden with Louisiana survey data. The solid line is the trend line from Pauly and Palomares (6).

from a higher trophic level to a lower trophic level. Results of our reanalyses clearly differ from those presented by Pauly and Palomares (6) who reported a negative trend. For the USA only and the GOM (including shrimp and menhaden), indices based upon commercial catches varied around a long-term mean trophic level near 2.5 (Fig. 1). Both slopes were positive ($P < 0.001$) rather than negative. Intercepts and slopes did not differ between USA only and the GOM [including shrimp and menhaden; ANCOVA, $P > 0.05$ (slopes and intercepts), b = 0.004 yr^{-1}, for USA only and GOM].

For other areas, attempts to reproduce declines in MTLI also have failed, e.g., compare the graphs for the Mediterranean and Black Sea (11) with that provided in 2005 by the European Environment Agency (http://dataservice.eea.europa.eu/atlas/viewdata/viewpub.asp?id=1848). Such discrepancies may be attributable to differences in landings data reported by different sources. Pauly and Palomares (6) used data compiled by the FAO that included some landings from Mexico, whereas we used data reported by NMFS. These data do not always agree. We chose to use the NMFS data because collection and management techniques are well described and based upon formal metadata guidelines (The Fisheries Information Network; www.gsmfc.org/fin.html) as recommend by the NRC (12), include data reported by state agencies for species not under federal jurisdiction, and are presumed to be the primary source of the FAO data.

The MTLI derived from the survey biomass data did not differ statistically from that derived from commercial landings data after catches of shrimp and menhaden had been excluded (ANCOVA, slopes and intercepts $P > 0.05$). Although we recognize that the survey data are based upon a smaller area (Louisiana only) than the commercial landings data, our comparison is useful because ≈75% of U.S. GOM landings occur in Louisiana (13). Moreover, >50% of all U.S. fishery yields have historically come from estuarine or estuarine-dependent species (14, 15); this fraction is higher in the GOM (15). The Louisiana surveys (see *Methods*) are performed where shrimp and menhaden are present in proportion to their abundance in nature, as are many adults and juveniles of higher trophic level species that also are present in commercial catches. However, all fishing gears are selective and thus constrained in their ability to provide unbiased samples from fish populations and communities. Resource surveys that use an assortment of gears to sample multiple species, sizes, life history stages, and habitats are designed to reduce such bias. Indices from such surveys are recognized as valuable fishery-independent tools for describing temporal and spatial changes in community structure and individual species abundances (16).

Regardless of the data source, each annual value of the MTLI is an average across many species, and the composition of the catches changes as new fisheries are added or removed. In the GOM, for example, the value for the 1950 index was based upon landings averaged over 27 species, whereas in recent years >70 species contribute to the annual index. The index also is influenced over time by removals (often sustainable) of fish biomass (10), and by inference, regulatory changes in landings. Other error is introduced because, whereas the trophic level is reported to vary with the location of study, one mean value for the species is calculated for the entire region (see www.fishbase.org). So, whereas the MTLI is a relatively simple concept, the uncertainty and subjectivity inherent in its calculation are not well expressed.

We recommend caution when interpreting shallow slopes in the mean trophic level over time, and over large geographical areas, especially if estimates are based upon commercial landings alone. Caution is especially warranted if information is not available about changes in fishing practices, markets, and data acquisition methods (10). For example, in a fishery ecosystem like the GOM, intense fishing on low trophic level species like menhaden and shrimps might be expected to cause an increase in the index as these species are reduced in abundance even if that harvest level were sustainable. Fortunately, both groups are essentially annual crops in the GOM and exhibit high stock productivity; therefore, large declines in abundance are not apparent.

Where sufficient data exist, we see value in calculating the MTLI from survey data, because these data at least provide a temporally and spatially consistent sampling methodology. The value of indices calculated from survey data has long been recognized by stock assessment scientists (16). In contrast, even subtle changes in fishing behavior by fleets can have dramatic influences on the composition of fisheries landings (17).

Indeed, when we calculated the MTLI from Louisiana survey data, the index had a higher intercept ($P < 0.001$) than the GOM fisheries dependent data. The survey data indicated that the MTLI rose slowly over most of the period of record (ANCOVA $P = 0.009$, b = 0.005, $R^2 = 0.20$) but may have begun a slow decline in the mid-1990s. We have no reason to believe that targeting and/or overfishing are what are driving the index from the survey. Alternatively, variability and the recent decline in the survey MTLI could be attributed to other factors, such as the degradation of nursery function in coastal Louisiana wetlands. Coastal Louisiana accounts for ≈80% of the wetland loss in the continental U.S. (18), but commercial landings of species other than gulf menhaden in Louisiana have been increasing over time (19). That said, the survey-derived MTLI may be reflecting significant but recent changes in the food web of a highly degraded nursery ecosystem.

Our ongoing studies focus on variability in the index rather than on shallow slopes. We have begun to calculate the MTLI for specific estuarine basins in Louisiana in an attempt to describe historical ecological baselines. Preliminary results indicate that variability in the MTLI at this scale may correspond to large-scale perturbations such as tropical storms and efforts to restore coastal ecosystems. Although we recognize the threat of overfishing to the sustainability of fisheries and the ecosystems to which they belong, we question whether a decline in the mean trophic level index from landings data is a useful index of such stresses (3, 10).

Fishery Collapses. We examined the extent to which collapses based solely upon commercial landings data provided an accurate measure of the status of fisheries using 72 commercial

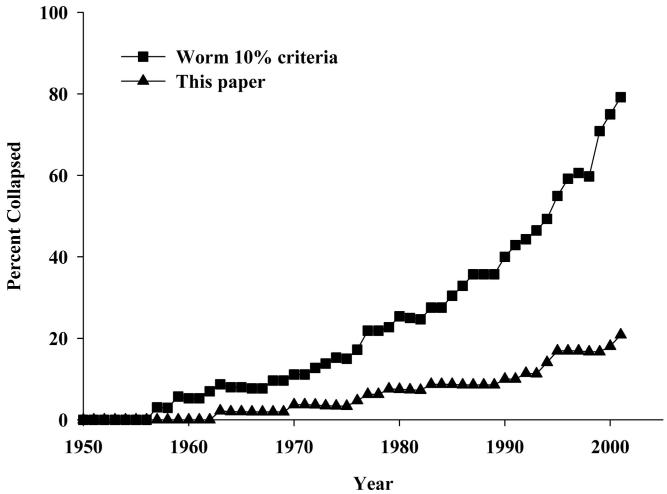

Fig. 2. The closed squares show the cumulative percentage of fisheries that collapsed in the Gulf of Mexico between 1950 and 2001 based upon the criterion used by Worm *et al.* (9), e.g., when an annual catch fell below 10% of the maximum observed catch in any year. The closed triangles show the same results after considering effects of the regulatory history of each fishery using existing management plans and stock assessments, and cases where changes in commercial fishing effort and market forces seemed to be driving observed variability.

fisheries currently listed in the GOM landings data by NMFS. We concluded that a total of 15 taxa of fish and shellfish, or ≈21% cumulatively between 1950 and 2001, had collapsed as defined by our management-informed criteria (Fig. 2); slightly >8% recovered during the same period. These taxa, and the year of collapse are listed in Table 1. In contrast, almost 80% of GOM fisheries cumulatively would be designated as having collapsed (Fig. 2) by Worm *et al*. (9) based solely on the 10% criterion, absent any management context.

A group of at least nine other species thought to be fully exploited or overexploited have not collapsed based on the 10% criterion but are actively managed in the GOM (data are not sufficient to define stock boundaries or support full stock assessments for these species). These species include goliath grouper *Epinephelus itajara*, gag grouper *Mycteroperca microlepis*, king mackerel *Scomberomorus cavalla* and Spanish mackerel *Scomberomorus maculatus*, Atlantic bluefin tuna *Thunnus thynnus*, cobia *Rachycentron canadum*, greater amberjack *Seriola dumerili*, and gray triggerfish *Balistes capriscus*.

Table 1. Taxa of fish and shellfish that we interpret to have collapsed from overfishing in the Gulf of Mexico after consideration of the regulatory history of each fishery using existing management plans and stock assessments

Taxa	Common name	Year of collapse
g. *Centropomus*	Snooks	1963
Argopecten irradians	Bay scallop	1970
Joturus pichardi	Bobo mullet	1976
f. Haemulidae	Grunts	1977
Sciaenops ocellatus	Red drum	1979
Epinephelus morio	Red grouper	1983
Lutjanus campechanus	Northern red snapper	1987
A. gibbus	Callico scallop	1990
g. *Octopus*	Octopus	1994
E. striatus	Nassau grouper	1994
*A. gibbus**	Callico scallop	1995
f. Squalidae	Dogfish sharks	1995
Spisula solidissima	Atlantic surf clam	2000
g. *Seriola*	Amberjacks	2001
g. *Paralichthys*	Flounder	2001

*Following a recovery from a previous collapse in 1990.

The differences in interpretation between our analyses and the 10% criterion for collapse are attributable to three factors. Some of these factors have been identified by others (20, 21).

First, many of the taxa listed in the GOM data do not support directed commercial fisheries, so landings are sporadic and related to variability in effort, not population biomass, e.g., Atlantic croaker *Micropogonias undulatus*, spot croaker *Leiostomus xanthurus*, lady fish *Elops saurus*, crevalle jack *Caranx hippos*, mojarras f. Gerridae, and many others. If the 10% criterion were strictly interpreted, Atlantic croaker populations collapsed 3 times and recovered twice in the period between 1983 and 1987, and 11 times over the entire period. This is unlikely given the Atlantic croakers life history (22) and highlights the effects of sporadic effort on landings data. Indeed, based solely on the 10% criterion, 72 GOM fisheries have experienced a combined 98 collapses and recoveries since 1950, which again is unlikely to reflect real changes in population biomass at this spatial scale. In another example, exploratory fisheries for butterfishes f. Stromateidae in the GOM were initiated in the late 1960s, the early 1970s, and again in the early 1980s, but did not persist owing to market forces. Similarly, market forces caused the failure of a small-scale industrial groundfish fishery that developed in the 1970s to supply pet food manufacturers.

Second, several species of which GOM catches vary widely have limited distributions in the GOM. This is important because most of the stock biomass for these species occurs outside of the GOM (mostly in the Caribbean), implying that removals can result in localized depletions and variable catches, but do not have much effect on stock status. Such species include scallops, centropomids, octopi, Nassau grouper, grunts, and bobo mullet that occur mainly from south Florida and/or the Bay of Campeche. Other species listed in the landings data do not occur at all, such as gray weakfish *Cynoscion regalis* and southern red snapper *Lutjanus purpureus*.

Third, the interplay among competing users in the GOM (20) should be considered in evaluating collapses, e.g., commercial and recreational fishers as well as a trawl fishery for penaeid shrimp that captures many juveniles as bycatch (23). In addition, the Gulf States Marine Fisheries Commission (www.gsmfc.org/) has encouraged member states to designate several species that once were fished commercially as game fish. This designation has greatly reduced commercial landings, but not necessarily all fishing pressure (24), on popular game fishes such as spotted sea trout *Cynoscion nebulosus*, red drum, Spanish mackerel, and tarpon *Megalops atlanticus*. Other species support both recreational and commercial fisheries, with management allocating a significant portion of the harvest to recreational fishers. For example, ≈70% of king mackerel are allocated to recreational fishers, as are ≈50% of northern red snapper. Recreational and commercial fishers are also harvesting notable species such as cobia and greater amberjack.

A poster child for illustrating the need for context when interpreting landings data from the GOM is the northern red snapper. Recreational and commercial fishers almost equally split the directed harvest, but >80% of the fishing mortality occurs as bycatch of juveniles in the shrimp fishery (Fig. 3). Early in the history of management, stock assessment scientists determined that reductions in the level of juvenile mortality attributable to bycatch would be required for the stock to recover in the absence of significant, some argued draconian, cuts in directed harvest. At the time, *ca*. 1990, stock assessments indicated that bycatch reductions of 40–50%, along with significant reductions in the directed harvest, would be necessary. Assess-

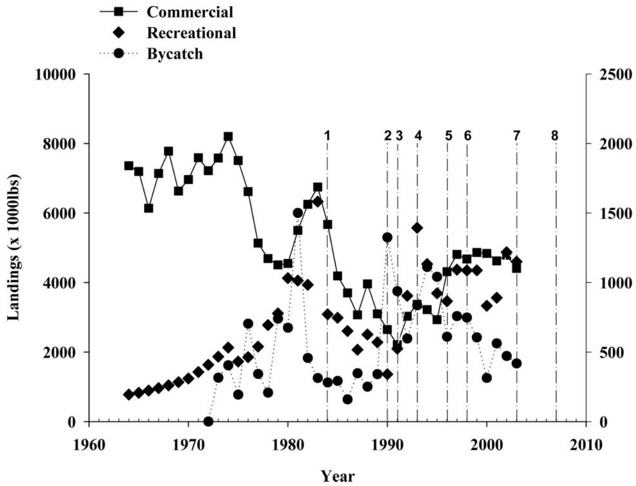

Fig. 3. Annual landings (×1,000 lbs) of red snapper attributable to different fisheries in the Gulf of Mexico. The figure is annotated to include the time sequences of major changes in harvest quotas, and changes in the projected time for recovery of the stock under various management practices. Bycatch landings occur in the shrimp fishery and comprise mostly age-0 and age-1 juveniles that have not yet recruited to the directed fishery. The annotations refer to: (line 1) development of the red snapper FMP (1984); (line 2) 3.1 million pounds (mp) commercial quota was set (1990); (line 3) 4 mp quota was set, allocation was set to 51% commercial and 49% recreational, and recovery was projected for 2007 (1991); (line 4) quota was raised to 6 mp, recovery was projected for 2009 (1993); (line 5) quota was raised to 9.12 mp, recovery was projected for 2019 (1996); (line 6) shrimp trawls in federal waters were required to contain bycatch reduction devices (1998); (line 7) recovery was projected for 2032 (2003); (line 8) quota was reduced to 5 mp.

ment models were used to generate a range of "allowable biological catches (ABC)" for the directed fishery that expressed both the uncertainties in the assessment process, and the probability of recovery given some future, but critically important, technological solution to reduce bycatch. From then on, rather than reducing catch by the directed fishery to levels that increased the likelihood of recovery, fisheries governance chose to manage predicated on the notion that bycatch reduction would occur. They selected "total allowable catches (TAC)" for the directed fishery from the high-risk range of ABCs. Others defended the choice of risk-prone TACs by suggesting that red snapper stock productivity increased in response to the addition of new habitat in the form of artificial reefs and oil and gas platforms in the northern GOM. However, evidence that habitat limited the stock size was absent or weak; habitat area added by all artificial structures combined represents less that 5% of available natural habitats. In this example with red snapper, commercial landings explain little of the red snapper saga.

To conclude our reanalyses of collapses, we again recognize the threat of overfishing to long-term sustainability, but we caution that the use of landings data without context leads to significant misunderstanding, spurious correlations, and erroneous predictions. The total number of collapses and recoveries based upon the 10% criterion alone differ greatly from the numbers from our management-informed criteria (Table 2). What is striking is the large number of false positives that became apparent when reductions in fishery catches were attributable to changes in regulations, market forces, or fishing effort.

Methods

The commercial catch data used are published on the National Marine Fisheries Service (NMFS) website (www.st.nmfs.gov/st1/commercial/landings/annual_landings.html). We excluded freshwater species that occur in the landings data that are not present in the areas of interest, e.g., carp, frogs, and landings not specified to genus.

Fishery-independent survey data used here have been collected by the Louisiana Department of Wildlife and Fisheries (www.wlf.louisiana.gov/) for >40 years at the same sampling locations in Louisiana estuaries and on the shallow shelf, using a variety of gears (otter trawls, gill nets, beach seines, and trammel nets). At each location in estuaries, the surveys use replicated tows of 3.9-m otter trawls against the prevailing current (with 3-mm cod-end liner), replicated hauls of 15.2-m bag seines with 3-mm mesh, and replicated sets of 225-m-long by 2.4-m-high experimental gill nets with five 45-m panels consisting of mesh sizes (cm bar) of 2.5, 3.2, 3.8, 4.4, and 5.1 cm. Trammel nets used are 225 m long by 1.8 m tall and have three walls. The inner wall is constructed of 4.1-cm bar mesh, and the two outer walls are constructed of a 15.2-cm bar. The trammel net is fished by setting it parallel to shore. It is fished as a strike net by running in concentric ever tightening circles around it with a powerboat. Only otter trawls, gills nets, and trammel nets are used at stations on the shallow shelf. If weather precludes use of any gear at any station, sampling is rescheduled. All fish and shellfish collected are identified, measured (nearest mm), and weighed (nearest 0.1 g). These methods have remained unchanged over the period of record because of their value as a relative measure of the abundance of species under management. Data are used in stock assessments for recreationally and commercially important finfish species, and for determining the opening day of shrimp seasons. Because each gear is designed to sample different members of the fish and shellfish community with respect to size and habitat affinity, we averaged over replicates, then summed weights over all gears over all stations for each species to estimate survey biomass values used to calculate the fishery-independent MTLI. We did not remove menhaden and shrimps in the MTLI calculations from the survey data because, when these species are included in proportion to their natural abundance, they do overly affect the index.

As in previous work (5), FishBase (www.fishbase.org) was used to obtain a trophic level for each species reported both in the fisheries landings and survey data. When more than one trophic level was reported, we used a simple arithmetic mean to assign a trophic level. We calculated the MTLI from reported fishery landings, and again from a reduced dataset from which catches of shrimps (*Farfantepenaeus aztecus*, *Farfantepenaeus duorarum*, *Litopenaeus setiferus*, *Sicyonia brevirostris*, *Pleoticus robustus*, *Xiphopenaeus kroyeri*) and menhaden (*B. tyrannus*, *B. patronus*) were removed. Analyses were conducted at two geographic scales: the GOM and US south Atlantic combined, and the GOM alone. To calculate the MTLI we used equation 2 from page 199 of ref. 6:

$$TL_y = \sum_i (TL_i \cdot Y_{yi}) / \sum_i Y_{yi}$$

where TL_y is the MTLI in year *y*, TL_i is the trophic level of species *i*, and Y_{yi} is the catch (in weight) of species *i* in year *y*.

We reanalyzed fishery collapses with the GOM landings data using the same algorithm to define a collapse as had Worm *et al*. (9) where collapse was defined as a reduction in landings by 90% from any previous annual catch

Table 2. The total number of collapses and recoveries based upon the 10% criterion alone, compared with the numbers we derived from our management-informed criteria

	10% criterion of Worm *et al*. (9)	Our criteria	Both	Misinterpretations
Collapses	58	15	12	43 False positives
Recoveries	40	6	6	36 False negatives

A false positive means that the 10% criterion identified a collapse in a case where reductions in fishery catches were attributable to changes in regulations, market forces, or fishing effort. A false negative means that catches increased for similar reasons.

level. We then eliminated instances where the Worm *et al*. (9) algorithm gave a false positive when changes in regulations, market forces, or commercial fishing effort were primarily responsible for reductions in fishery catches. To accomplish this reanalysis, we applied more rigorous criteria to estimate whether collapse had occurred. We defined a stock as having collapsed if any of the following criteria were met: (*i*) the stock was reported to be overfished by NMFS or the Gulf States Marine Fisheries Commission based upon formal assessments available, i.e., biomass levels or surrogates for biomass declined to levels considered to be risk-prone; (*ii*) landings not only declined to 10% of any previous annual catch after several years of high catches but also they remained at low levels for at least 1.5 generations of that species; and (*iii*) the stock was identified in fishery management plans and/or plan amendments as being overexploited and as a consequence catches were lowered or prohibited by regulation even when data to perform a formal stock assessment were absent.

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