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Contrasting Global Trends in Marine Fishery Status Obtained from Catches and from Stock Assessments

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Abstract: *There are differences in perception of the status of fisheries around the world that may partly stem from how data on trends in catches over time have been used. On the basis of catch trends, it has been suggested that about 70% of all stocks are overexploited due to unsustainable harvesting and 30% of all stocks have collapsed to <10% of unfished levels. Catch trends also suggest that over time an increasing number of stocks will be overexploited and collapsed. We evaluated how use of catch data affects assessment of fisheries stock status. We analyzed simulated random catch data with no trend. We examined well-studied stocks classified as collapsed on the basis of catch data to determine whether these stocks actually were collapsed. We also used stock assessments to compare stock status derived from catch data with status derived from biomass data. Status of stocks derived from catch trends was almost identical to what one would expect if catches were randomly generated with no trend. Most classifications of collapse assigned on the basis of catch data were due to taxonomic reclassification, regulatory changes in fisheries, and market changes. In our comparison of biomass data with catch trends, catch trends overestimated the percentage of overexploited and collapsed stocks. Although our biomass data were primarily from industrial fisheries in developed countries, the status of these stocks estimated from catch data was similar to the status of stocks in the rest of the world estimated from catch data. We conclude that at present 28–33% of all stocks are overexploited and 7–13% of all stocks are collapsed. Additionally, the proportion of fished stocks that are overexploited or collapsed has been fairly stable in recent years.*

Keywords: fishes, fisheries, indicators, inventory and monitoring, marine, population dynamics

Contraste de las Tendencias Globales en el Estatus de las Pesquerías Marinas Obtenido de Capturas y Evaluación de Reservas

Resumen: *Existen diferencias en la percepción del estatus de las pesquerías en el mundo que se pueden derivar en parte de la manera en que se utilizan los datos sobre tendencias en las capturas. Con base en las tendencias en las capturas, se ha sugerido que cerca de 70% de todas las reservas son sobreexplotadas debido a capturas no sostenibles y que 30% de todas las reservas se han colapsado a <10% de niveles sin pesca. Las tendencias en las capturas también sugieren que un mayor número de reservas serán sobreexplotadas y colapsarán. Evaluamos como afecta el uso de datos de captura a la evaluación del estatus de las reservas pesqueras. Analizamos datos simulados de capturas aleatorias sin tendencias. Examinamos reservas bien estudiadas y clasificadas como colapsadas con base en datos de captura para determinar si esas reservas estaban realmente colapsadas. También utilizamos evaluaciones de reservas para comparar el estatus de las reservas derivadas de datos de captura con el estatus derivados de datos de biomasa. El estatus de las*

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reservas derivado de las tendencias de captura fue casi idéntico al esperado si las capturas fueran generadas aleatoriamente sin tendencias. La mayoría de las clasificaciones de colapso asignadas con base en los datos de captura se debieron a reclasificaciones taxonómicas, cambios en las regulaciones de pesquerías y cambios en el mercado. En nuestra comparación de datos de biomasa con las tendencias en la captura, las tendencias en la captura sobreestimaron el porcentaje de reservas sobreexplotadas y colapsadas. Aunque nuestros datos de biomasa se obtuvieron principalmente de pesquerías industriales en países desarrollados, el estatus de esas reservas estimado a partir de datos de captura fue similar al estatus de reservas en el resto del mundo. Concluimos que actualmente 28–33% de todas las reservas están sobreexplotadas y 7–13% de todas las reservas están colapsadas. Adicionalmente, la proporción de reservas pesqueras que están sobreexplotadas o colapsadas ha sido medianamente estable en años recientes.

Palabras Clave: poblaciones, indicadores, inventario y monitoreo, marino, peces, pesquerías

Introduction

Conservation biology as a field has terrestrial roots, but marine topics are becoming increasingly emphasized (Marris 2010). Conservation researchers have focused on marine protected areas (e.g., McClanahan & Kaunda-Arara 1996), effects of fishing gear on ecosystems (e.g., Watling & Norse 1998), and effects of fishing on nontarget species (i.e., bycatch) such as skates and rays (e.g., Dulvy et al. 2000). Nevertheless, little emphasis has been placed by conservation researchers on direct effects of fishing on species targeted for commercial sale. Targeted species are divided by fisheries managers and researchers into individual stocks (i.e., units of management interest) on the basis of political boundaries, genetic divergence, and biological characteristics (Begg et al. 1999; Reiss et al. 2009). We use the terms *fish stock* and *fishery* synonymously.

Targeted species are usually the most abundant in an ecosystem, and their abundance has direct and indirect effects on predators, prey, and competitors of fished stocks (Cury et al. 2000; Myers et al. 2007; Baum & Worm 2009). Fisheries scientists and ecologists have defined stocks as "collapsed" or "overexploited" on the basis of catch and biomass data (e.g., Worm et al. 2006; Pauly 2007, 2008). Collapse is defined as current biomass of <10% of unfished biomass (or 20% of the biomass that would result in maximum sustained yield [B_{MSY}]). It is assumed that a stock in a state of collapse (i.e., collapsed) contributes little to ecosystem processes relative to its unfished state (e.g., Worm et al. 2006; Worm et al. 2009). Overexploitation is defined by the governments of the United States and Australia as biomass <50% of B_{MSY} (Hilborn 2010; Hilborn & Stokes 2010). There are uncertainties associated with estimating maximum sustained yield and B_{MSY}, but despite their long-predicted demise (Larkin 1977), these reference points are still widely used, either as management targets or as fishing limits not to be exceeded (Mace 2001; Punt & Smith 2001). We use the term *catch* to refer to reported catches, or "landings," which excludes discarded fish and illegal, unreported, and unregulated catches (Kelleher 2005; Zeller & Pauly 2005; Agnew et al. 2009). In some regions the number of catches and landings may differ considerably, but only landings data are available at a global extent.

We applied these definitions of *collapse* and *overexploited* to assess trends in status (relative to unfished levels) of marine fish stocks, a subject of considerable debate in the literature (e.g., Worm et al. 2006; Branch 2008; Worm et al. 2009). When status is assessed using biomass estimates from scientific stock assessments, it appears that 8–14% of the world's assessed fish stocks are collapsed (Garcia & Grainger 2005; Worm et al. 2009) and 24–28% are overexploited or collapsed (Garcia & Grainger 2005; Hutchings et al. 2010; FAO 2011). Nevertheless, several researchers have used worldwide catch data as a surrogate for changes in biomass and suggest that 24–36% of stocks are collapsed (e.g., Worm et al. 2006; Pauly 2007, 2008) and 68–72% are overexploited or collapsed (Pauly 2007, 2008; Pauly et al. 2008). Trends in fishery status also differ between the 2 approaches. Survey and assessment data indicate stabilization in overall biomass since the 1980s (Worm et al. 2009; Hutchings et al. 2010) and either a decrease (FAO 2011) or increase (Worm et al. 2009) in the fraction of stocks that are collapsed, whereas catch data suggest a rapid increase in the proportion of collapsed and overexploited stocks since 1950 (Worm et al. 2006; Pauly 2007, 2008).

Use of the catch-based method assumes that trends in the number of fish caught can be translated directly into trends in fishery status (i.e., in developing fisheries, catch initially is low, rises over time in intensively harvested fisheries, declines in overexploited fisheries, and declines further when fisheries collapse) (e.g., Froese & Kesner-Reyes 2002; Pauly 2007, 2008). Stocks can be classed as developing only in years preceding the maximum catch and as overexploited or collapsed only in years after the maximum catch.

The most reliable estimates of stock status come from stock assessments that use all available data (catches, research surveys, size, and age distributions) to estimate historical and current total biomass and effective spawning biomass of the stock. A key element in understanding stock status is the comparison of biomass in a given year to biomass reference points such as B_{MSY}.

Few fisheries classified as collapsed on the basis of either biomass or catch data would be considered to have high probability of extinction by the International Union for Conservation of Nature (IUCN) because even collapsed marine fish stocks typically contain millions of individuals over an extensive area, and stock status is evaluated at the level of regional populations, not species. For instance, the Norwegian coastal cod (*Gadus morhua*) stock has declined to the point where management advice since 2004 from the International Council for the Exploration of the Sea (ICES) has been to close the fishery (ICES 2010). Nevertheless, the population still contains tens of millions of individual fish (ICES 2010). This situation is not unusual. Commercial fisheries target highly abundant species (Sethi et al. 2010), so that the 76 marine fish species classified as endangered or extinct by the IUCN (2010) have never contributed much to global catches (0.02% of global catches between 1950 and 2006).

We used the most recent data available for global fisheries to consider the status and trends of fish stocks, and simulated random catch data to address the discrepancies between stock status estimated with catch-based methods and estimated directly from biomass data.

Methods

Application of Catch-Based Method to FAO Catch Data

We applied the catch-based method to the global catch database maintained by the United Nations Food and Agriculture Organization (FAO). The catch-based method (e.g., Froese & Kesner-Reyes 2002; Pauly 2007, 2008) divides time series of catches into 2 periods: before and after the year of the maximum catch (C_{max}). In the years before the maximum catch, fisheries are classified as either developed ($<0.5\ C_{max}$) or fully exploited ($\geq 0.5\ C_{max}$). In the years after the maximum catch, fisheries are classified as either fully exploited ($\geq 0.5\ C_{max}$), overexploited (0.1–$0.5\ C_{max}$), or collapsed ($<0.1\ C_{max}$).

We considered each taxon recorded in 1 of the 18 FAO areas a single stock and included that stock in our analyses if cumulative catches from 1950 through 2007 exceeded 10,000 t. The resulting catch data had 1938 stocks of 855 taxa and amounted to >99.7% of total catches in the FAO catch database. Results were not materially affected when we analyzed only stocks identified to species level (excluding taxa reported at the genus or family level) or stocks with cumulative catches <10,000 t.

Status Reports from FAO

The FAO has monitored the state of the world's fishery stocks since 1974, classifying about 445 stocks every 2 or 3 years (e.g., FAO 2011). The species assessed account for about 80% of global catch. For some species, diverse data are available whereas for others, little information other than catch is available. The FAO balances the goals of using the best available data and assessing stock status worldwide. For some fisheries, the FAO conducts formal model-based assessment, but for others the FAO assesses stock status on the basis of catch rates or surrogate measures of biomass. When data are insufficient for formal assessment, expert judgment and catch trends may be used to assess the state of stocks. Often, information on stock status is provided by regional fishery management organizations and FAO member states. Where expert judgment cannot be obtained and reliable data exist, the FAO carries out its own assessment of stock status. The FAO uses 2 quality-control measures. One is close consultation with local or regional experts on the fishery, and the other is seeking supplementary information when the assessment is based on qualitative diagnostics or unpublished information. The FAO status reports classify fish stocks as underexploited, moderately exploited, fully exploited, overexploited, depleted, and recovering (FAO 2011). In our categorization scheme, we treated the FAO categories of underexploited and moderately exploited as developing stocks and depleted and recovering stocks as collapsed stocks.

Comparison of Stock Status from Catches and from Biomass Data in Stock Assessments

We compiled a set of stock assessments containing time-series data on both catch and biomass for the same fisheries. The catch time series applies to the specific stocks in the stock assessments, which generally differed from the catch time series in the FAO catch database for much larger areas. We applied the catch-based method to the stock-assessment catches and classified stock-assessment biomass relative to B_{MSY}. We classified stocks as developing ($\geq 1.5\ B_{MSY}$), fully exploited (0.5–$1.5\ B_{MSY}$), overexploited (0.2–$0.5\ B_{MSY}$), or collapsed ($<0.2\ B_{MSY}$). The collapsed threshold of $<0.2\ B_{MSY}$ was also used by Worm et al. (2009), and corresponds to 10% of unfished total biomass under a Schaefer (1954) model.

We obtained stock assessments from the RAM Legacy database (Ricard et al. 2010; T.A.B., unpublished data). The extracted data contained information on 234 stocks of 124 species; catches from these stocks summed to 17–25% of global FAO catches in each year from 1970 through 2006. We obtained estimates of B_{MSY} either directly from stock assessments ($n = 126$) or by fitting a Schaefer (1954) model (logistic population growth) to time series of catch and biomass data ($n = 108$), as described elsewhere (Worm et al. 2009; Hutchings et al. 2010).

Collapses of Fisheries on the U.S. West Coast Inferred from Catch Data

Stock assessments are generally conducted only on important commercially harvested species. To explore the accuracy of the catch-based classification of a stock as collapsed, we examined in detail stocks along the West Coast of the United States. We downloaded catch data for the states of Washington, Oregon, and California from the official U.S. national database (NOAA 2010) to obtain catch-based estimates of the number of stocks and percentage of stocks collapsed. The resulting data spanned 1950–2008 and included 244 taxa. We explored the effect of different minimum catch thresholds on inferences based on the catch data, calculated which major stocks were classified as collapsed in 2008 with the catch-based method, and elicited expert opinion from local fisheries scientists on whether these stocks were indeed collapsed, and if not, why.

Test of Catch-Based Method with Simulated Stationary Time Series

We tested the accuracy of the catch-based method in classifying stationary autocorrelated catch series (i.e., simulated numbers fluctuating around a constant mean, with fluctuation magnitude determined by a specified variance). Successful classification of these data by the catch-based method should result in little change in status from the start to the end of the time series. We simulated $i = 1, \ldots, 20{,}000$ individual catch time series for $t = 1, \ldots, T + 10$ years ($C_{i,t}$) with an algorithm modified from Wilberg and Miller (2007):

$$
\begin{aligned}
X_{i,1} &= \varepsilon_{i,t}\sqrt{\frac{\ln(\sigma^2+1)}{1-\rho^2}}, \quad \varepsilon_{i,t} \sim N(0, 1^2),\\
X_{i,t+1} &= \rho X_{i,t} + \varepsilon_{i,t}\sqrt{\ln(\sigma^2+1)}, \qquad (1)\\
C_{i,t} &= \exp\left(X_{i,t} + \ln\mu - 0.5\sqrt{\frac{\ln(\sigma^2+1)}{1-\rho^2}}\right),
\end{aligned}
$$

where $C_{i,t}$ is the simulated catch for time series i in year t, $X_{i,t}$ stores intermediate calculations, σ is a measure of variability, ρ is a measure of autocorrelation, and μ is the stationary mean. To avoid transient effects in the initial years, we generated time series for $T + 10 = 60$ years and deleted the first 10 years of simulated values, resulting in time series of $T = 50$ years). We classified each simulated time series with the catch-based method. To test whether estimated status changed over time (retrospective bias), we ran the simulations for 160 years, again deleting the first 10 years of simulated values, and applied the catch-based method to the first 50 years, the first 100 years, and the full 150 years. If there were no retrospective bias, fishery status at any point in time (we chose 50 years) would not be a function of the year of the analysis.

Results

FAO Catch-Based Status and Status Reports

Global trends in fishery status differed substantially when estimated from catch time series and from FAO status reports (Fig. 1). The catch-based method showed a continuous increase in numbers of collapsed and overexploited fisheries over time, with 57% of fisheries currently overexploited (33%) or collapsed (24%), and none still developing. In contrast, FAO status reports estimated 33% of fisheries currently overexploited (26%) or collapsed (7%) and 15% still developing. The status reports from 1974 through 2008 estimated no trend over time in the percentage of stocks classified as collapsed (mean 9%, range 7–11%) or fully exploited (mean 49%, range 43–53%), but the percentage of overexploited stocks increased and developing stocks decreased.

Comparison of Stock Status from Catches and from Biomass Data in Stock Assessments

When status of the same stocks was estimated from catch and biomass time series obtained from the stock assessment database (Fig. 2), catch-based status was similar to that calculated from the FAO catch database, with 68% of fisheries overexploited (46%) or collapsed (22%) in the most recent year (2006), and none developing (Table 1). When status in 2006 was estimated directly with biomass data, 28% of fisheries were overexploited (15%) or collapsed (13%), whereas 24% were still developing (Table 1). Although the catch-based method estimated increasing percentages of overexploited and collapsed fisheries over time to 68% in 2006, the biomass data demonstrate that the proportion of overexploited and collapsed fisheries decreased from a maximum of 31% in 1994 to 24% in 2006. Thus, the catch-based method overestimated the percentage of overexploited (46% vs. 15%) and collapsed (22% vs. 13%) stocks, incorrectly classified all developing fisheries as either fully exploited, overexploited, or collapsed, and erroneously projected a trend toward overexploitation and collapse.

When summed over all stocks, the status of 57% of stocks was lower for catch-based methods than for biomass data, the status of 5% of stocks was lower for biomass data than catch-based methods, and the status of 38% of stocks was similar for both methods. Of the fisheries classified as collapsed by catch-based methods, biomass data showed 41% were actually collapsed, 12% were overexploited, 34% were fully exploited, and 12% were developing (Table 1).

Selected stocks illustrate the reasons why status estimated from catch-based methods differed from status estimated from biomass data (Fig. 3). For Bering Sea rougheye rockfish (*Sebastes aleutianus*) (Fig. 3a) and Cape horse mackerel (*Trachurus trachurus capensis*) (Fig. 3b), a peak in early catches followed by variable

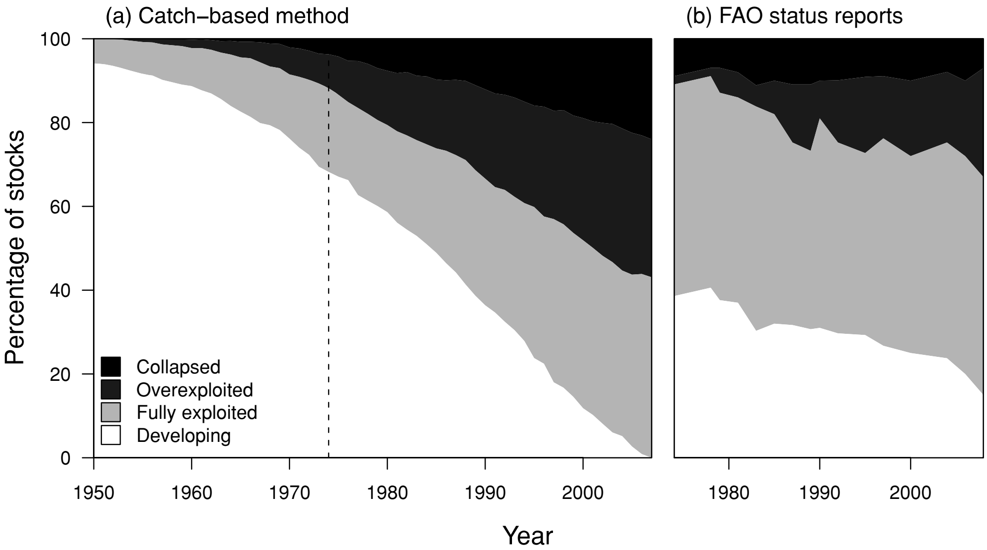

Figure 1. Trends in the status of global fisheries stocks on the basis of (a) the catch-based method applied to catch data from the Food and Agriculture Organization of the United Nations (FAO) and (b) FAO status reports. The vertical dashed line in (a) corresponds to the first year of the FAO status reports.

or low catches suggests stock collapse, whereas the actual biomass of both species was only slightly affected by fishing and remained high. For canary rockfish (*Sebastes pinniger*) on the U.S. West Coast (Fig. 3c), catches from 2000 onward were extremely low, which suggests stock collapse. In this situation, allowable catches were decreased and there were extensive area closures that resulted in substantial biomass increases. Conversely, fairly constant catches of summer flounder (*Paralichthys dentatus*) on the U.S. East Coast and New Zealand rock lobster (*Jasus edwardsii*) in area CRA5 (Figs. 3d-e) masked biomass collapses of both these species and the subsequent recovery of both stocks to high levels. The catch-based method also did not show Pacific chub mackerel (*Scomber japonicus*) as collapsed in the 1960s (Fig. 3f) because collapses can only occur in years after the maximum catch has been recorded, whereas this stock collapsed in the 1960s prior to a recovery in biomass and peak catches in the 1980s. Both methods estimated that Atlantic cod (*Gadus morhua*) in

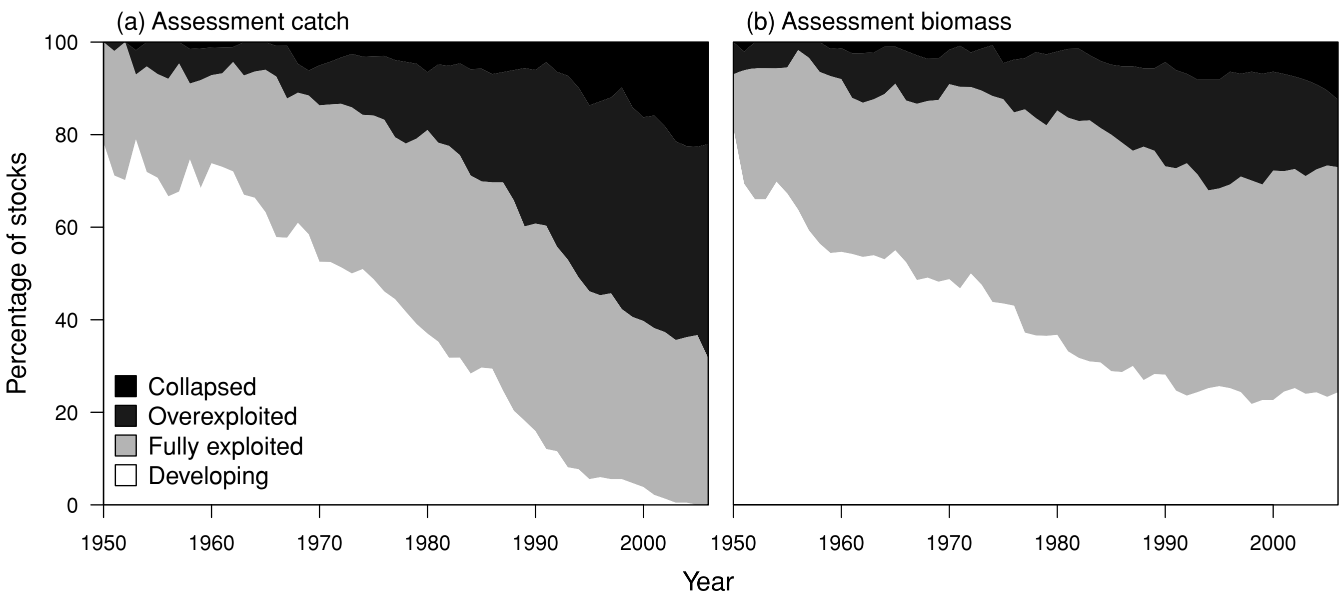

Figure 2. Trends in status of fisheries stocks on the basis of stock-assessment time series of (a) catches and (b) biomass for the same set of stocks (data from the RAM Legacy database; n = *234 stocks).*

Table 1. Comparison of catch-based and biomass-based fisheries stock classification.*

	Catch-based method				
Biomass-based method	*developing (%)*	*fully exploited (%)*	*overexploited (%)*	*collapsed (%)*	*total*
Developing	0	35	22	12	24
Fully exploited	0	60	48	34	49
Overexploited	0	5	22	12	15
Collapsed	0	0	7	41	13
Total	0	31	46	22	100

**Data come from stock assessments containing both catch and biomass data in 2006 in the RAM Legacy database (n = 183). The catch-based method classifies stocks on the basis of catch relative to maximum catch (C_{max}) and whether the year is before or after the year of peak catch: developing (before peak year, <0.5 C_{max}); fully exploited (≥0.5 C_{max}); overexploited (after peak year, 0.1–0.5 C_{max}); collapsed (after peak year, <0.1 C_{max}). The biomass-based method classifies stocks relative to the biomass that produces maximum sustainable yield (B_{MSY}): developing (≥1.5 B_{MSY}); fully exploited (0.5–1.5 B_{MSY}); overexploited (0.2–0.5 B_{MSY}); collapsed (<0.2 B_{MSY}). Due to rounding, column totals do not sum to 100%.*

area 3PN4RS, haddock (*Melanogrammus aeglefinus*) on Georges Bank, and Atlantic cod in the North Sea were collapsed (Figs. 3g-i). There was a lag in assessment of subsequent recovery in Georges Bank haddock on the basis of catch data, which estimated this fishery as collapsed since the 1990s despite increases in biomass to record high levels at present (Fig. 3h). Continued low haddock catches are due to the inability of the fishery to harvest the total allowable catch because of regulations to protect bycatch species.

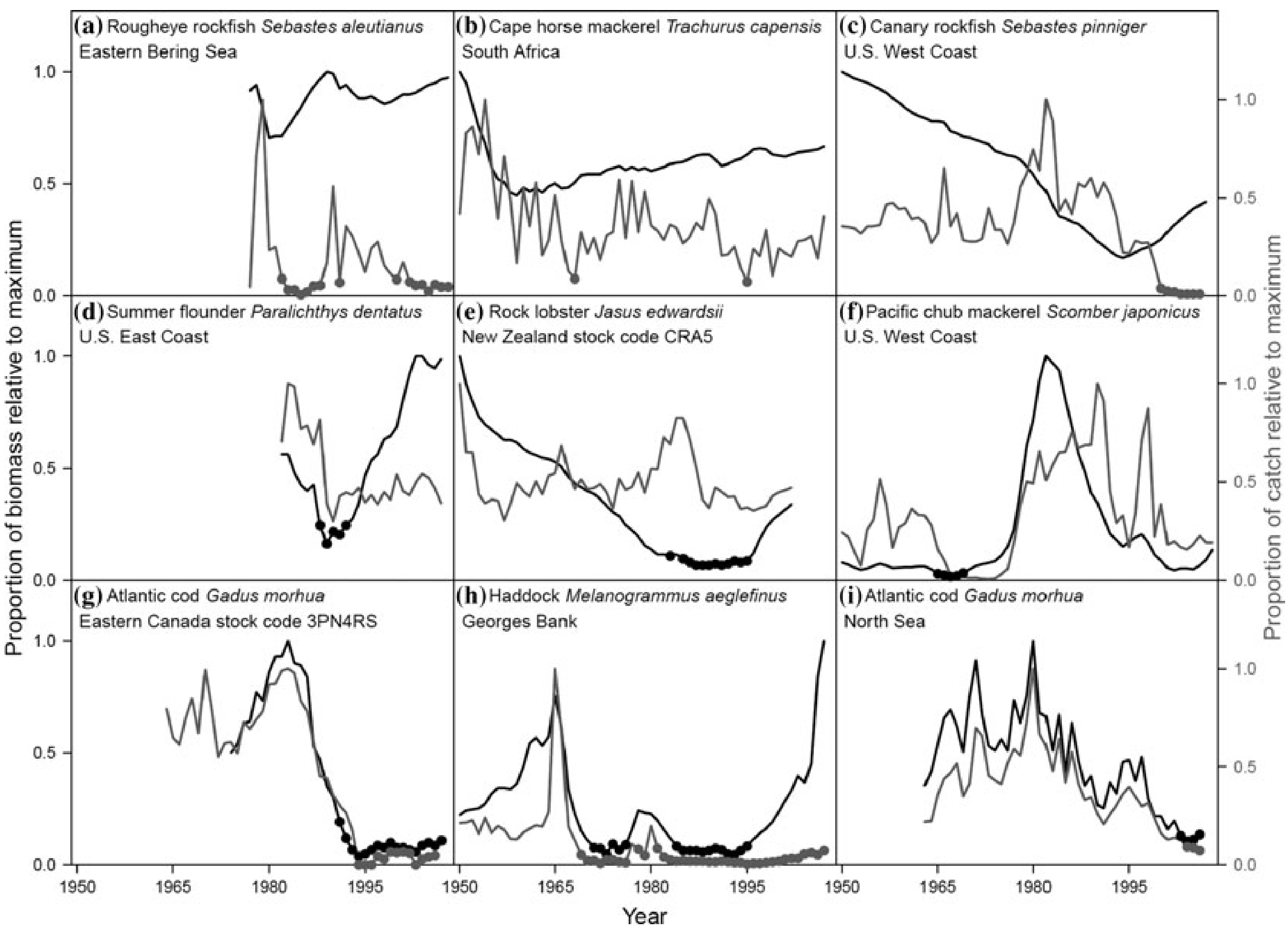

Figure 3. Time series of catches (gray) and biomass (black) for selected fisheries stocks that were classified as collapsed (solid circles) by the catch-based method only (a–c), by the biomass-based method only (d–f), and by both methods (g–i) (data from stock assessments in the RAM Legacy database).

Collapses of Fisheries on the U.S. West Coast Inferred from Catch Data

Application of the catch-based method to official data on catches for the U.S. West Coast revealed that estimated status was dependent on the size of the stock (as measured by summed catches from 1950 through 2007). For a catch threshold of 1 t (i.e., all fisheries with $\geq$1 t total catches from 1950 through 2007) there were 221 stocks (66% collapsed), for 100 t there were 177 stocks (60% collapsed), and for 10,000 t there were 70 stocks (49% collapsed). For the 34 collapsed stocks that were above the 10,000 t threshold, these classifications were often erroneous (Supporting Information). Of these 34 stocks, only 3 were definitely collapsed and another 6 were possibly collapsed but information was insufficient to determine their status. False identifications of collapses in the remaining 74% of stocks occurred when catches recorded at higher taxonomic levels (e.g., genus, family, order) were subsequently split to the species level (7 stocks); when management actions reduced fishing to rebuild stocks of other species (7 stocks); when the market for the species diminished (6 stocks); or for other reasons (5 stocks). In other words, at most 26% of the stocks classified as collapsed on the basis of catch data were actually collapsed.

Test of Catch-Based Method with Simulated Stationary Time Series

The simulated time series were stationary (constant mean over time); thus, we expected average estimated stock status to be constant over time. Nevertheless, the catch-based method resulted in decreasing numbers of developing stocks and increasing numbers of overharvested and collapsed stocks (Fig. 4). When the time series were examined, maximum catch increased over time, and therefore the average ratio of catch to maximum catch decreased. Thus, over time, the probability increases that the current catch will be <10% of the maximum catch. Additionally, low catches recorded prior to the peak year (in each time series) could be classified only as developing, whereas low catches recorded after the peak year could be classified only as overexploited or collapsed. The position of the peak year within the 50-year time series is random; thus, the probability of a year being the peak or after the peak increased linearly from 0.02 (1/50) in the first year to 1.00 in the final year. In other words, it was impossible for catches to be collapsed in the first year or developing in the final year. When the same time series was extended to 100 years or 150 years (Supporting Information), however, the estimated status at year 50 contained many more developing fisheries and many fewer overexploited and collapsed fisheries than when status was estimated from a 50-year time series.

Discussion

Debate continues over the current and potential future status of global fisheries (Beddington et al. 2007; Hilborn 2007b, 2007c). Estimates of fishery status from the catch-based method suggest that around 30% of all fisheries are collapsed, 40% more are overexploited, and the percentage of collapsed and overexploited fisheries will increase over time (e.g., Worm et al. 2006; Pauly 2007, 2008). If these estimates are robust, fished stocks will soon contribute little to species richness or ecosystem function, and these collapses will have major social and economic effects on coastal communities. Such effects have already been documented in some areas, such as the northwestern Atlantic. Nevertheless, estimates of fishery status obtained from biomass data and fisheries stock assessments differ from those derived from catch data (Worm et al. 2009; Hutchings et al. 2010; FAO 2011). We found that biomass data from scientific stock assessments indicate a much smaller percentage of fisheries (28%) are overexploited (15%) or collapsed (13%). Our results suggest fisheries management has led to stock stabilization and in some regions recovery of fished populations (Hilborn 2007c; Worm et al. 2009).

There are 2 main reasons why the catch-based estimates are inaccurate. First, catches often do not track changes in biomass; thus, collapses estimated on the basis of catch data can result from a variety of mechanisms other than an actual stock collapse, as shown for the Gulf of Mexico (de Mutsert et al. 2008) and the U.S. West Coast (this study). In the Gulf of Mexico, the catch-based method estimated that the majority of stocks (80%) had collapsed at least once, whereas biomass data showed that only 21% had collapsed at least once (de Mutsert et al. 2008). In the Gulf of Mexico, false detections of collapses resulted from inclusion of taxa that were not directly targeted and for which catches therefore were sporadic; taxa that mostly occurred outside the Gulf of Mexico; and taxa for which there was a major shift in allocation from commercial to recreational fisheries that resulted in lower reported commercial catches (de Mutsert et al. 2008). For fisheries on the U.S. West Coast, catch-based methods suggested 49% of stocks were collapsed, whereas biomass data showed 4–17% of stocks were collapsed (upper limit obtained by categorizing stocks with insufficient information as collapsed). In this case, false detections of collapses occurred when time series for a taxon ended in the year when higher level taxa were split into species; when management actions to rebuild overexploited rockfish species reduced fishing of other species; and when the market for a species diminished. Thus, many mechanisms other than the collapse of a fish population can cause lower catches, including regulations, markets, exclusion of distant water fleets, changes in oil prices, political changes, and shifts in the

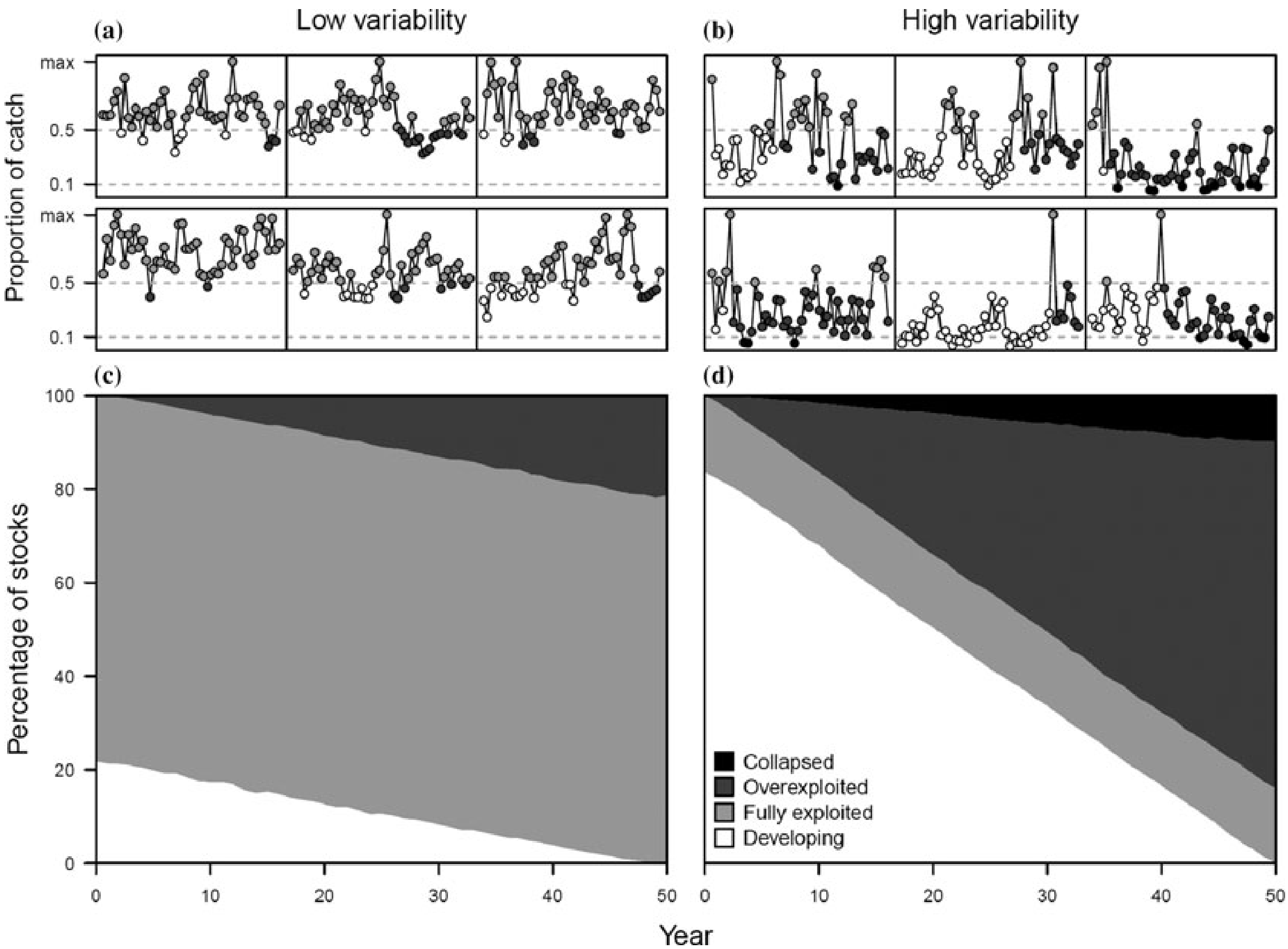

Figure 4. Estimated status of stocks from simulated catch trajectories with (a, c) low variability ($\sigma = 0.2$) and (b, d) high variability ($\sigma = 0.6$). Autocorrelated catch series ($\rho = 0.5$) fluctuate randomly around a stationary mean. Plots (a, b) show 6 trajectories from the 20,000 simulations, and plots (c, d) show the estimated status from all simulations. The legend applies to shading in all panels.

geographic distribution of the population (e.g., Hilborn 2007a; Longhurst 2007; de Mutsert et al. 2008).

Not only can catch data be misleading, but the catch-based method is biased toward assessing stocks as developing in early years and as collapsed in later years, as shown when we applied this method to simulated catches fluctuating around a mean value. One would expect analysis of stationary catch series to show no trend, but we observed a steady decline in percentages of developing fisheries, reaching 0% in the final year, and a steady increase over time in overexploited and collapsed fisheries, from 0% in the first year. This pattern arises partly because over time the maximum catch from the start year to the current year increases in any fluctuating but stationary time series (Wilberg & Miller 2007). Additionally, the year of the peak catch determines whether fisheries with catches that are low relative to the maximum are classified as developing (years preceding the peak year) or collapsed (years after the peak year). Under the assumptions of the catch-based method, it is impossible for a fishery to be classified as collapsed in the first year or as developing in the final year. The decreasing proportions of developing fisheries and increasing proportions of collapsed fisheries over time are identical whether the catch-based method is applied to stationary time series or to catch data (e.g., Mullon et al. 2005; Worm et al. 2006; Pauly 2007).

Thus, we think increases in percentage of collapses over time estimated from catch data should be disregarded unless validated with knowledge about biomass trends, market conditions, regulations, and other factors that can result in apparent collapses. For example, in the 1960s, Pacific chub mackerel (*Scomber japonicus*) were clearly collapsed (Fig. 3f): biomass and catches were close to zero. Nevertheless, the catch-based method classified this stock as developing during the 1960s because the low catches occurred in years before the peak catches in the 1980s. Conversely, rougheye rockfish

(*Sebastes aleutianus*) in the Bering Sea (Fig. 3a) were classified as collapsed because the spike in catches was early in the time series, although catches had little effect on the biomass of this lightly harvested stock. Therefore, overall stock status for this stock estimated from catch data would always appear worse over time, regardless of the underlying trend in biomass.

Biomass data are available for a limited number of regions because these data come from fisheries stock assessments that disproportionately represent industrial fisheries in developed countries. The FAO status reports assess a much broader range of fisheries, yet are also most reliable for developed countries. Trends estimated from the catch-based method were nearly identical whether applied to catch data from stock assessments or to global FAO catch data, which suggests the subset of stocks for which we had stock assessments could be similar in status to the stocks contained in the global FAO catch data.

Estimates of fishery status on the basis of biomass data and the FAO assessments of global fisheries contradict catch-based estimates that the percentage of overexploited and collapsed fish stocks is increasing (e.g., Worm et al. 2006; Pauly 2007, 2008). Instead, our results are similar to those of studies in which biomass data were used (Worm et al. 2009; Hutchings et al. 2010; FAO 2011): recent stability in status of most fisheries, about a quarter of global fisheries overexploited or collapsed, another quarter still developing, and about half fully exploited. Although the current global status of fisheries is stable, there is low likelihood, at a global extent, of increased catches from marine fisheries in the future (e.g., Watson & Pauly 2001; Hilborn et al. 2003; Sethi et al. 2010). To better understand the status of stocks, efforts to monitor biomass trends directly need to be maintained and expanded. There remain many overexploited and collapsed fish stocks, and reductions in harvest rates are necessary for these stocks to recover.

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Supporting Information

A list of the U.S. West Coast fishery stocks classified as collapsed by the catch-based method, a determination of whether these stocks were actually collapsed, and an example of how the catch-based method estimates stock status as worse in the most recent years are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

Literature Cited

Agnew, D. J., J. Pearce, G. Pramod, T. Peatman, R. Watson, J. R. Beddington, and T. J. Pitcher. 2009. Estimating the worldwide extent of illegal fishing. Public Library of Science ONE **4**: DOI:10.1371/journal.pone.0004570.

Baum, J. K., and B. Worm. 2009. Cascading top-down effects of changing oceanic predator abundances. Journal of Animal Ecology **78:**699–714.

Beddington, J. R., D. J. Agnew, and C. W. Clark. 2007. Current problems in the management of marine fisheries. Science **316:**1713–1716.

Begg, G. A., K. D. Friedland, and J. B. Pearce. 1999. Stock identification and its role in stock assessment and fisheries management: an overview. Fisheries Research **43:**1–8.

Branch, T. A. 2008. Not all fisheries will be collapsed in 2048. Marine Policy **32:**38–39.

Cury, P., A. Bakun, R. J. M. Crawford, A. Jarre, R. A. Quiñones, L. J. Shannon, and H. M. Verheye. 2000. Small pelagics in upwelling systems: patterns of interaction and structural changes in "wasp-waist" ecosystems. ICES Journal of Marine Science **57:**603–618.

de Mutsert, K., J. H. Cowan Jr., T. E. Essington, and R. Hilborn. 2008. Reanalyses of Gulf of Mexico fisheries data: landings can be misleading in assessments of fisheries and fisheries ecosystems. Proceedings of the National Academy of Sciences U.S.A. **105:**2740–2744.

Dulvy, N. K., J. D. Metcalfe, J. Glanville, M. G. Pawson, and J. D. Reynolds. 2000. Fishery stability, local extinctions, and shifts in community structure in skates. Conservation Biology **14:**283–293.

FAO (Food and Agriculture Organization of the United Nations). 2011. The state of world fisheries and aquaculture 2009. FAO, Rome.

Froese, R., and K. Kesner-Reyes. 2002. Impact of fishing on the abundance of marine species. ICES paper CM 2002/L **12**.

Garcia, S. M., and R. J. R. Grainger. 2005. Gloom and doom? The future of marine capture fisheries. Philosophical Transactions of the Royal Society of London B **360:**21–46.

Hilborn, R. 2007a. Biodiversity loss in the ocean: how bad is it? Science **316:**1281–1282.

Hilborn, R. 2007b. Moving to sustainability by learning from successful fisheries. Ambio **36:**296–303.

Hilborn, R. 2007c. Reinterpreting the state of fisheries and their management. Ecosystems **10:**1362–1369.

Hilborn, R. 2010. Pretty good yield and exploited fishes. Marine Policy **34:**193–196.

Hilborn, R., and K. Stokes. 2010. Defining overfished stocks: have we lost the plot? Fisheries **35:**113–120.

Hilborn, R., T. A. Branch, B. Ernst, A. Magnusson, C. V. Minte-Vera, M. D. Scheuerell, and J. L. Valero. 2003. State of the world's fisheries. Annual Review of Environment and Resources **28:**359–399.

Hutchings, J. A., C. Minto, D. Ricard, J. K. Baum, and O. P. Jensen. 2010. Trends in the abundance of marine fishes. Canadian Journal of Fisheries and Aquatic Sciences **67:**1205–1210.

ICES (International Council for the Exploration of the Sea). 2010. Report of the Arctic Fisheries Working Group. ICES CM 2010/ACOM:05. ICES, Copenhagen, Denmark.

IUCN (International Union for Conservation of Nature). 2010. IUCN Red List of threatened species. Version 2010.2. IUCN, Gland, Switzerland. Available from www.iucnredlist.org (accessed August 2010).

Kelleher, K. 2005. Discards in the world's marine fisheries. An update. FAO Fisheries Technical Paper **470**.

Longhurst, A. 2007. Doubt and uncertainty in fishery science: are we really headed for a global collapse of stocks? Fisheries Research **86:**1–5.

Larkin, P. A. 1977. An epitaph for the concept of maximum sustained yield. Transactions of the American Fisheries Society **106:**1–11.

Mace, P. M. 2001. A new role for MSY in single-species and ecosystem approaches to fisheries stock assessment and management. Fish and Fisheries **2:**2–32.

Marris, E. 2010. Researchers on a mission. Nature **466:**784–786.

McClanahan, T. R., and B. Kaunda-Arara. 1996. Fishery recovery in a coral-reef marine park and its effect on the adjacent fishery. Conservation Biology **10:**1187–1199.

Mullon, C., P. Fréon, and P. Cury. 2005. The dynamics of collapse in world fisheries. Fish and Fisheries **6:**111–120.

Myers, R. A., J. K. Baum, T. D. Shepherd, S. P. Powers, and C. H. Peterson. 2007. Cascading effects of the loss of apex predatory sharks from a coastal ocean. Science **315:**1846–1850.

NOAA (National Oceanic and Atmospheric Administration). 2010. Annual commercial landings statistics. NOAA, Washington, D.C. Available from http://www.st.nmfs.noaa.gov/st1/commercial/landings/annual_landings.html (accessed January 2010).

Pauly, D. 2007. The *Sea Around Us* project: documenting and communicating global fisheries impacts on marine ecosystems. Ambio **34:**290–295.

Pauly, D. 2008. Global fisheries: a brief review. Journal of Biological Research-Thessaloniki **9:**3–9.

Pauly, D., et al. 2008. Fisheries in Large Marine Ecosystems: descriptions and diagnoses. Pages 23–40 in K. Sherman and G. Hempel, editors. The UNEP large marine ecosystems report: a perspective on changing conditions in LMEs of the world's regional seas. United Nations Environment Programme, Nairobi, Kenya.

Punt, A. E., and A. D. M. Smith. 2001. The gospel of maximum sustainable yield in fisheries management: birth, crucifixion and reincarnation. Pages 41–66 in J. D. Reynolds, G. M. Mace, K. H. Redford, and J. G. Robinson, editors. Conservation of exploited species. Cambridge University Press, Cambridge, United Kingdom.

Reiss, H., G. Hoarau, M. Dickey-Collas, and W. J. Wolff. 2009. Genetic population structure of marine fish: mismatch between biological and fisheries management units. Fish and Fisheries **10:**361–395.

Ricard, D., C. Minto, J. K. Baum, and O. P. Jensen. 2010. RAM Legacy: a stock assessment database for exploited marine species. Department of Biology, Dalhousie University, Halifax, Nova Scotia. Available from http://fish.dal.ca (accessed July 2010).

Schaefer, M. B. 1954. Some aspects of the dynamics of the population important to the management of the commercial marine fisheries. Inter-American Tropical Tuna Commission Bulletin **1:**25–56.

Sethi, S. A., T. A. Branch, and R. Watson. 2010. Fishery development patterns are driven by profit but not trophic level. Proceedings of the National Academy of Sciences U.S.A. **107:**12163–12167.

Watling, L., and E. A. Norse. 1998. Disturbance of the seabed by mobile fishing gear: a comparison to forest clearcutting. Conservation Biology **12:**1180–1197.

Watson, R., and D. Pauly. 2001. Systematic distortions in world fisheries catch trends. Nature **414:**534–536.

Wilberg, M. J., and T. J. Miller. 2007. Comment on "Impacts of biodiversity loss on ocean ecosystem services." Science **316:**1285b. Available from http://www.sciencemag.org/content/316/5829/1285.2.full.pdf (accessed May 2007).

Worm, B., et al. 2006. Impacts of biodiversity loss on ocean ecosystem services. Science **314:**787–790.

Worm, B., et al. 2009. Rebuilding global fisheries. Science **325:**578–585.

Zeller, D., and D. Pauly. 2005. Good news, bad news: global fisheries discards are declining, but so are total catches. Fish and Fisheries **6:**156–159.