Comment on "Impacts of Biodiversity Loss on Ocean Ecosystem Services"

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Worm *et al*. (Research Articles, 3 November 2006, p. 787) reported an increasing proportion of fisheries in a "collapsed" state. We show that this may be an artifact of their definition of collapse as a fixed percentage of the maximum and that an increase in the number of managed fisheries could produce similar patterns as an increase in fisheries with catches below 10% of the maximum.

Based on an analysis of commercial catch data from 64 large marine ecosystems (LMEs) spanning from 1950 to 2003, Worm *et al*. (*1*) reported that an increasing proportion of fisheries were in a "collapsed" state. Extrapolation of these data further suggested the potential for the world's fisheries to collapse by 2048. We contend that their analysis and subsequent projections are inappropriate because the reported pattern of increasing prevalence of collapsed fisheries is largely an artifact of their definition of collapse. Furthermore, the analysis does not account for the increase in the number of stocks managed.

Worm *et al*. (*1*) compared the catch of each species within an LME in each year to the maximum catch of that species over the entire time series. They defined a fishery as collapsed in a single year if the observed catch occurred after the maximum catch and was less than 10% of the recorded maximum catch. They then fit a trend line to the proportion of collapses over time and found a significant increase. Implicit in Worm *et al*.'s analysis is the null hypothesis that the proportion of collapses should not increase over time if catches are not decreasing. However, a notably similar pattern of increasing collapses to that shown in figure 3A in (*1*) can be generated by applying their definition of collapse to stationary (constant mean and variance) time series of random numbers (see Fig. 1A). To produce appropriate expectations for the null model (i.e., evaluate consequences of the Worm *et al*. definition of collapse), we generated 5000 time series of random numbers, 34 to 54 years long (*2*), from an autocorrelated log-normal process with a coefficient of variation (CV) of 80% and an autocorrelation coefficient of 0.75 (*3*). These time series of random numbers represent catch time series for which catches are not declining on average. Our analyses make no assumptions about underlying population dynamics or fishing effort. Rather, we assume only that catch data from a non-trending fishery are log-normally distributed, with a constant mean and variance. We used the same definition of collapse as Worm *et al*. and scored a time series as collapsed in a given year if the value was less than 10% of the observed maximum and the value occurred after the maximum.

This analysis indicates that the null expectation of applying the Worm *et al*. definition is an increasing proportion of collapsed time series (i.e., below 10% of the maximum). This occurs because the expected value of the maximum is an increasing function of the length of a time series (*4*). The rate of increase in the proportion of collapsed time series depends on the CV of the time series. The curvature in the proportion of collapsed time series occurs because the time series begin at different times. Thus, about half of the observed collapses reported by Worm *et al*. in (*1*) are expected simply by chance in randomly generated time series with fixed mean values (without decreasing trends). Increasing the CV to 110% produced a similar magnitude of proportions of collapsed stocks to Worm *et al*. (Fig. 1B). Simply stated, applying Worm *et al*.'s definition of collapse produces an increasing pattern of collapses over time even when time series are not declining on average. Thus, their finding of a significant increase in collapses over time could be due to chance rather than to declining populations.

By comparing all subsequent catches to the maximum, Worm *et al*. seem to suggest that maximum historical catch represents an achievable and sustainable target for fisheries management. However, maximum historical catches are not likely to be sustainable and are therefore not ideal measures of sustainable ecosystem services or targets for fisheries management. Fisheries brought under management to reduce overexploitation would tend to have reductions in catch, which Worm *et al*.'s approach could erroneously categorize as being collapsed but which in fact represent an improvement in fisheries management. Without examining each, or at least many, of the time series for the proportion that have come under management, it is impossible to determine whether decreases in catch are due to management, overfishing, or other causes.

We believe people should be concerned about conserving the world's marine resources, and we are not arguing that some fisheries have not or are not collapsing. However, the analysis of Worm *et al*. may exaggerate the magnitude of the problem; ad hoc measures of overexploitation need to be evaluated to determine whether patterns are actually due to putative causes.

References and Notes

1. B. Worm *et al.*, *Science* **314**, 787 (2006).
2. We staggered the start time of the time series to mimic staggered entry of fisheries, where 5% of the time series were started each year until all of the time series were active in year 20. If our analysis is scaled so that year 0 is

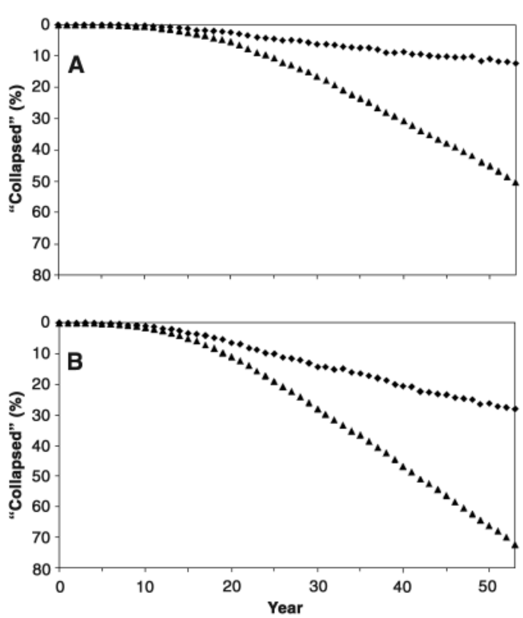

Fig. 1. Percentage of 5000 time series of randomly generated numbers that are below 10% of the maximum (collapsed) after the maximum has been reached (diamonds, percentage by year; triangles, cumulative percentage). Time series were generated from log-normal distributions with constant means, autocorrelation coefficients of 0.75, and a CV of (**A**) 80% and (**B**) 110%. Five percent of the time series begin in each year through year 20.

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1950, the average start date of a fishery is 1960. Worm *et al*. (*1*) found that the average time of a fishery starting in their analysis was 1962.

3. Catch data are often log-normally distributed. Chesapeake Bay fisheries, for example, had a median CV of 82% (*5*), and the median CV for fisheries aggregated at the ocean level was 72% (*6*), which is probably low relative to the variability of catch in the large marine ecosystems analyzed by Worm *et al*. (*1*), because catches were aggregated over larger areas. Generally, most fish populations are not thought to vary naturally by this amount (i.e., CVs of abundance would generally be lower), and some of this variability may be due to trends in catch rather than randomness. Our simulations used a mean of 1000, but the mean does not affect the results. Similar increasing patterns in the proportion of time series below a fixed threshold were obtained with time series of independent observations and with normal distributions, but the magnitude of the increase in collapses over time depended on the distribution, CV, and autocorrelation coefficient, with higher CVs and lower autocorrelation coefficients having a higher rate of increase.
4. The cumulative distribution function (CDF) for the maximum of a series of independent, identically distributed (iid) random variables is $F_{\max}(y) = [F(y)]^n$, where F_{max} is the CDF of the maximum of a series of n iid random variables with a CDF F. For any specified F, the longer the time series and higher the CV, the higher the maximum is likely to be, making it more likely that much of the time series will be less than a fixed percentage of the maximum. This is why more time series are scored as collapsed under the scenario with a higher CV. The maximum of a stationary time series has an equal probability of occurring in any single year. The overall increasing trend in collapses is due to patterns of when the maximum occurs in each time series because, by their definition, collapses can only occur after the maximum has been reached. Therefore, the probability of scoring a time series as collapsed is much higher at the end of a time series than at the beginning.
5. National Oceanic and Atmospheric Administration Annual Commercial Landings Statistics, www.st.nmfs.gov/st1/commercial/landings/annual_landings.html.
6. United Nations Food and Agriculture Organization Fishery Information, Data and Statistics Unit (FAO-FIDI, Rome, 2004), *Collation, Analysis and Dissemination of Global and Regional Fishery Statistics. FI Programme Websites*. Updated Monday, Oct. 9, 09:51:18 CEST 2006. Available through the Fisheries Global Information System (FIGIS) from www.fao.org/figis/servlet/static?dom=org&xml=FIDI_STAT_org.xml.
7. We thank D. Secor, J. Bence, G. Nesslage, and two anonymous reviewers for comments that improved this manuscript. This is contribution number 4090 of the University of Maryland Center for Environmental Science Chesapeake Biological Laboratory.

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