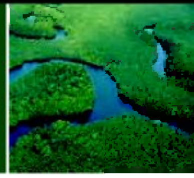

LETTERS

edited by Etta Kavanagh

Biodiversity Loss in the Ocean: How Bad Is It?

THE RESEARCH ARTICLE "IMPACTS OF BIODIVERSITY LOSS ON OCEAN ECOSYSTEM SERVICES" BY B. Worm *et al.* (3 Nov. 2006, p. 787) projects that 100% of seafood-producing species stocks will collapse by 2048. The projection is inaccurate and overly pessimistic.

Worm *et al.* define "collapse" as occurring when the current year's catch is <10% of the highest observed in a stock's time series. However, fish catch is rarely an adequate proxy for fish abundance, particularly for rebuilding stocks under management. A variety of biological, economic, and social factors and management decisions determine catches; low catches may occur even when stocks are high (e.g., due to low fish prices or the effects of restrictive management practices), and vice versa. The inadequacy of Worm *et al.*'s abundance proxy is illustrated by the time series of data for Georges Bank haddock (*Melanogrammus aeglefinus*). The highest catch for haddock occurred in 1965 at 150,362 tons (*1*). This catch occurred during a period of intense domestic and international fishing (*1*). In 2003, haddock catch was 12,576 tons, or 8% of the time series maximum. Under the Worm *et al.* definition, the stock would be categorized as collapsed in 2003. However, stock assessment data (*1*) estimate the total magnitude of the spawning biomass in 2003 to be 91% of that in 1965. Comparing the estimate of spawning stock biomass in 2003 to the level producing maximum sustainable yield (MSY), the stock was not even being overfished in 2003 (*2*).

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Because adequate stock abundance measures exist for only a portion of world fish stocks, this purported worldwide meta analysis required using data that represent the lowest common denominator of data—the total magnitude of the catch. However, if the catch ratio metric is so prone to misrepresentation of the true status of populations, as illustrated above, a synthesis of world fisheries based on these data is equally flawed. At the least, the authors should have conducted a calibration of their stock collapse metric with more complete stock abundance data available from the many worldwide sources where such data exist.

The extrapolation of their stock collapse metric to 100% by 2048 does not agree with the recent history of stock status, particularly in the United States. National Marine Fisheries Service data indicate that for 2005, about 26% of stocks were classified as "overfished" (*2*). For most stocks, overfished status occurs when the population size drops below 50% of the population required to support MSY. Even under this more conservative definition of stock reduction, the proportion of stocks classified as overfished is actually declining slightly; in 2004, 28% of stocks were so classified. Extrapolating a 2% decrease in the number of overfished stocks per year leads to a prediction that no stocks in U.S. jurisdiction would be overfished by the year 2018. However, such a meaningless projection does not incorporate a large number of complex factors, such as the differing life histories of species, impacts of variable ocean conditions on recruitment, and the increasing effectiveness of management measures, all significant shortcomings of the prediction method and data of Worm *et al.*

To address persistent overfishing issues, in December 2006 the U.S. Congress passed and the National Marine Fisheries Service is now implementing provisions of the Magnuson Stevens Fishery Conservation and Management Act Reauthorization Act (MSRA). The law mandates that overfishing be eliminated for all federally managed species by 2010 and that science-based annual catch limits will be calculated for all of the 532 stocks currently under regulation.

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THE PROJECTION FROM B. WORM *ET AL.* ("Impacts of biodiversity loss on ocean ecosystem services," 3 Nov. 2006, p. 787) that all of the world's wild fish will be collapsed by 2048 attracted international media attention. Such a projection is fallacious and inappropriate to appear in a scientific journal. The use of catch data to indicate stock status is misleading for several reasons. Catch may be low due to management restrictions,

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and healthy, well-managed stocks may be classified as collapsed. Many stocks naturally fluctuate dramatically in abundance, and as the length of the time series of data becomes longer, the chance that any particular low in abundance will cause catches to fall below 10% of the historical high catch becomes greater. Finally, many examples of dramatic declines in catch can result from political or market forces, such as declaration of the 200-mile zone. Worm *et al.* should have demonstrated that their index of collapse corresponded to stock abundance–based indices. This test clearly fails for U.S. fisheries, where the proportion of stocks classified as overfished is declining, not increasing.

Furthermore, the Worm *et al.* analysis fails to recognize that jurisdictions such as the United States, New Zealand, Iceland, and Australia have good fisheries management systems where the proportion of stocks that are overfished is declining. All of the fish will not be gone by 2048. Most importantly, Worm *et al.* advocate Marine Protected Areas as a way to rehabilitate collapsed fisheries. None of the well-managed jurisdictions use Marine Protected Areas as essential parts of their management strategy. Methods that have been shown to work in well-managed countries involve eliminating the competitive nature of fisheries by incentives and application of conservative harvest levels (*1*, *2*).

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IN THEIR IMPORTANT RESEARCH ARTICLE ON THE precarious condition of ocean ecosystems ("Impacts of biodiversity loss on ocean ecosystem services," 3 Nov. 2006, p. 787), B. Worm *et al.* introduced some confusing terminology that needs to be clarified. Although the term "biodiversity" is sometimes used to mean the general abundance of life, in publications on conservation biology, it is almost always used to indicate the relative number of species present in a given area or ecosystem. The conservation problem that the authors intended to emphasize is that the populations of many commercially valuable species have been reduced to the point that they no longer play important roles in the communities to which they belong. Although the phrase "population loss" may provoke less public reaction than "biodiversity loss," it would have been more accurate.

Additional confusion was introduced when it was stated that records over the past millennium revealed a rapid decline of native species diversity since the onset of industrialization. Surely, this statement, and the specific reference to extinctions (100% decline) of some species, must refer to some very limited localities. A thorough study of historic extinctions in the sea published in 1999 (*1*) showed that no fish species and only four or five invertebrate species had become extinct. Although many valuable species have suffered severe declines, they are still with us and may yet be saved. The authors also observed that the number of species invasions over time coincided with the loss of native biodiversity. But my own research on this subject has shown that almost all invasions have not resulted in the loss of native species and have produced gains in biodiversity (*2*). Increases in species diversity generally produce an increase in ecosystem services.

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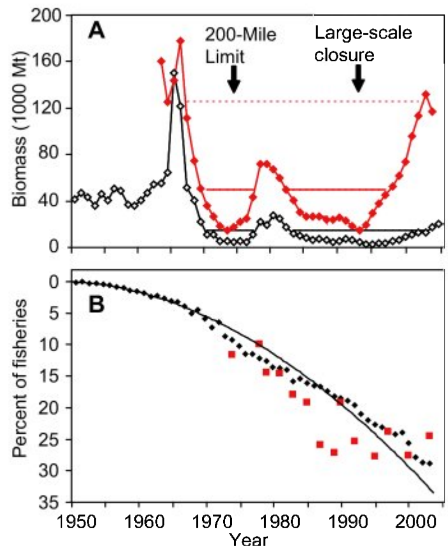
Response

MURAWSKI AND COLLEAGUES STATE THAT OUR assessment of the impacts of global marine biodiversity loss is overly pessimistic. They imply that management interventions are likely to reverse current trends of overfishing, and that the U.S. National Marine Fisheries Service (NMFS) has already met that goal. They cite Georges Bank haddock as an example and contest that catch metrics (as used in our global analysis) are sufficient to track the status of this particular fish stock and possibly others. We agree that precise biomass data are preferable, but these are rarely available. Here, we illustrate that catches are a good proxy of the status of haddock, although there can be a short delay in detecting recovery under intense management. While NMFS's own data show that full recovery is still uncommon (<5% of overfished stocks) (*1*), we strongly agree that destructive trends can be turned around and that rebuilding efforts need to be intensified to meet that goal. But we must not miss the forest for the trees: Continuing focus on single, well-assessed, economically viable species will leave most of the ocean's declining biodiversity under the radar.

The Georges Bank example illustrates well how intensive management can reverse the loss of marine biodiversity and ecosystem services (see figure) and was in fact included in our own recovery analysis. Haddock stocks collapsed from foreign overfishing in the 1960s and from domestic fleets in the 1980s. The first collapse was reversed by establishing a 200-mile Exclusive Economic Zone in 1977, the second by an emergency closure of half of the fishing grounds in 1994. Haddock biomass increased promptly in both cases, and catches followed with a 1- to 6-year delay (panel A of figure), indicating that fishing became again economically viable. The importance of large-scale protected areas for such unprecedented recovery is well documented (*2*).

The definition of "collapse" we used refers to a loss in catches of 90% below the historic maximum (*3*). According to this metric, the Georges Bank haddock stock, or more precisely the ecosystem service it supplied, collapsed from 1970 to 1977 and 1983 to 2003 (panel A of figure). Using stock assessment data from NMFS (*4*), we find that stock biomass similarly collapsed from 1970 to 1977 and from 1982 to 1997. The stock biomass was considered overfished under NMFS rules from 1967 to 2002 and in 2004 (panel A of figure).

Thus, available data suggest that catch records tracked biomass changes, overfishing status, and stock collapses reasonably well



Comparison of fisheries catch and biomass trends. (A) Georges Bank haddock (*Melanagrammus aeglefinus*) catches (white diamonds) and spawning stock biomass (red diamonds). Black line indicates collapsed status based on 90% reduction in catches; red solid line indicates collapse based on 90% reduction in biomass; and red dotted line indicates overfished status as defined by NOAA/NMFS. **(B)** Global fisheries trends. Shown is the proportion of fisheries where catches in a given year declined 90% or more below the historic maximum (black diamonds and trend line from our paper), and those that have been assessed by FAO as overfished, depleted, or recovering from depletion [red squares, from (*5*)]. The latter are only a subset of all stocks, i.e., those that have biomass estimates available.

(linear regression; catch against biomass 1963 to 2004; $r = 0.90$, $P < 0.0001$). By 2004, catches had increased to >10% of the maximum, or "recovered" by our definition. This example implies that use of stock biomass data (as opposed to catch data) would not change our overall conclusions.

The Georges Bank example is built on some of the best fisheries data in the world and on effective, but still uncommon management practices. In our global analysis, we could obviously not rely on precise stock assessments available only for a fraction of the world's fisheries. Even in the United States, half of the 903 species recognized by fisheries management are not assessed because of data gaps, and out of the 74 species that are assessed as overfished, 34 still experience further overfishing, while only 3 have recovered (*1*).

Murawski *et al.* imply that if we had used a different metric of collapse or had access to global stock abundance data, we would not have seen the steady decline in fisheries stocks that our analysis revealed. They provide no reanalysis of global fisheries data and rely on a single positive example to suggest that the future of seafood is currently safe. Our paper concentrates on the ability of high-diversity ecosystems to support services such as fisheries catch and suggests that efforts to support natural levels of marine diversity will be a powerful force in preventing the seafood collapse of which we warned. We share the fervent hope of Murawski *et al.* that changes in fisheries management can help reverse this troubling trend, and suggest that an honest recognition of the global problems we face, combined with a comprehensive assessment of successes and solutions, will be the best way forward.

Hilborn also raises concerns about the use of catch data in our analysis and calls for demonstration that catch trends approximate fish stock abundance trends. Although measures of stock abundance are critically important to fishery management, our study focused on the flows of goods and services from marine ecosystems to humankind; food supply was one of these critical services, and fisheries catches are the appropriate metric in this context. Recent assessments of the status of world fisheries used different approaches and data sources, yet they all reach pessimistic conclusions about the direction of global fisheries trends (*5*–*7*).

For example, Hilborn and co-authors [(*7*), p. 359] state that "we anticipate further declines in abundance, further loss of jobs and fishing communities, and potential structural change to marine ecosystems." They used catches in the same way as we do to distinguish well-managed, abundant fisheries from failed, depleted ones. Their "landings indicator" (current yield over maximum historic yield) [(*7*), tables 2 and 3] ranges from 0.28 to 1 for well-managed fisheries, from 0 to 0.11 for depleted stocks, and 0.14 for a recovering stock (*7*). Thus, our cutoff for "collapsed stocks" at 0.1 seems well supported, as suggested by others (*3*).

Hilborn does not provide any documentation to substantiate the argument that stock abundance data (as opposed to catches) may show a pattern different to ours. When we compare the United Nations Food and Agriculture Organization's (FAO) assessments of world fisheries (available since 1974) with our catch trends, the general magnitude of change appears similar (panel B of figure). There is more variability in the FAO estimates, as they are based on a smaller subset of fisheries, i.e., those that have proper

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abundance data available. The fact that within the last 7 years, both indices fall above the long-term trend may be optimistically interpreted as an early sign of positive change (panel B of figure).

Hilborn asserts that we have disregarded recent management successes in some jurisdictions. We focused on the relationship between biodiversity and services, not on fisheries management, in our paper. The maintenance and restoration of biodiversity consistently emerge as our critical management recommendation; this is consistent with previous work on the importance of stock complexity (*8*). In the context of our study, Marine Protected Areas (MPAs) provided a replicated experimental framework for studying recovery of biodiversity and services. We are not advocating the establishment of MPAs as the sole policy solution to resolving the problems of fisheries management. Rather, we suggest that sustainable fisheries practices, pollution control, maintenance of essential habitats, and creation of marine reserves all need to be part of a broader strategy to manage ocean ecosystems for their biodiversity and associated services. We fully support Hilborn's call to create incentives for conservative harvest levels as part of that broader strategy.

Briggs asks for clarification of some terminology. Although the term "biodiversity" is used in many ways, it has been clearly defined by the Convention on Biological Diversity as "the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems" (*9*). Our study focused on the variability within and between species. Briggs suggests that the term "population loss" would more accurately describe our study than "biodiversity loss" and felt that we mostly dealt with commercially valuable species. This is not the case. Our study concerns the accelerating loss of populations and species; both are essential elements of biodiversity (*9*).

Briggs is further concerned about the role of species extinctions in coastal ecosystems. We do not refer to "global" but "regional" extinctions within the 12 estuarine and coastal ecosystems studied, but these include several species that are now globally extinct. Local and regional extinctions are much more common than extinctions on a global scale (*10*, *11*) and are relevant for considering the effects of diversity on ecosystem services, because these are often provided at a local or regional level. In other words, the ecosystem consequences of species loss occur long before global extinction (*11*).

Finally, Briggs is confused about our statement that an increased number of species invasions over time coincided with the loss of native biodiversity, which he interpreted as invasions causing extinctions. However, the reference we cited (*12*) shows mechanistically that declining biodiversity can facilitate invasion and that diversity loss could be a contributing cause rather than a consequence of invasions in these systems. Briggs also suggests that invasions produce gains in biodiversity, which in terms of simple number of species is correct. However, we stated in our paper that invasions did not compensate for the loss of native biodiversity because they are comprised of other species groups (*13*). Briggs implies that biodiversity gains from invasions may enhance ecosystem services. This is an interesting idea. Although some invasive species may contribute to specific ecosystem services (such as invasive clams filtering the water of San Francisco Bay), there was no evidence in our study that invasions halted or reversed the marked loss of ecosystem services in coastal oceans.

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Problems of Searching in Web Databases

THE ISSUES DESCRIBED IN THE ARTICLE "EUROpean Union steps back from open-access leap" (M. Enserink, News of the Week, 23 Feb., p. 1065) mask a deeper problem. Simply putting scientific content into Web-accessible databases will not make it easily available, because commonly used search engines do not crawl databases.

The vast majority of Web-accessible scientific material resides in databases that can only be searched sequentially using manual input of search terms. This makes it prohibitively laborious for individuals to search more than a small fraction of the hundreds or thousands of existing databases. These databases are commonly called the "deep Web."

The U.S. R&D agencies have made a start at addressing this problem with www.science.gov, which allows simultaneous search across 35 massive federal document databases. A new project, Science.world, will extend this model to include content housed by other national governments. But in the long run, someone needs to coordinate searches to all the major Web-accessible document databases in the world, most of which are nongovernmental.

Simple Web accessibility is a necessary condition for the diffusion of scientific knowledge, but it is not sufficient. The issue of open access, although important, pales in comparison to the problem of deep Web access.

WALTER WARNICK

Office of Scientific and Technical Information, U.S. Department of Energy, 1 Science.gov Way, Oak Ridge, TN 37830, USA.

CORRECTIONS AND CLARIFICATIONS

Reports: "A single *IGF1* allele is a major determinant of small size in dogs" by N. B. Sutter *et al.* (6 Apr., p. 112). Affiliation 4 should have been the Department of Ecology and Evolutionary Biology. Also, in the Fig. 1B legend, the labels for two genotypes in the histogram were reversed. The black line with closed triangles represents I/I, and the gray line with closed circles represents B/B.

Policy Forum: "The obvious war" by M. R. Samardzija (12 Jan., p. 190). In paragraph 5, line 31, in the sentence "For example, in 1991, U.S. companies spent over $1 billion enforcing or defending against patent lawsuits, while only spending roughly $300 million on R&D expenditures (*11*)," "$300 million" should read, "$3.7 billion." The last sentence of the penultimate paragraph is incorrect. It should read "Mandel indicates that neither the Federal Circuit's test nor the Supreme Court's test completely resolve the hindsight problem (*21*)."

TECHNICAL COMMENT ABSTRACTS

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

John Jaenike

Worm *et al*. (Research Articles, 3 November 2006, p. 787) used a power relation to predict a global collapse of fisheries by the year 2048. However, a linear regression of the data for the past 40 years yields an excellent fit, with a predicted date of collapse of 2114. Thus, long-term projections of fisheries collapse are highly dependent on the specific statistical model used.

Full text at www.sciencemag.org/cgi/content/full/316/5829/1285a

Letters to the Editor

Letters (~300 words) discuss material published in *Science* in the previous 3 months or issues of general interest. They can be submitted through the Web (www.submit2science.org) or by regular mail (1200 New York Ave., NW, Washington, DC 20005, USA). Letters are not acknowledged upon receipt, nor are authors generally consulted before publication. Whether published in full or in part, letters are subject to editing for clarity and space.

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

Michael J. Wilberg and Thomas J. Miller

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.

Full text at www.sciencemag.org/cgi/content/full/316/5829/1285b

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

Franz Hölker, Doug Beare, Hendrik Dörner, Antonio di Natale, Hans-Joachim Rätz, Axel Temming, John Casey

Worm *et al*. (Research Articles, 3 November 2006, p. 787) investigated the importance of biodiversity to marine ecosystem services across temporal and spatial scales. In projecting the extent of future fisheries collapse, we argue that the authors inappropriately extrapolated beyond their available observations and used data on marine reserves and fishery closures that are not representative of global fisheries.

Full text at www.sciencemag.org/cgi/content/full/316/5829/1285c

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

Boris Worm, Edward B. Barbier, Nicola Beaumont, J. Emmett Duffy, Carl Folke, Benjamin S. Halpern, Jeremy B. C. Jackson, Heike K. Lotze, Fiorenza Micheli, Stephen R. Palumbi, Enric Sala, Kimberley A. Selkoe, John J. Stachowicz, Reg Watson

We show that globally declining fisheries catch trends cannot be explained by random processes and are consistent with declining stock abundance trends. Future projections are inherently uncertain but may provide a benchmark against which to assess the effectiveness of conservation measures. Marine reserves and fisheries closures are among those measures and can be equally effective in tropical and temperate areas—but must be combined with catch-, effort-, and gear restrictions to meet global conservation objectives.

Full text at www.sciencemag.org/cgi/content/full/316/5829/1285d