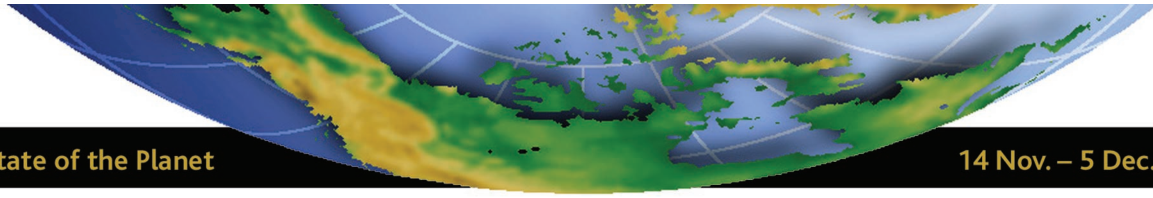

Tropical Soils and Food Security: The Next 50 Years

M. A. Stocking

An appreciation of the dynamism of the links between soil resources and society provides a platform for examining food security over the next 50 years. Interventions to reverse declining trends in food security must recognize the variable resilience and sensitivity of major tropical soil types. In most agro-ecosystems, declining crop yield is exponentially related to loss of soil quality. For the majority smallholder (subsistence) farmers, investments to reverse degradation are primarily driven by private benefit, socially or financially. "Tragedy of the commons" scenarios can be averted by pragmatic local solutions that help farmers to help themselves.

The UN Food and Agriculture Organization defines food security as "when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (*1*). Currently, more than a billion people have no food security. About 60% of rural communities in the tropics and subtropics are persistently affected by decline in household food production, with sub-Saharan Africa and parts of Latin America, the Caribbean, and Central Asia suffering worst (*2–4*). Technology, such as irrigation and improved crop varieties, has changed the situation for some people, but insecurity still prevails for the poorest and most vulnerable. The 1996 World Food Summit in Rome aimed to cut by half the number of undernourished people in the low-income food deficit countries (*5*). The target was reaffirmed in 2000 for achievement by 2015 in the Millennium Development Goals (*6*).

Reviews of techniques to improve soil management through conservation and better management are common [e.g., in Central America (*7*)]. The headline challenges for attaining global food security are political [e.g., conflict over land (*8*)], climatological [e.g., drought and global warming (*9*)], or epidemiological [e.g., impact of AIDS/HIV on farm labor (*10*)]. All too rarely is the underlying and changing quality of the natural resource base advanced as a key determinant of the increasing vulnerability of poor people to food insecurity. So what is the evidence that changing soil quality reduces food production? How may we better intervene to provide food security in the next 50 years?

Soil Quality

Soil quality is "the capacity of a soil to function within land use and ecosystem boundaries, to sustain biological productivity, maintain environmental quality and promote plant, animal and human health" (*11, 12*). As a concept, it differs from traditional technical approaches that focus solely on productive functions, including soil water and chemistry. Instead, soil quality is a holistic concept, recognizing soil as part of a dynamic and diverse production system with biological, chemical, and physical attributes that relate to the demands of human society (*13, 14*). Society, in turn, actively adapts soil to its needs, mining it of its nutrients on demand and replenishing these nutrients in times of plenty. Diverse interactions among soil, its productive output, and society are involved, including combination of plant nutrients (*15*), the complex processes of change in capturing carbon (*16*), and the potential positive effects of soil amendments such as green manure on crop productivity (*17, 18*).

Assessing soil quality is a major challenge because it varies spatially and temporally and is affected by management and the use of the soil resource. Integrated biological soil management is now recognized as essential (*19*). For example, traditional forms of conserving biodiversity in Ghana mean protecting at least 54 varieties of yam (*Dioscorea* spp.) while also managing the soil in sensitive ways that maintain soil-plant relationships. A product of this management is that the natural forest vegetation is kept to protect the climbing yams (*20*). Soil quality is a concept well understood by local farmers in this forest-savanna zone, and new assessment methods stress the importance of adopting a strong farmer perspective (*21*).

These situations are common throughout smallholder farming in the tropics [e.g., (*22*)]. Soil management is an intrinsic part of the overall management of biodiversity—now called "agrodiversity" (*23*)—and is therefore strategically a component of world developmental issues such as food security for growing populations and the provision of environmental services (*24*).

The Evidence of Impact

Ascribing a decline in food production unambiguously to the effects of changing soil quality is difficult because of the complex interactions involved. Yields decline for many reasons, such as excessive off-take of nutrients in crops without replenishment, pests and diseases, weed infestations, and increasing prevalence of climate change–induced drought (*25*). There is an emerging understanding of the importance of microbial communities for soil health through the use of DNA and RNA methods to determine soil physical and chemical changes (*26*). Many soil factors are involved, including soil depth and rooting, available water capacity, soil organic carbon, soil biodiversity, salinity and sodicity, aluminum toxicity, and general acidification.

The Soil Quality Institute has suggested several indicators that relate to yields (*27*), from which indexing approaches to measure soil quality have been devised (*28*). One of the main factors that integrate the effects of others is reduction in soil organic carbon (*29*). But these indicators do not offer a comprehensive measure of the spatial and temporal variability of soils, nor of the dynamic relationships of soils and the people who work them (*30*). This has led to calls for interdisciplinary studies to understand how soil properties and processes interact within ecosystems (*31*), how economic utility is affected (*32*), and how society, culture, and local knowledge are influenced (*33*). Two topics that have attracted considerable attention for tropical agro-ecosystems are (i) the effect of declining soil quality on production, and (ii) the rationality and private benefit of farmers' investments in soil conservation.

The cumulative loss of productivity from soil degradation of virgin land in all agro-climatic zones is estimated to be 5% (*34*). But this estimate hides large differences between zones and the vulnerabilities of some soils in the tropics (*35*). Since 1984, a series of experiments on major tropical soil types has attempted to determine the relationships between crop yield and cumulative soil loss (*36*). Results

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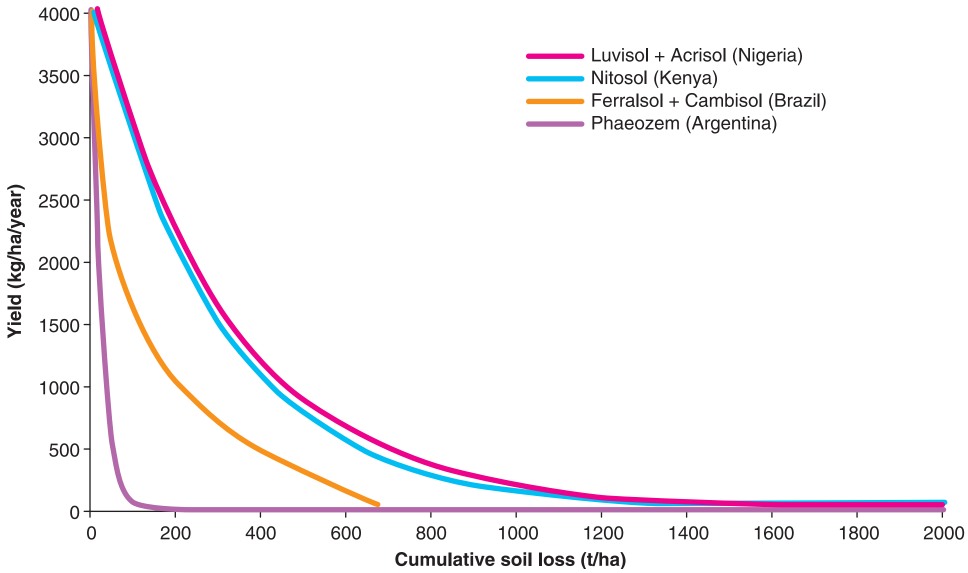

Fig. 1. Erosion-yield relationships for a selection of tropical soils, with initial maize grain yield on virgin land set to 4000 kg ha^{-1} [Source: (*53*)]. The initial yield level is artificially set at 4 tonnes on the basis of the amount of maize required by one typical household for 1 year in the subhumid tropics. Yields under subsistence agriculture are often well below this level. Exactly the same relationships hold true for lower starting levels, except that the time to reach critical food insecurity will be shortened, hence the serious challenge to agriculture and soil management.

[e.g., (*37, 38*)] indicate that yield decline follows a curvilinear, negative exponential that holds true for most tropical and many temperate soils (Fig. 1). Erosion selectively removes the finer and more fertile fraction, with enrichment ratios of eroded sediments being highest on virgin soil (*39*). As the soil progressively loses its quality, subsequent erosion has less proportional impact. Although productivity diminishes rapidly in the early stages of erosion, different soils show different degrees of impact after varying amounts of time and prior erosion (*40*).

Understanding these patterns of yield decline is crucial to determining the implications of changing soil quality on future yields and food security. But can tropical smallholder farmers access the resources to maintain soil quality in the face of these trends?

Resilience and Sensitivity

It is important to distinguish the intrinsic susceptibility of the soil to erosion (its resilience) from the variable impact of that erosion on yields (its sensitivity). These concepts for soil management combine through changing soil quality to affect actual production (Fig. 2). Resilience includes the "strength" of the soil or its resistance to shocks such as severe rainstorm events. Sensitivity denotes its fragility or its susceptibility to decline in production per unit amount of degradation (*41*). Resilience is manifested through specific degradation or erosion rates on different soils subject to the same erosive conditions, whereas sensitivity is a measure of how far the change induced in soil quality affects the soil's productive capability.

A simple matrix (Fig. 3) illustrates the possible permutations of resilience and sensitivity for a few tropical soils. The management strategies adopted for different permutations of sensitivity and resilience can thus be related to the capacity of local smallholder farmers to take remedial action. For example, ferralsols (35% of the tropics and subtropics) and acrisols (28%), typical of humid rainforests and shifting cultivation, have low to very low resilience and moderate sensitivity. Once vegetation is removed, they degrade quickly and irreversibly through intense acidification, increasing free aluminum and phosphorus fixation. Combinations of structures such as terraces and biological measures such as intercropping are the best response. Mechanical structures require human and financial resources, especially labor and money, and are out of the reckoning of most subsistence farmers. Nitosols (3%), by contrast, have moderate resilience and low sensitivity. They are typical of highland clay-rich areas, such as Ethiopia and Kenya, and are one of the safest and most fertile soils of the tropics and subtropics, with only small problems of increased erodibility if organic matter declines.

Biological conservation methods are effective ways to address both erosion rate and fertility decline. They include a wide array of techniques involving the management of biomass: crop residues, green manures, and alley cropping, for example. The principal limitation here is the availability of organic resources and the human resources to manage them for effective soil protection. However, even at moderate levels of management such as that available in most smallholder farming households, nitosols can effectively continue to withstand degradation and produce indefinitely, at least for the next 50 years (*42*).

Appropriate Responses to Changing Soil Quality

Doomsday scenarios of increasing population and declining soil resource quality fail to capture the diversity of soils, while presenting the worst-case outliers as the typical situation. There are some bad cases where degradation is rife and people are starving (*43*); these will continue to hold international attention for at least the next 50 years. However, smallholder

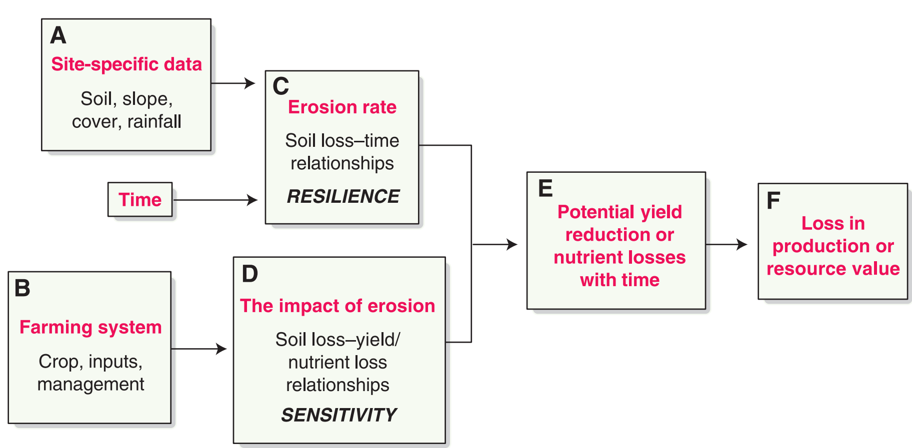

Fig. 2. Conceptual framework for modeling erosion-yield-time relationships.

		SENSITIVITY: High	SENSITIVITY: Low
RESILIENCE	High	Resists erosion well but, if allowed to degrade through poor management, yields and soil quality rapidly decline. Nevertheless, capability can be restored by appropriate land management [Phaeozems]	Only suffers degradation under very poor management and persistent mismanagement. Biological conservation methods adequately maintain production and protect soil [Nitosols; Cambisols]
RESILIENCE	Low	Easy to degrade, with disastrous effects on production - loss of nutrients and plant-available water capacity. Difficult to restore, and should be kept under natural vegetation or forestry [Acrisols]	Suffers considerable erosion and degradation without apparent influence on production or overall soil quality. Physical structures indicated to control off-site impacts [Ferralsols]

Fig. 3. A resilience-sensitivity matrix for tropical soils (using FAO/UNESCO Soil Map of the World names), with indicated approaches to conservation. Under this schema, the top right cell represents the best soils and the bottom left the worst. Different management strategies for each of the four permutations are indicated, which in turn affect the extent to which smallholder farmers have the resources and understanding to cope with specific scenarios of soil degradation (*54*).

farmers in the tropics have skills and social networks that give us cause for optimism for future soil quality and food security. Many are managing their soils sustainably and productively. Although they tend to be limited in labor resources (i.e., have low "human capital"), they compensate in forms of collective action and networking (i.e., "social capital") (*44, 45*). This means that they adapt technologies to their local needs (using indigenous knowledge and innovation) and avoid labor-demanding and expensive practices. Interventions that use community-based approaches that empower farmers to manage their own situation therefore hold the greatest promise for maintaining soil quality and ensuring food security.

One of the most interesting recent developments in soil quality research, as reflected in the agendas of the major development agencies, is the recognition that farming practices do not merely extract soil nutrients, but evolve in response to changing conditions over many years through informal experimentation and experience (*46*). Farmers may often make better decisions than the "experts," not because of any greater analytical skills, but because of the experience gained in integrating a vast array of local factors responsible for controlling production. Farmers are unlikely to undertake practices that undermine the future and put household livelihood and food security at risk unless immediate survival were in question. They will invest in soil conservation if the private benefits—financial, social, and cultural—are greater than the costs. The greatest damage to soils occurs where conditions are volatile with, for example, migrants and refugees. Here, local knowledge is poor and mining of the soil of its nutrients is essential for survival, at least in the short term. The greatest threat to soil quality and food security is if the security of tenure for smallholders is made even more difficult by changing world conditions.

The future rests in managing changes in soil quality through working with local communities and rethinking how soils change local society (*47*). In subhumid Benin, for example, *Mucuna pruriens* (velvetbean) is used as a green manure mulch and has become an accepted method to counter soil fertility decline. From 15 original farmers involved in experimentation and adaptation in 1987, 100,000 were reported to have embraced this practice by 1996 (*48*). This is evidence of adaptability, flexibility, and responsiveness to techniques that bring private benefits to smallholders. In semi-arid Kenya, farmers choose "trashlines" (bands of uprooted weeds and crop residues) to intercept sediment and runoff, a technique never promoted by the advisory services. Yet when the marginal rates of return and net present values over 10 years are calculated, trashlines are almost always the only technique of soil quality maintenance that consistently benefits the farmers' livelihoods (*49*).

Such findings point to some important, if uncomfortable, conclusions. Many farmers in the tropics are willing to invest in the future, protecting important public goods such as soils, and are often the best arbiters of choice when it comes to technologies. Science does not always get it right and does not necessarily provide workable or acceptable solutions (*50*). Soil resources are not a static, homogenous medium; they are a dynamic element, responding to the demands placed on them by human beings and governing expectations of food security. If simple provisions are made available, such as adequately resourced extension services and access to technologies, food production by smallholders can be transformed. The "tragedy of the commons" lies more in our simplistic, linear, disciplinary thinking than in reality. The challenge is to capture diversity by developing appropriate cross-disciplinary analytical methods and measures. Then, we must get closer to allaying the tragedy by providing realistic interventions for those who need it most—the poor, hungry, and disadvantaged, living on soils that are sensitive and lack resilience.

References and Notes

1. United Nations Food and Agriculture Organization, Special Programme for Food Security (www.fao.org/spfs).
2. "Partnerships to fight poverty," *Annual Report 2001* (United Nations Development Programme, New York, 2001).
3. "Reaching Sustainable Food Security for All by 2020: Getting the Priorities and Responsibilities Right," slideshow presentation (International Food Policy Research Institute, Washington, DC, 2002) (www.ifpri.org/2020/books/actionppt/actionppt.pdf).
4. "Making a difference," *World Health Report 1999* (World Health Organization, Geneva, 1999).
5. See, for example, the World Food Programme's goal for 2002–2005: "Excellence in providing food assistance that enables all . . . to survive and maintain healthy nutritional status, and enabling the social and economic development of at least 30 million hungry people every year" (www.wfp.org).
6. United Nations Development Programme, Millennium Development Goals (2003): "The global challenge: Goals and targets" (www.undp.org).
7. E. Lutz, S. Pagiola, C. Reiche, "Economic and Institutional Analysis of Soil Conservation Projects in Central America and the Caribbean" (Environment Paper No. 8, World Bank, Washington, DC, 1994).
8. *The Daily News*, Harare, Zimbabwe, 17 June 2003 (http://allafrica.com/stories/200306170585.html). The article reports: "Food production in Zimbabwe has fallen by more than 50%, measured against a five-year average, due mostly to the current social, economic and political situation and the effects of the drought," the UN agencies [WFP and FAO] said. The underlying cause was described as "unwise policies over land redistribution."
9. "Global Warming Threatens Food Shortages in Developing Countries" [International Maize and Wheat Improvement Centre (CIMMYT), 2003] (www.cimmyt.cgiar.org/english/webp/support/n_release/warming/nrelease_12May03.htm).
10. FAO Committee on World Food Security, *The Impact of HIV/AIDS on Food Security* (2001) (www.fao.org/docrep/meeting/003/Y0310E.htm).
11. An alternative definition used by the USDA's Natural Resources Conservation Service is, "SOIL QUALITY is how well soil does what we want it to do" (http://soils.usda.gov/sqi/soil_quality/what_is/index.html). The NRCS stresses that soil has both inherent and dynamic properties.
12. J. W. Doran, A. J. Jones, Eds., *Methods for Assessing Soil Quality*. SSSA Special Publication 49 (Soil Science Society of America, Madison, WI, 1996).
13. M. J. Swift, *Nat. Resour.* **35** (no. 4), 12 (1999).
14. P. Sanchez, C. A. Palm, S. W. Buol, *Geoderma* **114**, 157 (2003).
15. M. J. Mausbach, C. A. Seybold, in *Soil Quality and Agricultural Sustainability*, R. Lal, Ed. (Ann Arbor Press, Chelsea, MI, 1998), pp. 33–43.
16. C. A. Seybold, M. J. Mausbach, D. L. Karlen, H. H. Rogers, in *Advances in Soil Science*, R. Lal, J. M. Kimble, R. F. Follet, B. A. Steward, Eds. (CRC Press, Boca Raton, FL, 1998), pp. 387–404.
17. A. M. Whitbread, G. J. Blair, R. D. B. Lefroy, *Soil Tillage Res.* **54**, 63 (2000).
18. P. Dorward, M. Galpin, D. Shepherd, *Agric. Syst.* **75**, 97 (2003).
19. See UN/FAO's Soil Biodiversity Portal on how soil biodiversity can be assessed with the aim of promoting more sustainable agriculture (www.fao.org/ag/AGL/agll/soilbiod/default.htm).
20. E. A. Gyasi, in *Cultivating Biodiversity: Understanding, Analysing and Using Agricultural Diversity*, H. Brookfield, C. Padoch, H. Parsons, M. Stocking, Eds. (ITDG, London, 2002), pp. 245–255.
21. M. Stocking, N. Murnaghan, *Handbook for the Field Assessment of Land Degradation* (Earthscan, London, 2001).

22. F. Kaihura, M. Stocking, *Agricultural Biodiversity in Small-holder Farms of East Africa* (UNU Press, Tokyo, 2003).
23. H. Brookfield, *Exploring Agrodiversity* (Columbia Univ. Press, New York, 2001).
24. P. Sanchez, *Science* **295**, 2019 (2002).
25. M. Stocking, "Erosion and crop yield," in *Encyclopedia of Soil Science* (Dekker, New York, 2003).
26. M. S. Girvan, J. Bullimore, J. N. Pretty, A. M. Osborn, A. S. Ball, *Appl. Environ. Microbiol.* **69**, 1800 (2003).
27. Soil Quality Institute (http://soils.usda.gov/SQI).
28. S. S. Andrews, C. R. Carroll, *Ecol. Appl.* **11**, 1573 (2001).
29. Agriculture has a potentially large role in the sequestration of carbon in soils; see (*51*).
30. "Soil science has been brilliantly informed by reductionist physics and chemistry, poorly informed by ecology and geography, and largely uninformed by social science." Quote from M. J. Swift (*52*).
31. D. L. Karlen, C. A. Ditzler, S. S. Andrews, *Geoderma* **114**, 145 (2003).
32. J. Boardman, J. Poesen, R. Evans, *Environ. Sci. Policy* **6**, 1 (2003).
33. G. Prain, S. Fujisaka, M. D. Warren, Eds., *Biological and Cultural Diversity: The Role of Indigenous Agricultural Experimentation in Development* (Intermediate Technology, London, 1999).
34. P. Crosson, *Soil Erosion and Its On-farm Productivity Consequences: What Do We Know?* (Resources for the Future, Washington, DC, 1995).
35. S. J. Scherr, S. Yadav, *Food Agric. Environ. Disc. Pap. 14* (International Food Policy Research Institute, Washington, DC, 1995).
36. M. Stocking, *Soil Technol.* **1**, 289 (1988).
37. A. Tengberg, M. Stocking, S. C. F. Dechen, *Adv. Geoecol.* **31**, 355 (1998).
38. M. Stocking, F. Obando, A. Tengberg, in *Sustainable Use and Management of Soils in Arid and Semiarid Regions*, Á. Faz, R. Ortiz, A. R. Mermut, Eds. (Quaderna, Murcia, Spain, 2002), vol. 1, pp. 178–192.
39. R. Lal, Ed., *Soil Erosion Research Methods* (Soil and Water Conservation Society, Ankeny, IA, ed. 2, 1994).
40. A. Tengberg, M. Stocking, in *Response to Land Degradation*, E. M. Bridges *et al.*, Eds. (Oxford & IBH, New Delhi, 2001), pp. 171–185.
41. A. Tengberg, M. da Veiga, S. C. F. Dechen, M. Stocking, *Exp. Agric.* **34**, 55 (1998).
42. See the USDA-NRCS web site World Soil Resources for links to most global soil resource sites and commentaries on soil management (www.nrcs.usda.gov/technical/worldsoils).
43. IFPRI 2020 Vision Policy Brief No. 58 (1999) (www.ifpri.org/2020/briefs/number58.htm).
44. J. N. Pretty, H. Ward, *World Dev.* **29**, 209 (2001).
45. For further discussion on the capital assets framework and sustainable natural resource management, the Livelihoods Connect Web site (www.livelihoods.org) contains guidance sheets and a "sustainable livelihoods toolbox."
46. W. Hiemstra, C. Reijntjes, E. van der Werf, Eds., *Let Farmers Judge: Experiences in Assessing the Sustainability of Agriculture* (ILEIA Readings in Sustainable Agriculture, Intermediate Technology, London, 1992).
47. V. Mazzucato, D. Niemeijer, *Rethinking Soil and Water Conservation in a Changing Society* (Tropical Resource Management Papers 32, Wageningen University, Department of Environmental Sciences, 2000).
48. M. N. Versteeg, F. Amadji, A. Eteka, A. Gogan, V. Koudokpon, *Agric. Syst.* **56**, 269 (1998).
49. R. Kiome, M. Stocking, *Global Environ. Change* **5**, 281 (1995).
50. J. Pretty, *Regenerating Agriculture: Politics and Practice for Sustainability and Self-Reliance* (Earthscan, London, 1995).
51. A. Renwick, A. S. Ball, J. N. Pretty, *Philos. Trans. R. Soc. London Ser. A* **360**, 1721 (2002).
52. M. J. Swift, in *Carbon and Nutrient Dynamics in Natural and Agricultural Tropical Ecosystems*, L. Bergström, H. Kirchmann, Eds. (CABI, Wallingford, UK, 1998), p. 59.
53. M. Stocking, A. Tengberg, in *Integrated Soil Management for Sustainable Agriculture and Food Security in Southern and Eastern Africa*, H. Nabhan, A. M. Mashali, A. R. Mermut, Eds. (Publication AGL/MISC/23/99, UN Food and Agriculture Organization, Rome, 1999), pp. 91–120.
54. M. Stocking, in *Environmental Science for Environmental Management*, T. O'Riordan, Ed. (Prentice-Hall, Harlow, UK, ed. 2, 2000), pp. 287–321.

The Future for Fisheries

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Formal analyses of long-term global marine fisheries prospects have yet to be performed, because fisheries research focuses on local, species-specific management issues. Extrapolation of present trends implies expansion of bottom fisheries into deeper waters, serious impact on biodiversity, and declining global catches, the last possibly aggravated by fuel cost increases. Examination of four scenarios, covering various societal development choices, suggests that the negative trends now besetting fisheries can be turned around, and their supporting ecosystems rebuilt, at least partly.

Fisheries are commonly perceived as local affairs requiring, in terms of scientific inputs, annual reassessments of species-specific catch quota. Most fisheries scientists are employed by regulatory agencies to generate these quota, which ideally should make fisheries sustainable and profitable, contributors to employment and, through international trade, to global food security.

This perception of fisheries as local and species-specific, managed to directly benefit the fishers themselves, is conducive neither to global predictions nor the collaborative development of long-term scenarios. Indeed, recent accounts of this type, except those of the United Nations Food and Agriculture Organization (FAO) (*1*), tend to be self-conscious and layered in irony (*2–5*), perhaps an appropriate response to 19th-century notions of inexhaustibility.

The past decade established that fisheries must be viewed as components of a global enterprise, on its way to undermine its supporting ecosystems (*6–10*).

These developments occur against a backdrop of fishing industry lobbyists arguing that governments drop troublesome regulations and economists assuming that free markets generate inexhaustibility. The aquaculture sector offers to feed the world with farmed fish, while building more coastal feedlots wherein carnivores such as salmon and tuna are fed with other fish (*11*), the aquatic equivalent of robbing Peter to pay Paul.

The time has come to look at the future of fisheries through (i) identification and extrapolation of fundamental trends and (ii) development and exploration (with or without computer simulation) of possible futures.

The fisheries research community relied, for broad-based analyses, on a data set now shown to be severely biased (*10*). First-order correction suggests that rather than increasing, as previously reported, global fisheries landings are declining by about 500,000 metric tons per year from a peak of 80 to 85 million tons in the late 1980s. Because overfishing and habitat degradation are likely to continue, extrapolation may be considered (see below). This correction, however, does not consider discarded "by-catch" (about 30% of global landings), only one component of the illegal, unreported, or unregulated (IUU) catches that recently became part of the international fisheries research agenda (*12*, *13*).

The geographic and depth expansion of fisheries is easier to extrapolate (Fig. 1). Over the past 50 years, fisheries targeting benthic and bentho-pelagic organisms have covered the shelves surrounding continents and islands down to 200 m, with increasing inroads below 1000 m, whereas fisheries targeting oceanic tuna, billfishes, and their relatives covered the world ocean by the early 1980s (*9*).

Extrapolating the bottom fisheries trends to 2050 is straightforward (Fig. 1). With satellite positioning and seafloor-imaging systems, we will deplete deep slopes, canyons, seamounts,

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