How loss of ocean species threatens human well-being

Boris Worm
Dalhousie University
Halifax, NS, Canada

Marine ecosystem functions

- · Carbon and nutrient cycling
- Primary and secondary productivity
- Food and habitat provision
- Transformation of waste products

Linkage?

Marine ecosystem services

- Water quality control
- Seafood production
- Tourism and recreation
- Ecosystem resilience

Benefits

Science, Nov 3

RESEARCH ARTICLE

Impacts of Biodiversity Loss on Ocean Ecosystem Services

Boris Worm, 2* Edward B. Barbier, 2 Nicola Beaumont, 3 J. Emmett Duffy, 4 Carl Folke, 5.6 Benjamin S. Halpern, 7 Jeremy B. C. Jackson, 8.9 Heike K. Lotze, 1 Fiorenza Micheli, 10 Stephen R. Palumbi, 10 Enric Sala, 8 Kimberley A. Selkoe, 7 John J. Stachowicz, 12 Reg Watson 12

Human-dominated marine ecosystems are experiencing accelerating loss of populations and species, with largely unknown consequences. We analyzed local experiments, long-term regional time series, and global fisheries data to test how biodiversity loss affects marine ecosystem services across temporal and spatial scales. Overall, rates of resource collapse increased and recovery potential, stability, and water quality decreased exponentially with declining diversity. Restoration of biodiversity, in contrast, increased productivity fourfold and decreased variability by 21%, on average. We conclude that marine biodiversity loss is increasingly impairing the ocean's capacity to provide food, maintain water quality, and recover from perturbations. Yet available data suggest that at this point, these trends are still reversible.

That is the role of biodiversity in maintaining the ecosystem services on which a growing human population depends? Recent surveys of the terrestrial literature suggest that local species richness may enhance ecosystem productivity and stability (1-3). However, the importance of biodiversity changes at the landscape level is less clear, and the lessons from local experiments and theory do not seem to easily extend to longterm large-scale management decisions (3) These issues are particularly enigmatic for the world's oceans, which are geographically large and taxonomically complex, making the scaling up from local to global scales potentially more difficult (4). Marine ecosystems provide a wide variety of goods and services, including vital food resources for millions of people (5, 6). A large and increasing proportion of our population lives close to the coast; thus the loss of services such as flood control and waste detoxification can have disastrous consequences (7, 8). Changes in marine biodiversity are

Department of Biology, Dalhousie University, Halifax, NS. Canada B3H 411, 2Department of Economics and Finance, University of Wyoming, Laramie, WY 82071, USA. 3Plymouth Marine Laboratory, Plymouth PL1 3DH, UK. Virginia Institute of Marine Sciences, Glourester Point, VA 23/062-13/46, USA Department of Systems Ecology, Stockholm University, Stockholm, SE-106 91 Sweden, Beijer International Institute of Ecological Economics, Royal Swedish Academy of Sciences, SE-104 OS, Stockholm, Sweden, National Center for Ecological Analysis and Synthesis, Santa Barbara, CA 93101, USA. ⁸Center for Marine Biodiversity and Conservation, Scripps Institution of Oceanography, La Jolla, CA 92093-0202, USA. Smithsonian Tropical Research Institute, Box 2072, Balboa, Republic of Panama. 50 Hopkins Marine Station, Stanford University, Pacific Grove, CA 93950, USA. 11 Section of Evolution and Ecology, University of California, Davis, CA 95616, USA. 12 Fisheries Centre, University of British Columbia, Vancouver, BC, Canada V6T 1Z4,

directly caused by exploitation, pollution, and

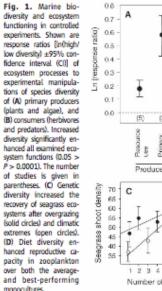
habitat destruction, or indirectly through climate change and related perturbations of ocean biogeochemistry (9-13). Although marine extinctions are only slowly uncovered at the global scale (9), regional ecosystems such as estuaries (10), coral reefs (11), and coastal (12) and oceanic fish communities (13) are rapidly losing populations, species, or entire functional groups. Although it is clear that particular

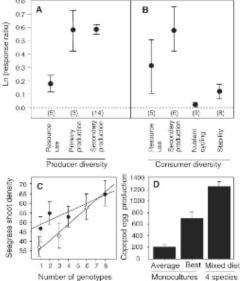
the role of biodiversity per se remains untested at the ecosystem level (14). We analyzed the effects of changes in marine biodiversity on fundamental ecosystem services by combining available data from sources ranging from smallscale experiments to global fisheries. Experiments. We first used meta-analysis of published data to examine the effects of

species provide critical services to society (6),

variation in marine diversity (genetic or species richness) on primary and secondary productivity, resource use, nutrient cycling, and ecosystem stability in 32 controlled experiments. Such effects have been contentiously debated, particularly in the marine realm, where high diversity and connectivity may blur any deterministic effect of local biodiversity on ecosystem functioning (1). Yet when the available experimental data are combined (15), they reveal a strikingly general picture (Fig. 1). Increased diversity of both primary producers (Fig. 1A) and consumers (Fig. 1B) enhanced all examined ecosystem processes. Observed effect sizes corresponded to a 78 to 80% enhancement of primary and secondary production in diverse mixtures relative to monocultures and a 20 to 36% enhancement of resource use efficiency (Fig. 1, A and B).

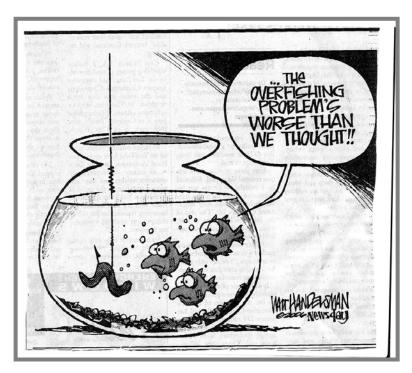
Experiments that manipulated species diversity (Fig. 1B) or genetic diversity (Fig. 1C) both found that diversity enhanced ecosystem stability, here defined as the ability to withstand recurrent perturbations. This effect was linked

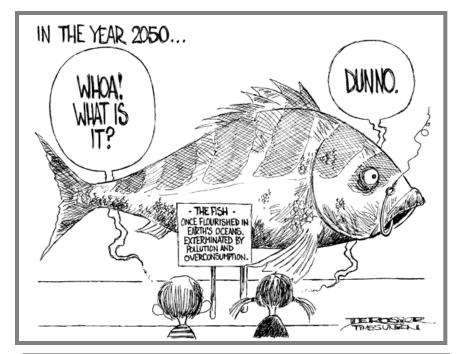


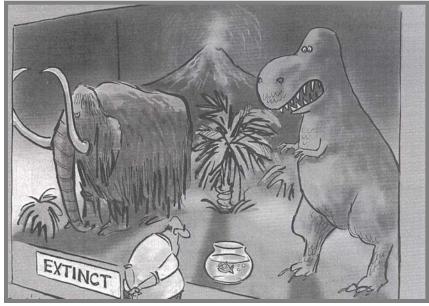


^{*}To whom correspondence should be addressed. E-mail: bworm@dal.ca

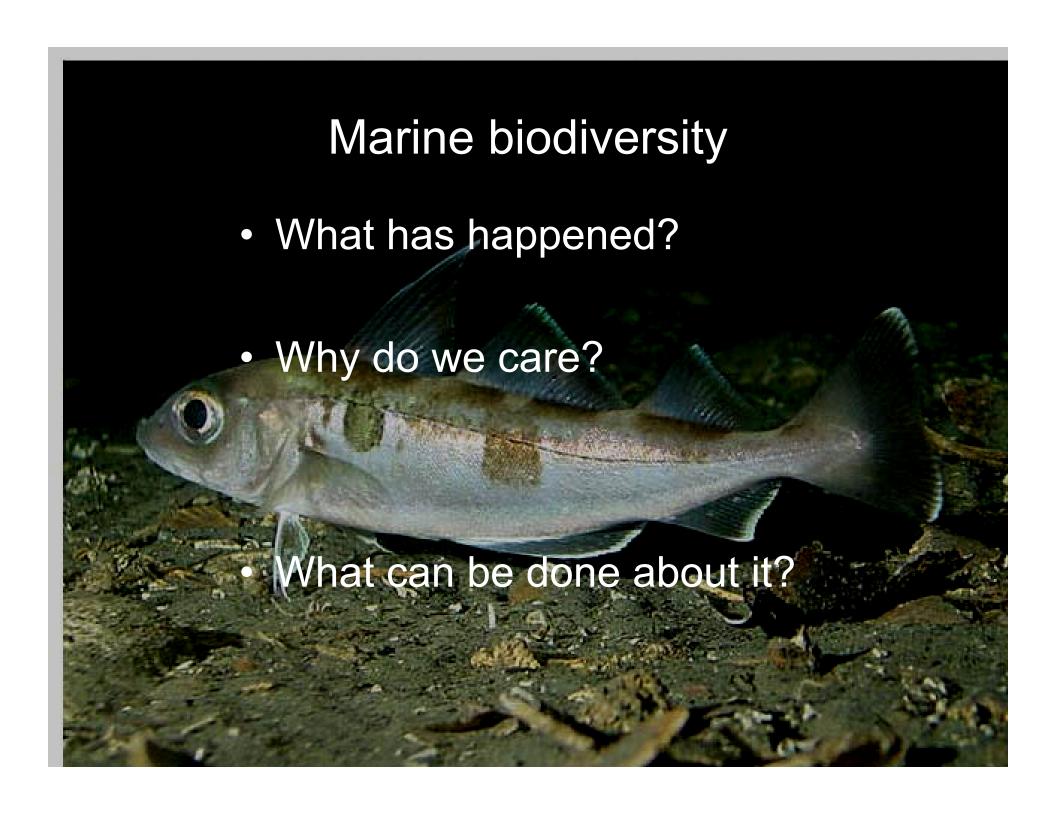
ATLANTIC COD STURGEON This ancient fish was around at the SWORDFISH SCIENCE Its abundance attracted Europeans settlers to America, but recent It was overfished in the late 1990s, time of the dinosaurs. Its eggs (true caviar) are a gourmet delicacy, but sturgeons of the Caspian Sea are but public pressure led to tighter regulations, which helped the overfishing has altered the ecosystem. Scientists say we are fishing the last 10% of this species **OCEANS OF** more fish ... species rebound. Today most of the ordfish Americans eat is imported CHILEAN SEA BASS The trendiness of this fish, also called the Patagonian toothfish, could be its downfall. The fish is often caught illegally, especially in the remote waters of the Antarctic 81.6 **NOTHING** 50 '60 '70 '80 '90 '00 rampant coastal development, clin A study says overfishing ... which could lead change and pollution-devastated the re will soon destroy the mangroves and seagrass beds where n to the extinction commercially valuable fish hatch. seafood supply of many species Steven Murawski, chief scientist at U.S. National Marine Fisheries Service, fi By UNMESH KHER Worm's headlining prediction far too simistic. Industry experts are even n PACIFIC SALMON -10% of their population Nearly 30 runs of salmon in Washington and Oregon are FISHERMEN ON THE HIGH skeptical. "There's now a global effort to duce or eliminate fishing practices that are seas have plenty of worries, not the least of sustainable," says industry analyst How dams and habitat loss. However, Alaska's salmon population thrives Johnson, "With that increased awarer which are boat-tossing storms, territorial squabthese projections just aren't realistic." bles and even pirates. Perhaps. Still, the destructive fish Now Boris Worm, a mapractices that have decimated tuna and These sedentary, long-living fish dwell in deep waters and reproduce for short periods. They're overfished in the Gulf of Mexico near Florida's SHARKS rine biologist at Dalhousie University in have not declined worldwide, as John Almost all are in trouble Halifax, Canada, has added another. After suggests. Up to half the marine life cau in part because they mature slowly and bear studying, among other things, global catch BLUEFIN TUNA by fishers is discarded, often dead, as One of the world's most valuable fish, these 300-lb. few offspring. They are being hunted to extinction, often to make traditional data over more than 50 years, he and a team catch, and vibrant coral forests are still be west coast and in Hawai stripped bare by dragnets. Worm arg A LOOK AT WHO DOES of 13 researchers in four countries have come giants are favored for sushi. The Atlantic population has declined almost 90% since the 1970s to a stunning conclusion. By the middle of that fisheries based on ecosystems strip THE MOST FISHING RED SNAPPER this century, fishermen will have almost of their biological diversity are especi-Not to be confused with "Pacific red," they are heavily fished in the Gulf of Mexico, exported by Mexico and Brazil and listed as overfished delicacies like shark-fin soup nothing left to catch. "None of us regular prone to collapse. At least 29% of fish Total marine harvest '84 '04 working folk are going to be able to afford species have already collapsed, accordin seafood," says Stephen Palumbi, a Stanford the study, and the trend is accelerating. by the U.S. since 1980 University marine biologist and co-author of So what's a fish eater to do? "Vote v the study published in Science. "It's going to your wallet," says Michael Sutton, who re 3.1 be too rare and too expensive." the Monterey Bay Aquarium's Seafood Wa Don't tell that to your local sushi chef. program in California. Since 1999, TIME Graphic by Ed Gabol and Lon Twosten Written by Kristins Dell Over the past three decades, the fish export aquarium has handed out pocket guides l trade has grown fourfold, to 30 million tons, ing sustainably harvested seafood. and its value has increased ninefold, to Marine Stewardship Council has partne \$71 billion. The dietary attractiveness of with corporations to similarly certify seafood has stoked demand. About 90% and farm-raised seafood. Some 370 produ 3.1 SPECIES DIVERSITY of the ocean's big predators-like cod in more than two dozen countries bear and tuna-have been fished out of British group's "Fish Forever" label of 3.6 HIGH RISK existence. Increasingly, fish proval. Wal-Mart and Red Lobster, amo and shrimp farms are filling others, have made commitments to sell s the shortfall. Though tainably harvested seafood. touted as a solution to But that's just a spit in the ocean unl overfishing, many Analyzing more than 50 years consumers in Japan, India, China a of data, researchers found that collapses in ecosystems of them have-Europe join the chorus for change. along with everyone in the U.S. started eating susta occur faster and recovery is slower in areas with low species able seafood," says Worldwatch Instisenior researcher Brian Halweil, "it wo diversity (red) than in areas with high diversity (light yellow) be wonderful, but it wouldn't address global issues. We're at the very beginn of this." -With reporting by Kathleen Kingsh

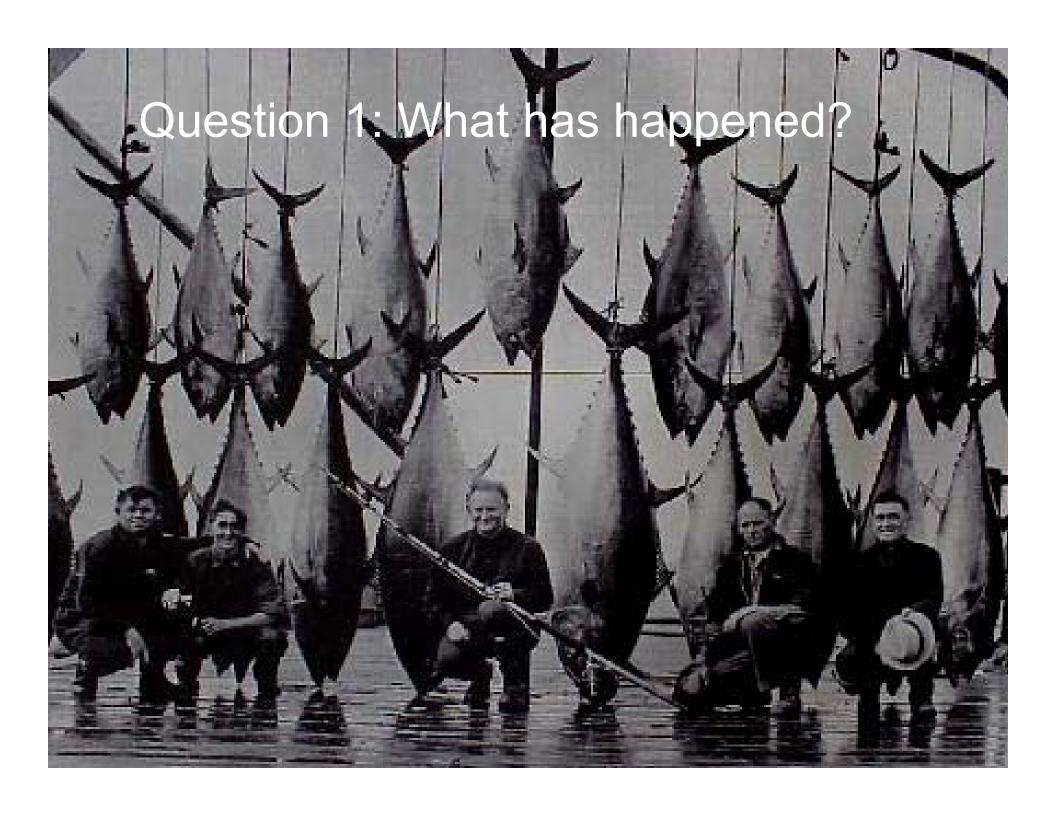










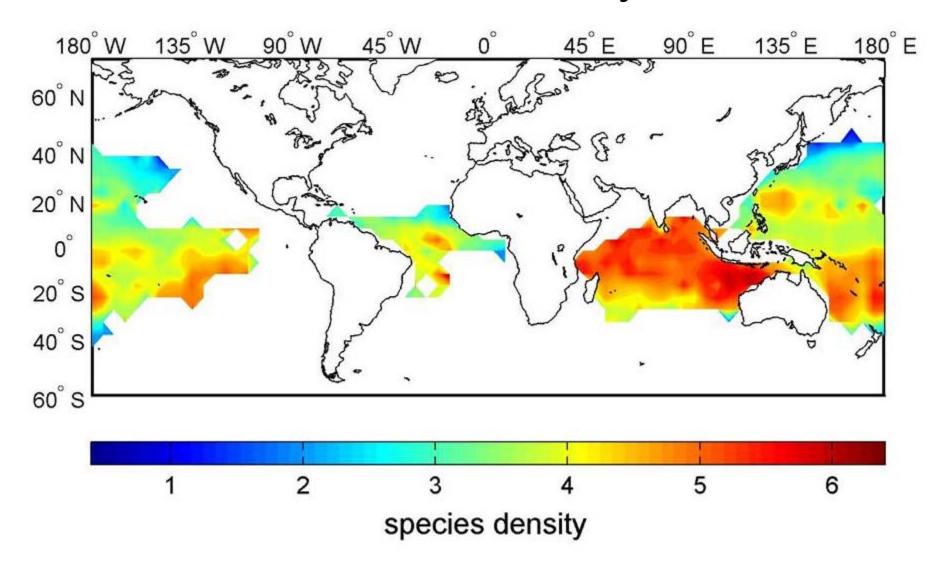


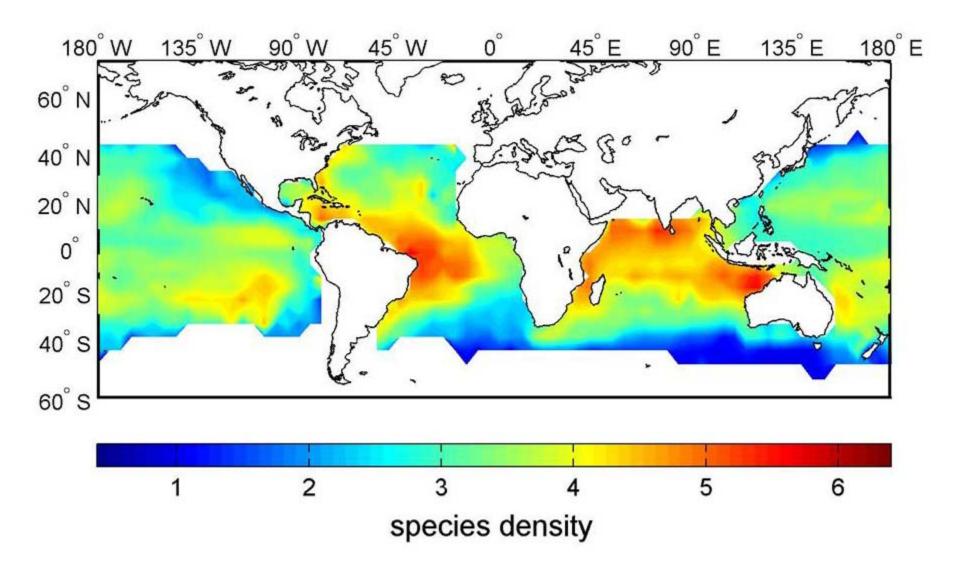
Large fish of the past

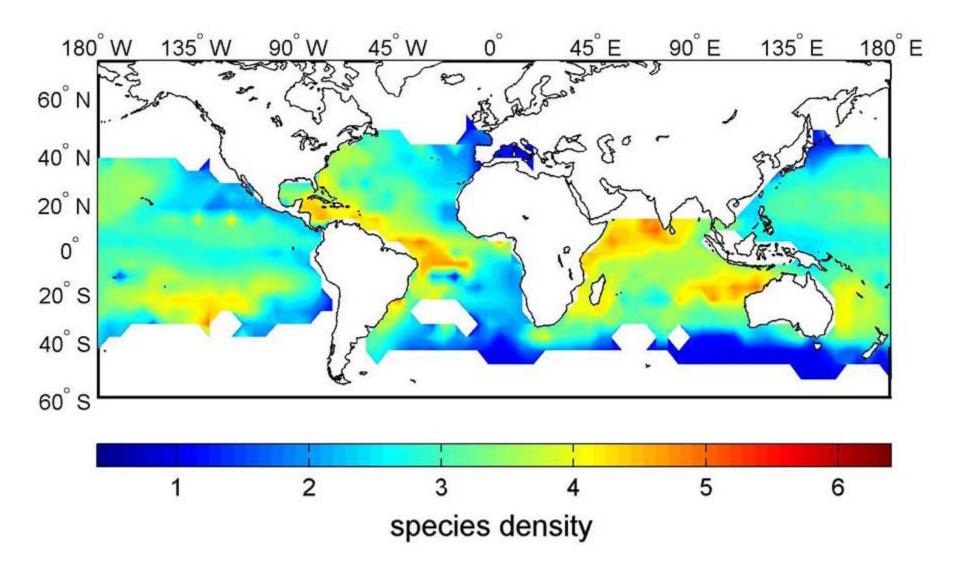


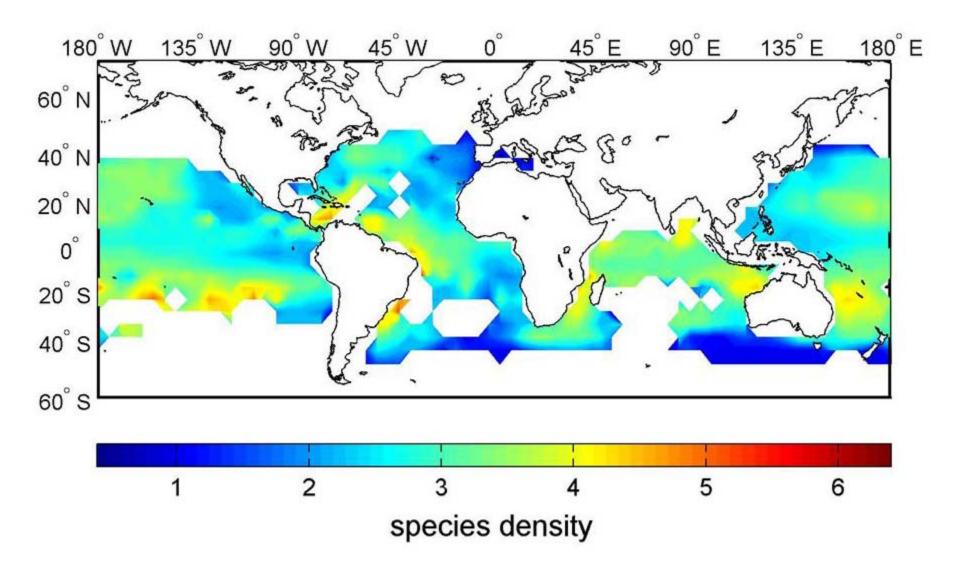


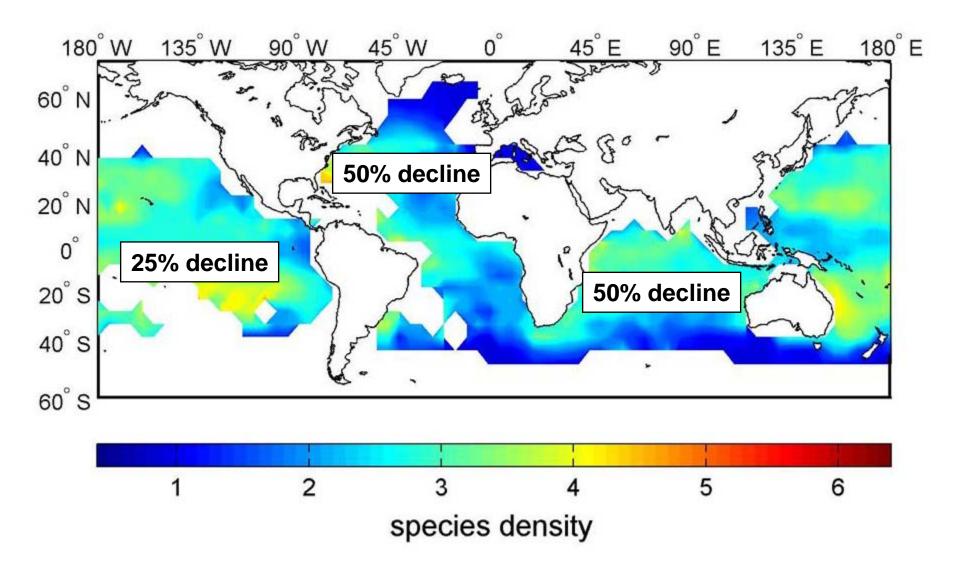
Loss of diversity



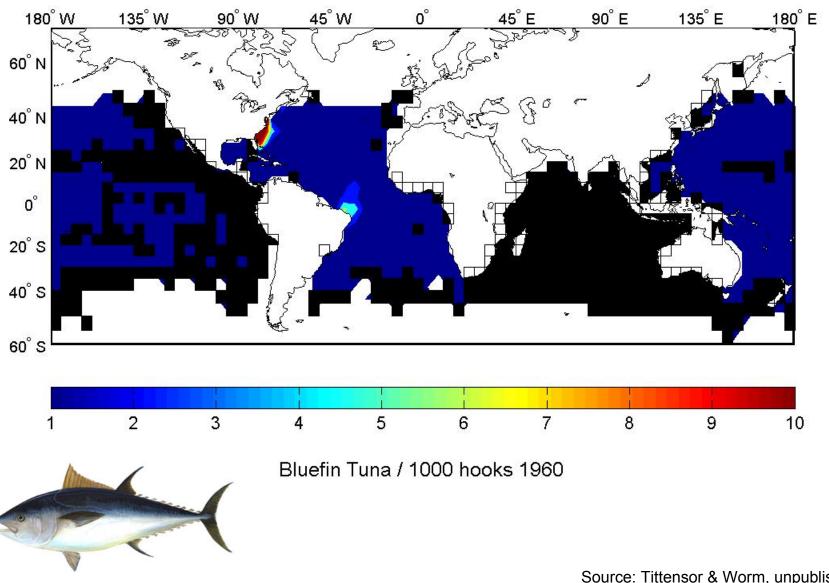




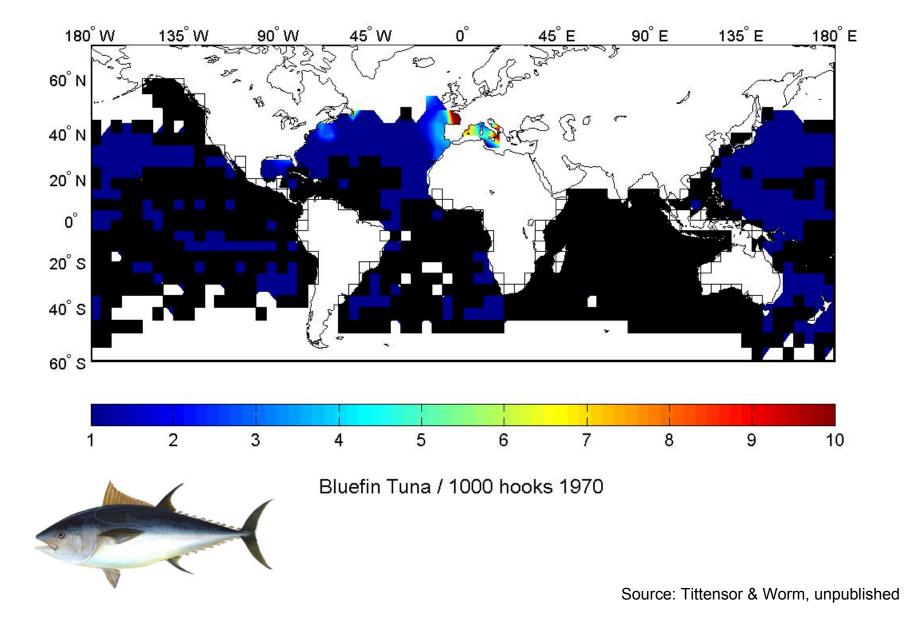


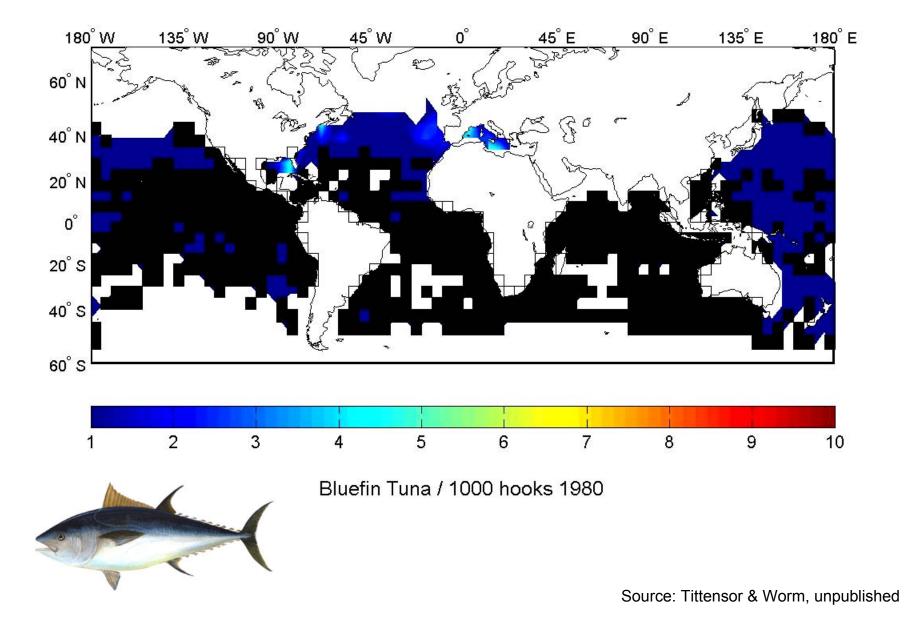


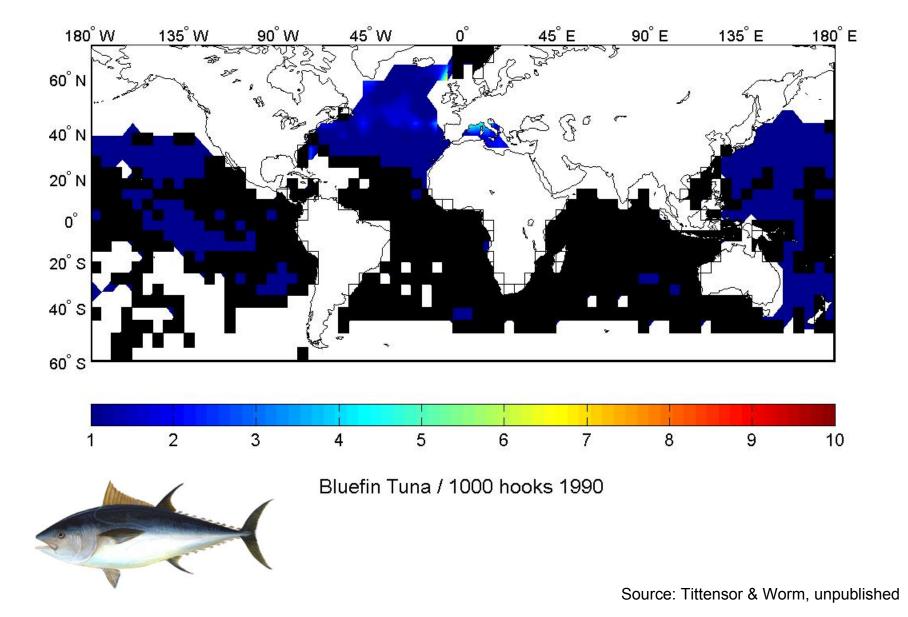
Bluefin tuna example



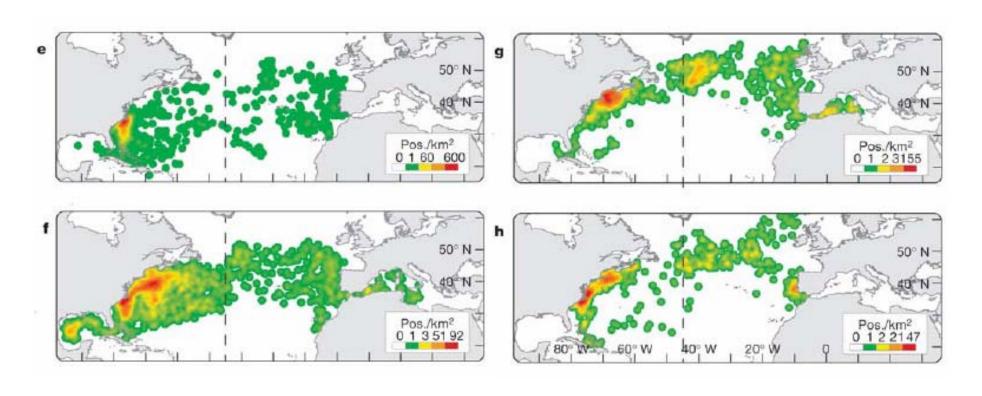
Source: Tittensor & Worm, unpublished







Tagging confirms bluefin to North Atlantic





Source: Block et al. 2005. Nature 434: 1121-1127

What are the causes?

Industrialized fishing is the driving cause



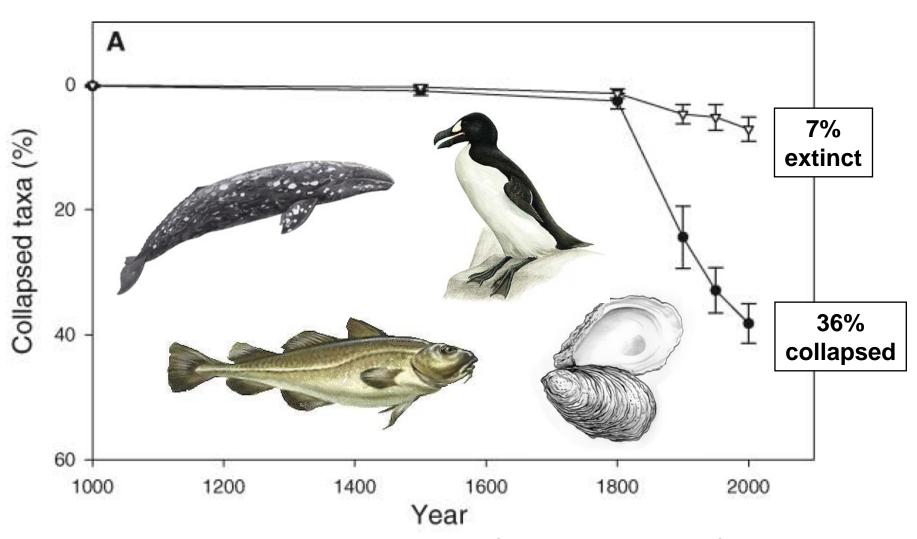
 Exacerbated by habitat destruction, pollution, and (increasingly) climate change



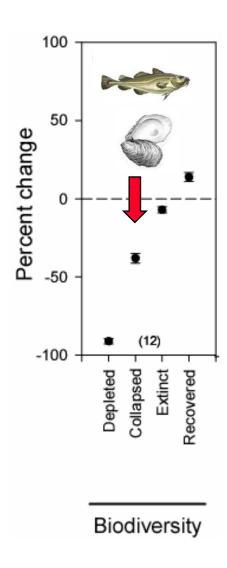




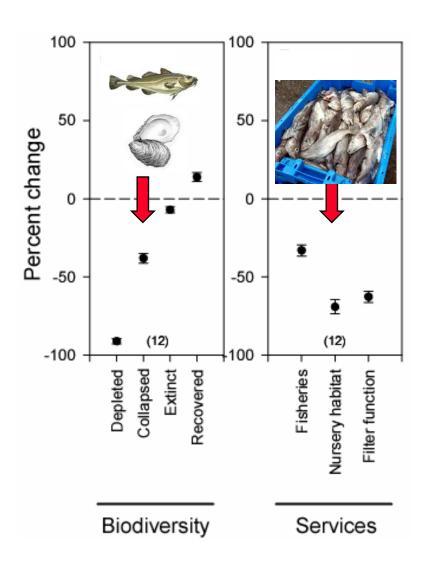
Loss of diversity



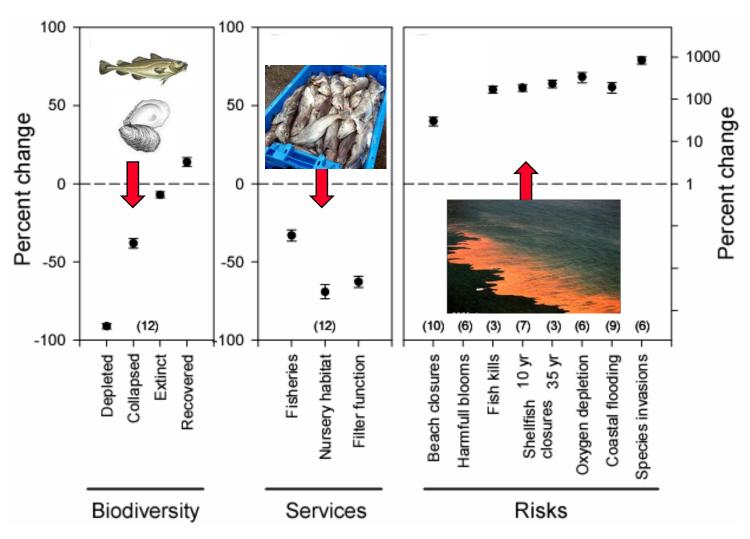
Loss of diversity



Loss of services



Increased risks



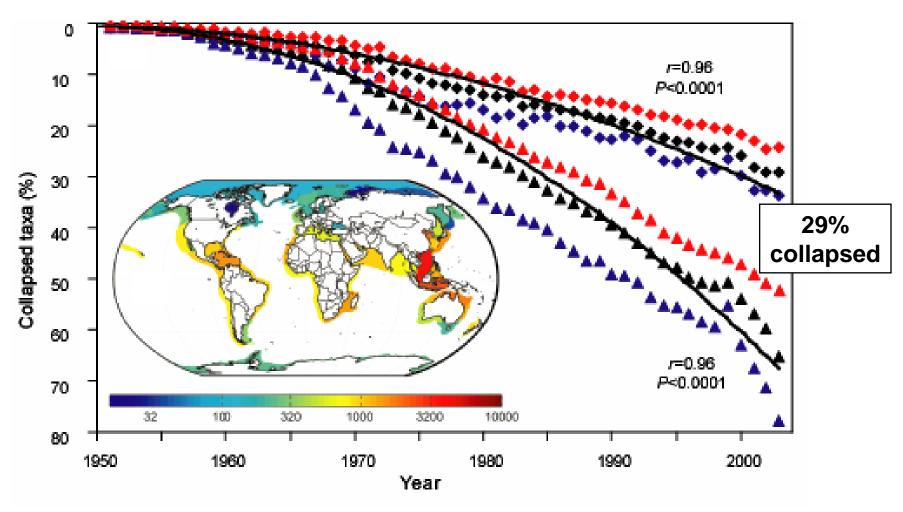
Oyster example

- Removal of Oysters
- Algal blooms

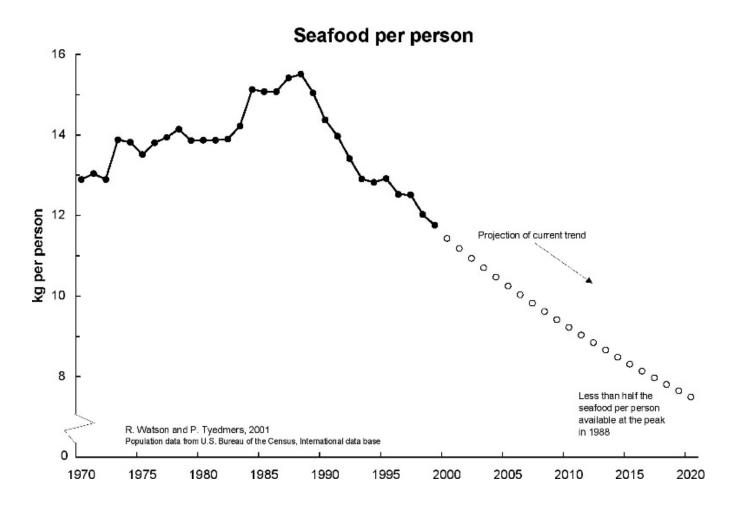




Burning through our natural capital

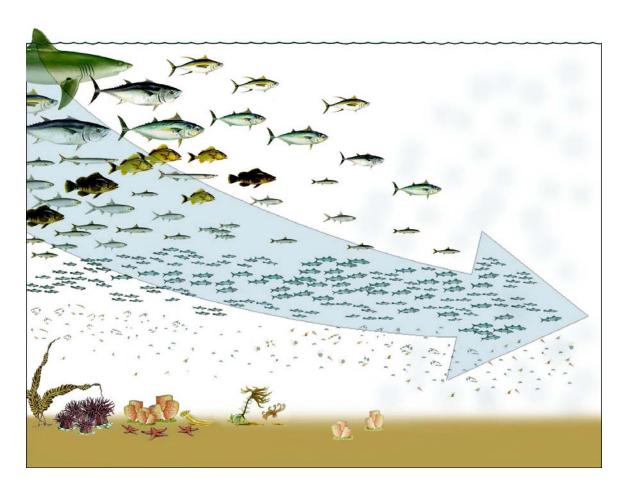


Declining global seafood supply



Sources: Watson & Pauly (2001) Nature 414:534 – 536, U.S. Bureau of the Census, International data base

Ecosystem changes



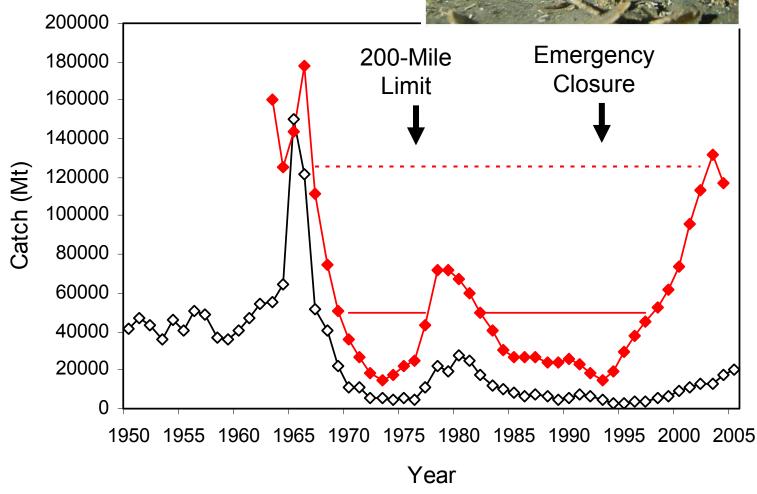
Source: Pauly & MacLean 2003, Island Press

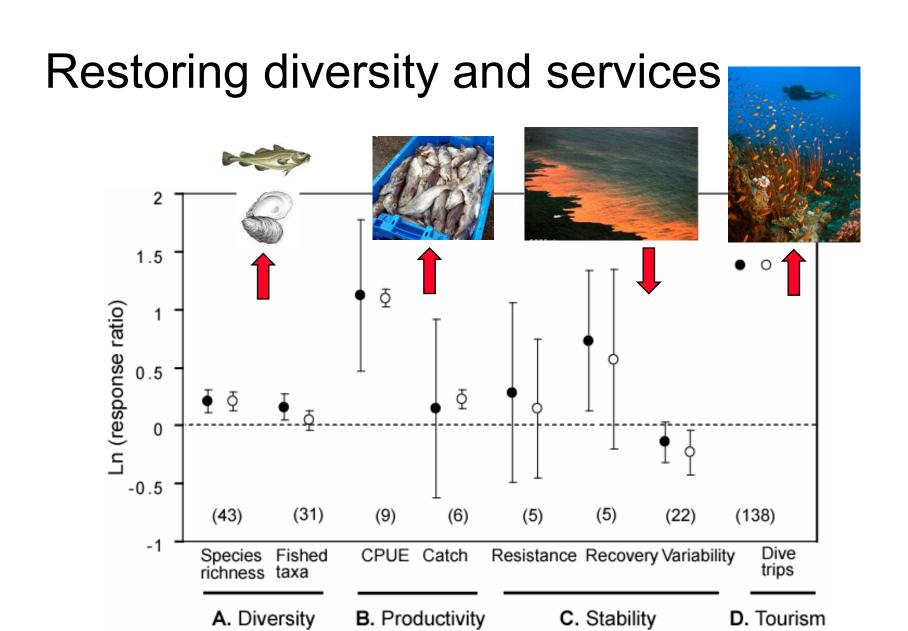
- Smaller fish, invertebrates increase
- Fisheries shift to lower levels
- Diversity decreases
- Ecosystems become
 - less resilient
 - less predictable
 - less productive



A success story: Georges Bank haddock



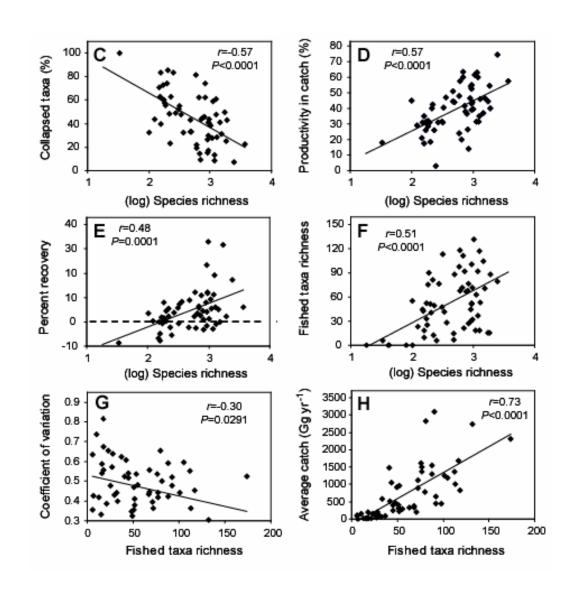




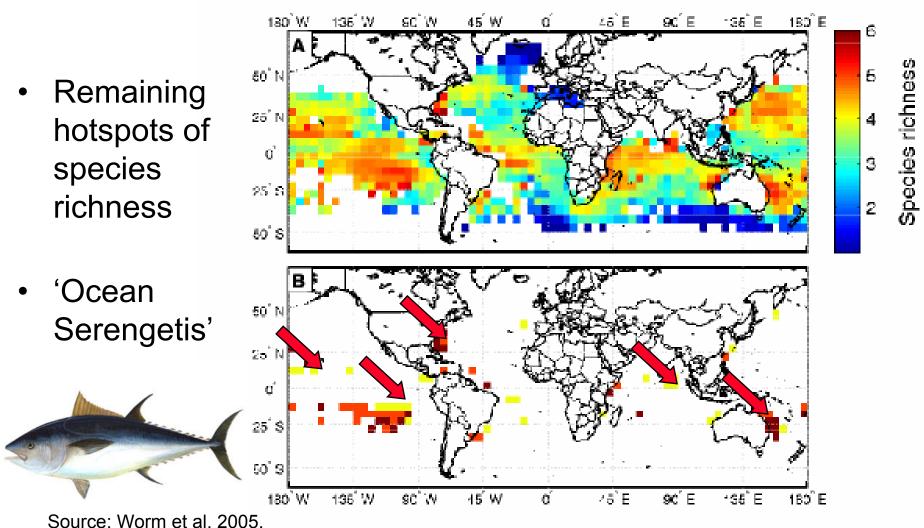
Biodiversity begets fisheries sustainability

More species →

- Fewer collapses
- Faster recovery
- More predictable
- More productive



Protecting global hotspots



Conclusions

- Ongoing depletion of ocean ecosystems worldwide
- Loss of biodiversity has impaired food supply, water quality, and resilience
- Restoration of marine biodiversity can recover ecosystem services
- It's not too late



Collaborators: Ransom Myers, Heike Lotze, Wade Blanchard, Derek Tittensor, Daniel Boyce

NCEAS group: Ed Barbier, Nicola Beaumont, Emmett Duffy, Carl Folke, Benjamin Halpern, Jeremy Jackson, Heike Lotze, Fiorenza Micheli, Stephen Palumbi, Enric Sala, Kim Selkoe, John Stachowicz, Reg Watson

Funding: CoML-FMAP, NSERC, NSF, DFG