December 4, 2014

Mr. John Bullard, Regional Administrator
NOAA Fisheries Service, Northeast Regional Office
55 Great Republic Drive
Gloucester, MA 01930-2276

Dear Mr. Bullard:

We, the 138 undersigned scientists, are writing to provide comments on the proposal to revise the ensemble of Essential Fish Habitat (EFH) areas in New England through the Omnibus Essential Fish Habitat Amendment 2 (Amendment).[1] The scientific community has followed this EFH discussion closely, cautioning NOAA Fisheries and the New England Fisheries Management Council (Council) about the risks associated with opening closed areas to relieve short-term fish shortages at the expense of future ecosystem recovery.[2] The Amendment, with the Draft Environmental Impact Statement (DEIS), presents a critically important vehicle for improving the network of EFH areas at a time when threats to the ocean are increasing and ecosystem states are changing, likely affecting ecological resilience and the potential for recovery of important goods and services.

The Magnuson-Stevens Fishery Conservation and Management Act (statute) appropriately dictates a broad approach to identifying and protecting the diversity of habitats needed by managed fishes through all their life history stages. This includes prey and prey habitat, and areas of the benthos and water column needed for all aspects of reproduction, including courtship, spawning, and the successful development of eggs, larvae, and young. Moreover, the statute mandates a schedule for continued improvements for the long-term conservation of EFH.

As scientists we remain deeply concerned that this Amendment will fall far short of providing the EFH protection needed to support the region's marine ecosystems, including its dependent fisheries. Wild-capture fisheries are the products of resilient natural ecosystems, and the EFH programs should be designed to support such ecosystems. In completing the Amendment, we strongly advise NOAA Fisheries to ensure that all of the following major goals are attained through the EFH Amendment:

- Enhance spawning of target species and other key components of the ecosystem, including prey species.
- Enhance survival and growth of juvenile fish (i.e., pre-recruit fish).
- Enhance growth of managed species through the protection of prey species and the habitats **they** require.

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[1] Draft Environmental Impact Statement (DEIS), dated October 1, 2014, available at: www.greateratlantic.fisheries.noaa.gov/regs/2014/October/14habo2anoa.html.

[2] See appended letters to NOAA Fisheries dated November 7, 2012, and April 9, 2013.

- Enhance habitat and biological diversity, the elements of the ecosystem that support and sustain managed species, represented within the selection of EFH areas, including robust representation within each of the subregions encompassed by this Amendment.
- Protect remaining areas that continue to support cold-water corals.
- Enhance habitat research by establishing a network of Dedicated Habitat Research Areas (DHRAs), including reference areas protected from all fishing and other local human disturbance. We view these areas as **essential** elements of adaptive and Ecosystem-Based Fishery Management (EBFM).
- Enhance approaches to integrate EFH elements within EBFM.

The statute does not develop a detailed scientific discussion of EFH. However, the definition of EFH is suitably comprehensive: *Essential fish habitat means those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity.* Under Findings, Purposes and Policy (Section 2) the statute indicates that a ***national program for the conservation and management of the fishery resources of the United States is necessary*** *to prevent overfishing, to rebuild overfished stocks, to insure conservation,* ***<u>to facilitate long-term protection of essential fish habitats</u>****, and to realize the full potential of the Nation's fishery resources.* Further, within Other Requirements and Authority (Section 305), it is specified that the *Secretary [of Commerce], in consultation with participants in the fishery, shall provide each Council with recommendations and information regarding each fishery under that Council's authority to* ***assist it in the identification of essential fish habitat, the adverse impacts on that habitat, and the actions that should be considered <u>to ensure the conservation and enhancement of that habitat</u>*** (emphasis added).[3]

The Amendment offers a range of alternatives for <u>reducing</u> habitat protection.
In every subregion, the Amendment includes a range of alternatives that span from the current EFH protections (*status quo*) to no protection for EFH whatsoever (no habitat management areas, or HMAs). With the exception of one subregion that has no protected EFHs (i.e., eastern Maine), each of the other alternatives to *status quo* represents a reduction in the overall area that is protected now—that is, a net decrease in area protected, in some scenarios by as much as 70%. In terms of area alone, the Amendment offers no alternatives to *status quo* that would enhance habitat protection through an expansion of the overall area protected in the region. Given the current state of some of the managed fish populations, protecting more, not less, habitat would seem to be an alternative worthy of consideration.

With the exception of a few small areas dedicated to research, the Amendment will likely permit significant fishing activity within new HMAs, including midwater trawls, gill nets, and possibly hydraulic clam dredges. Protection from mobile bottom-tending gear is a likely outcome of the Amendment and is clearly significant. However, this is by no means complete protection, especially at the spatial scale of the HMAs. In the context of EFH conservation, the goals delineated above, and an ongoing ecological crisis complete with a declared fisheries disaster, this Amendment must offer more comprehensive protection of habitat. The region was recently advised by NOAA Fisheries that Atlantic cod, once the mainstay of regional fisheries and an apex predator in the ecosystem, has been reduced to just 3-4% of the spawning biomass (SSB) thought to be associated with maximum sustainable yield (MSY), or SSB_{MSY}, the lowest SSB ever recorded for the Gulf of Maine stock.[4] The situation for cod on Georges Bank is similar. The loss of apex predators is well-known to

[3] Magnuson-Stevens Fishery Conservation and Management Act, as Amended Through January 12, 2007: Section 3 Definitions 16 U.S.C. 1802 MSA § 3104-297 (10); *Id* Section 2 Findings, Purposes, and Policy 16 U.S.C. 1801 104-297 (6); *Id* Section 305. Other Requirements and Authority 16 U.S.C. 1855, MSA § 305 104-297, (b) Fish Habitat 1B.

[4] 2014 Assessment Update of Gulf of Maine Atlantic Cod—Draft Working Paper for Peer Review Only.

produce cascading effects, shifting ecosystems to new states that may lack attributes valued by human users.[5] The situation with cod in New England must be heeded as a significant indicator of systemic ecological changes that extend well beyond this species alone.

Arguments for diminished habitat protection are not compelling.

It has been argued that less habitat area will be needed if the "right" areas are targeted as identified through the Swept Area Seabed Impact (SASI) model. This modeling effort was focused exclusively on hard-substratum habitats due to their high vulnerability to disturbance, leaving the role of other bottom types in supporting managed species unaccounted for. However, chronic disturbance of other bottom types still yields a deficit of habitat attributes that enhance survival and growth. We concede that under certain scenarios, a smaller amount of diverse habitat may in fact have greater ecological benefit than a larger amount of lower value. But we are not persuaded by the DEIS, or the extant scientific literature for the region, that there is sufficient evidence that this scenario can be applied here with a high degree of safety or certainty. Habitat protection must capture a diversity of habitat types if the Amendment is to enhance ecosystem resilience and meet all of the goals for EFH as indicated above. The *status quo* areas do capture a diversity of habitat types in a complex matrix. The SASI approach nominally used to identify the smallest areas of vulnerable EFH does not meet this important requirement. In fact, it only identifies the high-density patches of the most vulnerable habitat (LISA cluster analysis), leaving much unprotected when maximal protection is needed to recover depleted populations. The Council's technical teams have also analyzed the distribution of key biological variables, including some forage fishes, and juvenile and spawning groundfish, but the utilization of this important information in guiding the development of alternatives has been poor. In short, the DEIS does not make a strong case that a new network of HMAs built of the alternatives will be a net gain or even maintain the ecological *status quo* for the region as a whole.

The general tendency to define habitat only in terms of the physical structure of the seabed is overly narrow and is likely to miss areas of the bottom and water column that are vital habitat, due to a variety of factors the analyses have not considered. During peer review of the SASI approach, the Council was advised that this methodology was not, by itself, sufficient for deciding which areas to close or which to open.[6] Overall, the Amendment does not rely enough on the distribution of marine life as a guide to important habitat.[7] The Amendment fails to meaningfully advance protection for spawning fish, looking instead to future policy changes and repackaging the *status quo* system of seasonal closures.

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[5] Frank KT et al. (2007) The ups and downs of trophic control in continental shelf ecosystems. Trends in Ecology and Evolution **22**(5):236-242; Frank KT et al. (2006) Reconciling differences in trophic control in mid-latitude marine ecosystems. Ecology Letters **9**: 1–10; Frank KT et al. (2005) Trophic Cascades in a Formerly Cod-Dominated Ecosystem. *Science* 308:1621-3; Estes JA (2011) Trophic Downgrading of Planet Earth. *Science* 333 (6040): 301–306; Terborgh and Estes (2010) *Trophic Cascades*, 488 pages, Island Press, Washington, DC.

[6] The Council's Scientific and Statistical Committee advised that the SASI model be peer reviewed during 2011 (February 15–17); in brief, the peer reviewers advised that SASI should not be used to evaluate the practicability of opening or closing particular areas, generally characterizing SASI as preliminary—most useful for exploring ideas and stimulating discussion; see Sullivan PJ et al. (2011) Swept Area Seabed Impact (SASI) Model Peer Review on Behalf of the New England Fisheries Management Council, Final Report, April 14, 2011, and presentation to the Council, Mystic, Connecticut, April 26, 2011, available at: http://archive.nefmc.org/actions/council_audio/april2011/april2011audio.htm.

[7] Auster PJ et al. (2001) Fish species and community distributions as proxies for seafloor habitat distributions: The Stellwagen Bank National Marine Sanctuary example (northwest Atlantic, Gulf of Maine). *Environmental Biology of Fishes* 60: 331–346; Cook RR, Auster PJ (2005) Use of simulated annealing for identifying Essential Fish Habitat in a multi-species context. *Conservation Biology* 9: 876–886; Cook RR, Auster PJ (2013) The biodiversity value of marine protected areas for multi-species fishery management in the Gulf of Maine. *Aquatic Conservation: Marine and Freshwater Ecosystems*. 23: 429–440.

Some of the largest existing closure areas (e.g., on Georges Bank) were originally chosen based upon the presence of spawning and/or juvenile groundfish and have been tallied satisfying EFH requirements in the past. With some revision of history, the same places are now called *groundfish mortality areas* by some, because they were redesigned so as to reduce fishing mortality during an emergency. It has subsequently been suggested that these *status quo* areas are no longer needed because the fishery, as of 2010, operates under hard Annual Catch Limits (i.e., quota-based management with ACLs). This contention is not supported by science and experience in other regions.[8] Even with catch limits in place, areas that are protected from fishing gear will be needed to support ecosystem function and the goals for EFH envisioned when the language in the statute was drafted. Regardless of the language used when designating these areas, their current ecological functions, some protected for 20 years, must be carefully considered in revising plans for EFH conservation.

Ecosystem trouble demands enhanced habitat protection.
In 2009 NOAA Fisheries reported that the Northeast U.S. Continental Shelf Large Marine Ecosystem was subject to *ecosystem overfishing*,[9] as manifested by a host of indicators that signal ecosystem deterioration and conditions which undermine the yield of fish and other ecosystem services.[10] Among the main findings of the Ecosystem Status Report was:

> The Northeast U.S. Continental Shelf Large Marine Ecosystem (NES LME) has undergone sustained perturbations due to environmental and anthropogenic impacts over the last four decades, resulting in fundamental changes in system structure.

Regrettably, there are few signs that things have improved over the intervening years despite a successful transition to management grounded on science-based catch limits (i.e., ACLs). Fish growth, condition, and recruitment have deteriorated, and as of 2014 half of the 20 stocks in the Northeast Multispecies Fishery remain in a depleted state (i.e., overfished). Rebuilding programs have failed for Gulf of Maine cod and other important stocks. In the future, catch limits must be determined within an ecosystem framework wherein multiple factors are considered, including species interactions and system-level productivity.[11] However,

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[8] Melnychuk MC et al. (2012) Can catch share fisheries better track management targets? *Fish and Fisheries*, 13: 267–290. doi: 10.1111/j.1467-2979.2011.00429.x; Essington TE et al. (2012) Catch shares, fisheries, and ecological stewardship: A comparative analysis of resource responses to a rights-based policy instrument. *Conservation Letters* 5: 186–195; Steneck RS, Wilson JA (2010) A fisheries play in an ecosystem theater: Challenges of managing ecological and social drivers of marine fisheries at multiple spatial scales. *Bulletin of Marine Science,* 86(2): 387–411; Murawski S et al. (2005) Effort distribution and catch patterns adjacent to temperate MPAs. *ICES Journal of Marine Science,* 62: 1150–1167; Brown BK et al. (2010) Effects of excluding bottom-disturbing mobile fishing gear on abundance and biomass of groundfishes in the Stellwagen Bank National Marine Sanctuary, USA. *Current Zoology* 56(1): 134–43; Roberts CM, Hawkins JP (2012) Establishment of fish stock recovery areas. Prepared for the European Parliament's Committee on Fisheries; Svedäng H (2010) Long-term impact of different fishing methods on the ecosystem in the Kattegat and Öresund. Prepared for the European Parliament's Committee on Fisheries.

[9] Murawski SA (2000) Definitions of overfishing from an ecosystem perspective. *ICES Journal of Marine Science*. 57(3): 649-658.

[10] Ecosystem Assessment Program (2009) Ecosystem Assessment Report for the Northeast U.S. Continental Shelf Large Marine Ecosystem. U.S. Department of Commerce, Northeast Fisheries Science Center Reference Document 09-11: 61 pp.

[11] Balch WM et al. (2012) Step-changes in the physical, chemical and biological characteristics of the Gulf of Maine, as documented by the GNATS time series. Marine Ecology Progress Series 450: 11–35; McManus MC et al. (2014) The Western Maine Coastal Current reduces primary production rates, zooplankton abundance and benthic nutrient fluxes in Massachusetts Bay. *ICES Journal of Marine Science* 71(5): 1158–69; Fogarty MJ (2014) The art of ecosystem-based fishery management. *Canadian Journal of Fisheries and Aquatic Sciences* 71: 479–490.

habitat protection must also be recognized as a vital tool for improving ecosystem resilience and the chances for depleted stocks to recover. The region's approach to habitat protection, as reflected in Council discussions and the alternatives developed for the DEIS, do not meet these challenges, particularly when considering the new threats posed by climate change.

Unprecedented threats posed by climate change demand an unparalleled EFH program.

The EFH Amendment has been more than a decade in the making, a decade during which the ecological landscape within which the fisheries operate has changed rapidly and extensively. The Northwest Atlantic, including the Gulf of Maine, has seen steady manifestations of climate change and witnessed record-breaking temperatures in 2012. Awareness that the region is a global hot spot for oceanic climate change has grown through experiences on the water and with the emergence of new science.[12] NOAA and the global scientific community have recognized that habitat protection is a crucial tool for resilience and adaptation in the face of these and others problems exacerbated by climate change.[13] Even if the human-induced causes of climate change were eliminated today, the need for enhanced habitat protection and other steps to increase ecosystem resilience would continue for decades because greenhouse gases will remain elevated for centuries. The imperative for protecting marine habitat in the Northeast has never been greater.

Areas that continue to support cold-water coral must be protected now before the corals are lost.

Cold-water corals (of multiple taxa) represent a component of regional biological diversity as well as EFH that has been seriously compromised throughout New England over the last half-century, essentially eradicated from most of their historic range on the continental shelf by bottom-contact fishing gear. Recent expeditions to the eastern Gulf of Maine have revealed localized areas where cold-water corals have escaped damage due to the complexity of the seafloor.[14] With pressure to explore new areas for alternative fisheries resources, the risk of losing these remaining coral communities and the functions they serve is higher than ever. Scientific information made available in the summer of 2014 should be used to design and implement coral protection measures in eastern Maine, as highly vulnerable EFH, through this Amendment. These coral areas should be included in a new HMA and clearly meet the criteria for Habitat Areas of Particular Concern (discussed further below).

Habitat research areas are essential.

We support designation of the network of DHRAs, and associated *reference areas* in the Amendment. These areas should support well-designed observational and experimental programs on the effects of fishing and

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[12] Mills KE et al. (2013) Fisheries Management in a Changing Climate: Lessons from the 2012 Ocean Heat Wave in the Northwest Atlantic. *Oceanography* 26(2SI): 191–195; IPCC AR5 WG II Chapter 6. Ocean Systems; Union of Concerned Scientists; Northeast Climate Impacts Assessment; Third National Climate Assessment, 2014; Mooney H et al. (2009) Biodiversity, climate change, and ecosystem services. *Current Opinion in Environmental Sustainability* 1(1): 46–54; Friedland KD et al. (2013) Thermal habitat constraints on zooplankton species associated with Atlantic cod (*Gadus morhua*) on the US Northeast Continental Shelf. *Progress in Oceanography* 116: 1–13; Hollowed AB et al. (2013) Projected impacts of climate change on marine fish and fisheries. *ICES Journal of Marine Science* 70 (5): 1023–1037.

[13] National Fish, Wildlife and Plants Climate Adaptation Strategy, National Fish, Wildlife and Plants Climate Adaptation Partnership. 2012. Association of Fish and Wildlife Agencies, Council on Environmental Quality, Great Lakes Indian Fish and Wildlife Commission, National Oceanic and Atmospheric Administration, and U.S. Fish and Wildlife Service. Washington, DC, ISBN: 978-1-938956-00-3, DOI: 10.3996/082012-FWSReport-1: http://www.wildlifeadaptationstrategy.gov/pdf/NFWPCAS-Final.pdf.

[14] Auster PJ et al. (2014) Imaging Surveys of Select Areas in the Northern Gulf of Maine for Deep-sea Corals and Sponges during 2013-2014. Submitted to the New England Fisheries Management Council, October 30, 2014; Hanging Coral Gardens in Gulf of Maine Add to Excitement of Summer Full of Deep-Sea Coral Discoveries. Northeast Fisheries Science Center Newsroom, SS14.08, September 2, 2014: www.nefsc.noaa.gov/press_release/pr2014/scispot/ss1408.

other activities. Furthermore, these areas must be sufficiently large that they can be observed and sampled in order to extract management-critical data without being compromised or destroyed in the process. This is a critical step to improve information linking attributes of marine habitats and the impacts of fishing to the characteristics of EFH and, ultimately, to the core principles of EBFM. A changing climate and shifting oceanographic variables add further complications to management. A concerted effort is needed to understand the role that seafloor habitats play, in concert with other ecosystem attributes, in the long-term sustainability of managed species. New research in this area will improve decision-making at multiple points in the management process, reducing uncertainty and improving accountability.

Dedicated Habitat Research Areas. We strongly recommend DHRAs in all five subregions of the Northeast Shelf Large Marine Ecosystem. Determining which management actions, in particular environmental settings, produce the desired effects is fundamental to managing human activities within complex ecosystems. As one example, the effects of particular types of EFH closures on reproduction, growth, recruitment, and food-web relationships of managed species must be understood to evaluate the function of current EFH areas and to guide future decisions. Distinguishing the ecological consequences of management actions from effects that are part of background (non-anthropogenic) ecological variation requires long-term observations in areas where human impacts are controlled through experimental design. The proposed establishment of DHRAs in three of the five subregions (Alternatives 2, 3, and 4) is an important step forward that will foster synergies among researchers, the fishing community, and fisheries management by answering critical questions.

We note that the Amendment also includes the possibility of a relatively short sunset for the system of DHRAs (i.e., Alternative 5, three-year sunset). In the context of today's research-funding world, and also considering the lengthy temporal scale at which one can expect to see habitat responses to experimental manipulations, this sunset is unrealistic and could undermine the long-term success of this important part of the Amendment. We therefore recommend that NOAA Fisheries either eliminate the sunset provision as now outlined in the Amendment or make the time frame substantially longer.

Fully protected reference areas. Fully protected reference areas should also be established in all of the subregions. Fishing and other human disturbance must be minimized to the degree possible within the reference areas at all times to allow these areas to serve their intended function as indicators of the state that the broader ecosystem would likely assume without proximate direct or indirect human-caused disturbance. The proposed reference area within the Stellwagen Bank DHRA (Alternative 3, Option A) is of particular importance because it is in an area with significant levels of recreational fishing. As a result, this area will allow scientists and the community to begin distinguishing the effects of (1) direct removals of fish predators from (2) those produced by fishing gear that directly impacts the ecology of seafloor communities through contact (e.g., trawls).

Improve on the existing network of habitat management areas.

The New England Fishery Management Council manages a zone of approximately 232,156 square kilometers, which extends from 3 to 200 nautical miles offshore, and from the boundary with maritime Canada to the waters off Connecticut. The existing suite of habitat management areas made up of the combination of groundfish and habitat closures (i.e., *no action alternative*, or *status quo*) has a spatial extent of 24,812 km^2, or about 10% of the entire management zone. This suite includes a substantial diversity of habitat types. Improving habitat protections by reducing impacts through changes to the applicable management measures, and by adding new habitat management areas (e.g., Eastern Maine: Alternative 2, Option 1; Great South Channel: Alternative 3, Option 1), will benefit the region's ecology and dependent fisheries. However, a compelling case has not been presented to support the notion that substitution of smaller, new areas as defined in many of the alternatives offers any improvement over the *status quo* in terms of ecosystem support or the goals outlined above for EFH.

Gulf of Maine. In the Gulf of Maine, the Western Gulf of Maine (WGOM) Closure (3,030 km^2), Cashes Ledge (1,373 km^2), and Jeffreys Bank (499 km^2) are important areas that have been protected for an extended period and support a diversity of habitats and associated seafloor communities, including many of the remaining large Atlantic cod.[15] All of these areas are widely recognized as ecologically important and containing a mosaic of habitat types, important for animals to carry out their life histories.[16] Two of these areas (WGOM and Cashes) include Habitat Areas of Particular Concern (HAPC), discussed below. Cashes Ledge has a unique deep-water kelp forest and relatively high biological diversity, including a distinct resident cod population. Due to complex seafloor topography, distance from shore, and current protection, these sites are in comparatively good condition, and have served as important sites for marine ecosystem research.[17]

The ensemble of three areas in the western and central Gulf of Maine should be kept intact, absent a very well-developed scientific foundation for a new network that will perform better than these areas, which this DEIS does not provide. New protected habitat management areas should be added in the northeastern part of the Gulf of Maine (e.g., Eastern Maine: Alternative 2, Option 1). An HMA to encompass newly discovered cold-water coral should be incorporated here; the coral areas would clearly meet the criteria for an HAPC. Nearshore protection farther south in the Gulf of Maine remains inadequate and should also be improved as indicated by the analyses performed by the Council's Closed Area Technical Team on spawning and juvenile fishes.

Georges Bank. On Georges Bank, Closed Area I (3,939 km^2) and Closed Area II (6,862 km^2) inclusive of an existing HAPC are substantial, have been in place over decades, and have documented recovery of seafloor habitats. These areas were sited originally to protect juvenile and spawning groundfish.[18] The DEIS includes

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[15] Pershing AJ et al. (2013) The Future of Cod in the Gulf of Maine. Gulf of Maine Research Institute: www.gmri.org/sites/default/files/resource/gmri_-_the_future_of_cod_in_the_gulf_of_maine.pdf; Gulf of Maine Research Institute (2012) *The Role of Closed Areas in Maintaining Cod Health*, Waypoints—Gulf of Maine Fishing Industry Newsletter, Gulf of Maine Research Institute: www.gmri.org/news/waypoints/role-closed-areas-maintaining-cod-health; Brown BK et al. (2010) Effects of excluding bottom-disturbing mobile fishing gear on abundance and biomass of groundfishes in the Stellwagen Bank National Marine Sanctuary, USA, *Current Zoology* 56(1): 134–143.

[16] Ryan MR (2012) Predators and distance between habitat patches modify gap crossing behaviour of juvenile Atlantic cod (*Gadus morhua*, L. 1758). *Journal of Experimental Marine Biology and Ecology* 422–423: 81–87.

[17] McGonigle C et al. (2011) Detection of deep water benthic macroalgae using image-based classification techniques on multibeam backscatter at Cashes Ledge, Gulf of Maine, USA. *Coastal and Shelf Science* 91(1): 87–101; Sherwood GD, Grabowski JH (2010) Exploring the life-history implications of colour variation in offshore Gulf of Maine cod (*Gadus morhua*). *ICES Journal of Marine Science* 67 (8): 1640–1649; Brown BK et al. (2010) Effects of excluding bottom-disturbing mobile fishing gear on abundance and biomass of groundfishes in the Stellwagen Bank National Marine Sanctuary, USA, *Current Zoology* 56(1): 134–143; Tamsett A et al. (2010) Dynamics of hard substratum communities inside and outside of a fisheries closed area in Stellwagen Bank National Marine Sanctuary (Gulf of Maine, NW Atlantic). Marine Sanctuaries Conservation Series ONMS-10-05. 53 pp; Murawski SA et al. (2005) Effort distribution and catch patterns adjacent to temperate MPAs. ICES J. Mar. Sci. 62(6):1150-1167; Auster PJ et al. (1996) The impacts of mobile fishing gear on seafloor habitats in the Gulf of Maine (Northwest Atlantic): Implications for conservation of fish populations. *Reviews in Fisheries Science* 4: 185–202; Witman JD et al. (1993) Pulsed phytoplankton supply to the rocky subtidal zone: Influence of internal waves. *Proceedings of the National Academy of Sciences* USA 90: 1686–1690.

[18] Murawski SA et al. (2000). Large-scale closed areas as a fishery-management tool in temperate marine systems: The Georges Bank experience. *Bulletin of Marine Science* 66(3): 775–798; Murawski SA et al. (2005) Effort distribution and catch patterns adjacent to temperate MPAs. ICES J. Mar. Sci. 62(6):1150-1167; Halliday RG (1988). Use of seasonal spawning area closures in the management of haddock fisheries in the Northwest Atlantic. *NAFO Scientific Council Studies*, 12: 27–36.

seven alternatives to these areas (including no protection at all), but only one (Alternative 8, 4,791 km^2) could be considered as possibly improving EFH protection on the Bank. A move to Alternative 8 would decrease the overall extent of protection by half with a single large area along the northern edge of the Bank, including important habitat within the existing cod HAPC. This alternative would also include known spawning areas for Atlantic herring and important areas for a number of groundfish species, and would straddle a diversity of habitats, including the species-rich boundary between the Bank and the deep waters of the Gulf of Maine.

Great South Channel. The Great South Channel is a dynamic region that serves as a corridor for many species moving between southern New England and the Gulf of Maine and Georges Bank. It supports relatively high biological diversity.[19] At present there is no protected EFH in the channel proper, and the addition of protection in this area through the Amendment would be beneficial. Alternative 3, Option 1, appears to be the best alternative included in the DEIS and includes the preferred cod HAPC alternative presented in the DEIS (Volume 2, pp. 390-391).

Southern New England. The Southern New England (SNE) area includes EFH protection in the Nantucket Lightship area, made up of overlapping habitat and groundfish areas with a combined extent of 9,113 km^2. This area was established to protect juvenile yellowtail flounder.[20] The DEIS does not develop alternatives for SNE beyond the areas discussed above that are situated closer to the channel. We urge NOAA Fisheries to consider additional EFH protection in SNE south of the channel.

Essential Fish Habitat and Habitat Areas of Particular Concern.
Two important goals for the Amendment are dealt with in Volume 2 of the DEIS: Revision to the EFH designations for individual species and the development of HAPCs. In contrast to the presentation of alternatives for habitat management areas in Volume 3, the DEIS does not provide a clear juxtaposition of alternatives or encourage reviewers to consider alternatives. Public review of these elements of the Amendment was completed in a separate DEIS in 2007.[21]

According to the guidelines provided by the agency for addressing EFH provisions in Fishery Management Plans, areas of EFH that have important ecological functions, are sensitive to human disturbance, will be stressed by ongoing or future development, or are rare should be considered as HAPCs.[22]

We endorse the identification and **protection** of HAPCs, that is, areas of EFH that demand particular concern and corresponding protection. Thus, we support designation of the preferred alternatives identified in the DEIS. However, we are concerned that while the DEIS seeks to identify HAPCs, it specifically refrains from

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[19] Crawford JD, Smith J (2006) *Marine Ecosystem Conservation for New England and Maritime Canada: A Science Based Approach to Identifying Priority Areas for Conservation.* Conservation Law Foundation and WWF-Canada, 193 pp; Greene JK et al. (2010). *The Northwest Atlantic Marine Ecoregional Assessment: Species, Habitats and Ecosystems*. The Nature Conservancy, Eastern U.S. Division, Boston.

[20] Murawski SA et al. 2000. Large-scale closed areas as a fishery-management tool in temperate marine systems: The Georges Bank experience. *Bulletin of Marine Science* 66(3): 775–798

[21] Phase 1 work was published in a draft Environmental Impact Statement in April 2007. See 3.4 Notices of intent, scoping, and the amendment development process, in Omnibus Essential Fish Habitat Amendment 2, Volume 1, 86.

[22] § 600.758 50 CFR Ch. VI (10–1–13 Edition), Fishery Conservation and Management § 600.815, Contents of Fishery Management Plans.

offering measures that would protect such areas of particular concern from fishing gear or anything else.[23] We question the value of designation as areas of particular concern without accompanying management to measure up to this designation.

The newly discovered coral areas in eastern Maine (discussed above) clearly meet the criteria for HAPC designation and should be added to the areas that are to be classified as such.

Many of the HMAs discussed above include the identified HAPCs, including Cashes Ledge, western Gulf of Maine, Georges Bank, and areas in the Great South Channel and south. This overlap points to the importance of these HMAs, as discussed above.

Conclusion

Before final decisions on EFH areas are made, NOAA Fisheries and the Council must take a sober look at this Amendment, with fresh eyes toward a future that holds ever-greater threats to ocean ecosystems and their abilities to sustain fisheries in the long term. NOAA Fisheries must ensure a future for fishing, fishing communities, and other ocean uses that depend upon marine ecosystems rendered resilient by expanding the network of protected areas, and by reducing the impacts within the areas through management changes.[24] Plans that may have appeared appropriate a decade ago when the Amendment was initiated must be rigorously re-evaluated within a context that includes a changing climate and the associated stresses on marine ecosystems. The rapid deterioration of some critical fish stocks, combined with the rising stress from environmental change, makes reductions in habitat protection highly unwise and unsupportable by today's scientific understanding. Our concerns about habitat conservation in New England, and the future of fishing, remain very high.

Sincerely,

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[23] Omnibus EFH Amendment 2, Volume 2: EFH and HAPCs Alternatives, 379: "[M]anagement measures such as gear restrictions have not been associated with the HAPC designation itself in the past, and are not proposed as part of the HAPC designations in this amendment."

[24] Graham J et al. (2014) Global conservation outcomes depend on marine protected areas with five key features. *Nature* 506: 216–220.

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April 9, 2013

Mr. John Bullard, Regional Administrator
NOAA Fisheries Service, Northeast Regional Office
55 Great Republic Drive,
Gloucester, Massachusetts, 01930-2276

NOAA–NMFS–2013–0050
Dear Mr. Bullard:

We the undersigned scientists are writing to you to express our serious concerns about the course that NOAA Fisheries and the New England Fishery Management Council (i.e., Council) have set for allowing new commercial fishing in portions of the long-standing protected groundfish closed areas in the Northeast, including Cashes Ledge, Western Gulf of Maine Closed Area, Closed Areas I and II, and Nantucket Lightship Closed Area as well as the Jeffreys Bank essential Fish Habitat (EFH) Area and other EFH areas. This is an action (i.e., mediated by Framework 48 and sector operations plans) that would clearly have a significant impact on the environment, causing further harm to the region's marine ecology and fisheries. A number of the scientists signing the present letter raised similar concerns in a letter to Eric Schwaab, Acting Assistant Secretary for Conservation and Management, NOAA Fisheries, last November (2012).[1]

There is no question that the region's ecosystems are compromised and that the shortages of groundfish are just one of the manifestations of this depleted state. The fish are less abundant, they are smaller, and recruitment is poor for many, including the iconic species of New England, the Atlantic cod. These are all signs of ecosystem-overfishing. NOAA's Status Report for the Northeast U.S. Continental Shelf Large Marine Ecosystem concluded that the system has been experiencing ecosystem overfishing since at least four years ago, and the health and productivity of the fishery has continued to deteriorate.[2] The ecosystems that provide us with our marine resources and support our coastal communities have been fundamentally changed by years of excessive fishing, with too little regard for ecological interactions and habitat impacts. A changing climate is adding new stress to an already degraded ecosystem.

Under these circumstances, more habitat protection is needed, not less. A diversity of habitat types must be protected from those impacts that are within our control in order to restore ecological resilience as a hedge against those emerging threats that we cannot head off in the short term.

- Commercial fishing should not be resumed within the groundfish closed areas as currently proposed (i.e., through Framework 48 and sector operations plans during fishing year 2013).
- Stewardship of the existing groundfish closed areas should be improved so that more protection is afforded within these areas, not less.
- Additional areas should be added so that the protected habitat network includes a diversity of habitats within each of the ecological sub-regions delineated in the Council's nascent plans for ecosystem-based fisheries management (EBFM).[3]
- EBFM should be resurrected as a priority and indeed elevated to urgent status for implementation by NOAA Fisheries and the Council.

The proposed changes to closed areas are unwise

The Council, with encouragement from NOAA Fisheries, is moving ahead with a plan to open areas now closed to most commercial fishing.[4] This action is being pursued as a response to the historically low populations of groundfish and it is argued that new fishing in these areas will provide relief to commercial fishermen. You have also identified additional access to groundfish areas by the scallop fishery as a matter of economic urgency.[5] While the plan is well intentioned, we believe that it is the wrong response; a result will likely be ecological setbacks to the recovery of fish populations already at low levels, and serious economic harm shortly afterward. It will damage the marine ecosystem upon which all of our fisheries and other sectors in the coastal economy totally depend.

We are unaware of any sound scientific basis for concluding that opening these areas will benefit the groundfishery over the long-term. To the contrary, scientific information from these areas, and from similar closures in other temperate regions, strongly indicates that protecting adults of reproductive age and habitat that enhances survival, feeding and growth, especially for juveniles, is the only wise course of action in the face of dwindling stocks. The ongoing work of the Council's Closed Area Technical Team (CATT) has already confirmed that the existing areas encompass spawning grounds and habitat used by juvenile cod, yellowtail flounder and other beleaguered stocks.

Key recommendations

Safeguard the broodstock. The areas targeted for resumption of fishing have been spared most commercial fishing for Atlantic cod and other groundfish for many years. Even if the numbers of old female fish in these areas were small, the impact of allowing fishing now could be devastating to stock rebuilding. Considerable research on cods (gadids) and other long-lived fishes supports the conclusion that a relatively few older females hold a vastly disproportionate part of the stock recruitment potential and that management should seek to protect these older fish.[6] The plan to allow access to the New England groundfish areas amounts to encouraging the industry to target older fish, and as such, it ignores the best available science. In economic terms, the actions being considered trade the considerable future value of such older fish for a smaller, more immediate monetary gain.[7]

Don't disturb spawning aggregations. Atlantic cod have complex spawning behavior and are known to return to the same sites year after year, with variable timing.[8] Spawning aggregations that are now protected within the closed areas will be disrupted by fishing and further erode the value of closed areas in replenishing depleted stocks.[9]

Protect areas that offer food and shelter. Bottom-living invertebrates (benthic and epibenthic) provide food for fish, and some are referred to as ecosystem engineers since they build three dimensional relief that is used by fish, especially juvenile fish, as shelter from predators and physical stress.[10] The structure, provided by corals, sponges and other invertebrates, is diminished by trawls and bottom contacting gear. Recent research indicates an important local habitat role for groundfish closed areas on Georges Bank. The condition and growth of yellowtail flounder, a species that is in serious jeopardy, is enhanced by the areas.[11] Studies of juvenile Atlantic cod have also documented the importance of gravel habitat along the Northeast part of Georges Bank, suggesting that this area is vital to very young fish (i.e., post-settlement) for growth and survival.[12] This conclusion was reinforced by findings recently discussed by the CATT.[13] Even in relatively dynamic, sandy-bottom areas of Georges Bank, bottom-living invertebrate animals such as amphipods and sponges generate structures that serve as habitat for small fish, including the young of those species managers desperately seek to rebuild.[14]

Ecosystem-based fishery management must be a priority
An integrated approach to fisheries science and management is needed in New England and it is called EBFM. It is widely recognized that effective management requires more than implementing traditional single-species quotas to ensure that stock abundance and ecosystem resilience persist. Closed areas are one of the key tools that should be used in an effective ecosystem-based management system as has been pointed out by the Scientific and Statistical Committee (SSC) in a series of presentations to the Council. In this context, elimination of groundfish closed areas would be a regressive step.

The Council identified EBFM as a priority in 2009 and again in 2011, but it suspended work on EBFM last year because of the groundfish crisis; in November 2012 the Council removed EBFM from its list of priorities. Now NOAA Fisheries is poised to reduce habitat protection for groundfish, potentially by more than half the area. A significant course correction is needed. NOAA Fisheries and the Council must elevate the implementation of EBFM as an urgent priority for the New England region.

Scientists at the Northeast Regional Science Center of NOAA/NMFS have been working for years in preparation for the long-anticipated and much-needed shift to EBFM as the fishery management model.[15] In addition, this shift is an essential step in bringing fisheries into line with the National Ocean Policy, whose goal is to safeguard marine resources and marine-dependent jobs over the long term: ecosystem-based management is the first of the nine national priority objectives.[16] We request that NOAA Fisheries make rapid implementation of EBFM a high priority and that you encourage the Council to do so as well.

In 2011, NOAA Fisheries supported the Council in its decision to combine the analysis of the groundfish closed areas with its ongoing Omnibus Habitat Amendment (OHA). This was the right decision because New England needs an integrated, ecosystem-informed approach to habitat protection. The groundfish areas have been protecting habitat for nearly two decades and were specifically intended to protect places used by groundfish, i.e. habitat areas.[17] However, regardless of the original intent and siting methods, it is essential to thoroughly analyze the ecological role that these areas are playing now, before opening them or otherwise replacing them with new areas. The full suite of closure areas must be analyzed as an ensemble within the OHA Environmental Impact Statement (EIS) in order to make credible, science-based habitat decisions for the region. Opening the existing groundfish areas now, ahead of the omnibus habitat amendment, is misguided and could undermine population recovery goals.

Correcting some misconceptions
The plans unfolding now through Framework 48 and sector operations plans (i.e., access to areas by sector vessels) are predicated on a number of incorrect assertions and ignore the long history of these areas.[18] This course flies in the face of science as well as common sense, and is a magnet for scrutiny. Several misconceptions have been cited as part of the rationale for opening the groundfish areas, some of them by NOAA Fisheries in the Northeast:

Misconception #1: Groundfish closed areas are no longer necessary because we operate under a new quota management system, therefore input controls are not needed.[19] With perfect implementation of quota-based management (i.e., catch shares) catch limits might not be exceeded with or without closed areas. However, it is not accurate to state that closed areas would no longer be necessary to achieve sustainable fisheries and resilient ecosystems. For example, desired increases in stock biomass are often not realized any better with quota management than without, success depending on more than just the quotas.[20] Without closed areas, quota management at a coarse geographic scale may also lead to the extirpation of local stock components thereby creating dysfunctional metapopulations,[21] disruption of spawning, or degradation of habitat for juveniles.

Closed areas protect the targeted fish, other species, and habitat; the habitat is used by many marine animals, including species that serve as food or shelter for groundfish. The closed areas were put in places known as high abundance areas for spawning adults and juveniles. The recent work of the CATT corroborates this. These closed areas have invaluable ecological functions that go well beyond simply controlling mortality and this is supported by the available scientific information.[22]

The habitat value of these areas for managed species will be degraded rapidly with the resumption of bottom trawling. This will include damage to structure that is important for juvenile groundfish (e.g., shelter from predators), loss of older females crucial to population resilience and rebuilding, disturbance to spawning, and impacts to invertebrates that fuel fish growth and reproduction. Full recovery of benthic communities can take decades and what progress has been made in New England will be set back through new fishing activity.

Misconception #2: It has been proven that closed areas do not work – if they worked we would not be in the current groundfish crisis. This statement is inaccurate, reflecting a common but over-simplistic view of a complex issue. It may be that some of the benefits of the closed areas have been overwhelmed by several factors, including overfishing throughout the region, fishing gears other than bottom trawls still being allowed in closed areas (e.g., limited scallop access, herring midwater trawlers, and recreational fishing), and overall ecosystem degradation. Such factors in no way prove that closed areas do not work. The best peer-reviewed science strongly indicates that groundfish closed areas retain higher densities of fish, larger individuals, and serve to export fish to the fishery.[23] The benefits of closed areas in similar temperate ecosystems are also well known.[24]

Misconception #3: The work of the Council's habitat committee shows that the closed areas are in the wrong places. It has been said repeatedly that the work of the habitat committee, with its Plan Development team (PDT), shows that the groundfish areas are in the wrong places. The siting of the groundfish areas was originally informed by the distribution of fish (biological data). The EFH approach that the Council has been developing since 2004, the Swept Area Seabed Impact Model (SASI), uses different criteria to identify places judged to be vulnerable to bottom tending mobile gear. Given these differences, it is not surprising that the SASI approach identifies some different areas, areas that are primarily hard bottom, as this was the predetermined target of the model. There is no basis for concluding that these areas are anymore "correct" than those covered by the groundfish areas. The peer reviewers of the SASI approach concluded that the approach is not sufficient by itself for determining the biological or economic consequences of opening existing closed areas or closing new areas.[25]

The application of more comprehensive and up to date science might well suggest a better spatial arrangement for the closed area system. However, it is unlikely that any analysis that holds fishery sustainability in mind would justify such massive reduction in the total area closed to groundfishing as is currently being contemplated. Nor would a defensible analysis proceed blind to the recovery that has resulted from the long period of protection already afforded to the existing areas.

A monumental decision

NOAA Fisheries and the New England Council are on the precipice of a monumental decision – a decision that could allow fishing in huge areas that have been protected from the most damaging forms of fishing for many years. The plan contemplated is clearly a major federal action that will significantly affect the quality of the human environment.[26] There has not been sufficient analysis to know whether or not opening these areas can provide the fishery the immediate economic relief that is the intent of this proposal. To the best of our knowledge, there has been no quantitative discussion of how large these benefits might be or how long they would last. There has not been adequate consideration of the ecological function of the current areas, or how they are contributing to the status of groundfish or anything else of value to the fishermen of New England and all who depend on them. We urge you to look at the existing areas in the context of an integrated system of habitat areas, a system that provides the solid ecological support needed to sustain fishermen and fisheries. We also urge you to move the region quickly toward ecosystem-based management so as to avoid these sorts of errors in the future. The groundfish closed areas should be thoroughly examined within the context of the OHA, including a comprehensive EIS. The risks associated with opening these areas without a proper analysis are exceedingly high.

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Note: A Compact Disc (CD) has been delivered separately to the NOAA Fisheries Regional Administrator, John Bullard, containing all of the material referenced in this letter with the exception of those materials that are already in the Agency's possession as a result of being published in the Federal Register, such as rules and amendments. Please review all of the cited material as part of our comment and include it as part of the administrative record for the proposed rule (NOAA–NMFS–2013–0050).

[1] Letter to Eric Schwaab, November 7, 2012, signed by Drs. P Auster, JD Crawford, TE Essington, L Kaufman, J Roman, RS Steneck, L Watling, and JD Witman.
[2] Ecosystem Assessment Program. 2009. Ecosystem Assessment Report for the Northeast U.S. Continental Shelf Large Marine Ecosystem. US Dept Commer, Northeast Fish Sci Cent Ref Doc. 09-11.
[3] Fogarty M et al (2010). SSC White paper on ecosystem-based fishery management. November 2010.
[4] New England Fishery Management Council News Brief, September 28, 2012; those portions of the groundfish areas not also designated *habitat areas* would be accessed by sector vessels via revised operations plans.
[5] Comments NOAA Regional Administrator to New England Council, February 29-31, 2013, council meeting.
[6] See Field JG et al (2008) Exploring the BOFF Hypothesis Using a Model of Southern African Deepwater Hake (*Merluccius paradoxus*). In: K. Tsukamoto K et al eds (2008) Fisheries for Global Welfare and Environment, 5th World Fisheries Congress, pp. 17–26; See Palakovich-Carr J, Kaufman L (2009) Estimating the importance of maternal age, size, and spawning experience to recruitment of Atlantic cod (*Gadus morhua*) Biological Conservation **1 4 2**: 477 – 487; Sogard SM et al (2008) Maternal effects in rockfishes Sebastes spp.: a comparison among species. Mar Ecol Prog Ser **360**: 227–236.
[7] Xu C et al (2012) When reproductive value exceeds economic value: an example from the Newfoundland cod fishery. Fish and Fisheries online record DOI: 10.1111/j.1467-2979.2012.00464.x
[8] Rose GA et al (2008). Rebuilding Atlantic cod: lessons from a spawning ground in coastal Newfoundland. In: Kruse GH et al (Eds.) Resiliency of Gadid Stocks to Fishing and Climate Change Alaska Sea Grant College Program, Fairbanks, Alaska, pp. 197–219.
[9] Dean M et al (2012) Disruption of an Atlantic Cod Spawning Aggregation Resulting from the Opening of a Directed Gill-Net Fishery. North American Journal of Fisheries Management **32**(1):124–134; Morgan MJ et al (1997) An observation on the reaction of Atlantic cod (*Gadus morhua*) in a spawning shoal to bottom trawling. Can J Fish Aquatic Sci **54** (1):217-223.
[10] Lindholm JB et al (1999) Habitat mediated survivorship of juvenile (0-year) Atlantic cod *Gadus morhua*. Mar. Ecol. Prog. Ser. 180:247–255.
[11] Pereira JJ et al. (2012) Geospatial analysis of habitat use in yellowtail flounder *Limanda ferruginea* on Georges Bank. Mar Ecol Prog Ser **468**: 279–290.
[12] Lough RG (2010) Juvenile cod (*Gadus morhua*) mortality and the importance of bottom sediment type to recruitment on Georges Bank. Fish. Oceanogr. **19**(2): 159–181.
[13] Presentation by CATT Chair, Andrew Applegate, March 8, 2013, Braintree, MA.
[14] Vitaliano J (2013) Broad-scale, dense amphipod tube aggregations on the sea bed: implications for resource species that utilize benthic habitats. Fish. Oceanogr. **22**(1): 61–67; Auster PJ et al (1996). The impacts of mobile fishing gear on seafloor habitats in the Gulf of Maine (Northwest Atlantic): implications for conservation of fish populations. Reviews in Fisheries Science 4:185-202; Auster PJ et al (1997). Distributional responses to small-scale habitat variability by early juvenile silver hake, *Merluccius bilinearis*. Environmental Biology of Fishes 50, 195-200; Steves BP, Cowen RK (2000). Settlement, growth, and movement of silver hake *Merluccius bilinearis* in nursery habitat on the New York Bight continental shelf. Marine Ecology Progress Series 196, 279-290; Sullivan MC et al (2000). Spatial scaling of recruitment in four continental shelf fishes. Marine Ecology Progress Series 207, 141-154.
[15] See Northeast Fishery Science Center web content on ecosystems: www.nefsc.noaa.gov/ecosys/
[16] See US National Ocean Policy: www.whitehouse.gov/administration/eop/oceans/policy
[17] Auster PJ et al (2001). Fish species and community distributions as proxies for seafloor habitat distributions: the Stellwagen Bank National Marine Sanctuary example (Northwest Atlantic, Gulf of Maine). Environmental Biology of Fishes **60**:331–346.
[18] Murawski et al 2000. Large-scale closed areas as a fishery-management tool in temperate marine systems: the Georges Bank experience. Bulletin of Marine Science, 66(3): 775–798, 2000; Halliday RG 1988. Use of seasonal spawning area closures in the management of haddock fisheries in the Northwest Atlantic. NAFO Sci. Coun. Studies, 12: 27-36
[19] NOAA Fisheries Regional Administrator, Bullard, addressing the Groundfish Oversight Committee, September 19, 2012: *I commend you for coming here and dealing with this issue and potentially reopening areas that were closed for a method of managing Groundfish that we have left behind for a new management method.*

[20] Melnychuk MC et al (2012) Can catch share fisheries better track management targets?. Fish and Fisheries, 13: 267–290. doi: 10.1111/j.1467-2979.2011.00429.x; Essington TE et al (2012) Catch shares, fisheries, and ecological stewardship: a comparative analysis of resource responses to a rights-based policy instrument. Conservation Letters **5**:186–195

[21] Steneck RS, Wilson JA (2010) A fisheries play in an ecosystem theater: challenges of managing ecological and social drivers of marine fisheries at multiple spatial scales. Bulletin of Marine Science, **86**(2):387–411.

[22] Tamsett A et al (2010) Dynamics of hard substratum communities inside and outside of a fisheries habitat closed area in Stellwagen Bank National Marine Sanctuary (Gulf of Maine, NW Atlantic). Marine Sanctuaries Conservation Series ONMS-10-05. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries, Silver Spring, MD. 53 pp; Brown BK et al (2010) Effects of excluding bottom-disturbing mobile fishing gear on abundance and biomass of groundfishes in the Stellwagen Bank National Marine Sanctuary, USA. Current Zoology **56** (1): 134-43.

[23] Murawski et al (2005) Effort distribution and catch patterns adjacent to temperate MPAs. ICES Journal of Marine Science, **62**: 1150-1167; Brown BK et al (2010) Effects of excluding bottom-disturbing mobile fishing gear on abundance and biomass of groundfishes in the Stellwagen Bank National Marine Sanctuary, USA. Current Zoology **56** (1): 134-43.

[24] Roberts CM, Hawkins JP (2012) establishment of fish stock recovery areas. Prepared for the European Parliament's Committee on Fisheries; Svedäng H (2010) Long-term impact of different fishing methods on the ecosystem in the Kattegat and Öresund. Prepared for the European Parliament's Committee on Fisheries.

[25] SSC meeting March 30, 2011, Boston, MA – Peer Review Report, Dr. Patrick Sullivan; Sullivan P, Cournane JM, Holland DS, Langton R, Lipton D (2011) Swept Area Seabed Impact (SASI) Model Peer Review On Behalf of the New England Fisheries Management Council Providence, RI – February 15-17, 2011

[26] NEPA, The National Environmental Policy Act of 1969, as amended

November 7, 2012
Mr. Eric Schwaab
Acting Assistant Secretary for Conservation and Management
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U.S. Department of Commerce

Dear Mr. Schwaab

We are writing to you express our serious concern about the course that NOAA fisheries and the New England Fishery Management Council have set for opening large portions of the groundfish closed areas in the Northeast, outside of the habitat amendment process and without a full Environmental Impact Statement.

With support from NOAA Fisheries the Council is moving ahead with a plan to open areas now closed to commercial fishing.[1] This is being pursued as a response to the groundfish crisis. The plan is intended to offer relief to fishermen in the face of declining stocks. While this plan is well intentioned, we believe that it is the wrong response and that it could result in a significant ecological setback. There is scant scientific basis for concluding that opening these areas will benefit the fishing community over the long-term. To the contrary, scientific information from these areas and from similar closures in other temperate regions suggests that maintaining closed areas to protect adults of reproductive age and improving habitat protection that enhances feeding and growth, especially for juveniles, is warranted in the face of dwindling stocks. The plan is predicated on a number of incorrect assertions and ignores the long history of these areas.[2]

There is little question that the region's ecosystems are compromised and that the shortages of groundfish are just one of the manifestations of this. The fish are less abundant, they are smaller, and recruitment is poor for many of them including Atlantic cod, the iconic species of New England. The ecosystems that provide us with our marine resources and support our communities have been fundamentally changed by years of excessive fishing with too little regard for ecological interactions and habitat impacts. In 2009 NOAA's Status Report for the Northeast U.S. Continental Shelf Large Marine Ecosystem concluded that the system has been experiencing ecosystem overfishing.[3] Like all animals, fish need food, opportunities for reproduction and growth, and cover from

[1] New England Fishery Management Council News Brief, September 28, 2012; those portions of the groundfish areas not also designated *habitat areas* would be accessed by sector vessels via revised operations plans.
[2] Murawski et al 2000. Large-scale closed areas as a fishery-management tool in temperate marine systems: the Georges Bank experience. Bulletin of Marine Science, 66(3): 775–798, 2000; Halliday RG 1988. Use of seasonal spawning area closures in the management of haddock fisheries in the Northwest Atlantic. NAFO Sci. Coun. Studies, 12: 27-36
[3] Ecosystem Assessment Program. 2009. Ecosystem Assessment Report for the Northeast U.S. Continental Shelf Large Marine Ecosystem. US Dept Commer, Northeast Fish Sci Cent Ref Doc. 09-11.

predators - that is, they need intact habitats. Under the current circumstances development of ecosystem-based management and habitat protection is critically important and should be enhanced not reduced. The new stresses added by a changing climate point to additional precaution including improvements to habitat protection.

In response to the crisis the Council has already suspended work on ecosystem based fisheries management (identified as a Council priority in 2009 and again in 2011) and will substantially decrease habitat protection if the groundfish areas are opened, since the groundfish areas, while not technically designated as habitat closures, do protect habitat. While not yet final, the plan will likely reduce the combined area protected from trawling by approximately 57% percent. There is a promise of additional new habitat protection under the yet to be completed Omnibus Habitat Amendment 2 (OHA), but what that amendment will ultimately produce is presently unknown, although options being considered include substantially less area and focus only on hard bottom habitats.

NOAA Fisheries supported the Council in its decision to combine the analysis of the groundfish closed areas with its ongoing OHA process in 2011. This was the right decision because New England needs an integrated, ecosystem-informed, approach to habitat protection. The groundfish areas have been protecting habitat for nearly two decades and were intended to protect places used by groundfish, i.e. habitat areas.[4] Regardless of the original intent and siting methods, it is essential to thoroughly analyze the ecological supporting role that these areas are playing now before opening them or otherwise substituting new areas for them. The full suite of closure areas must be analyzed as an ensemble within the EIS for the OHA in order to make good, science-based, habitat decisions for the region.

We would like to briefly comment on a short list of misconceptions that are frequently cited as part of the rationale for opening the groundfish areas, some of them by NOAA Fisheries in the Northeast:

(1) ***Groundfish closed areas are no longer necessary because we operate under a new quota management system (i.e., input controls are no longer needed).***[5] While it could be true that, with a perfect implementation of quota-based management, quotas might not be exceeded without closed areas, it is not true that closed areas would no longer be necessary. First, quota management systems (i.e., catch shares) clearly do not achieve all

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[4] Auster PJ et al (2001). Fish species and community distributions as proxies for seafloor habitat distributions: the Stellwagen Bank National Marine Sanctuary example (Northwest Atlantic, Gulf of Maine). Environmental Biology of Fishes **60**:331–346.

[5] NOAA Fisheries Regional Administrator addressing, September 19, 2012: *I commend you for coming here and dealing with this issue and potentially reopening areas that were closed for a method of managing Groundfish that we have left behind for a new management method.*

fishery management objectives under all circumstances.[6] Second, closed areas protect the targeted species, other species, and habitat; the habitat is used by many species, including spawning places, and species that serve as food for groundfish. The closed areas were put in places known as high abundance areas for spawning adults and juveniles. These closed areas have ecological functions beyond controlling mortality and this is supported by the available scientific information.[7] The habitat value of these areas will be degraded rapidly with the resumption of bottom trawling. This will include damage to structure that is important for juvenile groundfish, loss of older females important for population rebuilding, and impacts to invertebrates that fish eat.

(2) ***We have proven that closed areas do not work – if they worked we would not be in the current groundfish crisis.*** This statement reflects an overly simplistic analysis of a complex issue. It may be that some of the benefits of the closed areas have been overwhelmed by overfishing throughout the region, by some of the fishing still permitted in these areas, and by degrading the ecosystem overall, but that in no way "proves that the closed areas do not work." The statement about closed areas is not supported by the best peer reviewed science, which indicates that groundfish closed areas do export fish to the fishery as expected, and that some species are more abundant and larger inside closures.[8] The benefits of closed areas in similar temperate ecosystems abroad are also well known.[9]

(3) ***The work of the Council's habitat committee shows that the closed areas are in the wrong places.*** It has been said repeatedly that the work of the habitat committee, with its Plan Development team (PDT), shows that the groundfish areas are in the wrong places. The siting of the groundfish areas was informed by the distribution of fish (biological data). The EFH approach that the council has been developing since 2004, the Swept Area Seabed Impact Model (SASI), uses different criteria to identify places judged to be vulnerable to bottom tending mobile gear. Given these differences, it is not surprising that the SASI approach identifies different areas, areas that are primarily hard bottom. There is no basis for concluding that these areas are anymore "correct" than those covered by the groundfish areas. The peer reviewers of the SASI approach concluded that the

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[6] Melnychuk MC et al (2012) Can catch share fisheries better track management targets?. Fish and Fisheries, 13: 267–290. doi: 10.1111/j.1467-2979.2011.00429.x; Essington TE et al (2012) Catch shares, fisheries, and ecological stewardship: a comparative analysis of resource responses to a rights-based policy instrument. Conservation Letters **5**: 186–195

[7] Tamsett A et al (2010). Dynamics of hard substratum communities inside and outside of a fisheries habitat closed area in Stellwagen Bank National Marine Sanctuary (Gulf of Maine, NW Atlantic). Marine Sanctuaries Conservation Series ONMS-10-05. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries, Silver Spring, MD. 53 pp; Brown BK et al (2010) Effects of excluding bottom-disturbing mobile fishing gear on abundance and biomass of groundfishes in the Stellwagen Bank National Marine Sanctuary, USA. Current Zoology **56** (1): 134-43.

[8] Murawski et al 2005. Effort distribution and catch patterns adjacent to temperate MPAs. ICES Journal of Marine Science, 62: 1150-1167; Brown BK et al (2010) at note 6.

[9] Roberts CM, Hawkins JP (2012) establishment of fish stock recovery areas. Prepared for the European Parliament's Committee on Fisheries; Svedäng H (2010) Long-term impact of different fishing methods on the ecosystem in the Kattegat and Öresund. Prepared for the European Parliament's Committee on Fisheries.

approach is not sufficient by itself for determining the biological or economic consequences of opening existing closed areas or closing new areas.[10]

NOAA Fisheries and the New England Council are on the precipice of a monumental decision – a decision that would allow fishing in huge areas that have been protected from the most damaging forms of fishing for many years. The plan contemplated is clearly a major federal action that will significantly affect the quality of the human environment.[11] There has not been sufficient analysis to know whether or not opening these areas can provide the fishery relief that is the intent of this proposal. There has not been sufficient consideration of the ecological function of the current areas nor how they are contributing to the status of groundfish or anything else. We urge you to look at the existing areas in the context of an integrated system of habitat areas that can provide the ecological support that the region needs to sustain fishermen and fisheries, and to move the region toward ecosystem-based management. The groundfish closed areas should be thoroughly examined within the context of the OHA, including a comprehensive EIS. The risks associated with opening these areas without a proper analysis are very high.

Sincerely,

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[10] SSC meeting March 30, 2011, Boston, MA – Peer Review Report, Dr. Patrick Sullivan; Sullivan P, Cournane JM, Holland DS, Langton R, Lipton D (2011) Swept Area Seabed Impact (SASI) Model Peer Review On Behalf of the New England Fisheries Management Council Providence, RI – February 15-17, 2011

[11] NEPA, The National Environmental Policy Act of 1969, as amended

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LETTER

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Global conservation outcomes depend on marine protected areas with five key features

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In line with global targets agreed under the Convention on Biological Diversity, the number of marine protected areas (MPAs) is increasing rapidly, yet socio-economic benefits generated by MPAs remain difficult to predict and under debate[1,2]. MPAs often fail to reach their full potential as a consequence of factors such as illegal harvesting, regulations that legally allow detrimental harvesting, or emigration of animals outside boundaries because of continuous habitat or inadequate size of reserve[3–5]. Here we show that the conservation benefits of 87 MPAs investigated worldwide increase exponentially with the accumulation of five key features: no take, well enforced, old (>10 years), large (>100 km^2), and isolated by deep water or sand. Using effective MPAs with four or five key features as an unfished standard, comparisons of underwater survey data from effective MPAs with predictions based on survey data from fished coasts indicate that total fish biomass has declined about two-thirds from historical baselines as a result of fishing. Effective MPAs also had twice as many large (>250 mm total length) fish species per transect, five times more large fish biomass, and fourteen times more shark biomass than fished areas. Most (59%) of the MPAs studied had only one or two key features and were not ecologically distinguishable from fished sites. Our results show that global conservation targets based on area alone will not optimize protection of marine biodiversity. More emphasis is needed on better MPA design, durable management and compliance to ensure that MPAs achieve their desired conservation value.

A multitude of socio-economic and biological factors influence the responses of species to protection within MPA networks, adding considerable uncertainty when making specific predictions regarding the conservation benefits of new MPAs. Even within well-designed MPAs, populations of marine species can respond quite differently to prohibitions on fishing as a consequence of species-specific factors such as mobility, larval dispersal, fecundity, longevity, indirect interactions among species, environmental context, and overall level of exploitation before protection[5,6]. To assess the extent to which MPAs fulfil their ecological potential, we used a database unprecedented in geographic scale to investigate how conservation value, characterized by ecological response of fish communities within MPAs, is affected by the cumulative effects of five key planning and management features: (1) degree of fishing permitted within MPAs; (2) level of enforcement; (3) MPA age; (4) MPA size; and (5) presence of continuous habitat allowing unconstrained movement of fish across MPA boundaries[6–10]. Although previous studies have considered these factors independently, this is the first study, to our knowledge, that considers them simultaneously, using data collected globally with standardized methods.

Observations from the subset of MPAs that seem to work effectively—that is, they include at least four of five 'NEOLI' (no take, enforced, old, large and isolated) features—are additionally used to infer ecological condition associated with unfished reefs. For this aspect, we used the global network of MPAs as a vast ecological experiment, where effective no-take areas represent human predator exclusion plots within a matrix of fished coasts[11].

Eight community-level metrics were assessed using data from 40 nations on shallow reef fish densities and sizes provided by researchers and trained volunteer divers participating in the Reef Life Survey (RLS) programme[12]. A total of 964 sites in 87 MPAs were surveyed (Extended Data Fig. 1a), with data aggregated into 121 MPA/ecoregion groupings for analysis. MPA means were compared with statistical predictions for fished coasts using data from 1,022 non-MPA sites surveyed in 76 of the 232 Marine Ecoregions of the World[13] (Extended Data Fig. 1b and Supplementary Data Table 1). The four community metrics investigated, each widely considered to respond to MPA declaration[14,15], were: (1) total biomass of all fishes; (2) total biomass of large (>250 mm length) fishes; (3) species richness of all fishes (number of species sighted per transect); and (4) species richness of large fishes. We also estimated the total biomass of three commercially important taxa (sharks, groupers and jacks), with unexploited damselfishes providing a control group for effects evident on targeted fishery groups. Effect size was calculated using the log ratio of measured values in MPAs relative to values predicted using global models for fished coasts.

Among 14 environmental and socio-economic covariates used in random forest models[16] to develop predictions for fished coasts, mean sea surface temperature, annual temperature range, photosynthetically active radiation, and latitude consistently exerted the strongest influence on the global distribution of species richness and biomass metrics (Extended Data Fig. 2). Biomass of groupers and jacks was also greatly influenced by human population density, and the biomass of sharks and groupers was influenced by phosphate concentration.

Fish species richness along fished coasts peaked in the southeast Asian 'coral triangle' region (Fig. 1a), as expected[12,17]. However, when only the number of large fishes sighted along transects was considered (Fig. 1b), the global centre of species richness shifted to more isolated locations within the Indo-Pacific region. Overfishing of large predatory fishes presumably contributed to these geographical patterns. Sharks, groupers and other large fishes were present within the coral triangle

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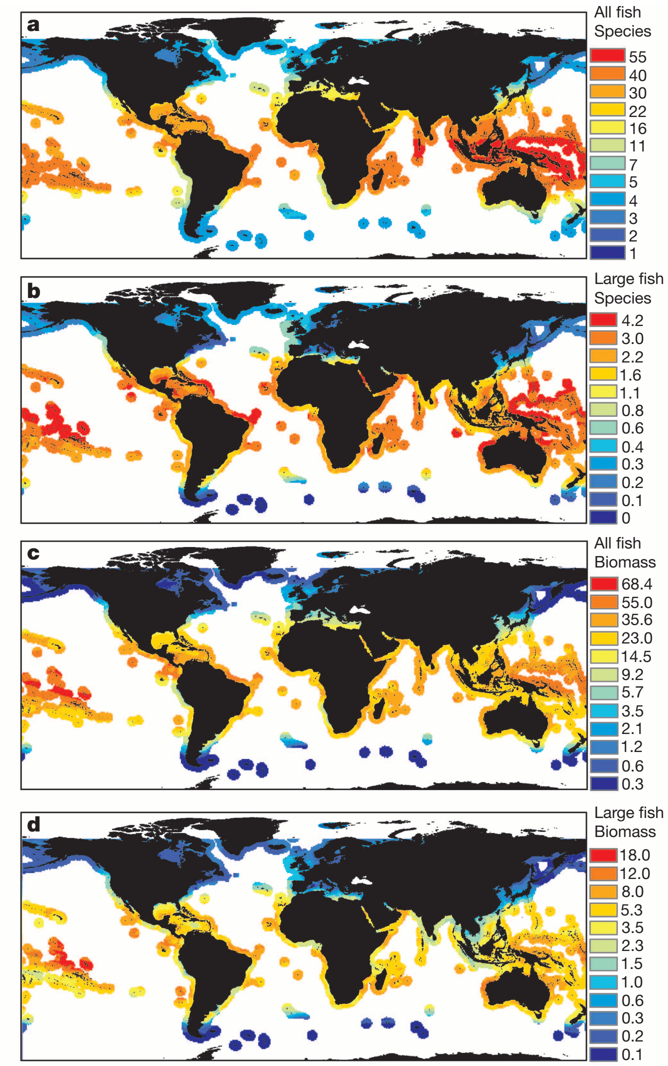

Figure 1 | Predicted global distribution of four community metrics for fishes associated with coral and rocky reefs outside of MPAs. Predictions are from random forest models developed using data from 1,022 sites in fished locations worldwide. **a**, Species richness of all fishes (number of species sighted per 250 m^2). **b**, Species richness of large (>250 mm total length) fishes (per 250 m^2). **c**, Total biomass of all fishes (kg per 250 m^2). **d**, Total biomass of large fishes (kg per 250 m^2).

region but had been exploited to near absence on most reefs, and so were rarely recorded on transects; consequently, observed species richness of large fishes was relatively low.

Our predictive models indicated that total fish and large fish biomass were highest in French Polynesia and the nearby Line Islands (Figs 1c, d), and sharks, groupers and jacks also had disproportionally high biomass in that region (Extended Data Figs 3a–c). Shark biomass on fished coasts was also very high off the Pitcairn Island group, and northeastern and northwestern Australia. Reassuringly, high shark and grouper biomass was accurately predicted for Galapagos, regardless that no data from fished sites in the oceanic tropical eastern Pacific region were used to generate the predictive models. At the time of the surveys, all islands in the region (Galapagos, Cocos and Malpelo) were within MPAs; however, data obtained before fishing restrictions in Galapagos indicate anomalously high shark and grouper biomass for fished coasts in that archipelago (S.B. and G.J.E., unpublished data). Damselfishes occurred in relatively high abundance in all tropical ocean basins (Extended Data Fig. 3d).

Across all 87 MPAs investigated, species richness of large fishes was 36% greater inside MPAs compared to fished areas (95% confidence interval (CI), 16–60% increase), biomass of large fishes was 35% greater (CI 3–78% increase) and sharks 101% greater (CI 17–239% increase). Nevertheless, for species richness of all fishes and the other four biomass metrics investigated, no significant difference ($P > 0.05$) was found between levels observed in MPAs and those predicted for fished coasts. Moreover, many MPAs possessed fish biomass well below predicted regional averages, as indicated by the large percentage of MPAs with negative log ratios for total biomass, ranging from 25% of MPAs for large fishes to 31% for sharks to 47% for groupers. These negative values indicate considerable site-scale variability in fish densities, with some MPA sites exhibiting low fish biomass due to local habitat variability between survey sites and, in other cases, a bias resulting from stakeholder consultation processes before MPA declaration aimed at minimizing lost fishing opportunity[18].

The poor overall performance of MPAs worldwide in terms of recovery of fish biomass relative to fished sites was due to a high frequency of ineffective MPAs and high spatial variability in fish densities, rather than an absence of recovery in all MPAs. The efficacy of MPAs was strongly influenced by the five NEOLI planning and management features (no take, enforced, old, large and isolated), with MPAs that scored highly with multiple NEOLI features typically having highly elevated biomass of exploitable fishes compared to fished sites (Fig. 2). MPAs with at least four NEOLI features were distributed across six countries in three oceans (Extended Data Fig. 1a) and a range of environmental conditions, indicating that model outputs and conclusions were not strongly regionally biased.

No significant differences were evident between fished sites (zero features) and MPAs with one or two NEOLI features; however, effect sizes rose rapidly when the number of features increased from three to five (Fig. 2 and Extended Data Fig. 4). For example, the measured rises in mean values within MPAs relative to fished areas for total fish biomass, total large fish biomass and shark biomass with three NEOLI features were 30%, 66% and 104%, respectively. These increases were, however, modest compared to values when all five NEOLI features were present, with large increases of 244%, 840% and 1,990%, respectively. Similar marked increases in biomass were evident for groupers (882%) and jacks (864%). Non-fished damselfishes showed a smaller mean increase of 111% at MPAs with five NEOLI features. This increase was on the margins of statistical significance, lying outside the 95% confidence interval (Extended Data Fig. 4) but nonsignificant ($P < 0.05$) when assessed with a *t*-test, which adjusts for small sample size.

All four MPAs with five NEOLI features were small oceanic islands (Cocos, Costa Rica; Malpelo, Colombia; Kermadec Islands, New Zealand; and Middleton Reef, Australia), raising a potential concern that calculated effect sizes were biased by plankton and pelagic fish subsidies that enlarge food webs at isolated oceanic locations. 'Oceanic island' was, however, included as a categorical covariate in random forest models, therefore model predictions should accommodate small island effects. Regardless, further investigation into the contribution of external subsidies to food webs at isolated MPAs is warranted. Alternative explanations for elevated damselfish numbers in the most effective MPAs compared with poorly protected MPAs include reduced fishing-related habitat deterioration such as dynamite damage to coral, and trophic cascades involving smaller predators that consume damselfishes and are prey to sharks and groupers.

No-take regulations, efficient enforcement, large area (>100 km^2) and old age (>10 years) each contributed similar increases in fish biomass within MPAs (Fig. 2). However, isolation, a categorical factor that distinguished MPAs with reef habitat surrounded by deep (>25 m) water or large expanses of sand from MPAs with shallow reef habitat extending to fished areas, seemed to exert a stronger influence for community-level biomass and richness metrics than the other four features. For example, the mean increase (95% CI) for total fish biomass associated with MPAs with three NEOLI features was 100% (14–252%) when one of the three features was isolation, compared to 14% (−18%–58%) for three NEOLI MPAs when isolation was not included. Compliance

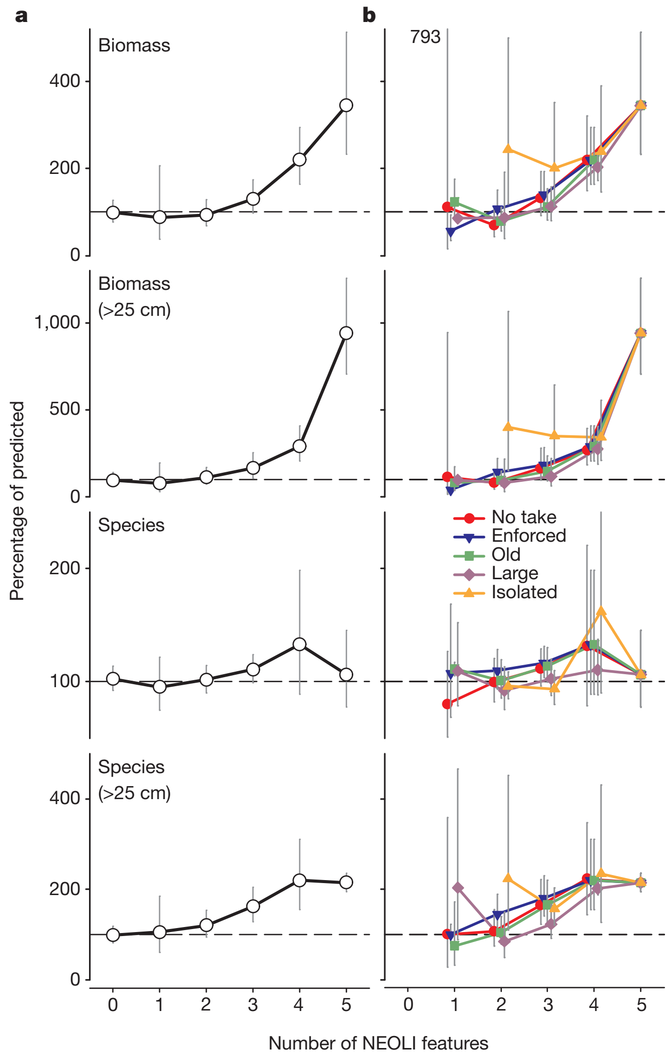

Figure 2 | Mean response ratios for MPAs with different numbers of NEOLI (no take, enforced, old, large, isolated) features. Mean ratio values have been back transformed from logs and expressed as percentages with 95% confidence intervals, with 100% equivalent to fished coasts. Sites on fished coasts have 0 NEOLI features. **a**, Mean response ratios for four community metrics. **b**, Mean response ratios for community metrics where each NEOLI feature was included within the set examined. The 'no-take' plot with two features, for example, depicts the mean response for no-take MPAs with a single other NEOLI feature. 95% confidence limits that lie off-scale are shown by number. Samples sizes are shown in Extended Data Table 1.

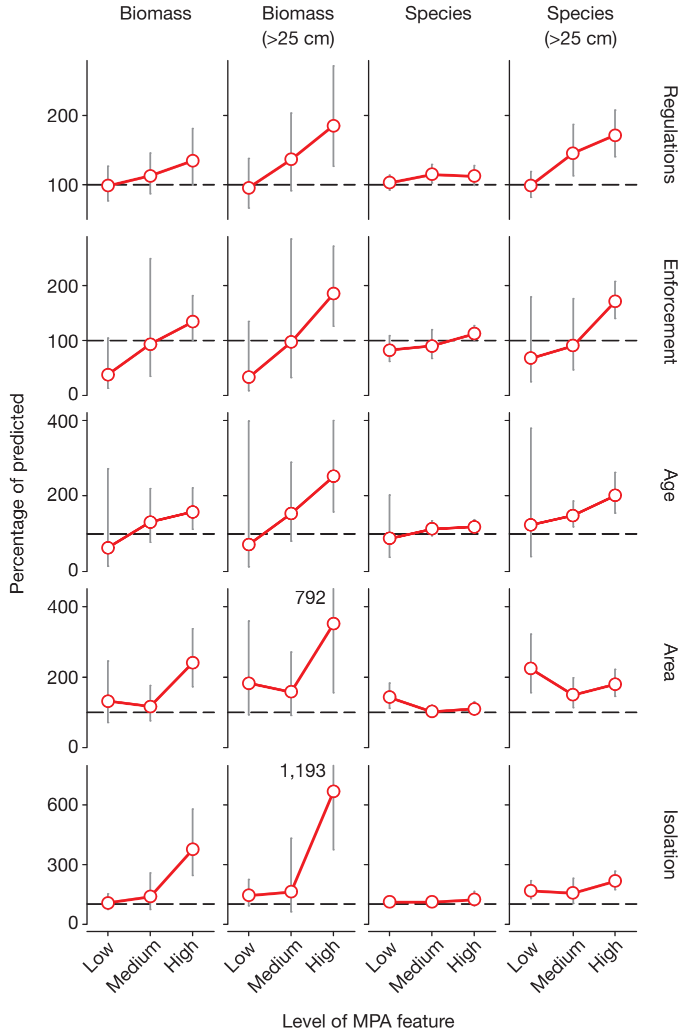

Figure 3 | Mean response ratios with 95% confidence intervals for four community metrics and low, medium and high levels of five MPA features. Values have been back transformed to per cent scale, with 100% equivalent to fished coasts. The feature 'regulations' was analysed using data from 82 MPAs with high enforcement; the feature 'enforcement' was analysed using data from 75 MPAs that are no-take; and the features 'isolation', 'age' and 'area' were analysed using data from 52 MPAs that are both no take and well enforced. 95% confidence limits that lie off-scale are shown by number. Samples sizes are shown in Extended Data Table 1.

may have contributed to the isolation effect, in that isolated MPAs are generally well demarcated for control purposes. They are readily recognized by fishers and more easily policed than coastlines with complicated mosaics of no take, restricted take and fishing zones. Although very important, the effect of isolation was similar in magnitude—rather than clearly superior—to other MPA features for biomass of sharks, groupers and jacks (Extended Data Fig. 4).

When MPAs that are no take and well enforced are considered, differences were evident in how the other MPA features affect different components of the fish community (Fig. 3 and Extended Data Fig. 5). Total fish biomass increased significantly from low to high levels for all five MPA features, and these same trends were magnified for large fishes (Fig. 3). Regardless of general concerns that large pelagic species move such great distances that few individuals are fully protected within MPAs[19], sharks and jacks seem to receive considerable protection from fishing mortality within the large, well-enforced, no-take MPAs studied here. The biomass of sharks and groupers rose exponentially when MPAs were fully isolated, and also greatly increased with area and age. The biomass of jacks showed little isolation and age effects, but rose greatly in MPAs that were large, well enforced and no take. Damselfish biomass did not increase significantly with the accumulation of individual NEOLI features.

The large number of MPAs investigated here has allowed relatively subtle and higher order interactive MPA effects to be detected. Previous studies of MPAs have shown, for example, negligible or weak patterns associated with MPA size[6,9,14,15,20], and those detected here were only evident for MPAs with at least three of the NEOLI features. However, MPA size was very important for such metrics as jack biomass, which showed a stronger response to MPA area than to other metrics (Extended Data Fig. 5). This response probably resulted from time spent by actively-swimming fishes outside park boundaries, which increases probability of capture for fishes associated with small MPAs.

Species richness of large fishes exhibited a highly significant difference between MPAs with five NEOLI features and fished locations (115% increase relative to predicted, CI 95–137%; *t*-test, $P < 0.0001$; Fig. 2). By contrast, MPAs with five NEOLI features did not differ significantly in total species richness (6% increase relative to predicted) from fished locations (t-test, $P = 0.42$; Fig. 2), nor did any of the five features individually have a clear effect on species richness (Fig. 3). Thus, total species richness along transects did not detectably increase in effective MPAs, despite the presence of additional large fish species, perhaps because of food web changes in the form of reduced presence of small fish species that comprised prey of the larger predatory species[5,21,22]. Regardless of these transect-scale effects, species richness at regional scales probably increased in areas with a mosaic of fished and effective MPAs because of the additional presence of large fishery-targeted species within the seascape[18].

Of the 87 MPAs investigated, only four possessed all five NEOLI features, whereas five MPAs possessed four features, and 39, 57 and 16 MPAs possessed three, two and one feature, respectively. The low proportion of MPAs possessing four or five NEOLI features (10%), and thus regarded here as effective, probably overstates the true proportion of effective MPAs worldwide. Our survey strategy deliberately targeted well-known and well-regarded MPAs, with most large and long-established MPAs included in this study.

Although only a small subset of MPAs are ever likely to qualify as large, most MPAs could achieve the remaining four NEOLI features. MPAs require additional time to age, and sufficient will among stakeholders, managers and politicians for increased implementation of no-fishing zones, increased levels of compliance, and extension of boundaries past the limits of reef systems or to deep water. If these could be achieved in tandem with current trends for declaration of large remote 'wilderness' MPAs[23,24], then conservation benefits from the global MPA network should increase markedly. However, the current base is very low with only 0.08% of the world's oceans within no-take MPAs in 2008 (ref. 25), and with opportunities for an expanded network diminishing as establishment and opportunity costs for large isolated MPAs escalate in line with human population growth[24,26].

By using effective MPAs as an unfished standard, our study allows the first global assessment of the magnitude of fishing effects on temperate as well as tropical reef communities. Fish biomass was greatly reduced overall, with 63% of all fish biomass, 80% of large fish biomass, 93% of sharks, 84% of groupers and 85% of jacks apparently removed from reefs by fishing.

In spite of their huge magnitude, these estimates are probably conservative because they are based on the assumption that MPAs with four or five NEOLI features provide an accurate non-fished baseline for inferring historical patterns. Yet fish populations are unlikely to have fully recovered from previous impacts of fishing in four NEOLI MPAs, which were found to be less effective than five NEOLI MPAs for some metrics. Moreover, high fishing mortality rates for sharks and wide-ranging predatory fishes outside MPAs will negatively influence total numbers within boundaries through reduced immigration rates, and further recovery of fish biomass within MPAs probably continues over much longer time spans than the 10-year threshold used here to define old MPAs[18]. Our estimates for effective MPAs include uncertainty associated with the low number of effective MPAs surveyed, most notably for sharks, as only five of the nine category 4 and 5 NEOLI MPAs had sharks present. Also, biomass may be overestimated because of diminished flee responses from divers of large fishes in well-enforced no-take MPAs[27]. Regardless, fishing clearly exerts a very large and ubiquitous impact on shallow reefs.

The 80% reduction in biomass of large fishes outside effective MPAs coincides with the threshold value used by the International Union for Conservation of Nature (IUCN) to categorize species as Critically Endangered for Red List assessments[28]. Although recognizing that application of current Red List thresholds to exploited fish stocks remains contentious[28], the high number of large-bodied species that together average 80% decline indicates that innumerable threatened fish species probably exist, and that effective MPAs probably have a large role in safeguarding populations of many of these species[4]. Even nations with relatively well-managed fisheries have few sharks and other large predatory coastal fishes outside well-designed and mature MPAs. Given the huge scale of fishing impacts, the rate of fish extinctions is likely to increase greatly through this century unless a refugial network of effective MPAs exists to allow persistence of large-bodied species and associated predator-dominated food webs, and broad-scale fisheries management practices significantly improve[29].

METHODS SUMMARY

Surveys were based on Reef Life Survey methodology[12,30], with support from volunteer SCUBA divers trained individually to scientific data collection standards. All fishes observed within 50 m × 5 m transect blocks were counted, and total fish lengths estimated, during swims on adjoining blocks up one side and down the other side of 50-m lines. Each transect was set along a depth contour, with two depth contours (mean 2.4) generally surveyed at each site. Sites located within 87 MPAs were investigated, with approximately half located in Australia (36) and New Zealand (8). In total, 48 MPAs were complete no take, 18 MPAs allowed limited fishing, whereas 21 MPAs were multi-zoned with interspersed no-take and limited fishing zones. Data were compiled from 171,331 underwater abundance counts of 2,544 species in 9,544 transect blocks at 1,986 sites.

We assessed effects of five MPA features (fishing regulations, enforcement, age, area and isolation), each categorized at low, medium and high levels, on eight fish community metrics (species richness of all fishes and large (>250 mm) fishes; total biomass of all fishes, large fishes, sharks, groupers, jacks and damselfishes). The magnitudes of effects were quantified using the log ratio of observed value within the MPA to predicted value at that location if the MPA did not exist (for example, $\log[B_m/B_p]$, where B_m is measured fish biomass and B_p is biomass predicted if the site was fished). Predictions were produced using random forest procedures[16], where each forest was created by generating 2,000 regression trees from a bootstrap sample of the data. Relationships were initially established between 14 covariates (environmental and socio-economic) and measured values of the eight response metrics at fished sites. These relationships were then used, with known covariate values at each MPA, to predict each of the eight community metrics at that MPA location.

Online Content Any additional Methods, Extended Data display items and Source Data are available in the online version of the paper; references unique to these sections appear only in the online paper.

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1. Hilborn, R., Micheli, F. & De Leo, G. A. Integrating marine protected areas with catch regulation. *Can. J. Fish. Aquat. Sci.* **63,** 642–649 (2006).
2. Gell, F. R. & Roberts, C. M. Benefits beyond boundaries: the fishery effects of marine reserves. *Trends Ecol. Evol.* **18,** 448–455 (2003).
3. Edgar, G. J. Does the global network of marine protected areas provide an adequate safety net for marine biodiversity? *Aquat. Conserv.* **21,** 313–316 (2011).
4. Mora, C. *et al.* Coral reefs and the global network of Marine Protected Areas. *Science* **312,** 1750–1751 (2006).
5. Babcock, R. C. *et al.* Decadal trends in marine reserves reveal differential rates of change in direct and indirect effects. *Proc. Natl Acad. Sci. USA* **107,** 18256–18261 (2010).
6. Claudet, J. *et al.* Marine reserves: size and age do matter. *Ecol. Lett.* **11,** 481–489 (2008).
7. Guidetti, P. *et al.* Italian marine reserve effectiveness: does enforcement matter? *Biol. Conserv.* **141,** 699–709 (2008).
8. Le Quesne, W. J. F. Are flawed MPAs any good or just a new way of making old mistakes? *ICES J. Mar. Sci.* **66,** 132–136 (2009).
9. Vandeperre, F. *et al.* Effects of no-take area size and age of marine protected areas on fisheries yields: a meta-analytical approach. *Fish Fish.* **12,** 412–426 (2011).
10. Forcada, A., Bayle-Sempere, J. T., Valle, C. & Sanchez-Jerez, P. Habitat continuity effects on gradients of fish biomass across marine protected area boundaries. *Mar. Environ. Res.* **66,** 536–547 (2008).
11. Walters, C. J. & Holling, C. S. Large-scale management experiments and learning by doing. *Ecology* **71,** 2060–2068 (1990).
12. Stuart-Smith, R. D. *et al.* Integrating abundance and functional traits reveals new global hotspots of fish diversity. *Nature* **501,** 539–542 (2013).
13. Spalding, M. D. *et al.* Marine ecoregions of the world: a bioregionalization of coastal and shelf areas. *Bioscience* **57,** 573–583 (2007).
14. Côté, I. M., Mosqueira, I. & Reynolds, J. D. Effects of marine reserve characteristics on the protection of fish populations: a meta-analysis. *J. Fish Biol.* **59** (Suppl. A), 178–189 (2001).
15. Halpern, B. S. The impact of marine reserves: do reserves work and does reserve size matter? *Ecol. Appl.* **13** (Suppl.), 117–137 (2003).
16. Breiman, L. Random forests. *Mach. Learn.* **45,** 15–32 (2001).
17. Roberts, C. M. *et al.* Marine biodiversity hotspots and conservation priorities for tropical reefs. *Science* **295,** 1280–1284 (2002).
18. Edgar, G. J., Barrett, N. S. & Stuart-Smith, R. D. Exploited reefs protected from fishing transform over decades into conservation features otherwise absent from seascapes. *Ecol. Appl.* **19,** 1967–1974 (2009).

19. Grüss, A., Kaplan, D. M., Guénette, S., Roberts, C. M. & Botsford, L. W. Consequences of adult and juvenile movement for marine protected areas. *Biol. Conserv.* **144,** 692–702 (2011).
20. Guidetti, P. & Sala, E. Community-wide effects of marine reserves in the Mediterranean Sea. *Mar. Ecol. Prog. Ser.* **335,** 43–56 (2007).
21. Graham, N. A. J., Evans, R. D. & Russ, G. R. The effects of marine reserve protection on the trophic relationships of reef fishes on the Great Barrier Reef. *Environ. Conserv.* **30,** 200–208 (2003).
22. Willis, T. J. & Anderson, M. J. Structure of cryptic reef fish assemblages: relationships with habitat characteristics and predator density. *Mar. Ecol. Prog. Ser.* **257,** 209–221 (2003).
23. Pala, C. Giant marine reserves pose vast challenges. *Science* **339,** 640–641 (2013).
24. Graham, N. A. J. & McClanahan, T. R. The last call for marine wilderness? *Bioscience* **63,** 397–402 (2013).
25. Wood, L. J., Fish, L., Laughren, J. & Pauly, D. Assessing progress towards global marine protection targets: shortfalls in information and action. *Oryx* **42,** 1–2 (2008).
26. Mora, C. *et al.* Global human footprint on the linkage between biodiversity and ecosystem functioning in reef fishes. *PLoS Biol.* **9,** e1000606 (2011).
27. Cole, R. G. Abundance, size structure, and diver-oriented behaviour of three large benthic carnivorous fishes in a marine reserve in northeastern New Zealand. *Biol. Conserv.* **70,** 93–99 (1994).
28. IUCN Standards and Petitions Working Group. *Guidelines for Using the IUCN Red List Categories and Criteria* Version 7.0 (downloaded 18 November 2013 from http://intranet.iucn.org/webfiles/doc/SSC/RedList/RedListGuidelines.pdf, 2008).
29. Mora, C. & Sale, P. F. Ongoing global biodiversity loss and the need to move beyond protected areas: a review of the technical and practical shortcomings of protected areas on land and sea. *Mar. Ecol. Prog. Ser.* **434,** 251–266 (2011).
30. Edgar, G. J. & Stuart-Smith, R. D. Ecological effects of marine protected areas on rocky reef communities: a continental-scale analysis. *Mar. Ecol. Prog. Ser.* **388,** 51–62 (2009).

Supplementary Information is available in the online version of the paper.

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Author Information Reprints and permissions information is available at www.nature.com/reprints. The authors declare no competing financial interests. Readers are welcome to comment on the online version of the paper. Correspondence and requests for materials should be addressed to G.J.E. (g.edgar@utas.edu.au).

METHODS

Survey methodology. Standardized visual census counts were made at 1,986 sites using Reef Life Survey (RLS) methodology (see RLS methods manual 'Standardised survey procedures for monitoring rocky and coral reef ecological communities' at http://reeflifesurvey.com/files/2008/09/NEW-Methods-Manual_15042013.pdf). Divers made counts and estimates of total lengths of all fish species observed during swims at ~2 m s^{-1} along the centre of a 5-m-wide swathe up one side and then down the other side of 50-m transect lines. Fishes sighted in transect blocks were recorded on an underwater slate, with abundance estimates made by counting individuals of less abundant species and, in locations with high fish densities, estimating the number of more abundant species. The abundance of schooling fishes was recorded by counting a subset within the school which was combined with an estimate of the proportion of the total school. Nearly all fishes were recorded to species level, with exceptions classified at the highest taxonomic resolution possible. The use of digital photography typically allowed later identification of most unidentified species, with assistance of taxonomic experts as required.

Experienced scientists and skilled recreational divers both contributed data to the RLS programme, all divers having either substantial previous experience in fish surveys or extensive one-on-one training by R.D.S.-S. or G.J.E. To provide a major element of consistency in diver contributions at the global scale, G.J.E. and R.D.S.-S. participated in most surveys, providing 31% of all data analysed. Validation tests indicated no difference in quality or composition of data provided by volunteers participating in this programme when compared to professional biologists[30].

Each transect was set along a depth contour, with two depth contours generally surveyed at each site (mean of 2.4 depths per site; minimum, maximum, mean ± s.d. depth contours surveyed: 0.1 m, 42 m, 7.5 ± 4.1 m, respectively). Sites located within 87 MPAs were investigated, with approximately half located in Australia (36) and New Zealand (8). In total, 48 MPAs were no take where all fishing was prohibited, 18 MPAs allowed limited fishing, whereas 21 MPAs were multi-zoned with interspersed no-take and limited fishing zones. Data were compiled from 171,331 underwater abundance counts of 2,544 species in 9,544 transect blocks (50 m × 5 m).

MPA features and community metrics investigated. We assessed the influence of five MPA features on eight fish community metrics calculated using field survey data. The MPA features investigated were each categorized at three levels: low (L), medium (M) and high (H). (1) Regulations. Extent that regulations restrict fishing at survey site. L, site can be openly fished with no fishing restrictions additional to those generally applied within the state; M, site located within an MPA but with some fishing methods allowed; H, no-take area within an MPA. (2) Enforcement. Extent of compliance to regulations that restrict fishing, both through overt policing and through community support for regulations. Level was decided at the time of surveys after discussion with local park authorities, and on the basis of observations of the extent of infractions while conducting fieldwork. L, little attempt at control, a 'paper park'; M, a moderate level of policing attempted, although infractions were apparent; H, appears to be well enforced, although clandestine poaching may occur. (3) Age. Period between when regulations restricting fishing were first enacted and field surveys undertaken. L, MPA zone <5 years old; M, MPA zone 5–10 years old; H, MPA zone >10 years old. (4) Area. MPA zone area, as described in management plan or documents provided locally to users. L, <1 km^2; M, 1–100 km^2; H, >100 km^2. (5) Isolation. Degree that reef habitat surveyed is isolated by habitat boundaries from adjacent fished reef. L, shallow (<25 m) reef habitat extends continuously across MPA boundary; M, a small (1–20%) percentage of zone boundary breached by continuous shallow reef habitat; H, MPA zone isolated from fishing areas by depth (>25 m) or sand barriers of at least 20 m width.

We investigated eight community metrics. (1) Species richness of all fishes. Total number of all fish species sighted within 50 m × 5 m transect blocks. (2) Species richness of large fishes. Total number of fish species sighted within 50 m × 5 m transect blocks for the set of individuals observed on transects exceeding the 250 mm size class bin (that is, 300 mm size and above). (3) Total fish biomass. Total biomass of all fishes sighted in 50 × 5 m transect blocks. Estimated by combining abundance counts with size estimates using length-weight relationships provided for total length of each fish species (in some cases genus and family) in Fishbase (http://www.fishbase.org). Bias in divers' perceptions of fish size underwater was additionally corrected using relationships presented in ref. 31. (4) Total biomass of large fishes. Total biomass of individuals sighted in 50 × 5 m transect blocks that exceeded the 250 mm size class bin. (5) Total biomass of sharks. Sum of biomass of all fishes in transect that belong to orders Carcharhiniformes, Heterodontiformes, Lamniformes and Orectolobiformes. (6) Total biomass of groupers. Sum of biomass of all fishes in transect that belong to family Serranidae, genera *Dermatolepis*, *Epinephelus*, *Gracila*, *Mycteroperca*, *Paralabrax*, *Plectropomus*, *Trachypoma* and *Variola*. Small serranids such as *Pseudanthias* spp. were not considered. (7) Total biomass of jacks. Sum of biomass of all fishes in transect that belong to family Carangidae. (8) Total biomass of damselfishes. Sum of biomass of all fishes in transect that belong to family Pomacentridae.

Data aggregation. To reduce spatial confounding resulting from highly clumped distribution of sites surveyed, data were aggregated before analyses as means for each ecoregion, MPA and zone type. Thus, fished sites were aggregated as mean values for each of 76 Marine Ecoregions of the World[13], whereas MPA data were aggregated into 121 MPA zones by ecoregion combinations. Multi-zoned MPAs contributed two data points to analyses (no-take sites and restricted fishing sites), whereas very large MPAs that extended across ecoregional boundaries (for example, Great Barrier Reef Marine Park, Galapagos Marine Reserve) were also partitioned with aggregated data from each ecoregion.

Global models. Models were developed using random forest procedures[16], as available in the 'extendedForest' packages for R (https://r-forge.r-project.org/projects/gradientforest), to predict the distribution of the eight community metrics in inshore habitats globally, including the MPA locations investigated. Each random forest consisted of numerous (2,000 in this case) regression trees, where each tree is fit to a bootstrap sample of the biological data using a recursive partitioning procedure. Random forest analyses also contain cross-validation routines based on random subsets of survey sites and covariate predictors that are excluded during development of each tree (the 'out-of-bag' data). Cross-validation using out-of-bag data allows estimation of prediction performance (R^2).

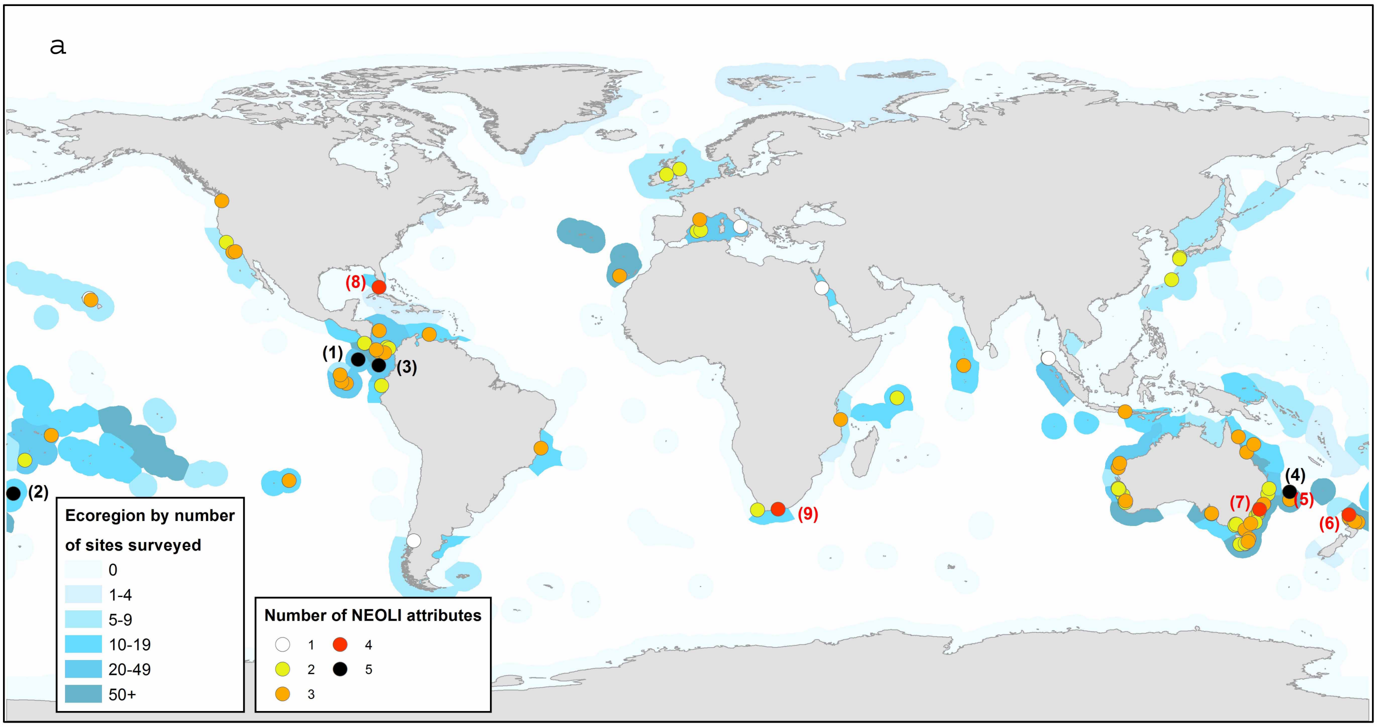
Using random forests, relationships were identified between mean densities of different fish species observed per transect in 76 marine ecoregions[13] and the global distribution of 14 environmental and socio-economic covariates (Extended Data Table 2). Data for each ecoregion were logged after aggregation as a mean of mean values for sites within each ecoregion, with a total of 1,022 fished sites investigated overall. Ecoregions with a value of zero for a particular metric (for example, grouper biomass in temperate locations) were removed from analysis and treated as missing values when generating predictive models associated with individual MPAs. To estimate prediction error, cross-validation was used where observations not selected in the bootstrap sample for a tree were compared to their predictions. The per cent change in accuracy was measured to assess the importance of each predictor variable (Extended Data Fig. 2). This is the change in accuracy of the predictions between models that include or do not include a given covariate, where accuracy was measured by the mean of the residuals squared using the 'out-of-bag' data.

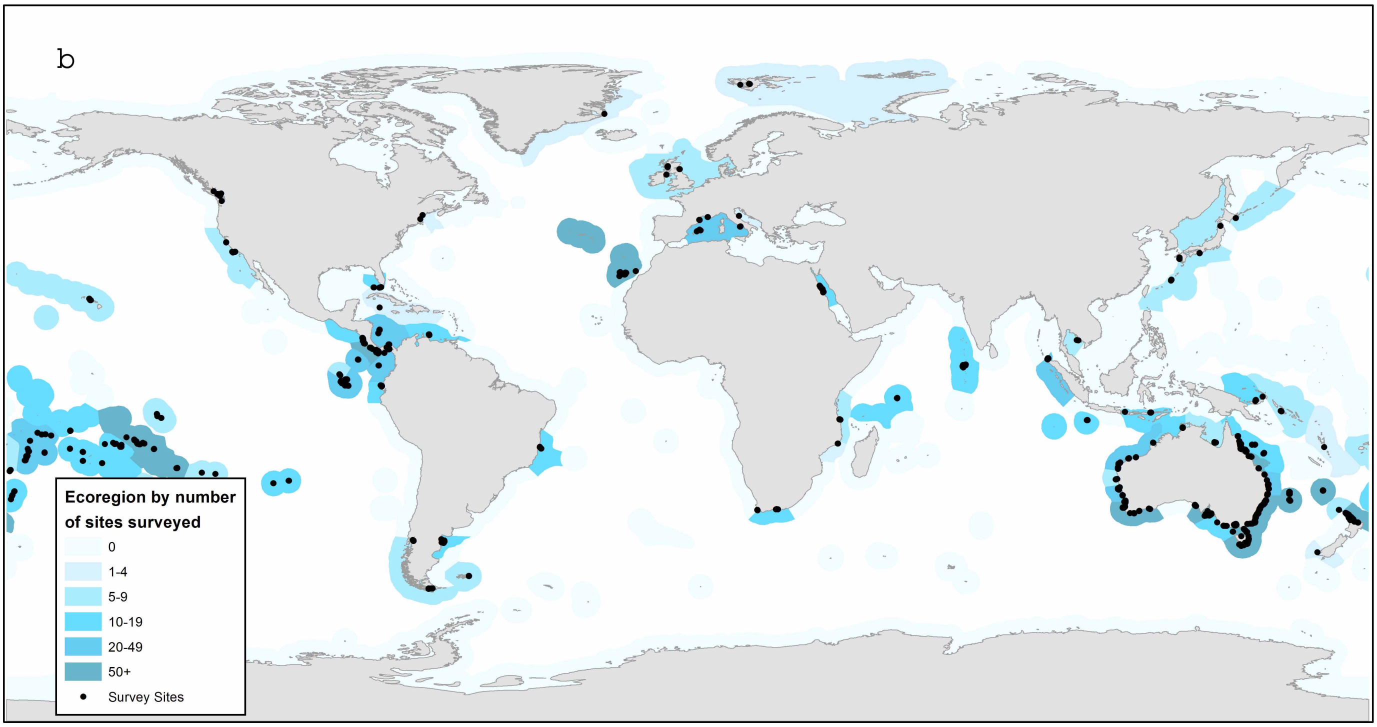
Linear least-squares regression of survey observations at fished sites with random forest predictions indicated that the models provided a reasonable fit. R^2 values for predicted versus observed plots were 63%, 38%, 80% and 64% for total biomass, large fish biomass, species richness and large fish species richness, respectively, whereas the percentages of observations > predictions were 46%, 46%, 53% and 54%, so observed data were well balanced with an even scatter above and below predictions.

Relationships generated between response metrics and environmental covariates were combined with available data on environmental and socioeconomic covariates at 964 sites surveyed in 87 MPAs to predict each of the eight fish community metrics within each unique combination of MPA zone type (no take or restricted fishing) and ecoregion. From generated random forests, predictions were made at new sites by taking the average of response metrics derived from each tree individually. MPA effects for each MPA zone type were then calculated using the log ratio of predicted/observed value (for example, $\log[B_m/B_p]$, where B_m is measured fish biomass and B_p is biomass predicted if the site was fished). When no individuals of one of the four fish groups (sharks, groupers, jacks or damselfishes) were recorded within a particular MPA, then that MPA was excluded from calculations of effect size. Mean effect sizes and confidence intervals thus relate to the subset of sites where each of the various fish groups were observed.

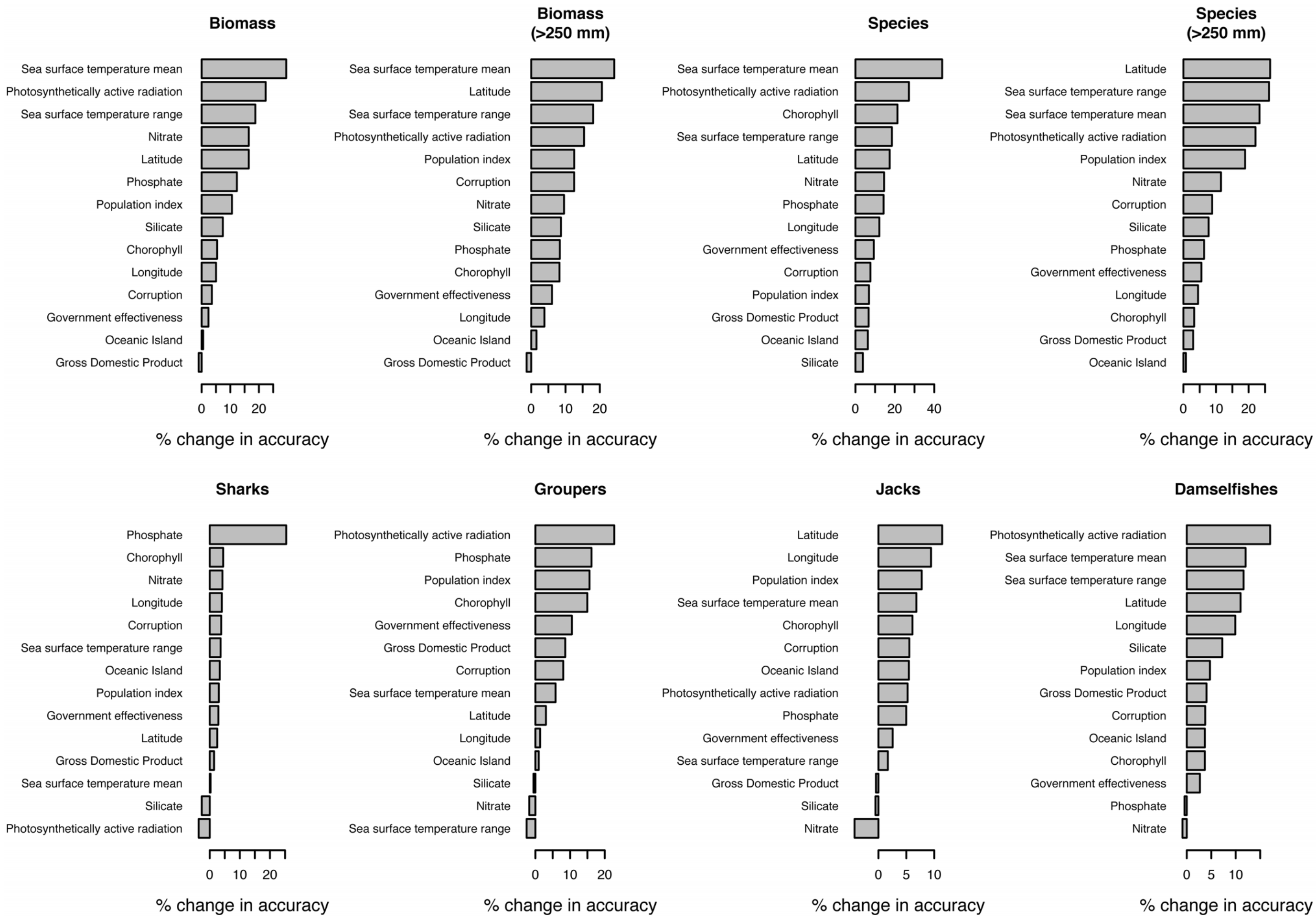
Random forest models were also used to predict values of each metric for fished sites across 5 arcmin grid cells globally, which were then plotted on maps within a coastal buffer. The calculations underlying random forest models used to generate global maps differed from calculations used to predict MPA values in two ways: (1) they were based on 10 rather than 14 environmental covariates, with government effectiveness, corruption, GDP and oceanic island not considered given their small contribution to models (Extended Data Fig. 2) and difficulty in compilation through the full global prediction space; and (2) data for the four fish groups were $\log[x +$ minimum value for metric$]$ transformed before analysis and back transformed post hoc to compensate for the many zeroes associated with global mapping predictions.

31. Edgar, G. J., Barrett, N. S. & Morton, A. J. Biases associated with the use of underwater visual census techniques to quantify the density and size-structure of fish populations. *J. Exp. Mar. Biol. Ecol.* **308,** 269–290 (2004).
32. CIESIN & CIAT. *Gridded Population of the World, Version 3* (Columbia Univ., 2005).
33. Silverman, B. W. *Density Estimation for Statistics and Data Estimation* (Chapman & Hall, 1986).
34. Kaufmann, D., Kraay, A. & Mastruzzi, M. The Worldwide Governance Indicators: a summary of methodology, data and analytical Issues. World Bank Policy Research Working Paper no. 5431, http://ssrn.com/abstract=1682130 (2010).
35. Tyberghein, L. *et al.* Bio-ORACLE: a global environmental dataset for marine species distribution modeling. *Glob. Ecol. Biogeogr.* **21,** 272–281 (2012).

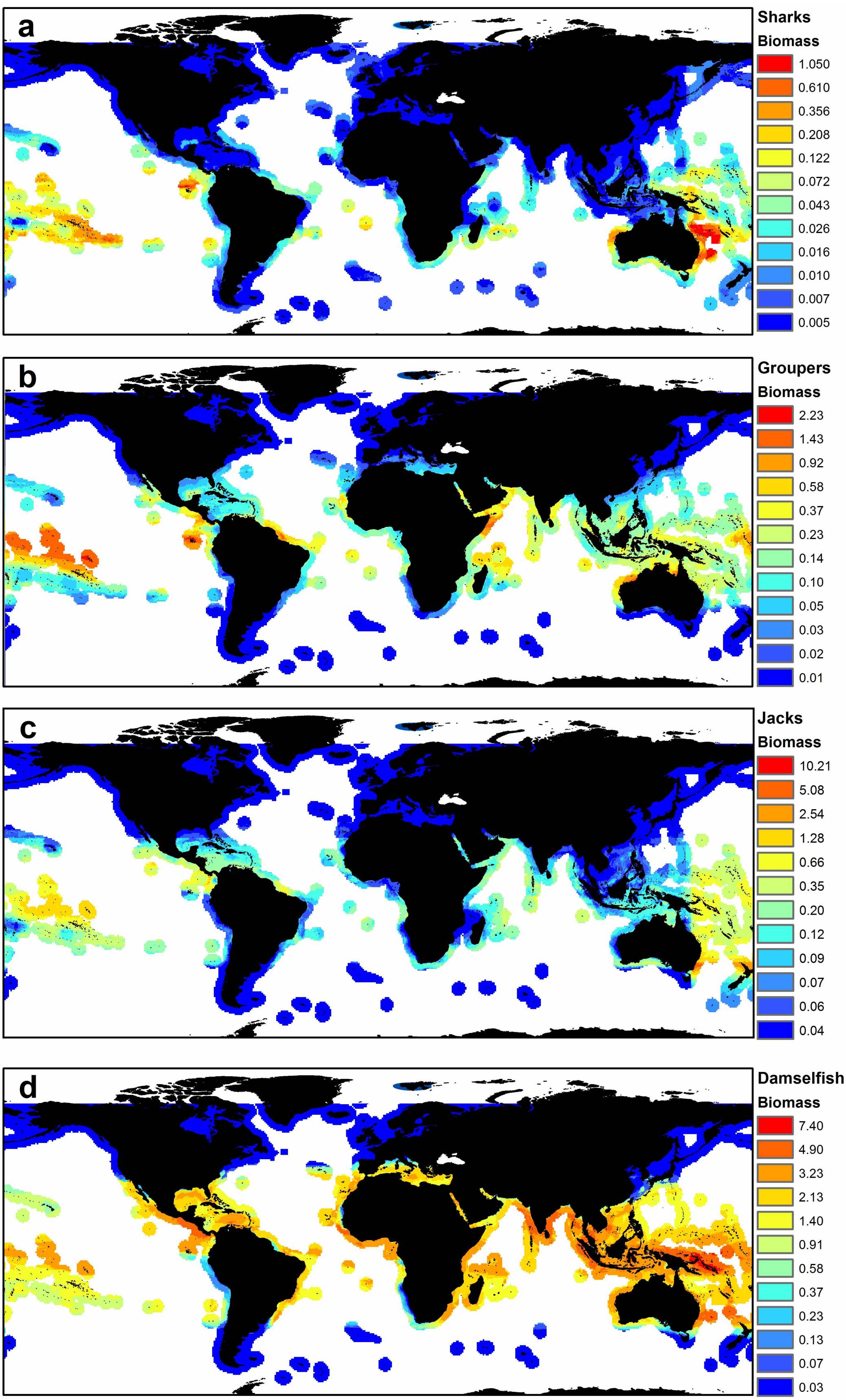




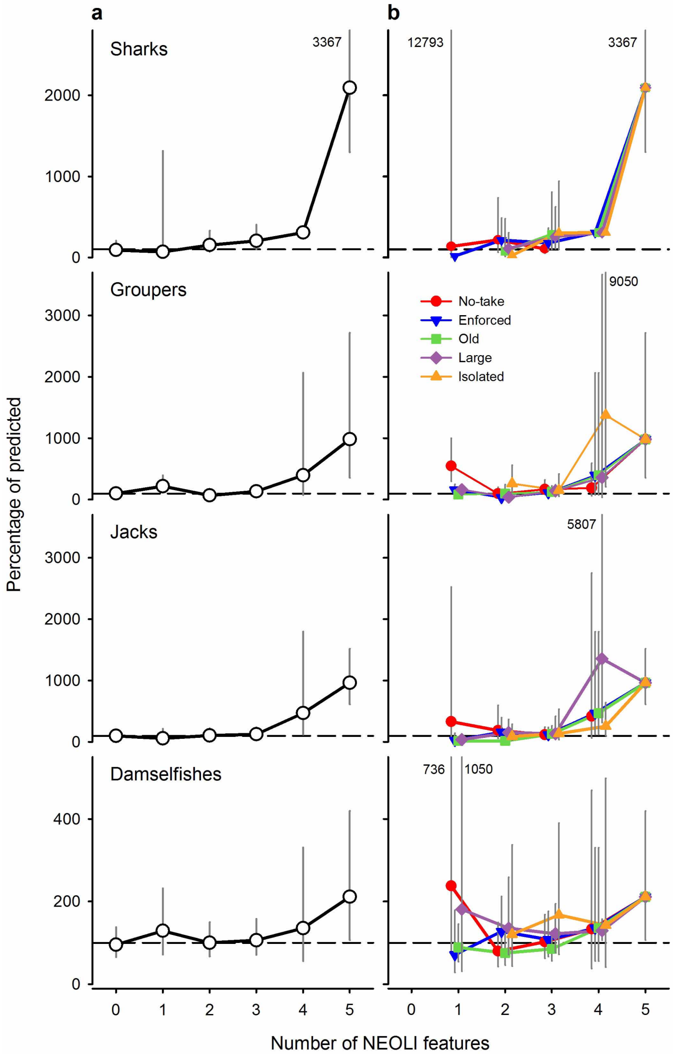
Extended Data Figure 1 | Distribution of sites surveyed. a, Number of NEOLI (no take, enforced, old, large and isolated) features at MPAs investigated (coloured circles). MPAs with most NEOLI features are overlaid on top; consequently numerous MPAs with one and two features are not visible. MPAs with five NEOLI features are (1) Cocos, (2) Kermadec Islands, (3) Malpelo, (4) Middleton Reef; MPAs with four NEOLI features are (5) Elizabeth Reef, (6) Poor Knights Islands, (7) Ship Rock, (8) Tortugas and (9) Tsitsikamma. **b**, All MPA and fished sites surveyed (black circles). Blue shading summarizes the number of sites surveyed within each ecoregion.



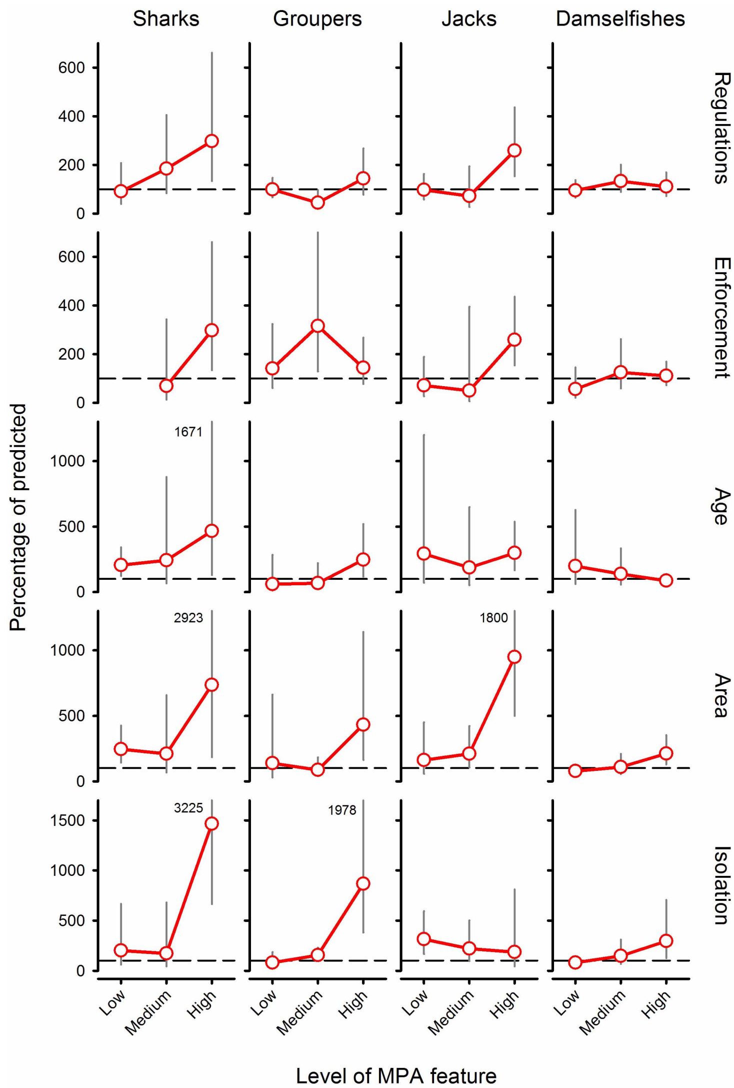
Extended Data Figure 2 | Relative importance of the 14 covariates used in global prediction models developed with random forests. Per cent change in accuracy for a given predictor variable is measured by the change between models that include or do not include that predictor variable, with accuracy assessed as the mean of the residuals squared. Residuals are based on a cross-validation technique to avoid bias, and the change in accuracy is divided by the standard error for a given tree then averaged across all trees.



Extended Data Figure 3 | Predicted global distribution of fish biomass (kg per 250 m^2) on fished coasts. Predictions are from random forest models developed using data from 1,022 sites in fished locations worldwide. **a**, Sharks. **b**, Groupers. **c**, Jacks. **d**, Damselfishes. Note that scales in colour schemes differ among maps, and numbers represent predicted values represented by each colour after smoothing of log-transformed site-level data.



Extended Data Figure 4 | Mean response ratios for MPAs with different number of NEOLI features. Mean ratio values have been back transformed from logs and expressed as percentages with 95% confidence intervals. The number of NEOLI features varies from 0 at sites along fished coastlines to 5 for MPA sites with all NEOLI features. **a**, Plots calculated for sites where sharks, groupers, jacks and damselfishes were present and the subsets of MPAs with different numbers of NEOLI (no take, enforced, old, large, isolated) features. **b**, Mean response ratios for community metrics where each NEOLI feature was included within the set examined. 95% confidence limits that lie off-scale are shown by number. Sample sizes are shown in Extended Data Table 1.



Extended Data Figure 5 | Mean response ratios for the subsets of sites at which sharks, groupers, jacks and damselfishes were observed. Values have been back transformed to per cent, with 100% equivalent to fished coasts, and with 95% confidence intervals. The feature 'regulations' was analysed using data from 82 MPAs that are well enforced; the feature 'enforcement' was analysed using data from 75 MPAs that are no take; and the features 'isolation', 'age' and 'area' were analysed using data from 52 MPAs that are both no take and well enforced. Sharks were not observed in any no-take MPA with low enforcement, so the associated response ratio could not be calculated. 95% confidence limits that lie off-scale are shown by number. Sample sizes are shown in Extended Data Table 1.

Extended Data Table 1 | Sample sizes applied in figures

Figure 2a

Metric	MPA subset	No. of NEOLI features					
		0	1	2	3	4	5
All metrics	All	76	16	57	39	5	4

Figure 2b

Metric	MPA subset	No. of NEOLI features					
		0	1	2	3	4	5
All metrics	No-take		7	31	29	4	4
	Enforced		5	36	32	5	4
	Old		2	22	31	5	4
	Large		2	16	16	3	4
	Isolated			8	9	3	4

Extended Data Figure 4a

Metric	MPA subset	No. of NEOLI features					
		0	1	2	3	4	5
Sharks	All	29	3	26	14	1	4
Groupers	All	46	8	36	22	4	4
Jacks	All	50	6	29	27	4	4
Damselfishes	All	62	12	48	36	4	4

Extended Data Figure 4b

Metric	MPA subset	No. of NEOLI features					
		0	1	2	3	4	5
Sharks	No-take		2	13	9		4
	Enforced		1	22	10	1	4
	Old			5	8	1	4
	Large			9	9	1	4
	Isolated			3	6	1	4
Groupers	No-take		3	19	14	3	4
	Enforced		2	21	16	4	4
	Old		2	14	18	4	4
	Large		1	11	12	3	4
	Isolated			7	6	2	4
Jacks	No-take		2	12	20	3	4
	Enforced		2	21	21	4	4
	Old		1	10	20	4	4
	Large		1	10	11	2	4
	Isolated			4	9	3	4
Damselfishes	No-take		4	25	26	3	4
	Enforced		4	31	29	4	4
	Old		2	17	28	4	4
	Large		2	14	16	2	4
	Isolated			8	9	3	4

Figure 3

Metric	Feature	Level of feature		
		Low	Medium	High
All metrics	Regulations	76	30	52
	Enforcement	9	14	52
	Age	5	19	28
	Area	14	30	8
	Isolation	35	9	8

Extended Data Figure 5

Metric	Feature	Level of feature		
		Low	Medium	High
Sharks	Regulations	29	15	23
	Enforcement	0	5	23
	Age	3	12	8
	Area	3	14	6
	Isolation	12	6	5
Groupers	Regulations	46	20	27
	Enforcement	7	9	27
	Age	3	8	16
	Area	6	14	7
	Isolation	16	6	5
Jacks	Regulations	50	19	33
	Enforcement	2	6	33
	Age	3	10	20
	Area	8	19	6
	Isolation	19	6	8
Damselfishes	Regulations	62	28	44
	Enforcement	8	10	44
	Age	3	17	24
	Area	11	26	7
	Isolation	29	7	8

Extended Data Table 2 | Covariates used as predictor variables in global random forest models

Variable	Variable abbreviation	Units	Scale	Reference (if applicable)
Index of population pressure	POP_index	index	2.46 arcmin (4.6 km)	
Government Effectiveness	Govt Eff	index	country	35
Control of Corruption	Corruption	index	country	35
Per capita GDP	GDP	US$	country	#
Mean nitrate	Bio_nitrate	umol/l	5 arcmin (9.2 km)	36
Mean phosphate	BIO_phosphate	umol/l	5 arcmin (9.2 km)	36
Mean silicate	BIO_silicate	umol/l	5 arcmin (9.2 km)	36
Mean chlorophyll A	BIO_chlomean	mg/m^3	5 arcmin (9.2 km)	36
Photosynthetically active radiation	BIO_parmean	$Einstein/m^3/day$	5 arcmin (9.2 km)	36
Mean sea surface temperature	BIO_SST_mean	°C	5 arcmin (9.2 km)	36
Range of sea surface temperature	BIO_SST_range	°C	5 arcmin (9.2 km)	36
Oceanic island isolated from continental shelf	Oceanic island	yes/no		
Site latitude	Latitude	decimal degrees	0.0001°	
Site longitude	Longitude	decimal degrees	0.0001°	

The index of population pressure was calculated by fitting a smoothly tapered surface to each settlement point on a year 2000 world population density grid[32] using the quadratic kernel function[33]. Populations were screened for a density greater than 1,000 people per 0.04 degree cell, and the search radius was set at 3.959 degrees. This table contains refs 34 and 35.
Per capita GDP was obtained from IMF for 2012 at http://en.wikipedia.org/wiki/List_of_countries_by_GDP_%28PPP%29_per_capita.