Written testimony of John F. Bruno, PhD, Professor, Department of Biology, The University of North Carolina at Chapel Hill, before the Subcommittee on Water, Power, and the Oceans, March 15, 2017.

Chairman Lamborn and Ranking Member Huffman,

My name is John Bruno and I am a marine community ecologist and Professor of Biology at The University of North Carolina at Chapel Hill.

I appreciate the invitation to talk with you today about marine reserves and how they simultaneously benefit people and wildlife.

Our ocean ecosystems are being degraded by a range of factors such as plastic pollution, over-fishing, and global warming[1–4]. Nearly a billion people (including tens of millions of Americans) depend on healthy ocean ecosystems for their food and livelihoods. Whether through the seafood we eat, our jobs in the fisheries and tourism industries, or via recreation and personal enrichment, nearly all of us benefit from clean and healthy oceans.

Marine reserves are a proven policy tool that can lead to win-win ocean stewardship:

- Dozens of studies indicate that well-designed and strictly enforced **reserves increase the density, diversity and size of fishes, invertebrates and other marine organisms important to recreational and commercial fishermen**[5–8]. Fish biomass in fully-protected reserves quickly grows to be fourfold greater on average than in fished areas[9].

- **Reserves contain more apex predators, many of which are rare or absent from unprotected areas**[9]. Edgar et al.[5] report that shark biomass is 14 times greater and the number of large fish species was 36% greater in Marine Protected Areas (MPAs, which includes fully protected marine reserves and other protected areas where fishing is limited but not banned). Likewise, Valdivia at al. found that apex predators are almost entirely restricted to marine reserves that cover only a small fraction of the Caribbean[10].

- The restoration of many fished predatory species in reserves (e.g., sharks, grouper, lobster, etc.) **restores key ecological functions and species interactions** that can have strong cascading effects on lower trophic levels[11–13].

- Big, old, fat, and fecund female fishes (BOFFFFs) contribute a large number of eggs that produce future generations. The presence and successful reproduction by large fish generally leads to greater larval recruitment, population growth rate, and fisheries productivity and sustainability. **Marine reserves are the best way to protect large females, enabling them to grow old and large, thereby enhancing fisheries productivity, and stability**[14]**.**

- The increased population density and reproductive output seen within well-designed and enforced reserves **often leads to a "spillover effect" when adult and juvenile (or larval) fishes migrate outside of the reserve** where they are then captured by recreational or commercial fishers[15–18]. This "leaky" aspect of marine reserves is one of their primary benefits to fisheries and is a phenomenon well-known to fishers, whom tend to concentrate fishing on reserve boundaries (termed "fishing the line"). Spillover can offset the loss of fisheries catch caused by the implementation of reserves[18].

- For some species and systems, marine reserves may increase resistance to or recovery from human-caused disturbances like ocean warming and acidification. For example, **by increasing population size, and thus genetic diversity, reserves can increase the adaptive potential** (i.e. resilience) of populations to changing environmental conditions[19]. Thus, reserves can counteract the deleterious loss of genetic diversity caused by overfishing.

- **These and other positive outcomes for harvested species protected in marine reserves have obvious commercial benefits**, not only for fisheries but also for other commercial enterprises such as shark and other SCUBA-based tourism.

Research over the last 10-15 years has refined the reserve characteristics that can maximize benefits to humanity and improve the conservation of biodiversity. A recent synthesis found that to meet the biodiversity and fisheries goals of MPAs, global coverage needs to be increased from its **current extent of just ~3% (of which ~1.6% is "strongly protected") to 30%** or greater[20] (note for U.S. waters:16.5% in MPAS and 13.5% in no take reserves).

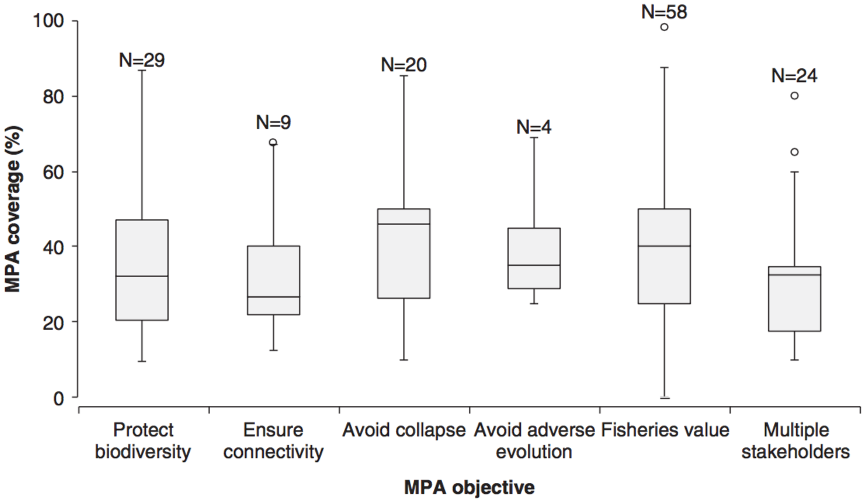


Figure 1 Tukey boxplot showing the range of required coverage for each MPA objective: (1) protect biodiversity (*N* = 29, median 32%, range 9–80%); (2) ensure population connectivity (*N* = 9, median 27%, range 13–68%); (3) minimize the risk of fisheries/population collapse and ensure population persistence (*N* = 20, median 46%, range 10–76%); (4) mitigate the evolutionary effects of selective fishing (*N* = 4, median 35%, range 25–59%); (5) maximize or optimize fisheries value or yield (*N* = 58, median 40%, range 0–98%); and (6) satisfy multiple stakeholders (*N* = 24, median 33%, range 10–80%). Outliers shown by open circles.

In a synthesis of studies of the effectiveness of 87 MPAs around the world, Edgar et al.[5] identified five features that influenced conservation and economic outcomes:

1) **Level of protection:** Fully protected or "no-take" reserves are far more effective than general use MPAs where harvesting is only partially restricted[7].

2) **Enforcement:** The effective and durable compliance with and enforcement of fisheries restrictions is crucial to reserve success. Most MPAs and reserves around the world are poorly enforced and amount to little more than "paper parks" that achieve no measurable outcomes for people of wildlife[5,21].

3) **Reserve age:** Many of the benefits of reserves accrue over time, e.g., trophic cascades are restored as predator populations recover. Effective reserves are generally at least ten years old (i.e., have been enforced for ten or more years) and often 25-40 years old[13,22]. An exception is when an area was relatively pristine when protection began, as in the Papahānaumokuākea Marine National Monument [23,24].

4) **Reserve size**: Given the movement of many fishes, and marine birds and mammals, size can be a key feature defining reserve success. Small size is a primary reason so many MPAs fail. If animals frequently swim or fly outside the reserve boundary, it will have limited positive effects on their populations.

5) **Isolation:** Effective coastal reserves are typically isolated by deep (~75 ft.) water from fished habitat. This feature appears to have the largest effect on biomass and diversity and is thought to limit the movement of animals out of the protected area.

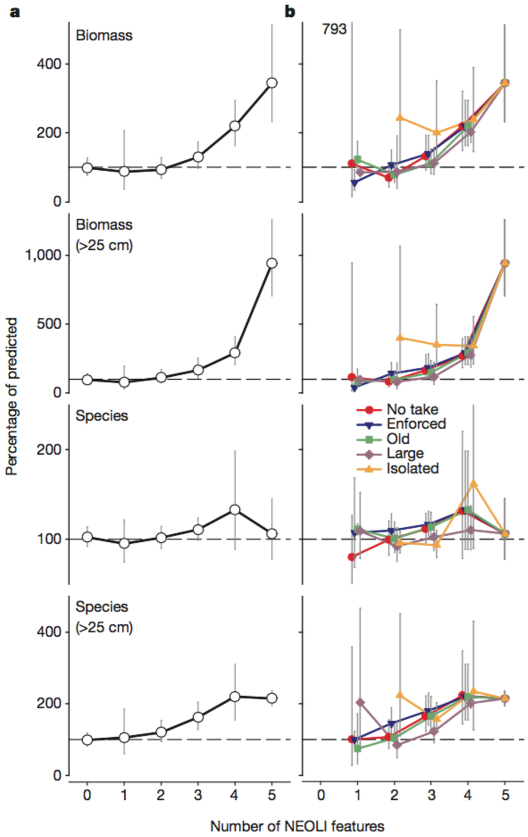


Figure 2 | Mean response ratios for MPAs with different numbers of NEOLI (no take, enforced, old, large, isolated) features. Mean ratio values have been back transformed from logs and expressed as percentages with 95% confidence intervals, with 100% equivalent to fished coasts. Sites on fished coasts 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.

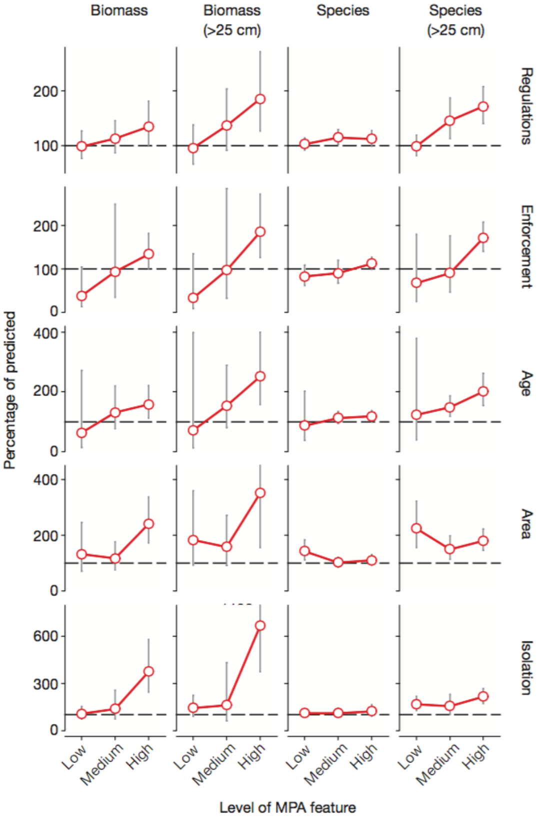
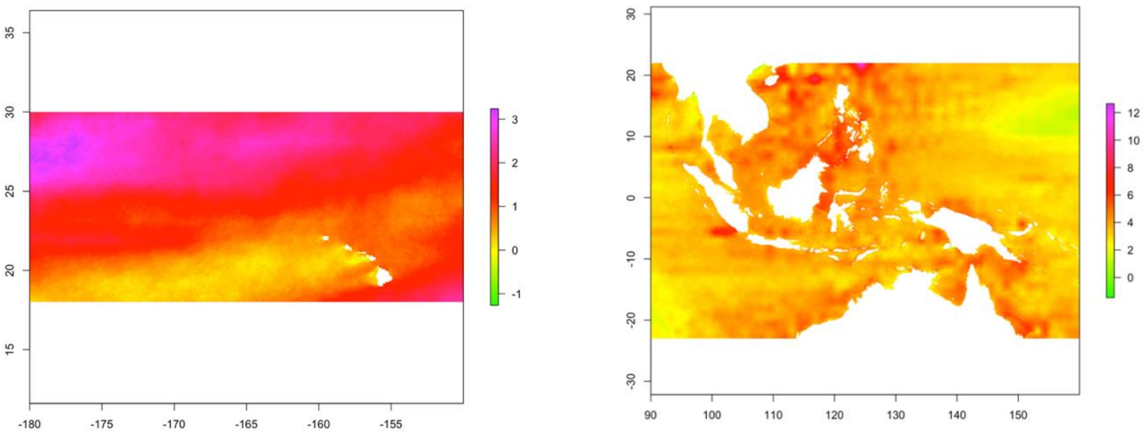


Figure 3 | Mean response ratios with 95% confidence intervals for four community metrics and low, medium and high levels of five MPA features. Values have been back transformed to per cent scale, with 100% equivalent to fished coasts. The feature 'regulations' was analysed using data from 82 MPAs with 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.

Edgar et al.[5] found that reserve success was much more likely when three or more of the "NEOLI" features (no take, enforced, old, large and isolated) were met. Reserves that met only one or two NEOLI criteria rarely had greater fish biomass than unmanaged locations. When all five criteria were met, total fish, total large fish, and total shark biomass increased by 244%, 840% and 1,990%, respectively[5] (see graphics above from Edgar et al.[5]). The few reserves that met this standard were 10-20 times more effective than reserves with only three NEOLI features. This and numerous similar studies emphasize the crucial importance of design and post-implementation management features in marine reserve outcomes.

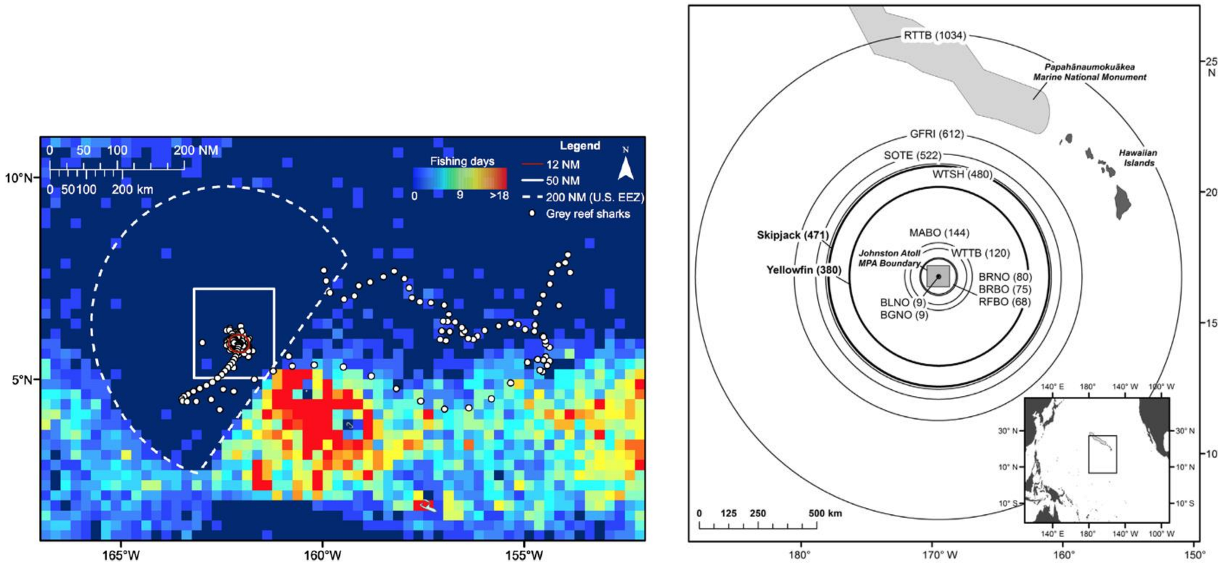
There is also a growing consensus in the field that ecosystem representativeness, locations with unique geological and/or biodiversity attributes, and the global change context be considered when planning reserve implementation at regional or global scales.

Papahānaumokuākea Marine National Monument
The PMNM is a rare example of a near-pristine[23,24] marine reserve that includes all five NEOLI features considered essential for maximum efficacy. It also encompasses a unique high latitude coral reef ecosystem, is inhabited by endangered species including the Hawaiian monk seal, and probably most importantly it is predicted to warm far less than most other tropical systems this century (see graphic below). Tropical MPAs are highly threatened by ocean warming: the predicted average warming under the IPCC A2 emissions scenario for tropical MPAs is 3 °C for annual mean Sea Surface Temperature and 6 °C for maximum annual SST by 2100. It is believed that many topical marine species cannot survive warming of this magnitude. Although some will migrate to higher latitudes, many will go extinct and biodiversity in these ecosystems will likely crash regardless of local protection from fishing and other stressors. Therefore, at least some conservation resources should be focused on the small subset of marine ecosystems that will experience substantially less warming and are likely to survive the century, regardless of our national energy policy (i.e., as an insurance policy against a worse-case climate scenario). In addition, PMNM offers an additional benefit given that its extent, stretching from tropics through the subtropics, and orientation may offer an important migration pathway for species retreating from climate change.



Predicted increase in Maximum SST (°C in 2100) for the Hawaiian Islands (left) compared to that for the coral triangle in the western Pacific (right). based on the coupled ocean–atmosphere model simulations (CMIP3 downscaled to 9.5x9.5km) under the A2 high / business-as-usual emissions scenario. Maximum SST for coral reefs of the Papahānaumokuākea reserve are predicted to increase by < 2.5 °C compared to 3-8 °C for much of the western Pacific.

The PMNM reserve was recently expanded based in part on new science detailing the movements of many of the target species (information that was not available for the original design and designation). For example, recent findings indicate that numerous ecologically important apex predators travel beyond the historical 50nmi PMNM boundaries [25–27]. The larger 200nmi boundary provides a minimum buffer for these species, reducing the risk of mortality and populations declines. White et al. found that grey reef sharks swim far beyond the original 50nmi boundaries of Palmyra Atoll in the Pacific Remote Islands Marine National Monument (see graphic below). Maxwell and Morgan 2013 report that many species of breeding seabirds frequently forage at distances well over 50 nm from their colonies, where they rely on schools of predatory fish like tuna to drive small fish to the surface [26].



Left: Movement of six satellite tagged grey reef sharks (Carcharhinus amblyrhynchos) at Palmyra Atoll. From [25]. ***Right***: foraging ranges of seabirds (thin lines) and tuna (thick lines), centered around Johnston Atoll, part of the US Pacific Remote Islands Marine National Monument. Maximum foraging ranges and median lifetime displacement are shown in () following species names or abbreviations. RTTB: red-tailed tropicbird; GFRI: great frigatebird; SOTE: sooty tern; WTSH: wedge- tailed shearwater; MABO: masked booby; WTTB: white-tailed trop- icbird; BRNO: brown noddy; BRBO: brown booby; RFBO: red-footed booby; BLNO: black noddy; BGNO: blue-grey noddy. From [26].

The PMNM's deep-sea beds more than 1,000 feet down are home to black corals, which bide their time in quiet currents and virtual darkness and are among the oldest animals on earth, living for thousands of years. Typical shallow water coral colonies are highly productive and fueled by sunlight; black corals slow their metabolisms to a crawl, with centuries clicking by like years to a human. Hawaii researchers explored a forest of large colonies of the black coral, *Leiopathes glaberrima,* living in deep water throughout the Hawai'ian Islands. The oldest specimens elongate branches at about 1/64 of an inch a year, about the width of

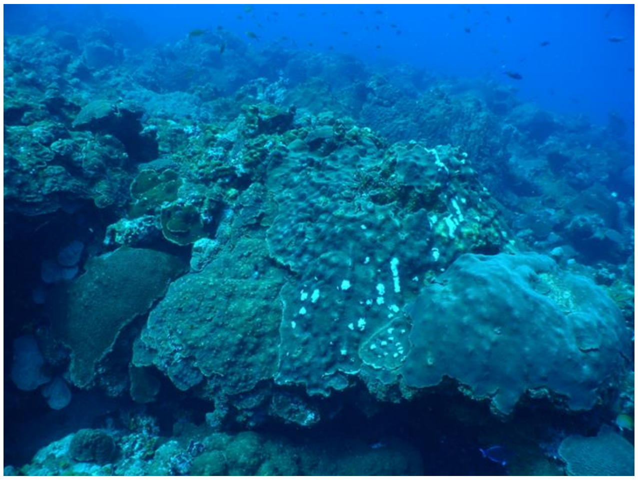
four hairs. Isotope aging of the skeletons showed that some of these simple animals had been living for over 4,000 years: before some the pyramids of Egypt were built. *Leiopathes* looks like a gangly explosion of orange wire, 3–6 feet high, with bright orange polyp flowers spread across comb-like branches that sprout in chaotic tangles from tough black stems. All are fragile, like blown glass sculptures, and are found only where the water is cold and calm. If subjected to strong currents, the smallest wave, or barest touch of a rogue fishing net, a black coral would be destroyed.

U.S. Pacific Remote Islands Marine National Monument

The PRIMNM is a reserve network that surrounds five remote and near-pristine atoll groups in the central Pacific (Wake, Johnston, Howland and Baker, Kingman and Palmyra, and Jarvis). The coral reefs and shallow seas surrounding these atolls support some of the few remaining intact tropical coral reef ecosystems on earth. Coral cover is substantially higher than average and the biomass of predatory fishes is extraordinary [28,29]. The PRIMNM was expanded in 2014 to better protect highly migratory species that inhabit the nearshore reefs and offshore seamounts including sharks, tuna, and marine mammals (such as false killer whales, melon-headed whales, spotted dolphins, minke, and humpback whales). As with PMNM, science has shown that several keystone species have migratory and forage ranges that extend well beyond the original 50 nm boundary. They are also crucial habitat to numerous other threatened and at-risk species including humphead wrasses, humphead parrotfishes, and seabird populations. Seabirds are an important and disproportionately threatened group of birds, which have declined by almost 70% since 1950[30]. After the expansion, these atoll reserves now have all five NEOLI features.

Flower Garden Banks National Marine Sanctuary

NOAA has proposed to expand the FGNMS to buffer the unique coral reefs within the current boundaries from chemical contamination from nearby extractive activities and to add protection for several other deeper sea mounts (formally on salt domes). These additional sites contain a remarkable diversity of sponge and deep sea coral communities and are essential fish habitat for the region. The FGNMS currently meets four of the five NEOLI criteria; all except size (it is currently rather small). The coral communities within the FGNMS have by far the highest living coral cover of any reefs in the southwest Atlantic (mean living coral cover on the FGNMS reefs is ~60%, compared to the Caribbean average of ~15%[31,32]). Moreover, these reefs are still dominated by massive *Orbicella faveolota and O. franksi* colonies (see image to the right), species federally listed as threatened under the U.S. endangered species act. At nearly every other reef in the Caribbean, *Orbicella* corals have been wiped out by disease and bleaching due to ocean warming. They have survived within the FGNMS because these reefs are warming more slowly than the Greater Caribbean. These *Orbicella* populations need additional protection to ensure their survival and to act as larval sources for the highly-degraded populations in the Florida Keys and other US reefs in the Caribbean (e.g., Puerto Rico). Additionally, the fish community in the FGNMS is near pristine and boasts the highest predatory fish biomass in the region.



Orbicella colonies of the FGBNMS. Photo by William Precht.

Northeast Canyons and Seamounts Marine National Monument
At just under 5,000 square nautical miles, the Northeast Canyons and Seamounts Marine National Monument is by far the smallest of the marine monuments created under President Obama and yet it encompasses two distinct areas of unique habitat in the United States' north Atlantic exclusive economic Exclusive Economic Zone, with the closest point of the NCSMNM to land being roughly 150 miles east southeast of Cape Cod, MA. The northern area includes a section of the continental shelf that includes three canyon complexes—Oceanographer, Gilbert, and Lydonia Canyons—each of which plunges deeper than the Grand Canyon from the southeast edge of Georges Bank to the deep seabed. The southwest area encompasses the only four seamounts in the U.S. Atlantic EEZ. These underwater mountains loom up from the deep ocean, to a height taller than any mountain east of the Rockies. Together, these features and the water column above them provide habitat for countless species, from ancient, thousand year-old coral structures the size of small trees, to threatened seabirds, whales, and other marine mammals, which feed on the nutrients welling up from the deep ocean around the canyon heads. Ocean warming in this area has been a major concern, with the Gulf of Maine just north of Georges Bank warming faster than 99 percent of the world's oceans[33]. Ocean warming has already taken a toll on fisheries in this region, particularly the lobster fishery, which has declined precipitously in southern New England in recent years. Protecting these areas free from further commercial activity will not only safeguard these living resources from potentially damaging encounters with fishing gear, but also provide scientists a living laboratory in which to measure and quantify the impact of warming and acidifying oceans on these species in an environment otherwise free of human interference.

Conclusion: The United States has made substantial progress in protecting our marine resources via the implementation and expansion of several critical marine reserves. We lead the world in this regard, with nearly 15% of our national waters within no-take marine reserves (up from 6% in 2014). This common-sense zoning of recreational and commercial activities is maximizing the economic output of our oceans while ensuring sustainable use and the conservation of biodiversity for the long term.

Thank you,

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