Biodiversity metrics and use of these metrics to understand ecosystem health

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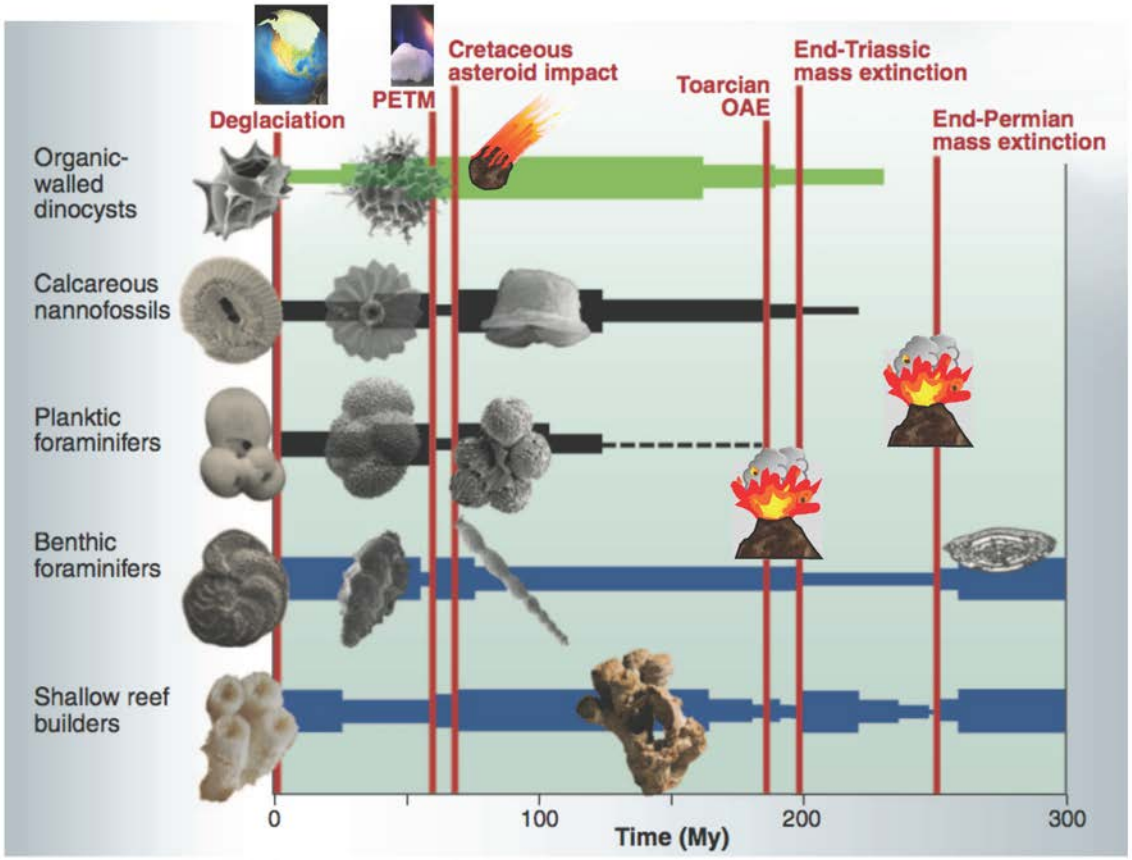
Outline

- Introduction – Where are we? → Anthropocene
- **Why?** - numerous legislative mandates, policies drivers, management goals & objectives require conservation of biodiversity
- **Why?** - Ample science shows that biodiversity increases ecological resilience & ecosystem function
- → Need to monitor biodiversity metrics for the other 99% of reef biodiversity to understand resilience & health
- **How?** - ARMS provide a cost-effective and robust tool for monitoring indices of biodiversity needed to assess effectiveness of management.

Losses of Biodiversity



Hönisch et al., Scien 2012

Mass Extinction Events (50-96% losses of diversity)

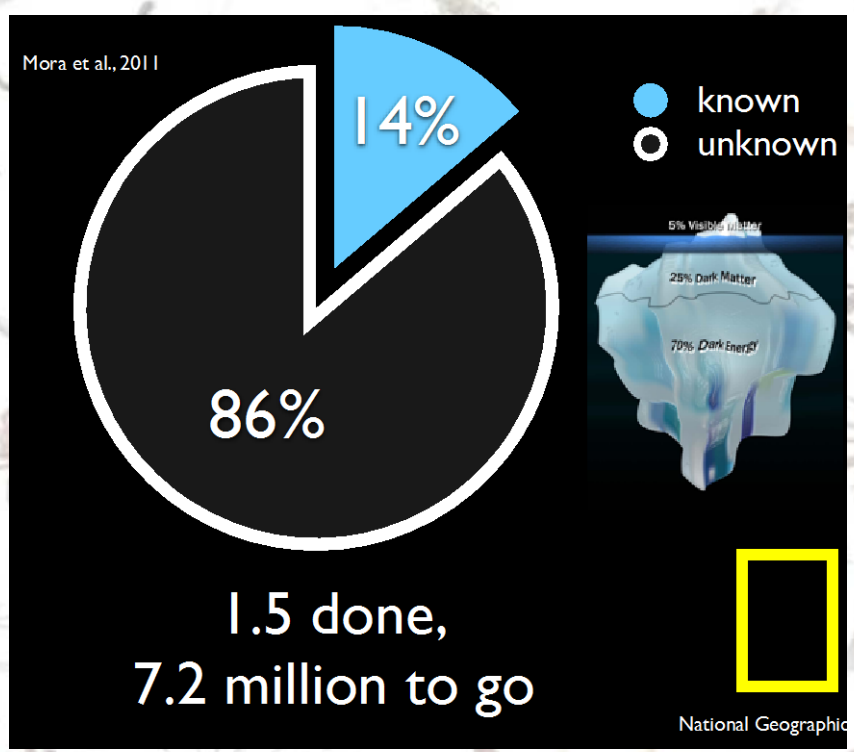
Now in 6th Mass Extinction!

- Overfishing (local)
- Land-based Sources of Pollution (local)
- Climate Change & Ocean Acidification (global)

➢ Extinction rates have already increased ~1000-fold

➢ Predicted to increase at least 100-fold this century

Gaps in Biodiversity Knowledge



- Scientists don't know the majority of species in the ocean (or on coral reefs)
- Scientists don't know the functional roles most species play in maintaining viable ecosystems (or on coral reefs)
- The most recent estimate of the number of species on coral reefs globally is 830,000 (550,000-1,330,000) Fisher et al. (2015)

How will coral reefs function and provide the ecosystem goods and services that people depend on?

Why Conserve Biodiversity?

Legislation & Policy Drivers

- U.N. Convention on Biological Diversity (CBD, 1992)
- U.N. Convention on International Trade in Endangered Species (CITES, 1973)
- U.S. Endangered Species Act (ESA, 1973)
- U.S. National Ocean Policy (NOP, 2010)
- NOAA Next Generation Strategic Plan (NGSP, 2010)
- Coral Reef Conservation Act (CRCA, 2000)
- CRCP Goals and Objectives (2011-2015)
- National Marine Sanctuaries Act

UN Convention on Biological Diversity

Reaffirming also that States are responsible for conserving their biological diversity and for using their biological resources in a sustainable manner.

Aware of the general lack of information and knowledge regarding biological diversity and of the urgent need to develop scientific, technical and institutional capacities to provide the basic understanding upon which to plan and implement appropriate measures,

Aware that conservation and sustainable use of biological diversity is of critical importance for meeting the food, health and other needs of the growing world population, for which purpose access to and sharing of both genetic resources and technologies are essential.

Determined to conserve and sustainably use biological diversity for the benefit of present and future generations,

"*Biological diversity*" means the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems.

"*Sustainable use*" means the use of components of biological diversity in a way and at a rate that does not lead to the long-term decline of biological diversity, thereby maintaining its potential to meet the needs and aspirations of present and future generations.

UN CBD Targets (2011-2020)

THE VISION

"By 2050, biodiversity is valued, conserved, restored and wisely used, maintaining ecosystem services, sustaining a healthy planet and delivering benefits essential for all people."

THE MISSION

"Take effective and urgent action to halt the loss of biodiversity in order to ensure that by 2020 ecosystems are resilient and continue to provide essential services, thereby securing the planet's variety of life, and contributing to human well-being, and poverty eradication. To ensure this, pressures on biodiversity are reduced, ecosystems are restored, biological resources are sustainably used and benefits arising out of utilization of genetic resources are shared in a fair and equitable manner; adequaate financial resources are provided, capacities are enhanced, biodiversity issues and values mainstreamed, appropriate policies are effectively implemented, and decision-making is based on sound science and the precautionary approach."

10 By 2015, the multiple anthropogenic pressures on coral reefs, and other vulnerable ecosystems impacted by climate change or ocean acidification are minimized, so as to maintain their integrity and functioning.

U.S. Endangered Species Act

(b) PURPOSES.—The purposes of this Act are to provide a means whereby the ecosystems upon which endangered species and threatened species depend may be conserved, to provide a program for the conservation of such endangered species and threatened species, and to take such steps as may be appropriate to achieve the purposes of the treaties and conventions set forth in subsection (a) of this section.

(4) the United States has pledged itself as a sovereign state in the international community to conserve to the extent practicable the various species of fish or wildlife and plants facing extinction, pursuant to—

(A) migratory bird treaties with Canada and Mexico;

(B) the Migratory and Endangered Bird Treaty with Japan;

(C) the Convention on Nature Protection and Wildlife Preservation in the Western Hemisphere;

(D) the International Convention for the Northwest Atlantic Fisheries;

(E) the International Convention for the High Seas Fisheries of the North Pacific Ocean;

(F) the Convention on International Trade in Endangered Species of Wild Fauna and Flora; and

Department of the Interior
U.S. Fish and Wildlife

(3) The terms "conserve", "conserving", and "conservation" mean to use and the use of all methods and procedures which are necessary to bring any endangered species or threatened species to the point at which the measures provided pursuant to this Act are no longer necessary. Such methods and procedures include, but are

U.S. National Ocean Policy

This Plan presents a common-sense, science-based approach to achieve these benefits through resource management that considers entire ecosystems. The goal of ecosystem-based management supported by this Plan is to maintain a healthy, productive, and resilient ocean that can continue to provide the benefits and resources humans want and need. Achieving this goal will require both a sound scientific foundation and a commitment to management practices that are adaptable to changing conditions and responsive to new challenges and opportunities that emerge. Working together, resource managers,

NATIONAL OCEAN

- **Protect, conserve and restore coastal and ocean habitats.** Agencies will coordinate to use and provide scientifically sound, ecosystem-based approaches to achieving healthy coastal and ocean habitats. For example, working through the U.S. Coral Reef Task Force, agencies will

- **Advance fundamental scientific knowledge through exploration and research.** Through Federal research and exploration activities and partnerships with non-governmental organizations, new ocean discoveries will expand our knowledge and understanding of oceanic and Great Lakes biodiversity, biogeochemical processes, ecosystem services, and climate interactions. Agencies will use the Ocean Research Priorities Plan, a document built with input from the

Council

APRIL 2013

and implement them, are critical to improving our understanding of the underlying physical and ecological processes driving the ocean, coasts, and Great Lakes, as well as to identifying more efficient means of monitoring these ecosystems. Federal agencies will evaluate how to most

NOAA Next Generation Strategic Plan

NOAA's Mission: ***Science, Service, and Stewardship***
To understand and predict changes in climate, weather, oceans, and coasts,
To share that knowledge and information with others, and
To conserve and manage coastal and marine ecosystems and resources.

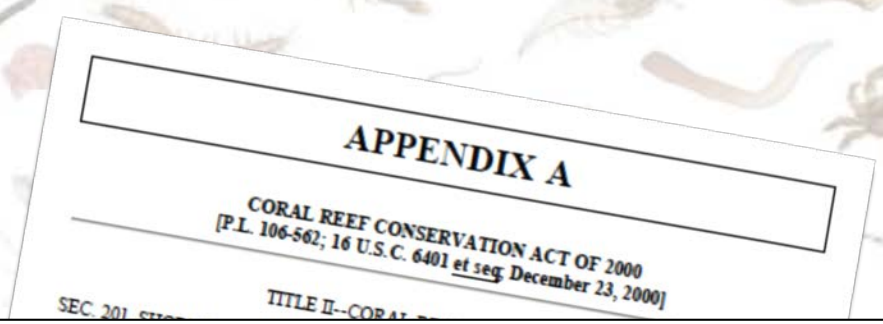
NOAA'S NEXT-GENERATION
STRATEGIC

Long-term goal: Healthy Oceans
Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems

NOAA will continue to work with partners to acquire, protect, and restore habitat, biodiversity, and ecosystem services to support the resilience of both ecosystems and the built environment.

- Assess and understand the roles of ecosystem processes and biodiversity in sustaining ecosystem services;

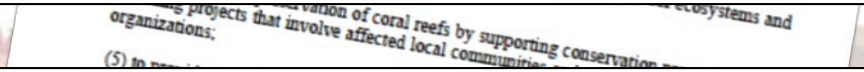
Coral Reef Conservation Act


APPENDIX A

CORAL REEF CONSERVATION ACT OF 2000
[P.L. 106-562; 16 U.S.C. 6401 et seq. December 23, 2000]

TITLE II--CORAL

The purposes of this title are--
(1) to preserve, sustain, and restore the condition of coral reef ecosystems;
(2) to promote the wise management and sustainable use of coral reef ecosystems to benefit local communities and the Nation;
(3) to develop sound scientific information on the condition of coral reef ecosystems and the threats to such ecosystems;


organizations;

(2) CONSERVATION- The term `conservation' means the use of methods and procedures necessary to preserve or sustain corals and associated species as diverse, viable, and self-perpetuating coral reef ecosystems, including all activities associated with resource management, such as assessment, conservation, protection, restoration, sustainable use, and management of habitat; mapping; habitat monitoring; assistance in the development of management strategies for marine protected areas and marine resources…

CRCP Goals & Objectives

- Increase coral reef resilience to climate change and ocean acidification through effective management strategies.
- Identify, understand, and communicate risks and vulnerability of U.S. coral reef ecosystems, ecosystem services, and dependent human communities to climate change and ocean acidification.

- Increase the abundance and average size of key coral reef fishery species to protect trophic structure and biodiversity and improve coral reef ecosystem condition.
- Support effective implementation and management of marine protected areas (MPAs) and ecological networks of MPAs that protect key coral reef ecosystem components and functions.

Reducing impacts from fishing can enhance coral reef integrity, stability and aesthetics by increasing the abundance and average size of targeted species, restoring biodiversity, and maintaining coral reef ecosystem function.

Well designed ecological networks of MPAs are needed to effectively protect biodiversity, habitats and ecosystem functions.

Management Goal – Conserving Biodiversity

- Papahanaumokuakea Marine National Monument

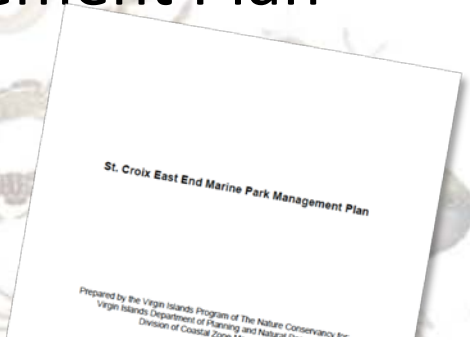
Monument Goals
Goal 1: Protect, preserve, maintain, and where appropriate restore the physical environment and the natural biological communities and their associated biodiversity, habitats, populations, native species, and ecological integrity.
Goal 2: Support, promote, and coordinate research, ecosystem characterization, and monitoring that increases understanding of the NWHI, improves management decisionmaking, and is consistent with conservation and protection.

The five thematic areas in the draft Natural Resources Science Plan are:

- Research on ecological processes and connectivity
- Research on biodiversity and habitats
- Research on human impacts
- Research on ecosystem change, indicators, and monitoring
- Modeling and forecasting ecosystem change

Management Goal – Conserving Biodiversity

- St. Croix East End Marine Park Management Plan


St. Croix East End Marine Park Management Plan

2. MANAGEMENT OBJECTIVES

2.1 Overall Goals for Management

The Marine Park being developed will be a protected area managed mainly for the sustainable use of natural ecosystems. However, within the Park, other objectives will guide operations including: managing the area for ecosystem protection and tourism, and managing the area for conservation of specific natural features. Ultimately, this Management Plan should serve as a guide for Park operations and future activities to Park managers and planners. The following goals were taken from IUCN's description of a Managed Resource Protected Area (MRPA), and will be used as guidelines for management of the Park:

- Protect and maintain the biological diversity and other natural values of the area in the long term
- Promote sound management practices for sustainable production purposes
- Protect the natural resource base from being alienated for other land use purposes that would be detrimental to the area's biological diversity
- Contribute to regional and national development

Management Goal – Conserving Biodiversity

- Florida Keys National Marine Sanctuary

The NMSP Mission:
To serve as the trustee for the national system of marine protected areas to conserve, protect, and enhance their biodiversity, ecological integrity and cultural legacy.

Florida Keys
National Marine Sanctuary
Revised Management Plan

December 2007
U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Ocean Service
National Marine Sanctuary Program

Ecological Reserves

Ecological Reserves seek to protect biodiversity by setting aside areas with minimal human disturbance. Ecological Reserves encompass large, contiguous, diverse habitats, in order to protect and enhance natural spawning, nursery, and permanent-residence areas for the replenishment and genetic protection of fish and other marine life. Allowing certain areas to evolve in or return to a natural state preserves the diverse range of resources and habitats throughout the Sanctuary.

Why Conserve Biodiversity?

Ecosystem Health and Resilience

CONSERVING OCEAN BIODIVERSITY: TRENDS AND CHALLENGES

Thomas F. Hourigan
National Marine Fisheries Service, NOAA

The ocean's biological diversity—the living resources that compose it and the ecological processes that sustain it—forms a foundation for the quality of human life as well as the raw materials to enrich it.

The ocean's biological diversity—the living resources that compose it and the ecological processes that sustain it—forms a foundation for the quality of human life as well as the raw materials to enrich it.

Hourigan, *Trends in Managing the Environment (1999)*

IDEAS AND PERSPECTIVES

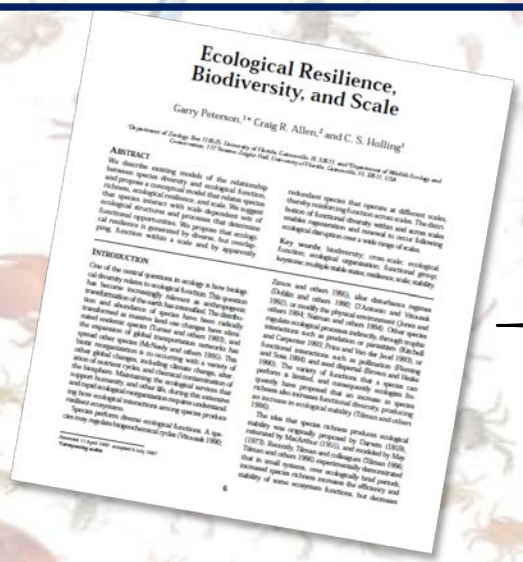
Biodiversity loss, trophic skew and ecosystem functioning

the dominant impacts of biodiversity change on ecosystem functioning appear to be trophically mediated, with important implications for conservation.

Duffy, *Ecology Letters* (2003)

Why Conserve Biodiversity?

Ecosystem Health and Resilience



Ecological Resilience, Biodiversity, and Scale

Garry Peterson,[1*] Craig R. Allen,[2] and C. S. Holling[1]

We propose that ecological resilience is generated by diverse, but overlapping, function within a scale and by apparently redundant species that operate at different scales, thereby reinforcing function across scales. The distribution of functional diversity within and across scales enables regeneration and renewal to occur following ecological disruption over a wide range of scales.

Peterson et al., *Ecosystems* (1998)

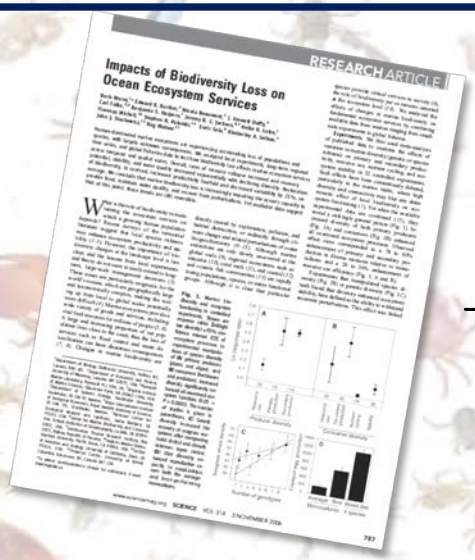
Biodiversity enhances reef fish biomass and resistance to climate change

diversity and climate interact, with biomass of diverse communities less affected by rising and variable temperatures than species-poor communities. Biodiversity thus buffers global fish biomass from climate change, and conservation of marine biodiversity can stabilize fish production in a changing ocean.

Duffy et al., *PNAS* (2016)

Why Conserve Biodiversity?

Ecosystem Health and Resilience


RESEARCH ARTICLE

Impacts of Biodiversity Loss on Ocean Ecosystem Services

Rates of resource collapse increased and recovery potential, stability, and water quality decreased exponentially with declining biodiversity. Restoration of biodiversity increased productivity fourfold. We conclude that marine biodiversity loss is increasingly impairing the ocean's capacity to provide food, maintain water quality, and recover from perturbations.

Worm et al., *Science* (2006)

Trends in Ecology & Evolution

Biodiversity and Resilience of Ecosystem Functions

Although potentially less important in the short term, biodiversity, empassing variation from within species to across landscapes, may be crucial for longer-term resilience of ecosystem functions and the services they underpin.

Oliver et al., *Trends in Ecology & Evolution* (2015)

Why Conserve Biodiversity?

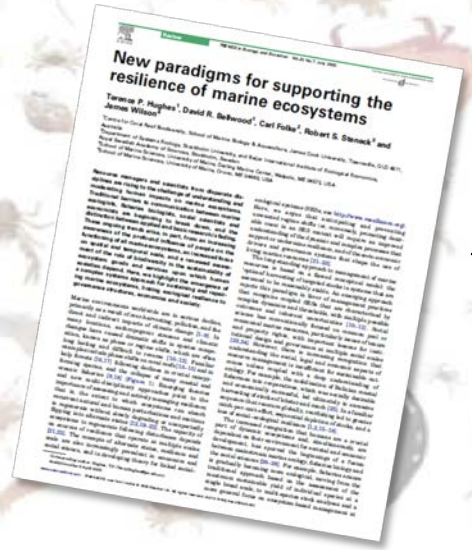
Ecosystem Health and Resilience

REGIME SHIFTS, RESILIENCE, AND BIODIVERSITY IN ECOSYSTEM MANAGEMENT

Carl Folke,[1,2] Steve Carpenter,[2,3] Brian Walker,[4] Marten Scheffer,[5] Thomas Elmqvist,[1] Lance Gunderson,[6] and C.S. Holling[7]

The likelihood of regime shifts may increase when humans reduce resilience by such actions as removing response diversity, removing whole functional groups of species, or removing whole trophic levels…..
ecosystems may suddenly shift from desired to less desired states in their capacity to generate ecosystem services.

Folke et al., *Annu. Rev. Ecol. Evol. Syst.* (2004)



New paradigms for supporting the resilience of marine ecosystems

Terence P. Hughes[1], David R. Bellwood[2], Carl Folke[3], Robert S. Steneck[4] and James Wilson[5]

Recognition of functional groups provides a deeper understanding of the role of biodiversity in ecosystem processes. Certainly, depauperate marine assemblages are often functionally compromised, and richer biotas are more likely to have greater levels of functional redundancy.

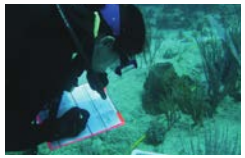
Hughes et al., *Trends in Ecology & Evolution* (2005)

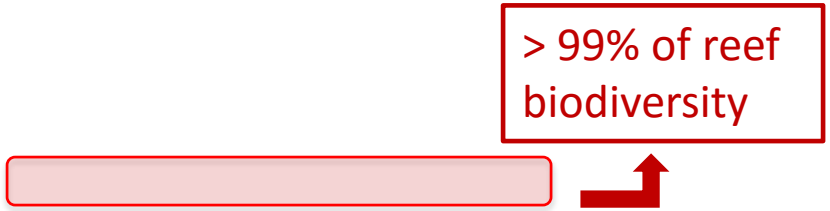
Monitoring Biodiversity

- The aforementioned legislative drivers clearly show that we have numerous mandates and policy drivers that require us (including NOAA) to manage and conserve biodiversity.
- The aforementioned science papers highlight the importance of biodiversity in maintaining ecological resilience and ecosystem function.

→ We need to monitor metrics of biodiversity to assess the effectiveness of management actions in achieving management goals and objectives.

NCRMP – Biodiversity Monitoring





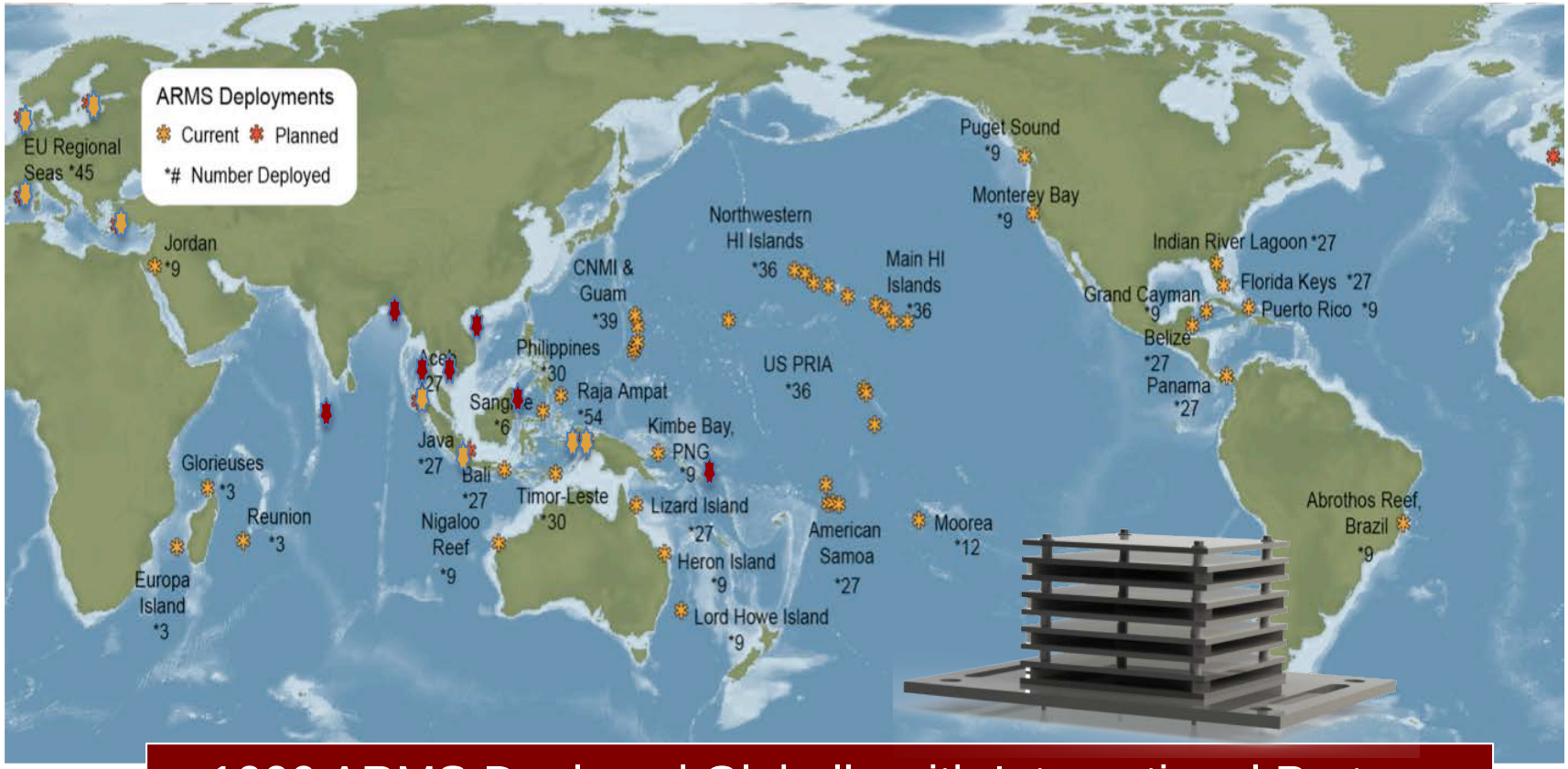
In the Pacific Islands, NCRMP has been implemented thru the Pacific Reef Assessment and Monitoring Program since 2001.

dence on coral reefs

NOAA-PIFSC - actively developing tools to monitor coral reef biodiversity since 2005 as part of Census of Marine Life with Smithsonian, Univ. Florida, AIMS, UH, SDSU, MLML,,

Autonomous Reef Monitoring Structures (ARMS)

Autonomous Reef Monitoring Structures (ARMS) are a systematic tool to assess and robustly monitor and detect changes in indices of coral reef biodiversity (the other 99%)

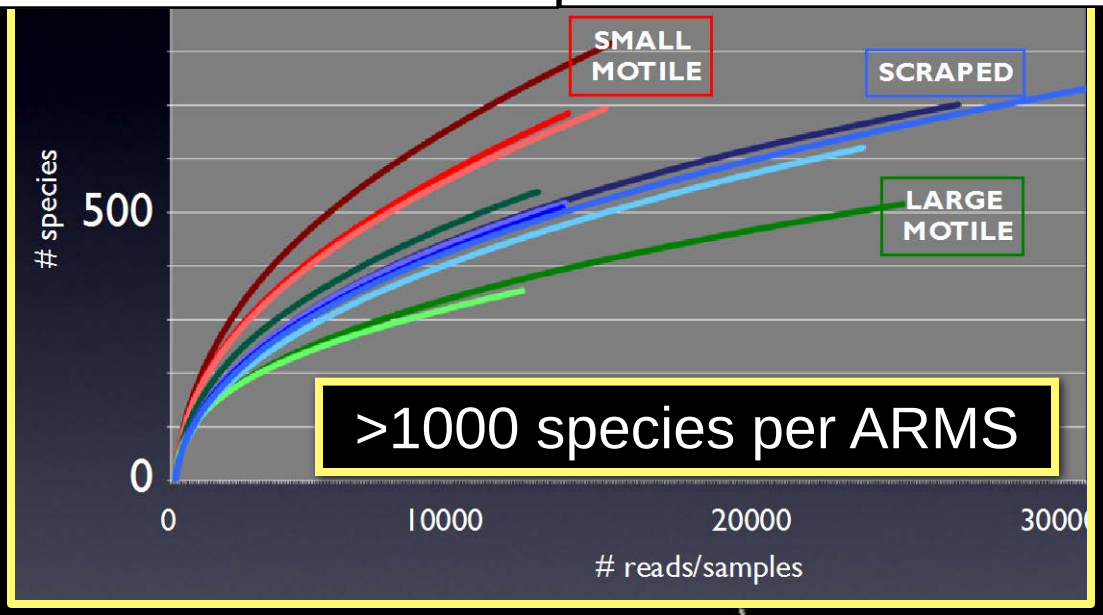


~1000 ARMS Deployed Globally with International Partners

Sessile Biodiversity (Image Analysis)

Sorting & Identifying Organisms

Prepping for DNA Sequencing



Early Products

Commonness and rarity in the marine biosphere

Sean R. Connolly[a,1], M. Aaron MacNeil[b], M. Julian Caley[b], Nancy Knowlton[c,1], Ed Cripps[d], Mizue Hisano[e], Loïc M. Thibaut[a], Bhaskar D. Bhattacharya[a], Lisandro Benedetti-Cecchi[f], Russell E. Brainard[g], Angelika Brandt[h], Fabio Bulleri[f], Karl E. Ellingsen[i], Stefanie Kaiser[j], Ingrid Kröncke[k], Katrin Linse[l], Elena Maggi[f], Timothy D. O'Hara[m], Laetitia Plaisance[n], Gary C. B. Poore[m], Santosh K. Sarkar[o], Kamala K. Satpathy[o], Ulrike Schückel[p], Alan Williams[q], and Robin S. Wilson[m]

Contributed by Nancy Knowlton, April 28, 2014 (sent for review November 25, 2013; reviewed by Brian McGill and Fangliang He)

Explaining patterns of commonness and rarity is fundamental for understanding and managing biodiversity. Consequently, a key test of biodiversity theory has been how well ecological models reproduce empirical distributions of species abundances. However, ecological models with very different assumptions can predict similar species abundance distributions, whereas models with similar assumptions may generate very different predictions. This complicates inferring processes driving community structure from model fits to data. Here, we use an approximation that captures common features of "neutral" biodiversity models—which assume ecological equivalence of species—to test whether neutrality is consistent with patterns of commonness and rarity in the marine biosphere. We do this by analyzing 1,185 species abundance distributions from 14 marine ecosystems ranging from intertidal habitats to abyssal depths, and from the tropics to polar regions. Neutrality performs substantially worse than a classical nonneutral alternative: empirical data consistently show greater heterogeneity of species abundances than expected under neutrality. Poor performance of neutral theory is driven by its consistent inability to capture the dominance of the commonest or most abundant species. Previous tests showing poor performance of a neutral model for a particular system often have been followed by controversy about whether an alternative formulation of neutral theory could explain the data after all. However, our approach focuses on common features of neutral models, revealing discrepancies with a broad range of empirical abundance distributions. These findings highlight the need for biodiversity theory in which ecological differences among species, such as niche differences and demographic trade-offs, play a central role.

metacommunities | marine macroecology | species coexistence | Poisson-lognormal distribution

Determining how biodiversity is maintained in ecological communities is a long-standing ecological problem. In species-poor communities, niche and demographic differences between species can often be estimated directly and used to infer the importance of alternative mechanisms of species coexistence (1–3). However, the "curse of dimensionality" prevents the application of such species-by-species approaches to high-diversity assemblages: the number of parameters in community dynamics models increases more rapidly than the amount of data, as species richness increases. Moreover, most species in high-diversity assemblages are very rare, further complicating the estimation of strengths of ecological interactions among species, or covariation in different species' responses to environmental fluctuations. Consequently, ecologists have focused instead on making assumptions about the overall distribution of demographic rates, niche sizes, or other characteristics of an assemblage, and then deriving the aggregate assemblage properties implied by those assumptions (4–8). One of the most commonly investigated of these assemblage-level properties is the species abundance distribution (SAD)—the pattern of commonness and rarity among species (9–11). Ecologists have long sought to identify mechanisms that can explain common features of, and systematic differences among, the shapes of such distributions, and have used the ability to reproduce empirical SADs as a key test of biodiversity theory in species-rich systems (4, 6, 11–14).

Over the last decade, one of the most prevalent and influential approaches to explaining the structure of high-diversity assemblages has been neutral theory of biodiversity (12, 15, 16). Neutral models assume that individuals are demographically and ecologically equivalent, regardless of species. Thus, variation in relative

Significance

Tests of biodiversity theory have been controversial partly because alternative formulations of the same theory seemingly yield different conclusions. This has been a particular challenge for neutral theory, which has dominated tests of biodiversity theory over the last decade. Neutral theory attributes differences in species abundances to chance variation in individuals' fates, rather than differences in species traits. By identifying common features of different neutral models, we conduct a uniquely robust test of neutral theory across a global dataset of marine assemblages. Consistently, abundances vary more among species than neutral theory predicts, challenging the hypothesis that community dynamics are approximately neutral, and implicating species differences as a key driver of community structure in nature.

Author contributions: S.R.C., M.A.M., and M.J.C. designed research; N.K., B.D.B., L.M.-C., R.E.B., A.B., F.B., K.E.E., S.K., I.K., K.L., E.M., T.D.O., L.P., G.C.B.P., S.K.S., K.K.S., U.S., A.W., and R.S.W. performed research; S.R.C., S.C., M.H., and L.M.T. analyzed data; S.R.C. designed analytical approach; M.J.C. initiated the collaboration between Census of Marine Life and S.R.C.; N.K. was the initiator of Census of Marine Life Project (producer of dataset) for coral reefs; N.K. designed data collection protocols; B.D.B., L.B.-C., R.E.B., A.B., F.B., K.E.E., S.K., I.K., K.L., E.M., T.D.O., L.P., G.C.B.P., S.K.S., K.K.S., U.S., A.W., and R.S.W. provided advice on treatment of data for analyses; and S.R.C., M.A.M., M.J.C., N.K., and E.C. wrote the paper.

Reviewers: B.M., University of Maine; F.H., University of Alberta.

The authors declare no conflict of interest.

Freely available online through the PNAS open access option.

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Current Biology

Species Richness on Coral Reefs and the Purs
Convergent Global Estimates

Highlights

- We estimate that there are 830,000 (550,000–1,330,000) species on coral reefs worldwide
- Species richness and asymmetrical uncertainties were estimated using expert knowledge
- Uncertainties differ among taxa and should guide future research effort

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In Brief

Fisher et al. use expert taxono knowledge to estimate global richness on coral reefs. Uncer were strongly right skewed, in that more species on coral re plausible than fewer. These m results should guide future es global species richness for co and other ecosystems.

Differences among Major Taxa in the Extent of Ecological Knowledge across Four Major Ecosystems

Rebecca Fisher[1*], Nancy Knowlton[2,3], Russell E. Brainard[4], M. Julian Caley[5]

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Abstract

Existing knowledge shapes our understanding of ecosystems and is critical for ecosystem-based management of the world's natural resources. Typically this knowledge is biased among taxa, with some taxa far better studied than others, but the extent of this bias is poorly known. In conjunction with the publically available World Registry of Marine Species database (WoRMS) and one of the world's premier electronic scientific literature databases (Web of Science®), a text mining approach is used to examine the distribution of existing ecological knowledge among taxa in coral reef, mangrove, seagrass and kelp bed ecosystems. We found that for each of these ecosystems, most research has been limited to a few groups of organisms. While this bias clearly reflects the perceived importance of some taxa as commercially or ecologically valuable, the relative lack of research of other taxonomic groups highlights the problem that some key taxa and associated ecosystem processes they affect may be poorly understood or completely ignored. The approach outlined here could be applied to any type of ecosystem for analyzing previous research effort and identifying knowledge gaps in order to improve ecosystem-based conservation and management.

Citation: Fisher R, Knowlton N, Brainard RE, Caley MJ (2011) Differences among Major Taxa in the Extent of Ecological Knowledge across Four Major Ecosystems. PLoS ONE 6(11): e26556. doi:10.1371/journal.pone.0026556

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Introduction

Existing knowledge shapes our understanding of ecosystems and determines our ability to identify which drivers ecosystem function and promote ecosystem resilience and understand the nature and role of keystone species. Such information is critical to the successful conservation of the world's biodiversity and increasingly underpins management, particularly the broad approach referred to as ecosystem-based management (EBM). However, while a large and growing body of ecological knowledge is stored in the scientific literature, representing a broad range of the world's ecosystems, this existing knowledge may not adequately represent the range of taxa present in these ecosystems. An understanding of this potential bias is becoming increasingly urgent as biodiversity is lost [1], ecosystems are degraded [2] and the vitally important goods and services that they provide are threatened [3,4].

By concentrating on four major marine ecosystems, we examine the taxonomic distribution of existing ecological knowledge and the extent to which various taxonomic groups may be under- or over-represented in our knowledge of these systems. We analyzed the literature for coral reefs, seagrass beds, mangroves and kelp beds because these ecosystems provide important ecosystem goods and services both individually and as functional linkages [4,5,6,7,8,9,10]. In addition, each ecosystem is relatively discrete and therefore easy to delineate and is defined by its dominant habitat-forming organisms. Also, these ecosystems are at considerable risk from both direct and indirect anthropogenic pressures such as pollution, development, overfishing and now global warming and ocean acidification [11,12]. Indeed, few if any areas remain where these ecosystems have not been impacted in some extent [13]. Therefore, now more than ever, it is important to assess our current knowledge of these ecosystems and consider how future research efforts may be best allocated to maximize our chance of achieving sustainable management. Using text mining (following [13]) of papers contained within the Web of Science® (WoS), we examined how existing ecological knowledge and associated research efforts are distributed among different taxonomic groups.

Methods

Sampling the scientific literature

Web of Science® (WoS) is one of the world's largest literature databases and includes much of the published information relevant to marine ecology. WoS was searched between the years 1957–2009 by using the following keywords: "coral reef* n", "mangrove forest* n", "help forest* n" "seagrass bed* n" and "seagrass meadow* n". "Coral", "mangrove", "help" and "seagrass" were not used on their own as search terms. This was done to ensure that returns were relevant to the ecosystems of interest, rather than simply including all possible studies of these particular organisms. The resulting 13,229 papers were exported in EndNote® format

Chapter 4

Coral Reef Biodiversity

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4.1 Introduction

Coral reefs are often called the rainforests of the sea, but not because of their vastness. Being largely limited to warm shallow waters, their extent is surprisingly small – in total only 260,000–600,000 km², or approximately 5% that of rainforests, less than 0.1% of the earth's surface, or 0.2% of the ocean's surface (Reaka-Kudla 1997) – and thus smaller in total land area than France. One might therefore think that assessing the diversity of coral reefs would be far easier than for some of the other realms, geographic regions, and taxonomic groups that make up the 14 field projects of the Census of Marine Life that concern ocean life today. Yet coral reefs are the most diverse marine habitat per unit area, and perhaps the most diverse marine habitat overall – the deep sea being the only other contender, in part because of its huge area. As with rainforests, most of this diversity is not found in the organisms that create the three-dimensional structure of reefs – there are, in fact, fewer than 1,000 species of stony corals (scleractinia Cairns 1999). Rather, the multitude living with corals – the equivalent o forest – are responsible for the sta species associated with reefs.

Coral reefs share another, more du with tropical rainforests, namely th human impacts, both global (associa sions) and local (poor water quality, fishing, invasive species). Although t the future of coral reefs dominate the ture (see, for example, Bellwood *et al.* the state of coral reefs was slow in 2006). The first modern concerns are because of mass mortalities associat explosions of the crown-of-thorns *planci*, in the Pacific (Chesher 1969). reefs in the Caribbean, caused by dise ing corals and the keystone urchin *antillarum*) coupled with overfishing, alarm (Hughes 1994), with paleoecol cating that these levels of mortality h the past several thousand years (Pa recently, surprisingly high losses to

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Review

An Overview of Marine Biodiversity in United States Waters

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Marine biodiversity of the United States (U.S.) is extensively documented, but data assembled by the United States National Committee for the Census of Marine Life demonstrate that even the most complete taxonomic inventories are based on record established in space and time. The best known taxa are those of commercial importance. Body size is directly correlated with knowledge of a species, and knowledge also diminishes with distance from shore and depth. Measures of biodiversity differ from species diversity, such as ecosystem and genetic diversity, are poorly documented. Threats to marine biodiversity in the U.S. are not different from those in the rest of the world: overexploitation of living resources, reduced water quality, coastal development, shipping, invasive species, rising temperature and concentrations of carbon dioxide in the surface ocean, and other changes that may be consequences of global change, including shifting currents, increased number and size of hypoxic or anoxic areas, and increased number and duration of harmful algal blooms. More information must be obtained through field and laboratory research and monitoring that involve innovative sampling techniques (such as genetics and acoustics), but data that already exist must be made accessible. And all data must have a temporal component so trends can be identified. As data are compiled, of global change and in many forms [1]. The Census has highlighted the importance of preserving natural marine biodiversity as a critical part of maintaining marine ecosystem functions and services, including fisheries, water quality, recreation, and shoreline protection [2].

This overview summarizes the knowledge—and some of the major gaps in knowledge—of marine biodiversity of the United States (U.S.) as of late 2008, when the data were assembled. The inventories and the summaries provided in Table S1 and its condensed version, Table 1, are all the species listed, but there is discussion of broader taxa, of ecosystems and particular habitats, which are also vital (e.g., [3]). Although it does not include information about regions administered by or associated politically with the U.S., the area that is covered is enormous, bordering on all but five major named bodies of water, and extending from 67.4W to about 172.5u E, and from the Arctic (just south of 71u N) to 7u N). The regions differ greatly in history of exploration and knowledge of their biodiversity. Because the birds of a place such as Alaska may have more in common with that of Japan than with that of another part of the U.S., such as the Gulf of Mexico, a single list of marine species reported from the U.S. or an annotation that a

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Article

Using DNA Barcoding and Standardized Sampling to Compare Geographic and Habitat Differentiation of Crustaceans: A Hawaiian Islands Example

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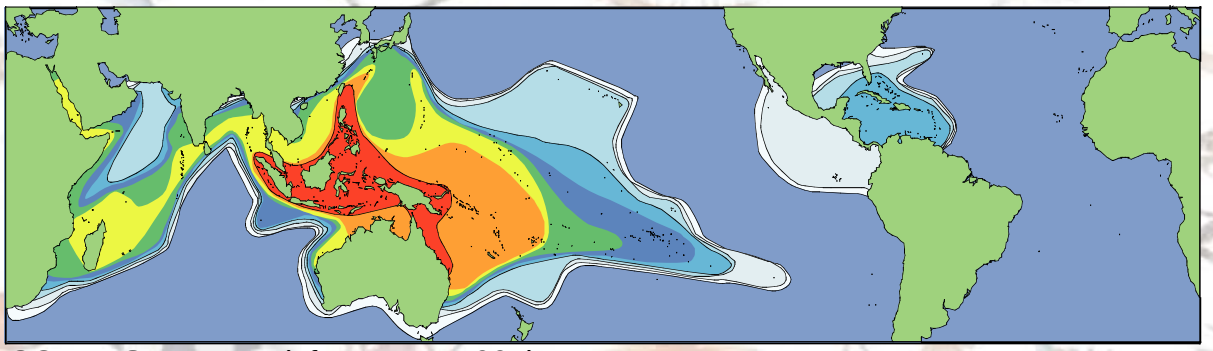
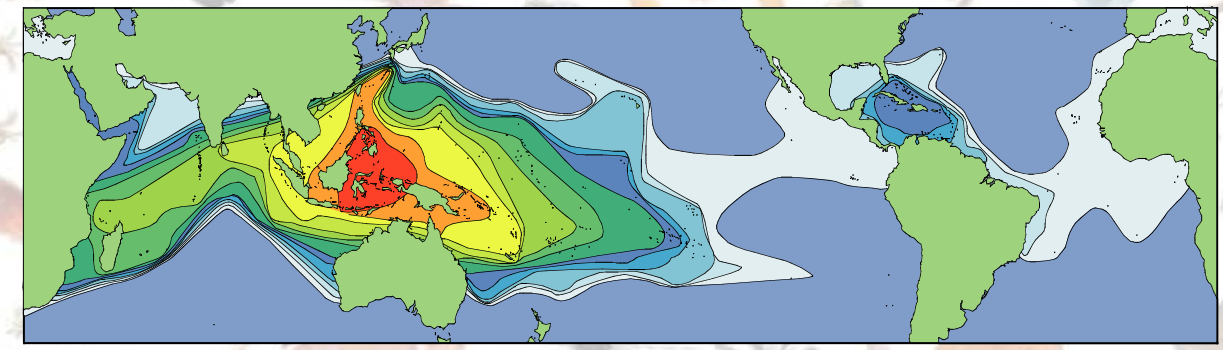
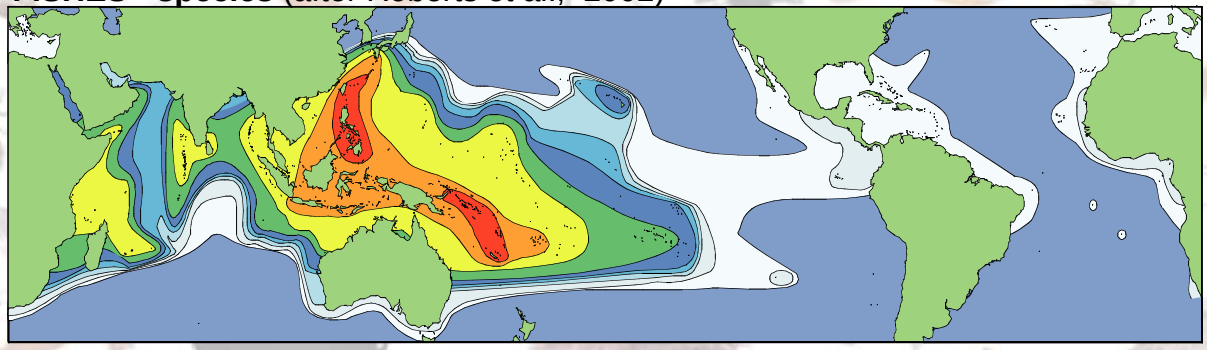
Patterns of Biodiversity



CORALS - genera (after Veron 1994)



FISHES - species (after Roberts et al., 2002)

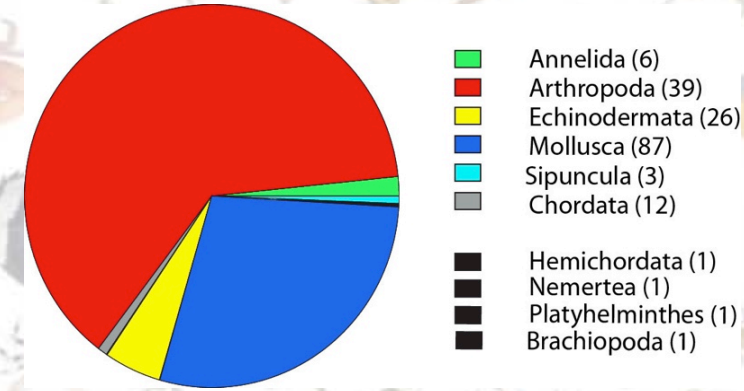


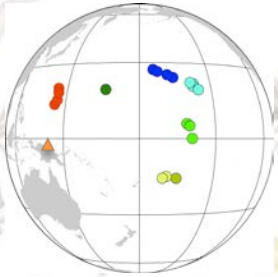
COWRIES - ESUs (Meyer)

Preliminary Results from ARMS

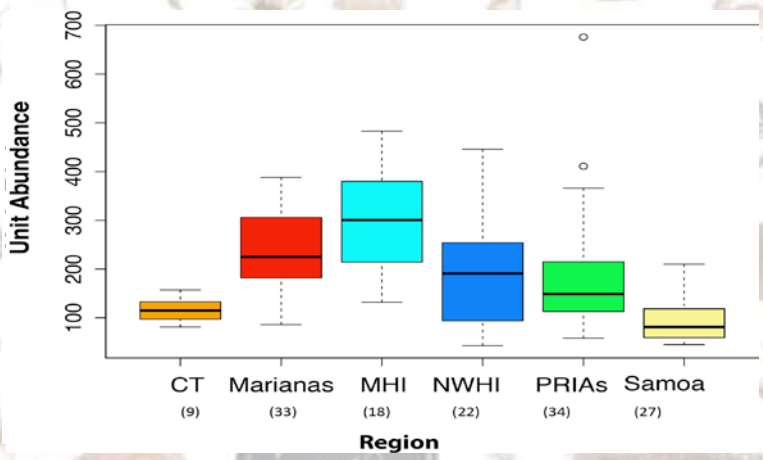
32571 Organisms from the equivalent **60** cubic feet
~ **237** organisms **per Unit**

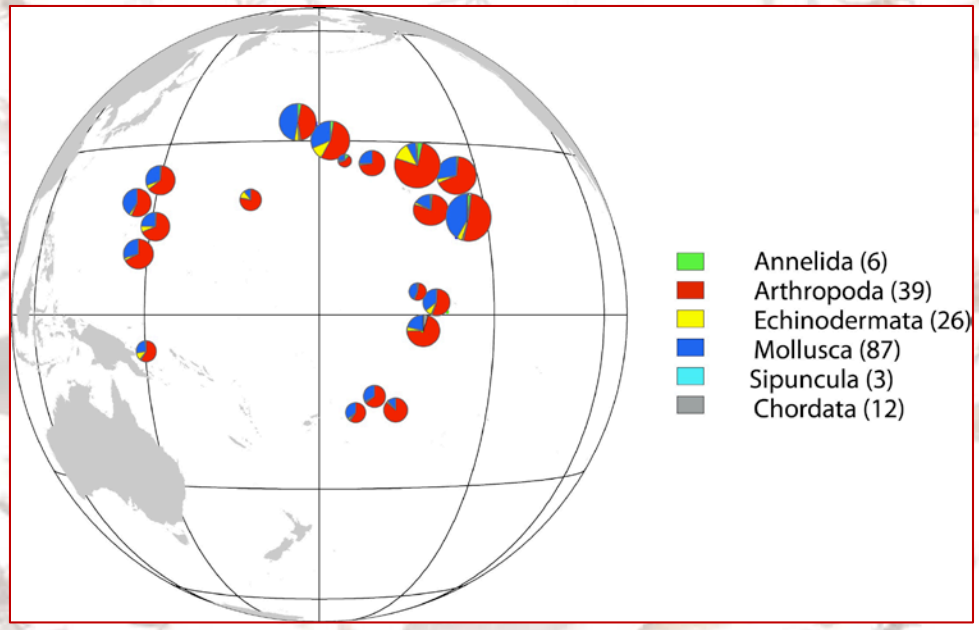
10 Phyla





6 Regions
21 Islands
143 ARMS Units

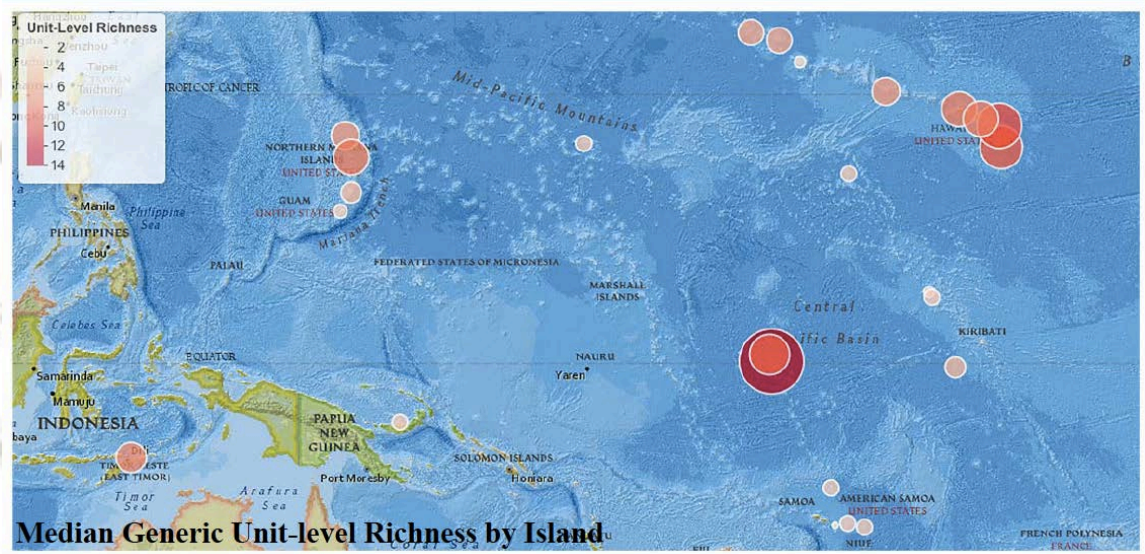


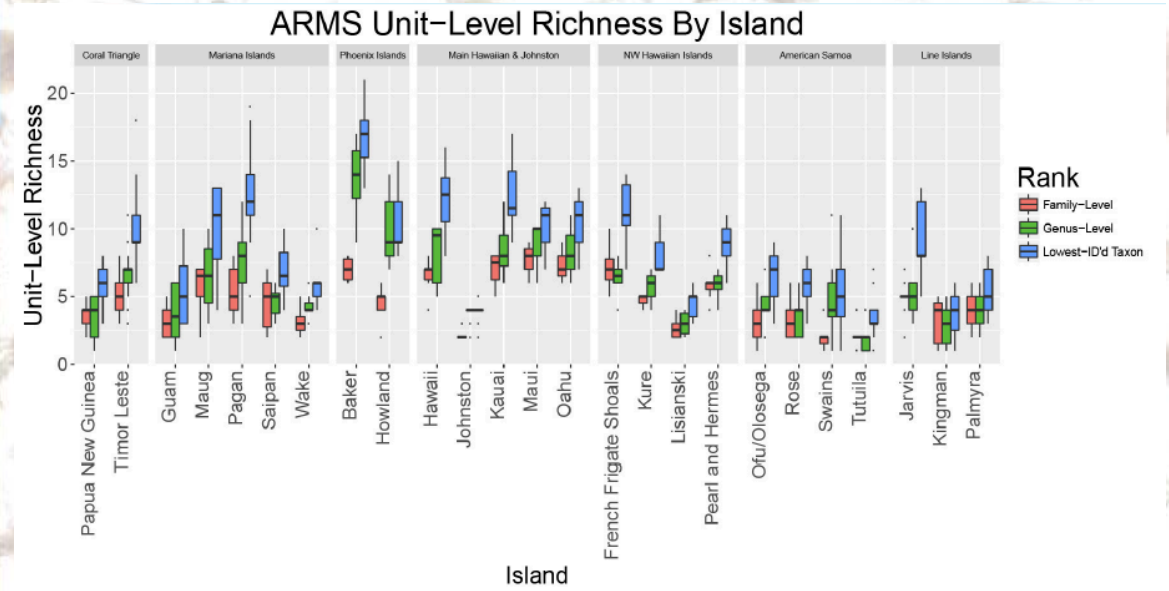


Molly Timmers, Reardon, Paulay, Donahue, Oliver, Brainard (ICRS 2016)

Preliminary Results from ARMS

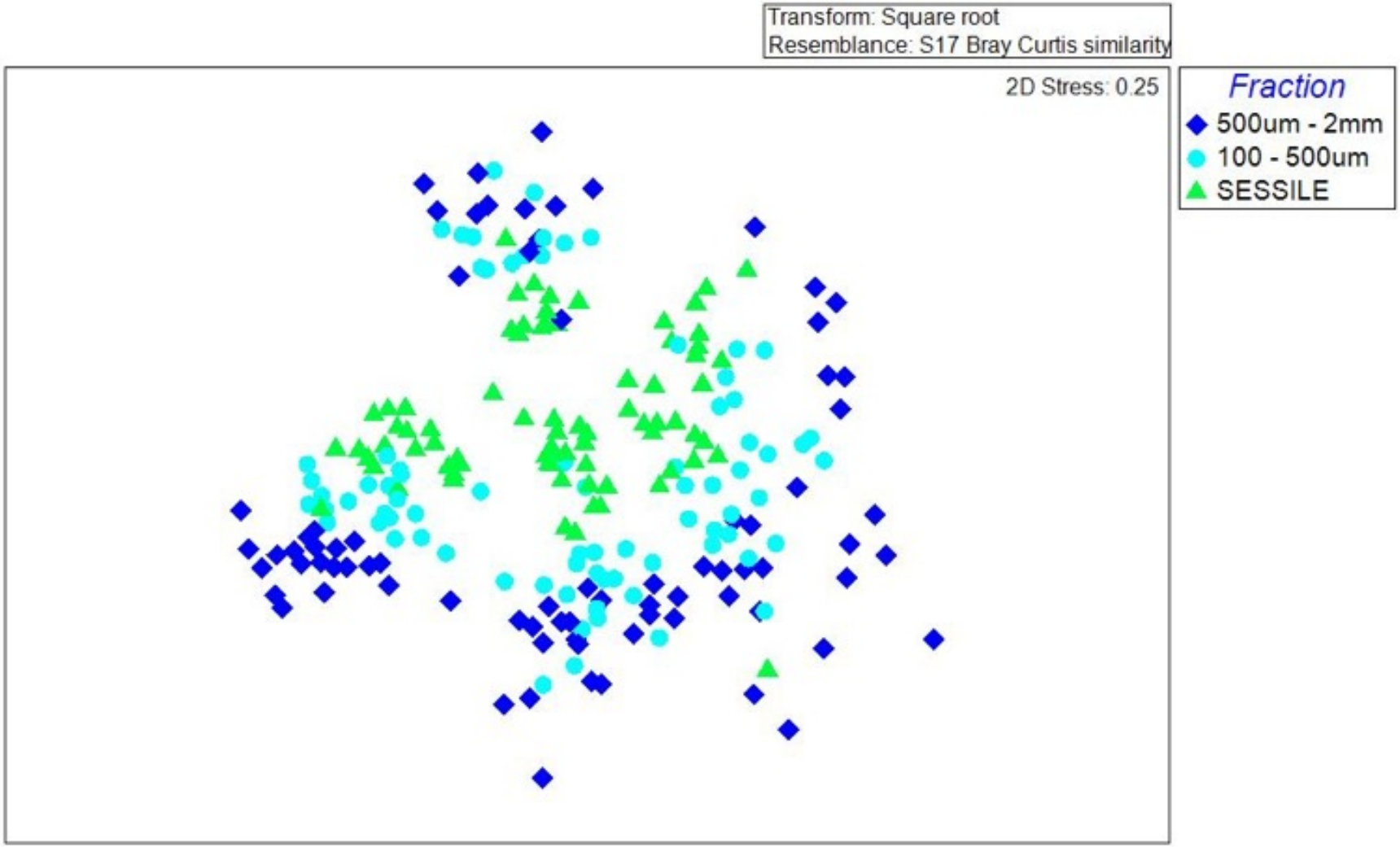
Brachyuran Crab Diversity





Kerry Reardon, Timmers, Oliver, Godwin, Paulay (ICRS 2016)

Preliminary Results from ARMS



Emma Ransome, Meyer, Knowlton, Rohwer, Barber, Timmers, Brainard (ICRS 2016)

Nancy Knowlton et al. (ICRS Plenary 2016)

Rusty Brainard et al. (ICRS 2016)

Costs of Monitoring Biodiversity

Estimated Total Cost Per Year for NCRMP ARMS	Supplies + Lab Work (people)	Supplies + Lab Work + Metabarcoding	Supplies + Lab Work + Metabarcoding + Field + 2 mm work
Hawaiian Archipelago (48 ARMS, 4 islands)	$47,000	$64,000	$143,000
Marianas Archipelago & Wake (45/4)	$50,000	$67,000	$146,000
Am Samoa & Pacific Remote Islands (54/5)	$44,000	$62,000	$141,000

Significant leverage from NOAA – OMAO, NOAA Ocean Acidification Program, NMFS S&T, Smithsonian Institution, Univ of Florida, San Diego State, UCLA, University of Hawaii (HIMB & JIMAR)

Management Applications

- Assessing effectiveness of management actions toward conserving biodiversity and ecosystem health.
- Early warning of changes in community composition, phase shifts, and potential loss of functional diversity and resilience.
  - Fishing impacts
  - Land-based pollution impacts
  - Climate change and ocean acidification impacts
- Early warning of alien or invasive species

Conclusions

- Numerous legislative mandates & policies drivers & management goals & objectives require conservation of biodiversity
- Available science shows that biodiversity increases ecological resilience, ecosystem function & biomass production!
- Fish and coral monitoring are important but they only represent <<1% of biodiversity
- Need to commit to monitoring other biodiversity metrics for the other 99% of biodiversity
- ARMS provide a cost-effective and robust tool for monitoring indices of biodiversity needed to assess effectiveness of management.

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