Introducing Mangroves as a Climate Change Adaptation Strategy:

Potential Ecosystem Service Shifts in the Republic of the Marshall Islands (RMI)

Prepared for LIVING ISLANDS, NGO

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(Japan)

(and you thought
Hawaii, USA
was the middle of
nowhere☺)

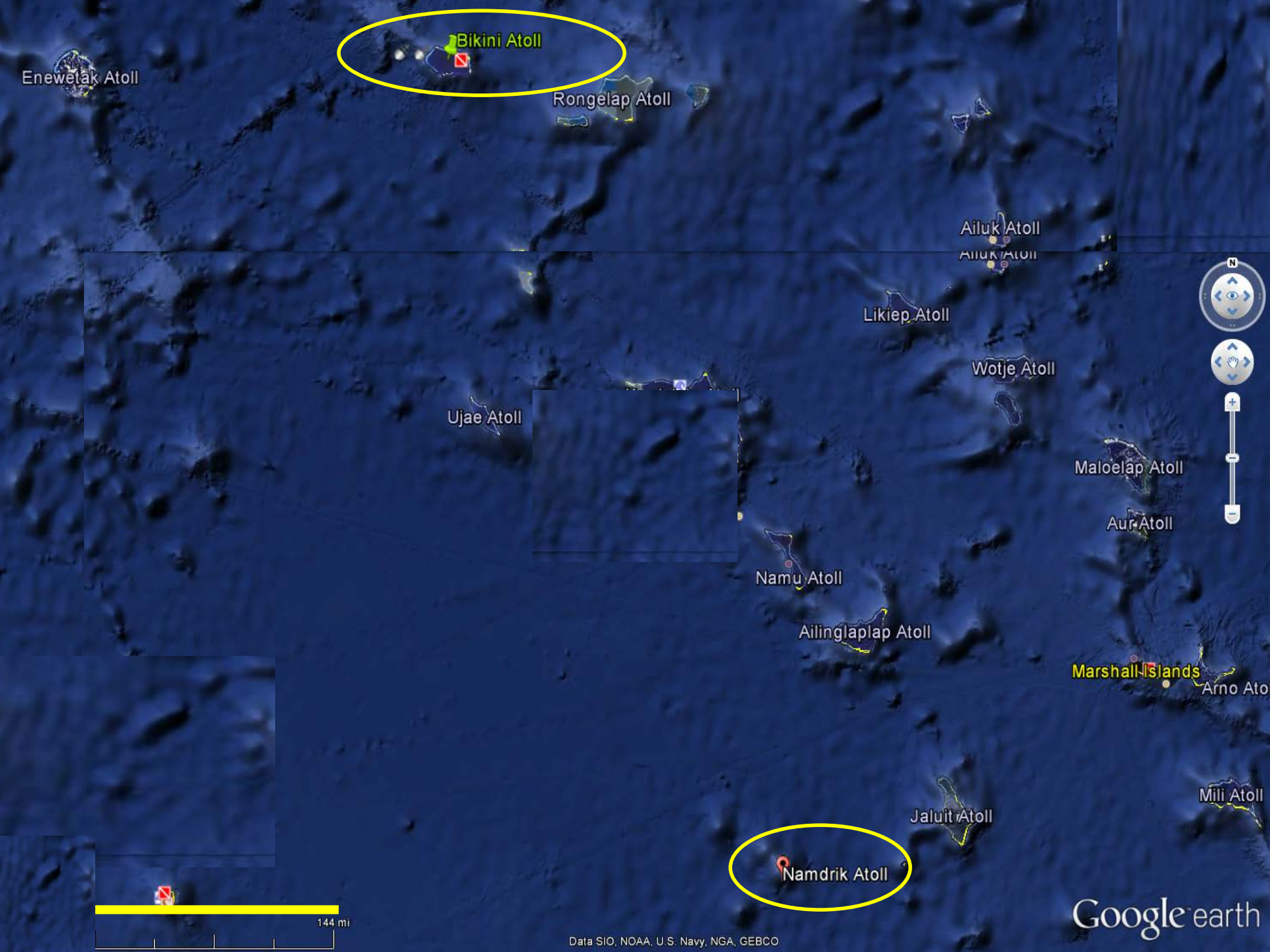
(Marianas Trench)

The Republic of the Marshall Islands

~ 55,00 People on 29 Atolls

(Guadalcanal/
Solomon Islands)

(Coral Triangle)

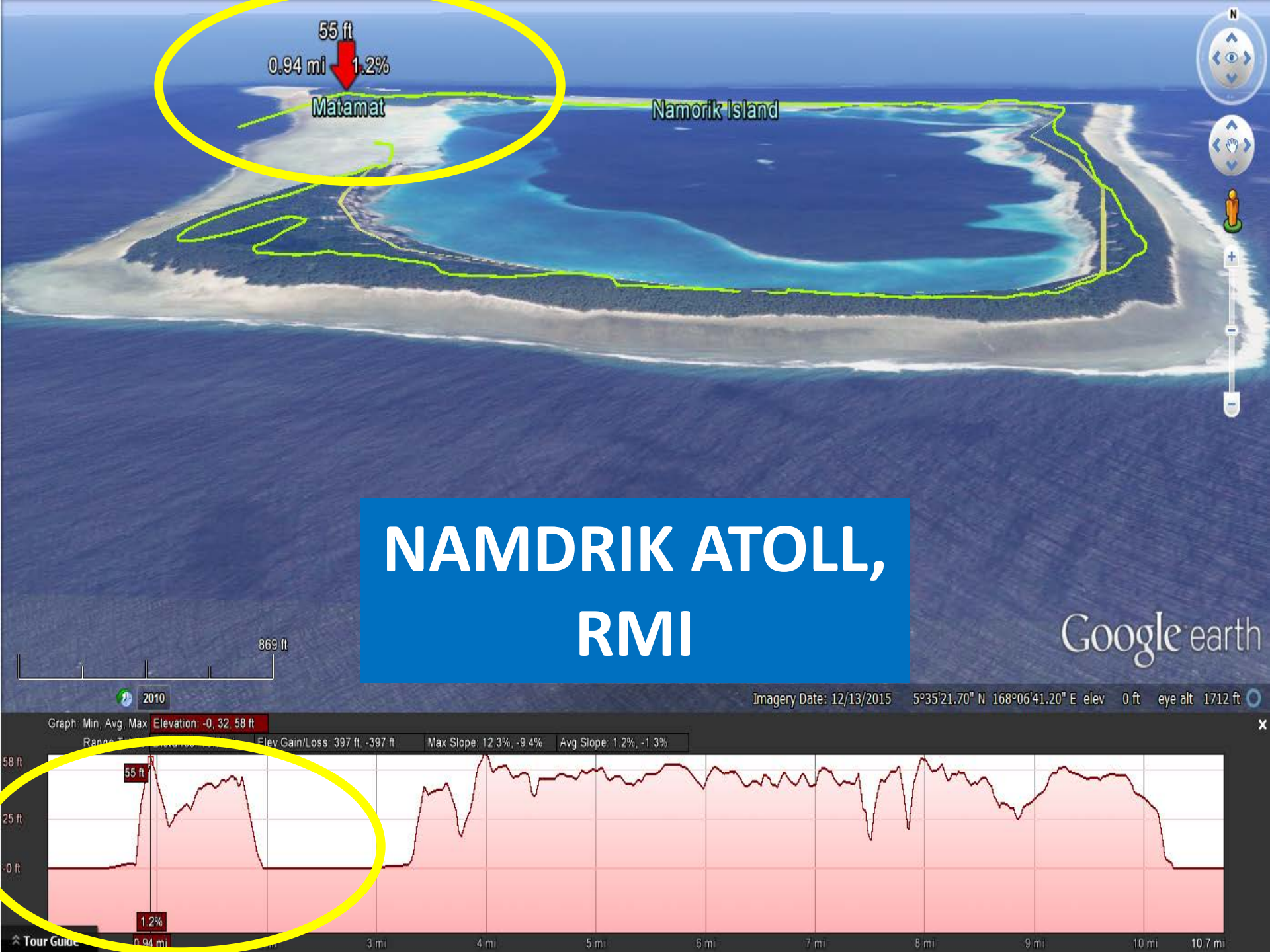

Bikini Atoll
Enewetak Atoll
Rongelap Atoll
Ailuk Atoll
Likiep Atoll
Wotje Atoll
Ujae Atoll
Maloelap Atoll
Aur Atoll
Namu Atoll
Ailinglaplap Atoll
Marshall Islands
Arno Ato
Mili Atoll
Jaluit Atoll
Namdrik Atoll
144 mi
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Google earth

The United States conducted scores of nuclear tests in the Marshall Islands between 1946 and 1958 (AFP Photo/)

The Hague (AFP) - The Marshall Islands Monday painted a vivid picture of the horrors of nuclear war decades after some of its atolls were vaporised in atomic tests, in an unusual legal battle against the nuclear arms race.

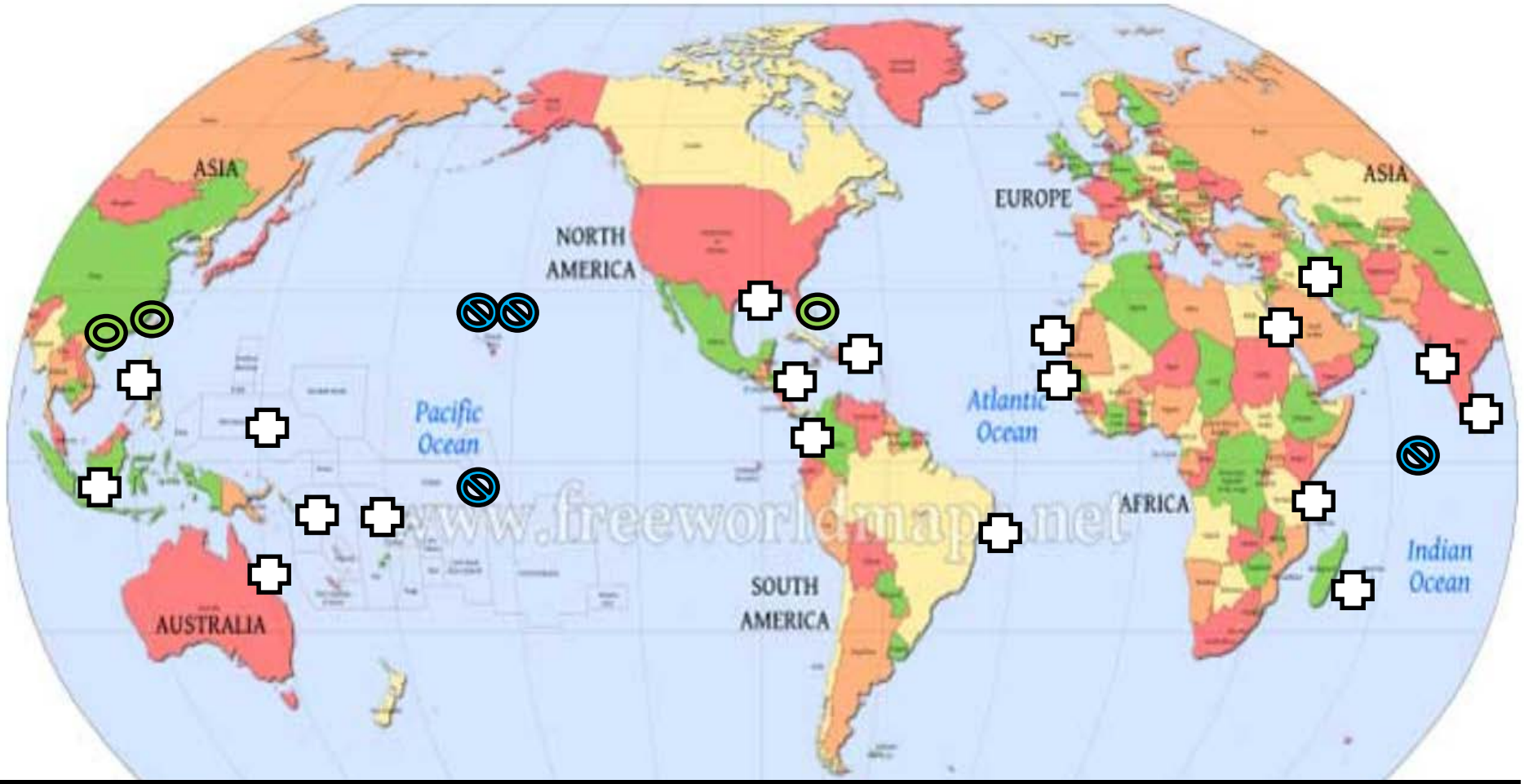
The small Pacific island nation opened a case against India, Pakistan and Britain in a David-versus-Goliath fight before the UN's highest tribunal based in The Hague.

What it Looks Like Now☺


55 ft
0.94 mi
1.2%
Matamat
Namorik Island
NAMDRIK ATOLL, RMI
869 ft
2010
Google earth
Imagery Date: 12/13/2015 5°35'21.70" N 168°06'41.20" E elev 0 ft eye alt 1712 ft
Graph: Min, Avg, Max
Elevation: -0, 32, 58 ft
Elev Gain/Loss: 397 ft, -397 ft
Max Slope: 12.3%, -9.4%
Avg Slope: 1.2%, -1.3%
58 ft
25 ft
-0 ft
55 ft
1.2%
0.94 mi
3 mi
4 mi
5 mi
6 mi
7 mi
8 mi
9 mi
10 mi
10.7 mi
Tour Guide

Monsanto fields on Molokai. The island of Lanai is seen in the background. (Photo by PF Bentley/Civil Beat)

Literature Review (n=99; 35=Non-Native)



Native Mangrove Studies

ESI Non-Native Mangroves (Exotic Species Introductions): Mangroves Historically ***Absent***

SSI Non-Native Mangroves (Similar Species Introductions): Mangroves Historically ***Present***

1) Theoretical Framework: **Historic Community Structure Influences**

- Similar Species Introduction vs. Exotic Species Introduction comparisons examine the historic species composition of recipient ecosystems.

  - **SSI =** Historic mangrove species present
    - Neutral Theory, and Functional Equivalence (Hubbell, 2005)
    - Evidence: *Sonneratia apetala* mangroves in China (Chen *et al.* 2008; Xin *et al.* 2013).
  - **ESI** = No historically present mangrove species
    - Exert stronger influences (Hoopes and Hall, 2002)
    - Stochastic Niche Theory (Tillman, 2004)
    - Evidence: *Rhispohora* and *Bruguiera* ~Space, light, and nutrient availability (Krauss *et al.* 2008)

Historic Mangroves in the RMI

- *Rhizophora apiculata* –Used locally in the RMI for conditioning nets due to it's fungicidal properties, and construction/fuel wood.
- *Bruguiera gymnorrhiza* – Used for rot-resistant house posts, and to treat nets due to fungicidal properties.
- *Lumnitzera littorea* – Strong timber for ***outrigger*** and home construction.
- *Sonneratia alba* – This rot resistant wood is used for constructing ***outriggers*** and for floor timbers in the Marshall Islands
- *Xylocapus moluccensis* – Used in traditional medicines, its bark is boiled to relieve gastric upset, while its hardwood is valued for construction.

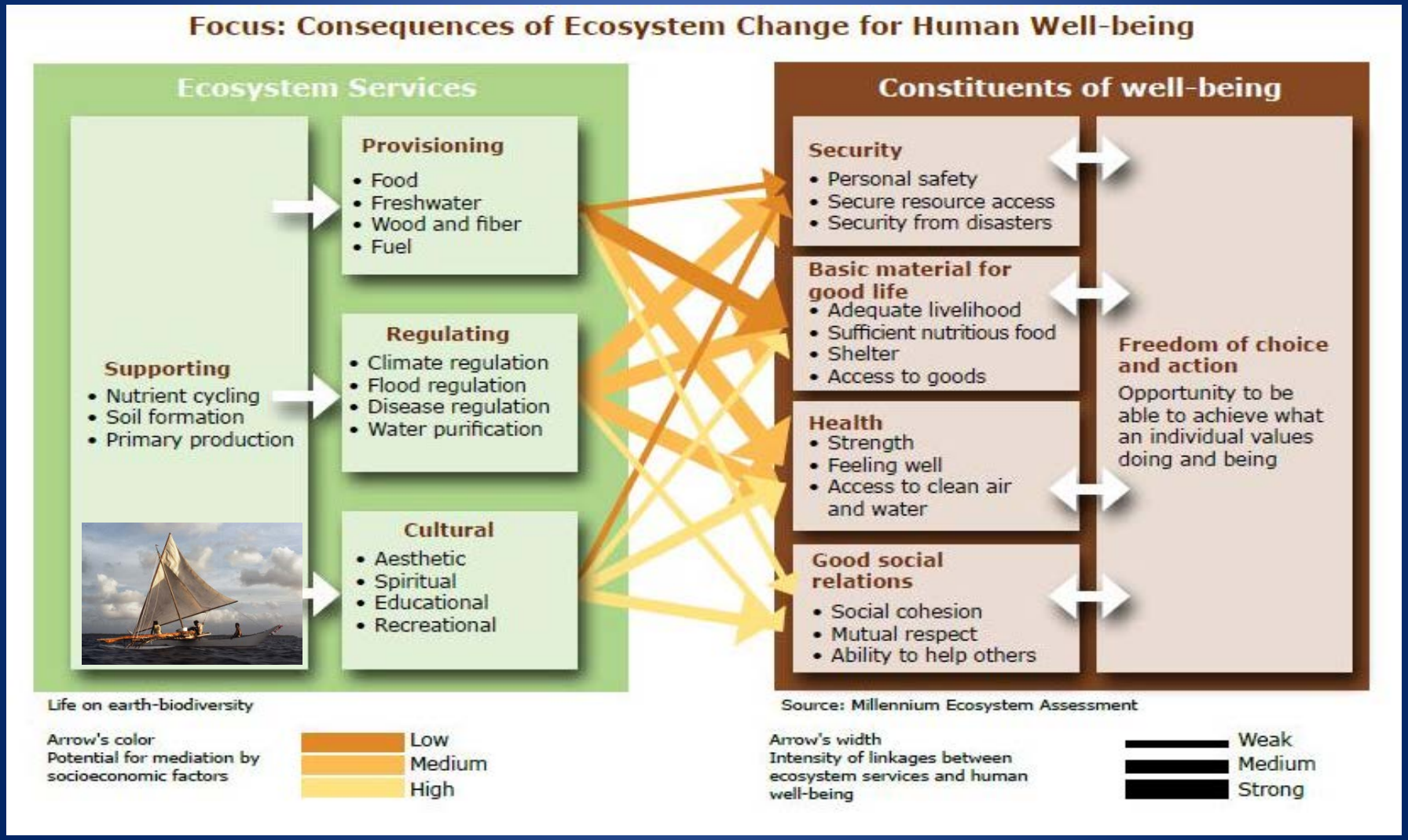
2) Theoretical Framework Contined: **Recipient Community Responses**

- **Niche Conservatism (NC)**: Lack of local adaptation
  - Evidence: Birds, mammals and butterflies (Peterson *et al.* 1999),
- **Niche Evolution (NE):** Local adaptation increases novel resource utilization
  - Evidence: Southwestern willow flycatchers and tamarisk (Davis *et al.* 2011), and hawthorn flies and apple trees (Feder *et al.* 1994)

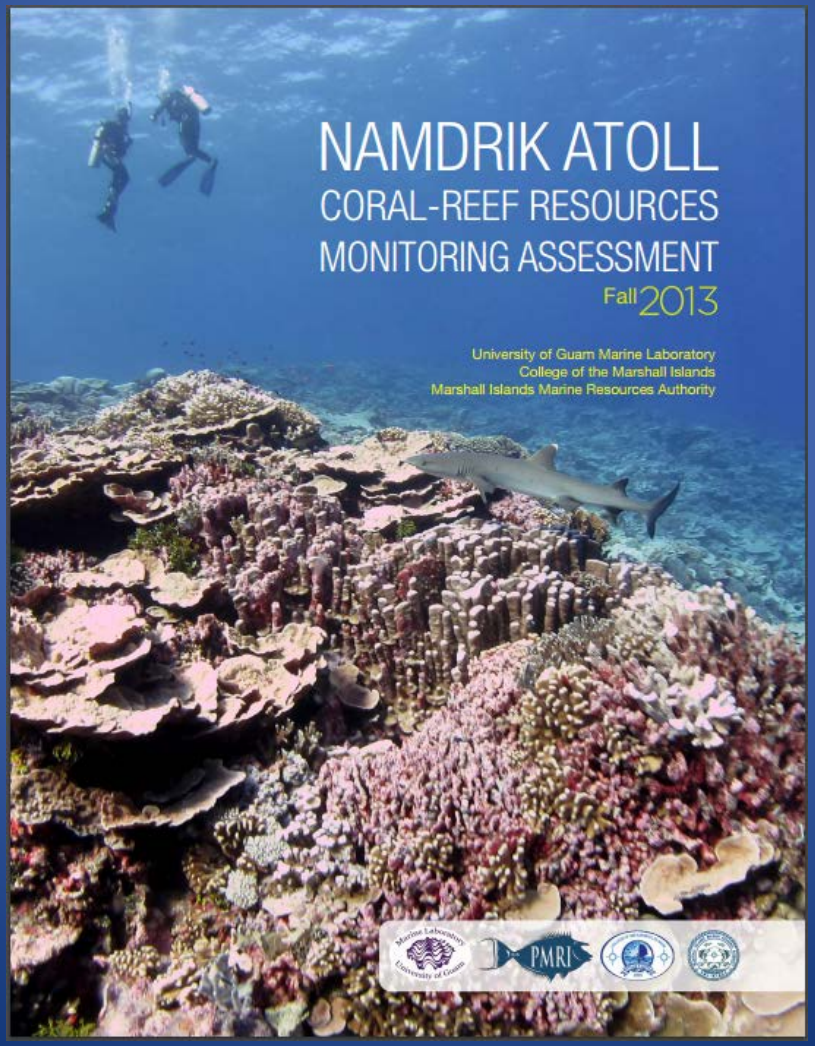
- **Facilitation:** Non-natives provide resources which increase fitness of other non-natives (NC?) or native species (NC?/NE?)
  - Evidence: Non-native barnacles, sponges, and crustaceans (Demopoulos *et al.* 2007), Native hoary bats (Frasher *et al.* 2007)

- **Enemy Release:** Increase fitness of non-natives themselves because of a lack of co-evolved predators helps explain range expansion
  - Propagule predation (Steele et al. 1999)
  - Fungal pathogens (Volkmann-Kohlmeyer and Kohlmeyer, 1993)
  - Non-natives may facilitate the colonization of these predators

- **Millennium Ecosystem Assessment Categories**
  - Values differ among communities (Warren-Rhodes *et al.* 2011; Pernetta *et al.* 2013)
  - Values are not temporally static (McNally *et al.* 2011)



,2Peter Houk, 1 David Benavente, 1 Matthew McLean, 1 Rodney Camacho, 4 Jessie Capelle, 4 Melvin Silk, 4 Melba White, 3 Dean Jacobson, 3 Don Hess *1 University of Guam Marine Laboratory, UOG Station, Mangilao, Guam. 96923; 2 Pacific Marine Resources Institute, Saipan, MP. 96950; 3 College of the Marshall Islands, Majuro, RMI. 96960; 4 Marshall Islands Marine Resources Authority, Majuro, RMI. 96960



Provisioning Services

- **Fisheries**:
  - Native Mangroves:
    - Nursery ground uncertainties in the Carribean vs. Indo-Pacific (Mumby *et al.* 2004; Dorenbosch *et al*. 2004)
    - Fish and shrimp in the Philippines (Ronnback *et al.* 1999).
  - ESI Non-Native Mangroves:
    - Oyster Fishery (Langer and Lipps, 2006)
    - Tidepool assemblages (MacKinzey and Kryss, 2013)
    - Samoan crabs (Nakahara, 2007; Demopoulos *et al.* 2007)
      - Theoretically: Mangrove overgrowth of historic fishponds will exclude native fisheries species such as mullet
      - Effects will be less pronounced under niche evolution
  - ESI Non-Native Mangroves
    - Knowledge Gap
    - Potential increases in historically provisioned species
      - Theoretically: Niche evolution less important in SSI systems than ESI.

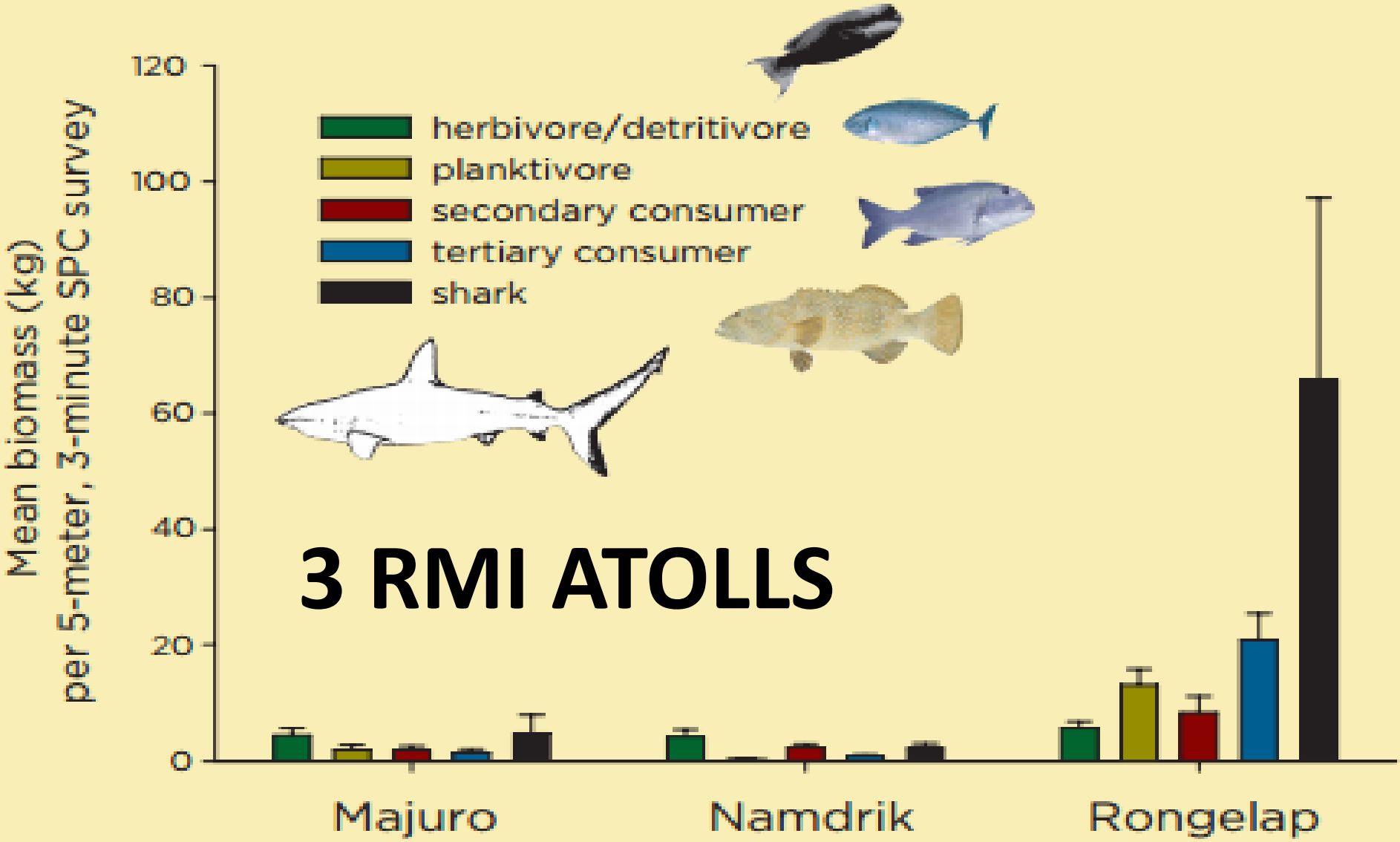


Figure 7. Fish biomass averaged across a suite of representative sites from Majuro, Namdrik, and Rongelap for comparison purposes.

Provisioning Services Continued

- **Directly provisioned services:**
  - Native Mangrove Systems
    - Wood for fuel and construction (Conchedda *et al.* 2011)
    - Resources for dyes, medicines and handicrafts (Everard *et al.* 2014; Walters *et al.* 2008)
  - ESI Non-Native Mangrove Systems
    - Minimal use as native species already satisfy these services
    - Exceptions: *Bruguiera* flowers (Krauss and Allen, 2003), some wood use (Dibbons-Young Per. Comm.)
      - Theoretically: Humans may shift behaviors to utilize mangroves in line with Niche Evolution, but overgrowth of native habitats may decrease native ES provisioning
      - Emerging threats, such as termites, may increase EESI mangroves value
  - SSI Non-Native Mangrove Systems
    - Historical uses of native species may lead to increase utilization of non-native species over EESI scenarios
      - Theoretically: Non-native mangroves will increase ES provisioning in SSI habitats as social and cultural practices may already value similar species.

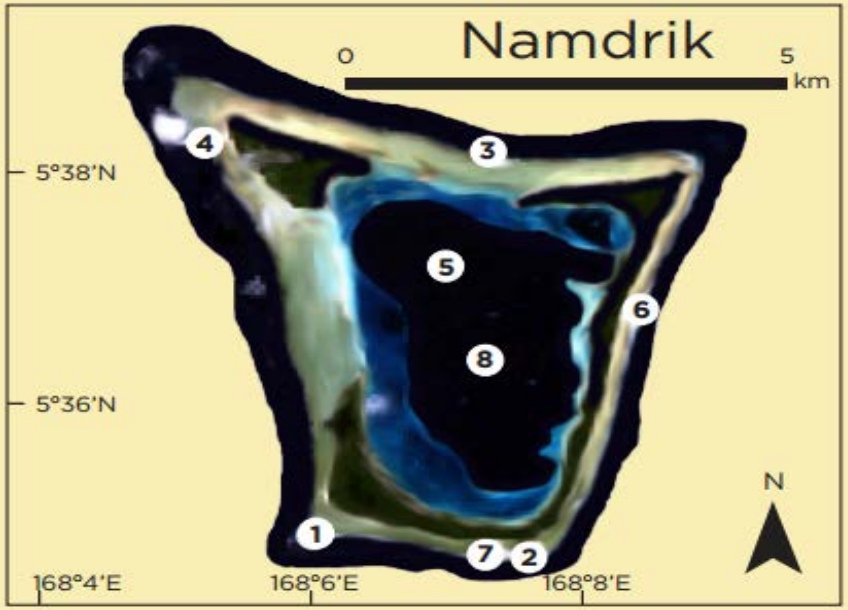
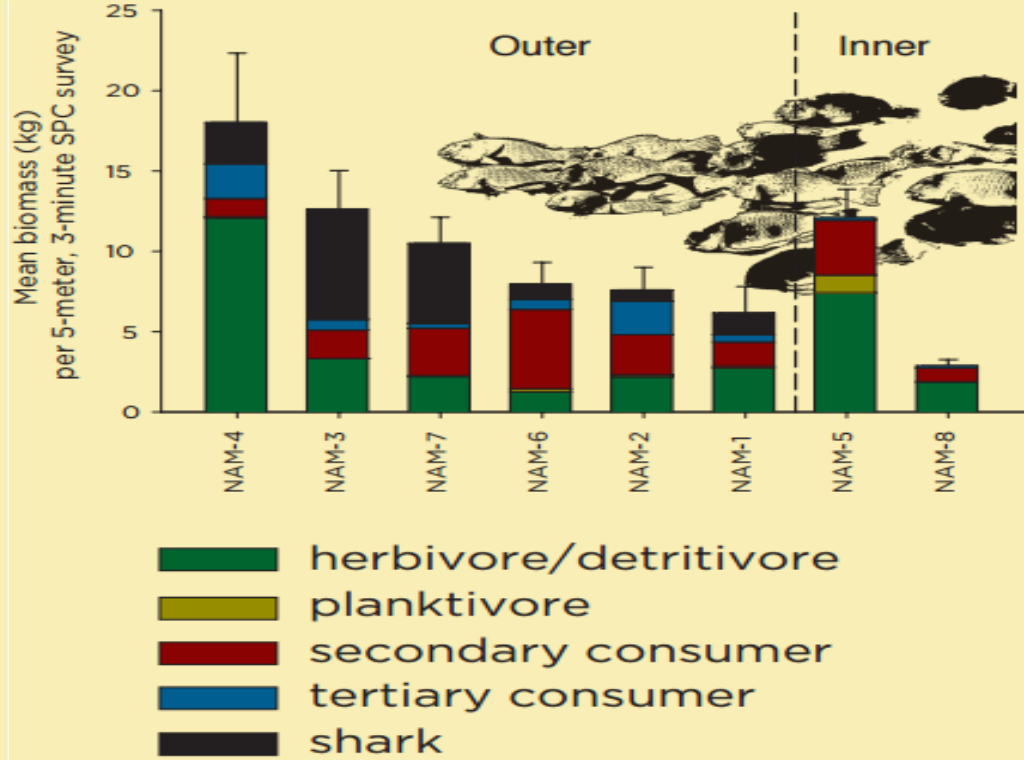
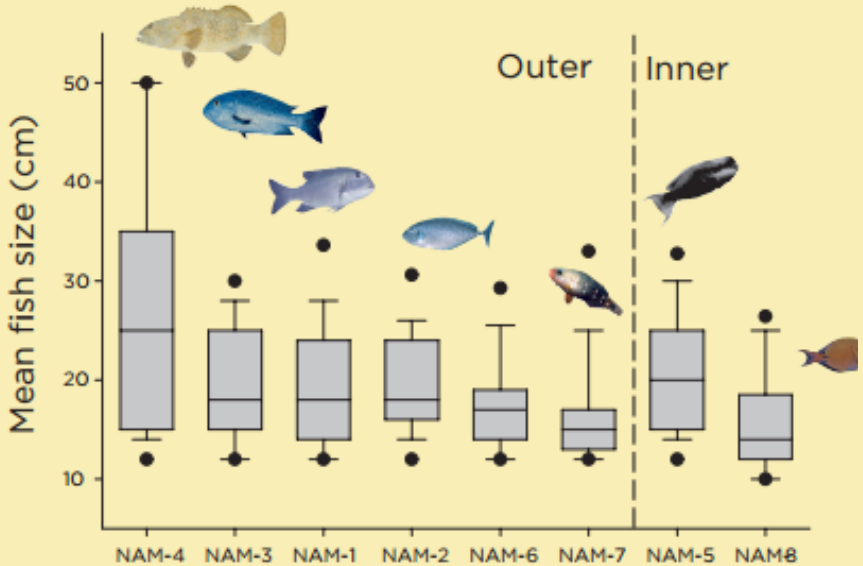


Figure 12. A map of the Marshall Islands and Namdrik highlighting the sites where marine resource assessments were conducted.





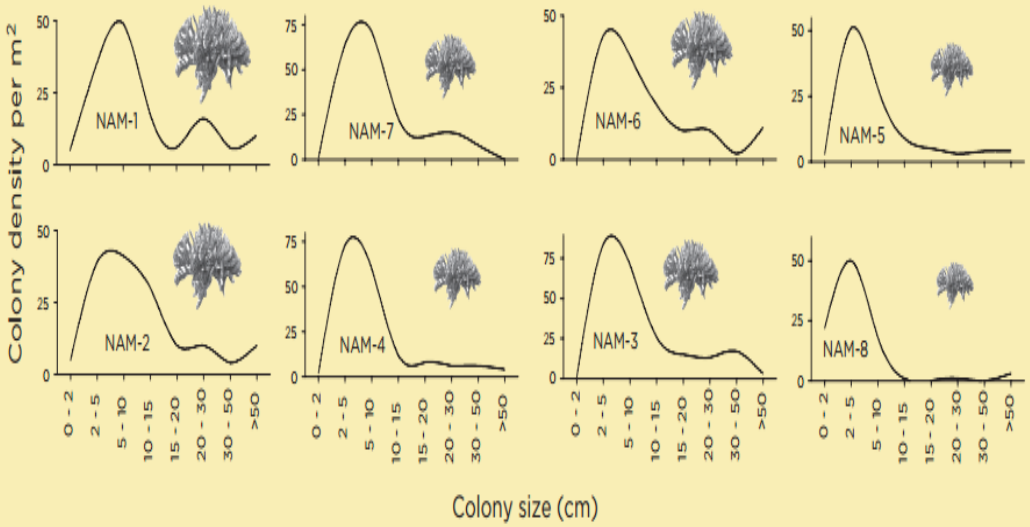
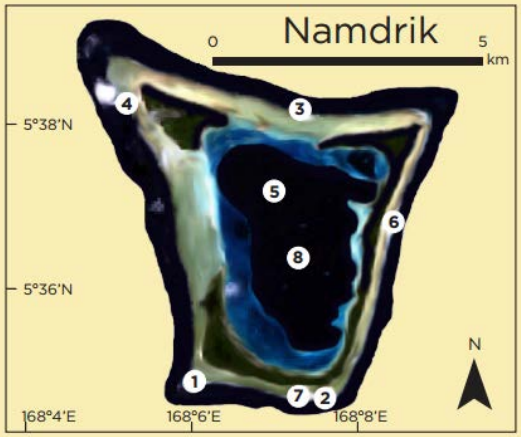


Figure 15. Coral colony-size distribution across Namdrik survey sites.

Percent Coral Cover



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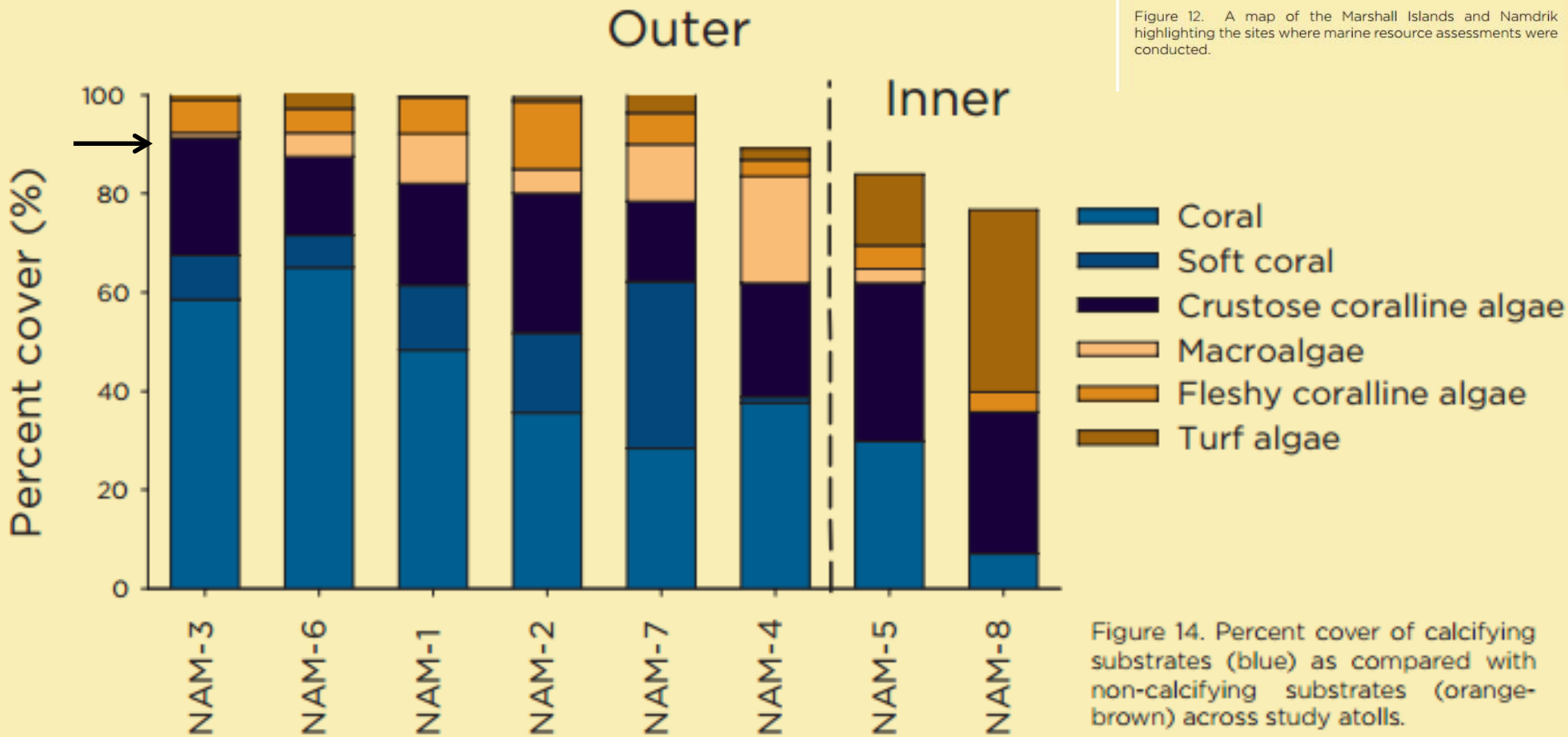
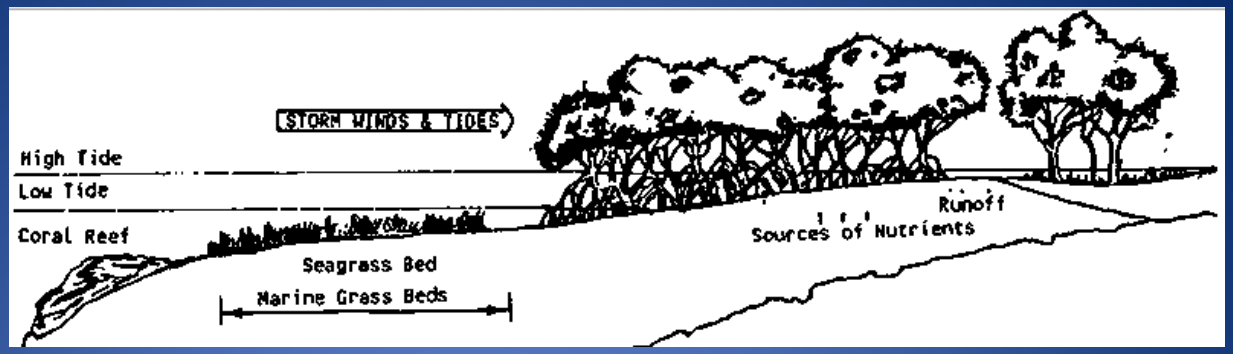


Figure 14. Percent cover of calcifying substrates (blue) as compared with non-calcifying substrates (orange-brown) across study atolls.

Regulating Ecosystem Services

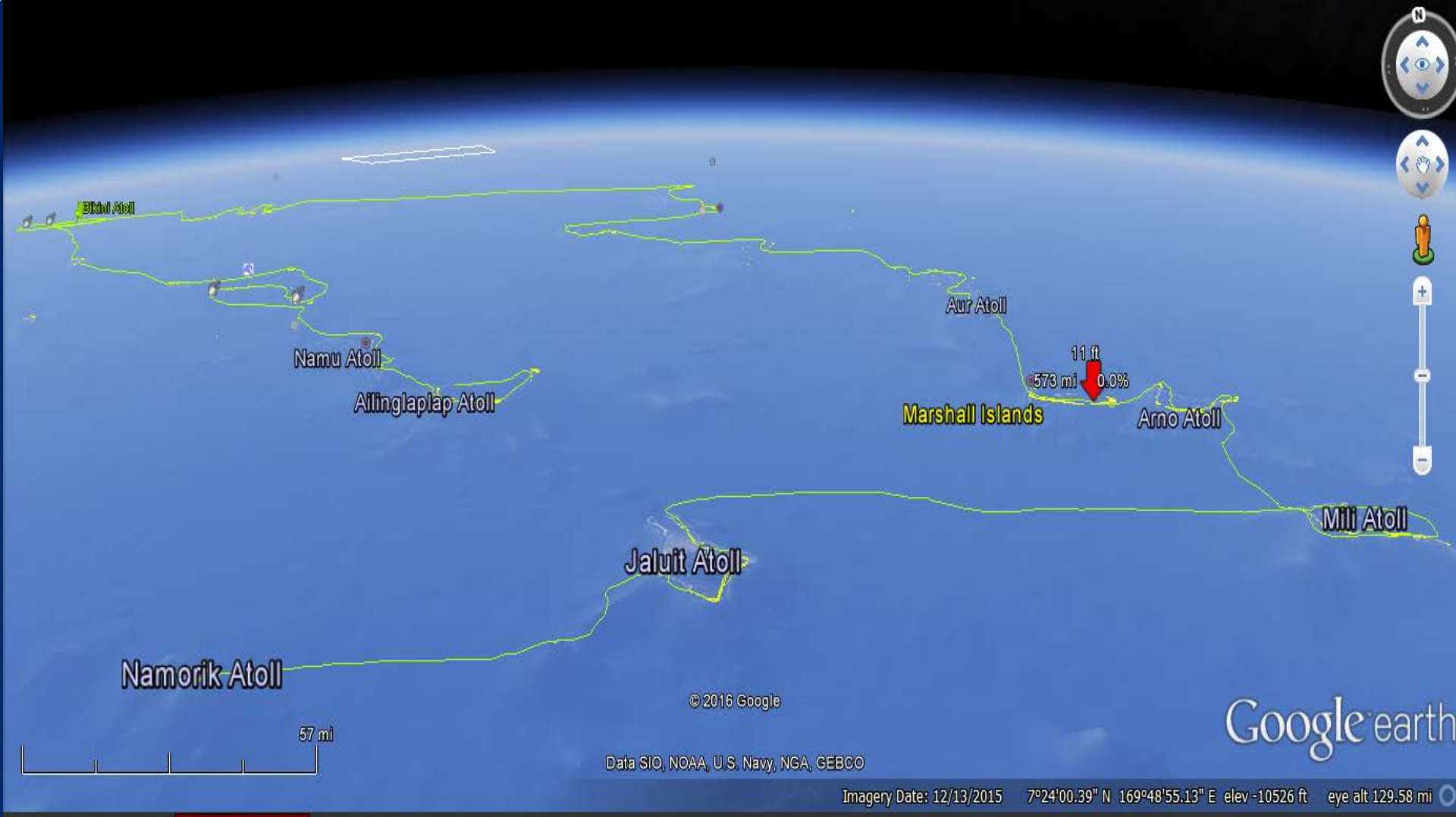


- **Coastal Protection:**

Non-linear protection: 60% dissipation in first 20m (Koch *et al.* 2009; Gedan *et al.* 2010)

- Native Mangrove Systems
  - 2004 Indian Ocean Tusnami (Danielsen *et al.* 2005)
  - 2006 Cyclone Larry in Australia (Bell and Lovelock, 2013)
- ESI Non-Native Systems
  - Lack of historic shoreline vegetation (Allen, 1998)
    - Theoretically largest increases in ES provisioning
    - However mangroves may also promote coastal flooding (Allen, 1998)
- SSI Non-Native Systems
  - Reforestation increases coastal protection
    - Theoretically: Protect property and human lives along urbanizing coastlines

Coast to Mt. Hood Profile



Graph: Min, Avg, Max Elevation: -5, -2, 11 ft

Range Totals: Distance: 2215 mi | Elev Gain/Loss: 47 ft, -42.5 ft | Max Slope: 0.0%, -0.0% | Avg Slope: 0.0%, -0.0%

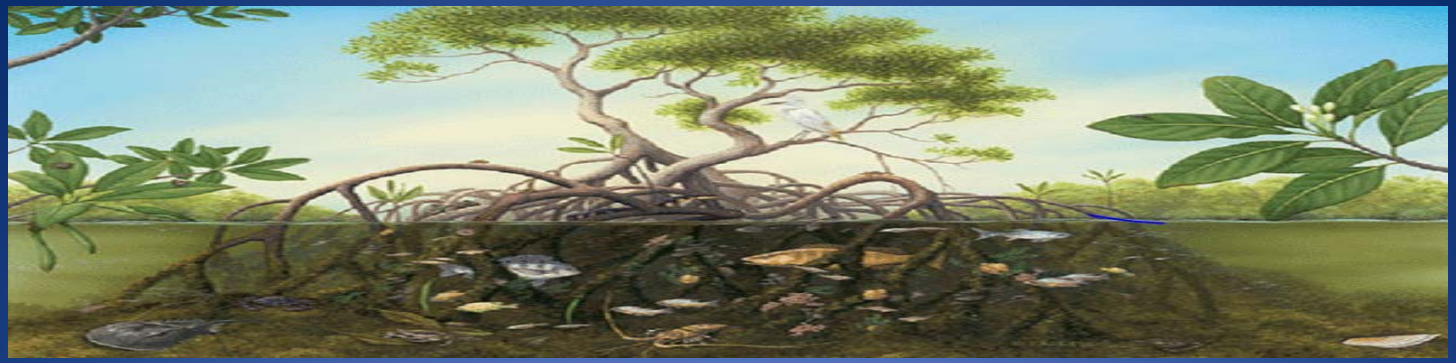
Regulating Services Continued

- **Carbon Sequestration**
  - Native Mangrove Systems
    - Extremely high carbon storage rates
      - Vertical sediment accretion (McLeod *et al.* 2011)
      - 5x greater carbon storage than shrimp ponds in the Dominican Republic (Kauffman *et al.* 2014)
    - High carbon emissions following deforestation
      - <1% of tropical forest area, but >10% tropical forest emissions (Lau, 2013; Escobedo *et al.* 2010)
    - Spatially and temporally variable
  - ESI Non-Native Systems
    - Rapidly expanding EESI forests increase younger age classes (Livesley and Andrusiak, 2011)
    - Dependent on local geomorphology, hydrology, and climate (Livesley and Andrusiak, 2011)
      - Theoretically: Increased carbon storage due to decreased detritivore processing of mangrove material
      - Rapid range expansion increases both above and below ground C pools
  - SSI Non-Native Systems
    - Interspersed SSI mangroves do not increase carbon storage over native stands (Lu *et al.* 2014)
      - Theoretically: Reforestation increases accretion and both above and below ground carbon storage in cleared areas

Regulating Services Continued

- **Bioremediation**
  - Native Mangrove Systems
    - Process excess nutrients (Genthner *et al.* 2013)
    - Break down PAH under anoxic conditions (Santos *et al.* 2010; Andrade *et al.* 2012)
    - Tolerate and utilize high levels of ammonium (Krauss *et al.* 2008)
      - 22ha can process all nutrients from 1ha of intensive shrimp farming (Walters *et al.* 2008)
      - ~2-5 acres of mangroves can process nitrates from 1 acre of shrimp ponds (Primavera, 2008)
    - Increased microbial activity processes human waste (Yang *et al.* 2008; Bouchez *et al.* 2013).
  - ESI Non-Native Systems
    - 2x growth rate in nutrient rich areas (Fry and Cormier, 2011)
    - However microbial processing may be inhibited in ESI non-native soils (Demopoulos and Smith, 2010)
      - Theoretically: Uptake and sequestration of coastal nutrients from run-off and aquaculture may add resilience to coastal ecosystems suffering from eutrophication.
      - Niche evolution would increase ES provisioning as detritivores adapt to process tannin rich material.
  - SESI Non-Native Systems
      - Theoretically: SSI mangrove soils will be colonized by detritivores from adjacent native mangrove habitats and increase coastal bioremediation on par with native mangrove forests.

Supporting Ecosystem Services



Biodiversity

- Native Mangrove Systems
  - Marine: High abundance and diversity of fish, gastropods, nematodes, and crustaceans (Nagelkerken *et al.* 2008)
  - Terrestrially: Birds, mammals, insects, fungus (Nagelkerken *et al.* 2008; Volmann-Kohlmeyer and Kohlmeyer, 1993)
  - Zooplankton diversity was 50% greater in intact mangrove vs. cleared areas in Panama (Granek and Frasier, 2007).
  - Few obligatory relationships (Mumby *et al*. 2004)
- ESI Non-Native Mangrove Systems
  - Higher abundance and diversity of sediment macrofauna in mangrove vs. sandflat systems (Demopoulos and Smith, 2010; Nakahara, 2007)
  - Higher abundance and diversity of non-native species (barnacle, sponges, etc.)
    - Theoretically: This may support the hypothesis of niche evolution
      - » Also supports the hypothesis of non-native facilitation
      - » May increase Supporting ES as more diverse ecosystems may be more resilient to emerging threats
  - Reduced native shorebird abundance
    - Theoretically: Supports niche conservatism for many native bird species
- SSI Non-Native Mangrove Systems
  - Increased abundances of deposit and filter feeders following introductions in Futian, China (Leung and Tam, 2013)
  - Of 34 non-native species identified in bays in Southern China, only 1 species, the mangrove *Sonneratia apetala,* was found in native mangrove forests (Ren *et al.* 2014)
  - This provides support for niche conservatism for plants in these environments.
    - Theoretically: SSI mangrove systems are more resistant to shifts in local biodiversity
      - » Also more resistant to invasion and non-native facilitation

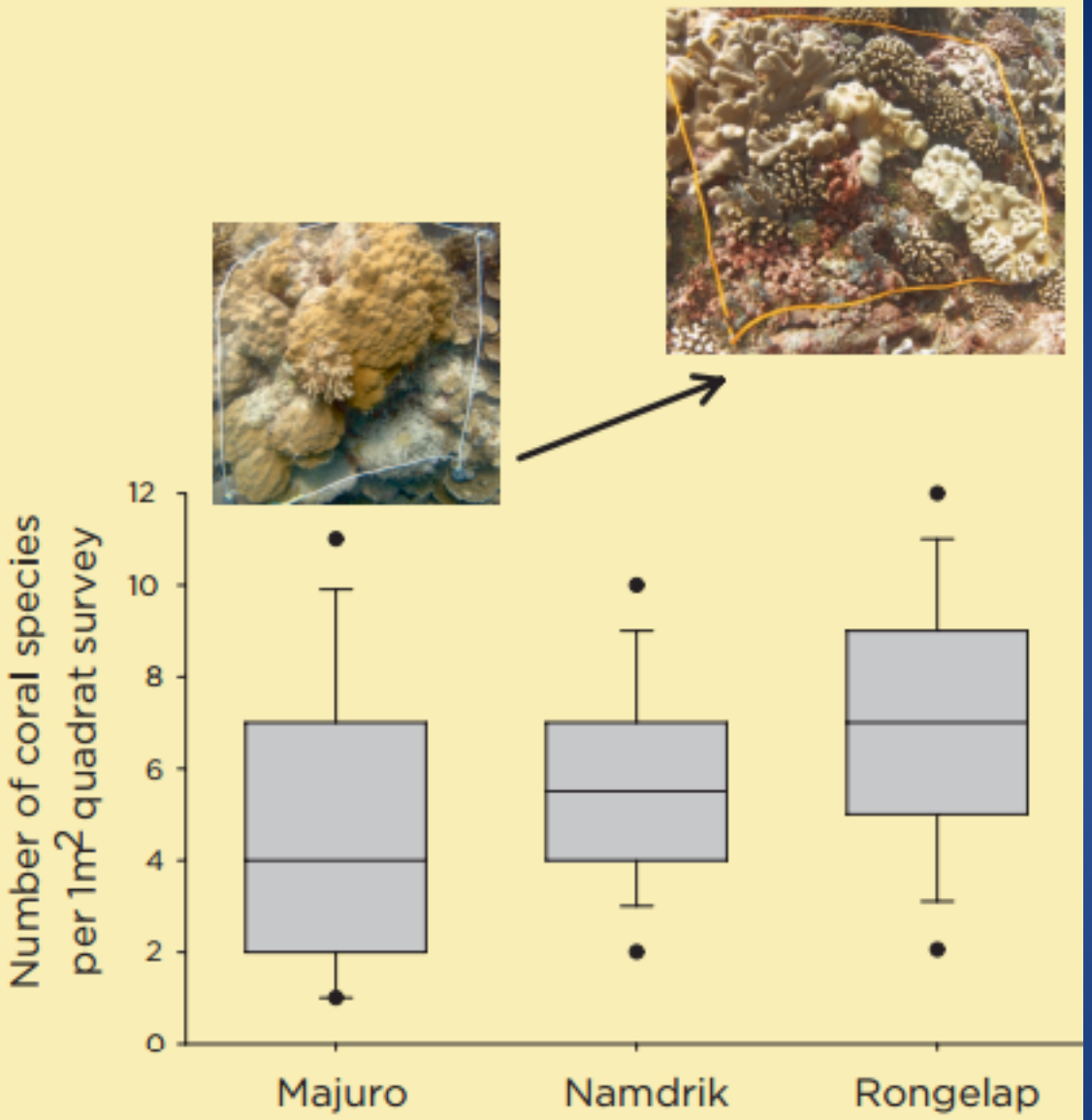


Figure 11. Coral diversity across the study atolls. Thin black lines represents the median, boxes indicate the 25th (lower) and 75th (upper) percentiles, error bars indicate the 5th and 95th percentiles, and dots indicate magnitude of outliers.

Supporting Services Continued

Other Supporting Services

- Native Mangrove Systems
  - Detritivore processing of mangrove nutrients promotes benthic-pelagic coupling (Lenihana and Micheli in Bertness *et al.* 2001)
  - Aeration of sediments by burrows detoxifies hydrogen and metal sulfides (Lenihana and Micheli in Bertness *et al.* 2001)
- ESI Non-Native Mangrove Systems
  - Reduced food web complexity utilization of mangrove derived nutrients in ESI systems vs. native mangrove systems (Demopoulos *et al.* 2007)
    - Theoretically: Reduces benthic-pelagic coupling in ESI systems
- SSI Non-Native Mangrove Systems
  - Increased abundances of deposit and filter feeders following mangrove introductions in Futian, China (Leung and Tam, 2013)
    - Theoretically: Leading to increased nutrient processing due to higher litterfall and lower C/N ratios of introduced *Sonneratia*

How About Hawaii for a Honeymoon?

Ummm…
Honey….
:/

I Wansn’t
Thinking
Swamp????

Cultural Ecosystem Services

- **Spiritual**
  - Native Mangrove Systems
    - Java creation legend (Walters *et al.* 2008)
    - Solomon Islands *kastom* art (Warren-Rhodes *et al.* 2011)
      - Theoretically: Increased awareness of the ES benefits of mangroves should strengthen spiritual bonds of locals to mangroves and mangrove ecosystems
  - ESI Non-Native Mangrove Systems
    - Overgrowth of archeological and spiritual sites (Farber, 1997; Fronda *et al.* 2008)
    - Decrease sense of place (Alula Bay Community Outreach)
      - Theoretically: Continued decline in native spirituality associated with historic coastlines as mangroves spread
  - SSI Non-Native Mangrove Systems
    - Spiritual significance already established
    - Promotion of more historic landscapes
      - Theoretically: Minimal impact to native spirituality

- **Recreation and Ecotourism**
  - Native Mangrove Systems
    - Tourism in Hara Biosphere Reserve in Iran (Dehghani *et al.* 2010)
    - Tourism in Red Sea in Egypt (Hergazy *et al.* 2002)
    - Boardwalks in Tanbi Wetland National Park in Gambia (Satyanarayana *et al.* 2012)
      - Theoretically: Increasing awareness of the ES benefits of mangroves should increase recreation and ecotourism in mangrove ecosystems
  - ESI Non-Native Mangrove Systems
    - Decreased beach access (Farber, 1997)
    - Noxious odors and mosquitos deter recreation (Allen, 1998)
    - Overgrowth of tide pools decreases ecotourism (Ex: snorkelers at Wai O'Pae)
      - Theoretically: Economic declines as historic recreational and ecotourism opportunities decrease
  - SSI Non-Native Mangrove Systems
    - Increased mangrove ecotourism in Dongzhai Harbor Mangrove Nature Reserve, China, following reforestation (Xin *et al.* 2013)
    - Reforestation of abandoned shrimp ponds increases more historically valued landscapes
      - Theoretically: Reforestation projects utilizing non-native mangroves will increase recreation and ecotourism opportunities as more historic ecosystems are restored

Educational Opportunities

- Native Mangrove Systems
  - School trips to the Muthurajawela Wetland in Sri Lanka (Emerton and Kekulandala, 2003)
  - Biosphere 2 Project (Finn, 1996)
  - Post-larval tiger prawn harvest techniques for aquaculture in the Sundarbans of India (Sarkar and Bhattacharya, 2003).
    - Theoretically: Increased educational opportunities as mangrove ES benefits are better understood
- ESI Non-Native Mangrove Systems
  - Non-native mangroves provide natural conditions to test hypotheses relating to ecology, evolution, and biogeography (Sax *et al.* 2005)
  - Increase local understanding of the shifts non-native species can cause in novel locations
    - Theoretically: Invasions provide an educational platform for locals to understand and help protect native ecosystems
- SSI Non-Native Mangrove Systems
  - Hypothesis testing (Chen *et al.* 2008; Lockwood *et al.* 2010; Li *et* al. 2011; Xin *et al.* 2013)
  - Economic education (Ex: mangroves ~ shrimp aquaculture (Ronnback *et al.* 1999; Walters *et al.* 2008; Primavera, 2008)
    - Theoretically: Restoration will increase public awareness, increase the number of locations for educational fieldtrips.

- **Building Social Capital**
  - Native Mangrove Systems
    - Including TEK increases social capital (O'Garra, 2013)
    - Strong social capital increases effective management (Vilardy *et al.* 2011)
      - Theoretically: As communities realize the economic and environmental importance of native mangroves, social capital will increase
  - ESI Non-Native Mangrove Systems
    - Decreases in social capital due to controversial management (Kobsa, 2010)
    - Fishpond restoration increases social capital
      - Theoretically: Increasing in social capital as management efforts and impacts are better understood
  - SSI Non-Native Mangrove Systems
    - Replanting and restoration efforts increase social capital
      - Theoretically: Restoration increases community and stakeholder involvement and fosters cross-cultural dialogue

STRENGTH AND DIRECTION OF ECOSYSTEM SERVICE SHIFTS FOLLOWING MANGROVE INTRODUCTIONS

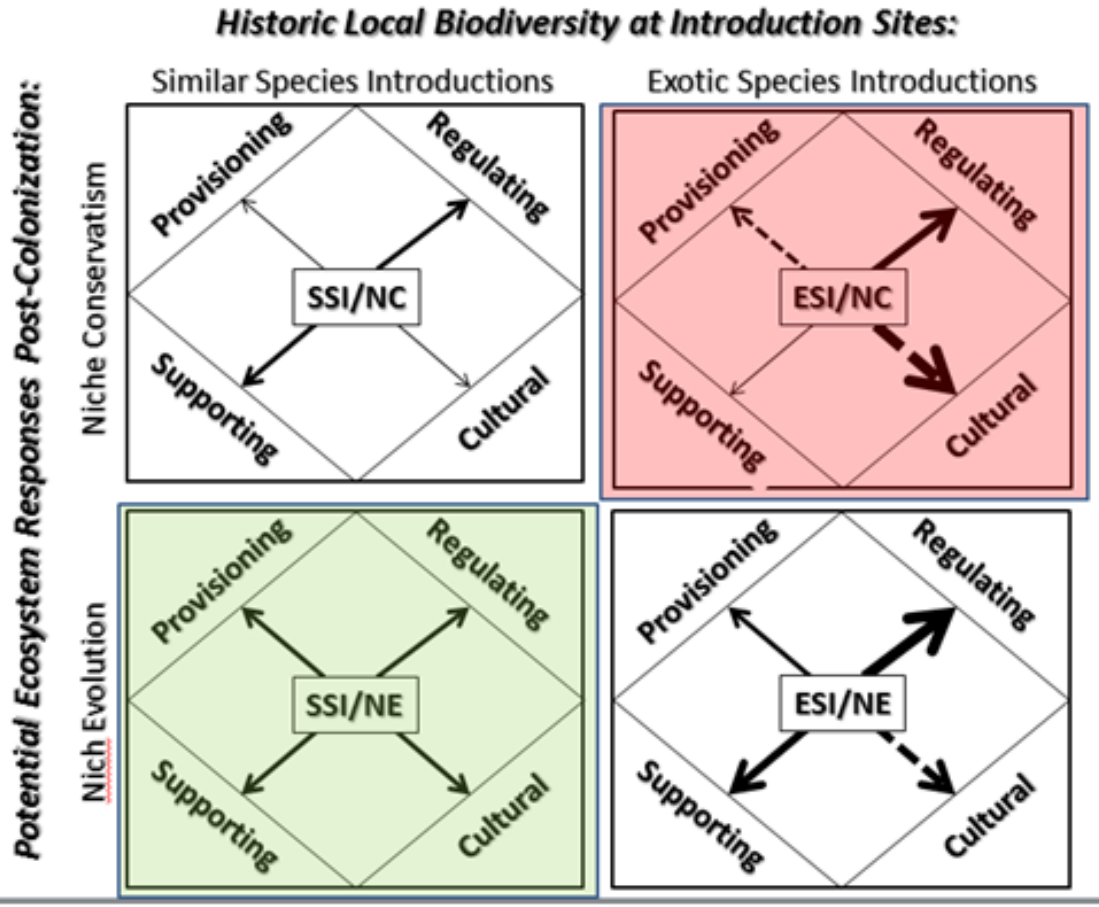


Figure 1. Theoretical increases (solid arrows) and decreases (dashed arrows) in ecosystem service provisioning under four ecological scenarios. SSI scenarios indicate native mangroves are historically present, while in ESI scenarios native mangrove species are historically absent. In niche conservation (NC) scenarios, native species are not able to adapt to novel conditions created by mangroves faster than extinction rates, but in niche evolution (NE) scenarios native species undergo physiological or behavioral changes allowing them to capitalize on newly created mangrove habitats. The weight/thickness of the arrows indicates the theoretical strength (how much) of a change in ecosystem service provisioning. The red shaded box (upper right) shows the greatest potential deterioration in net ecosystem services, under ESI/NE conditions; the green shaded box (lower left), conversely, shows a potential overall increase in all ecosystem service categories, under SSI/NE conditions.

Tiny Marshall Islands Taking On 3 World Nuclear Powers In Court

March 7, 2016 · 2:35 PM ET

MERRIT KENNEDY

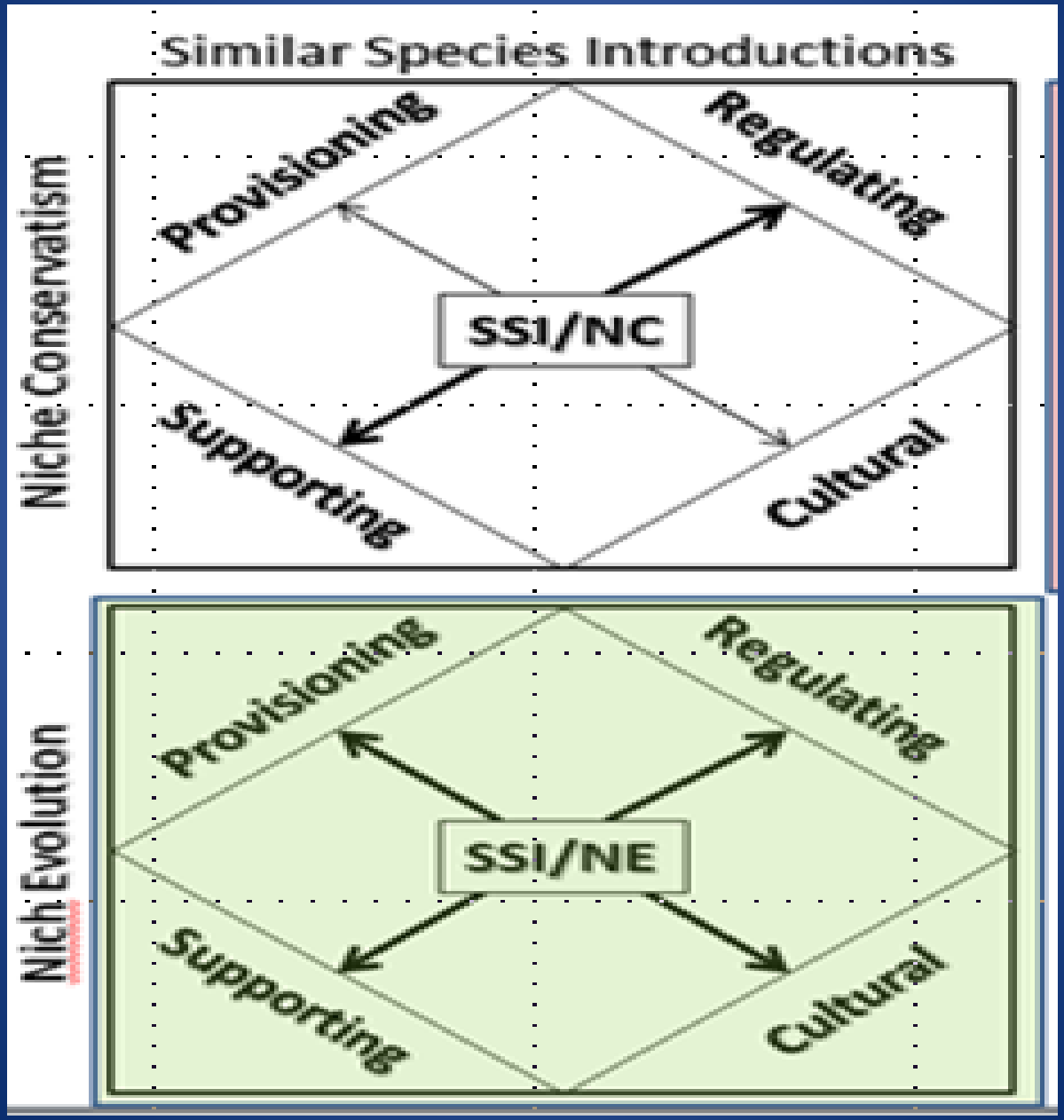
A U.S. nuclear test at Bikini Atoll, Marshall Islands, in July 1946.

Specific Recommendations

It is recommended that only the following 5 species of mangrove that currently inhabit the Marshall Islands be used during mangrove restoration efforts in the RMI (Ellison, 2007 w/UH hyperlink: http://www.hawaii.edu/cpis/MI/):

- *Rhizophora apiculata* –Used locally in the RMI for conditioning nets due to it's fungicidal properties, and construction/fuel wood.
- *Bruguiera gymnorrhiza* – Used for rot-resistant house posts, and to treat nets due to fungicidal properties.
- *Lumnitzera littorea* – Strong timber for outrigger and home construction.
- *Sonneratia alba* – This rot resistant wood is used for constructing canoes and for floor timbers in the Marshall Islands
- *Xylocapus moluccensis* – Used in traditional medicines, its bark is boiled to relieve gastric upset, while its hardwood is valued for construction.

Net Effects for the RMI



Questions?

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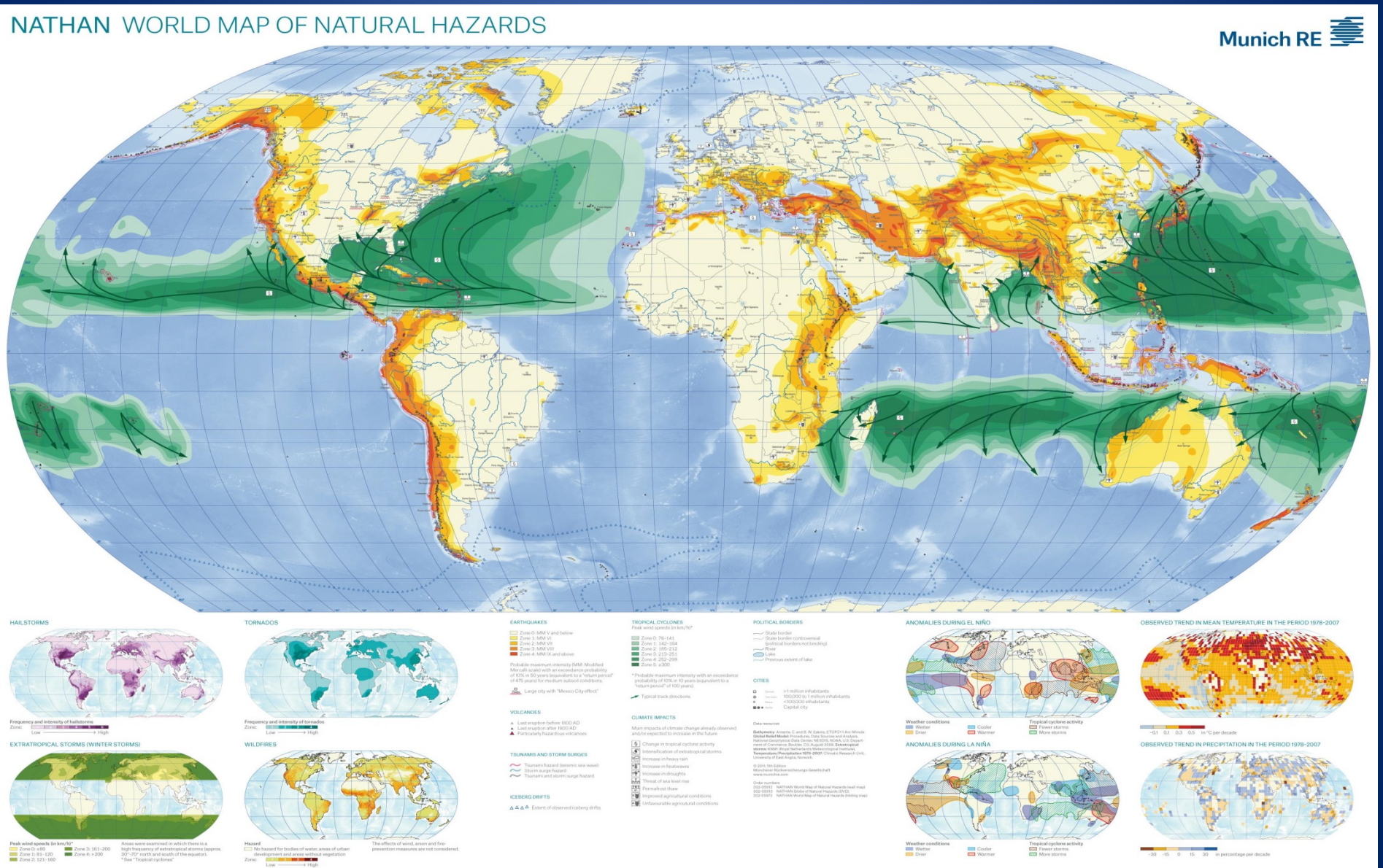
Non-Native Mangrove Ecosystem Services

- Provisioning
  - Fisheries (Langer and Lipps, 2006)
  - Fuel & Construction Wood, Meds & Dyes
- Regulating
  - Coastal Protection (Perry and Berkeley, 2009; Allen, 1998)
  - Bioremediation (Bouchez *et al.* 2013*;* Krauss *et al.* 2008)
  - Carbon Storage
- Supporting
  - Biodiversity/Reforestation (Liu *et al*. 2014)
  - Nutrient Cycling,
- Cultural
  - Spiritual/Customs, Ecotourism/Recreation,
  - Education (Walters *et al*. 2008; Hergazy *et al.* 2002)

2) Overview of Clear Processes for each Category of Services

- Provisioning
  - Fisheries
  - Fuel & Construction Wood, Meds & Dyes
- Regulating
  - Coastal Protection (Danielsen *et al. 2005*; Williams *et al*. 2007)
  - Bioremediation (Bouchez *et al.* 2013*;* Krauss *et al.* 2008)
  - Carbon Storage
- Supporting
  - Biodiversity (Nagelkerken *et al.* 2008)
  - Nutrient Cycling,
- Cultural
  - Spiritual/Customs,
  - Ecotourism/Recreation,
  - Education (Walters *et al*. 2008; Hergazy *et al.* 2002)
  - Social Capital

Regulating Ecosystem Services

- Coastal Protection