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Supplementary information

The value of US coral reefs for flood risk reduction

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Supplementary Information

Coral reefs reduce flood damage in the U.S.

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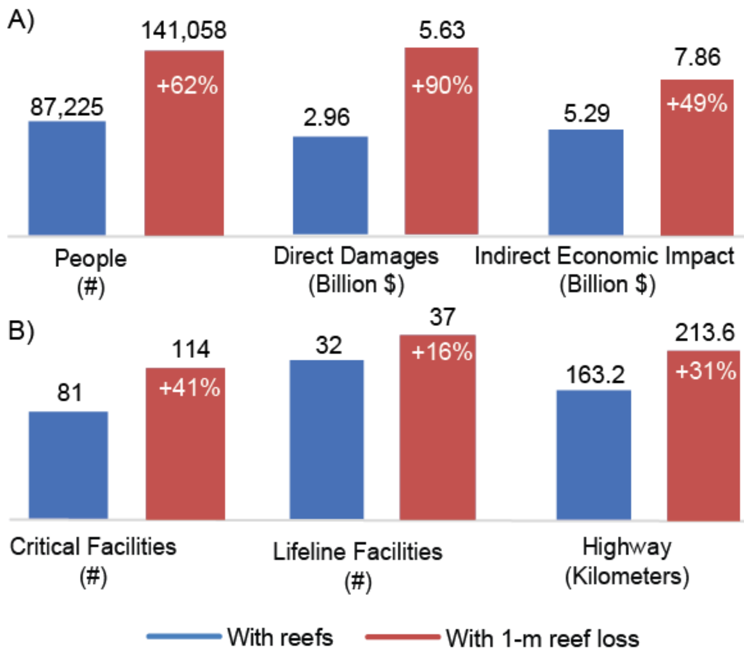
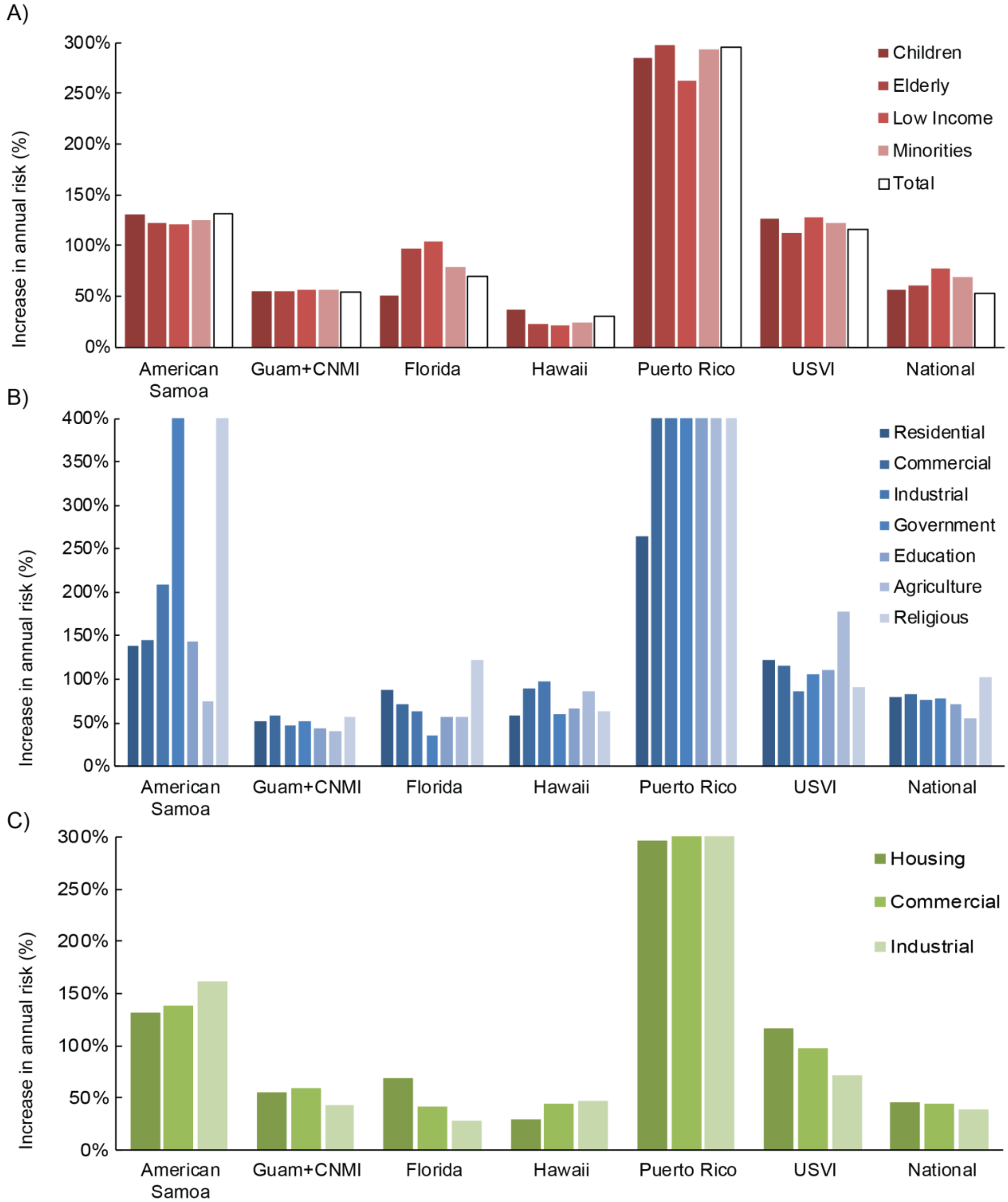
Supplementary Figures

Fig. S1.



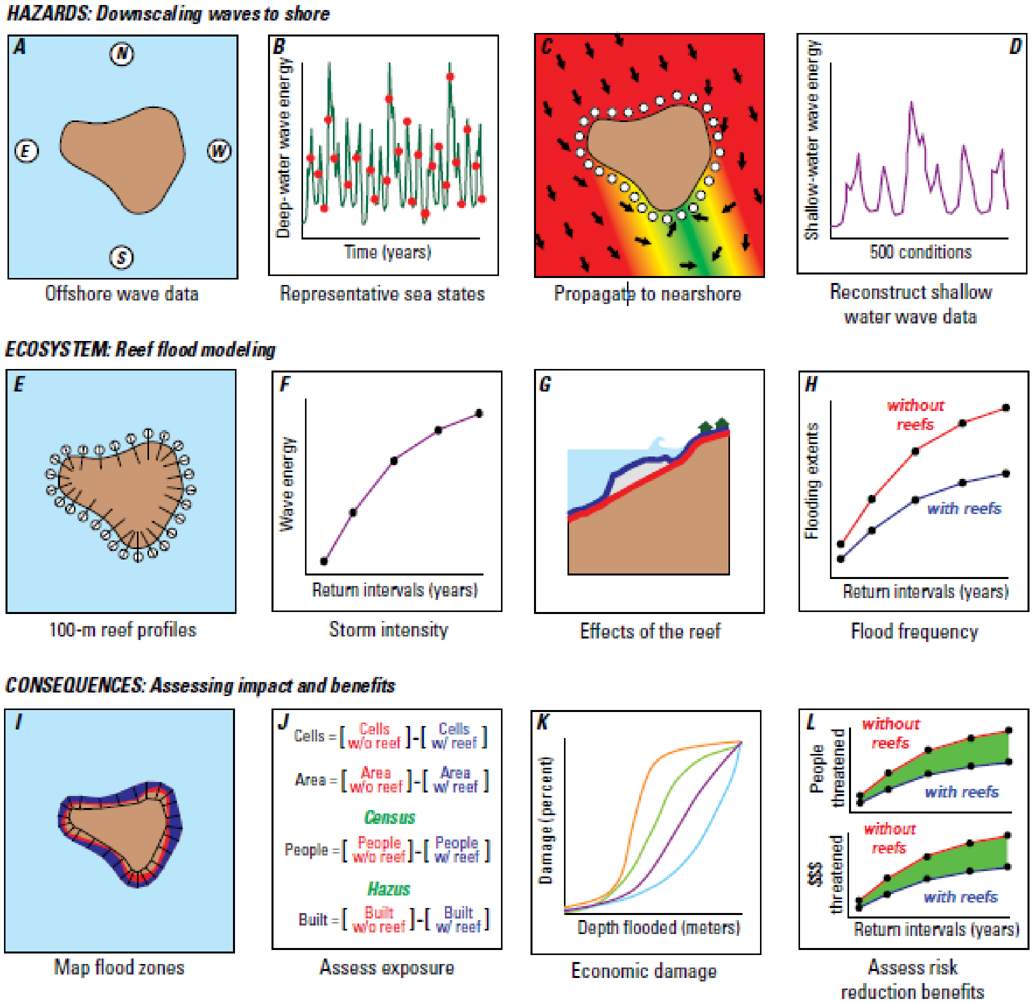
Nation-wide estimates of the 100-yr flood risk in reef-lined coasts. The blue bars and lines represent the damage in the 100-yr flood zone with reefs and the red bars with 1-m reef loss. (A) Risk and benefits for people, direct damages to buildings, and indirect economic impact. (B) Breakdown of Expected Annual Damages by type of critical infrastructure.

Fig. S2.



Regional breakdown of the risk reduction provided by coral reefs. The bar represents percent increases in Annual Expected Damages with 1-m reef loss. (A) Demographic breakdown. (B) Breakdown by building types. (C) Breakdown of economic disruption by type of sector.

Fig. S3



Modeling approach. Sequential steps to evaluate the role of coral reefs in hazard risk reduction.

Supplementary Tables

Table S1.

People			
City	State	County	Population
Hallandale Beach	Florida	Miami/Broward	1,169
Lahaina	Hawaii	Maui	786
Kihei	Hawaii	Maui	724
Maunalua Bay	Hawaii	Oahu	722
Hollywood	Florida	Broward	647
Economic Value			
City	State	County	Total Dollars
Lahaina	Hawaii	Maui	$ 85,359,099
Kihei	Hawaii	Maui	$ 66,614,447
Hallandale Beach	Florida	Miami/Broward	$ 65,778,240
Hollywood	Florida	Broward	$ 62,081,371
Maunala Bay	Hawaii	Oahu	$ 55,655,957

Top five communities receiving the highest annual risk reduction benefits from coral reefs in terms of people and economic value (direct and indirect), per kilometer of coastline.

Table S2.

Region	Sublocation	Population	Adverted direct damages to buildings	Averted economic disruption
American Samoa	Tutuila	570	$25,019,327	$7,010,804
	Ofu-Olosega	3	$77,852	$40,707
	Tau	8	$753,845	$146,998
CNMI	Saipan	396	$5,003,426	$7,970,049
	Tinian	7	$672,257	$140,812
Guam	Guam	107	$6,839,500	$10,078,571
Florida	Mainland	4,947	$323,835,761	$276,082,074
	Keys	716	$32,125,237	$41,870,102
Hawaii	Hawaii	336	$23,997,824	$26,407,938
	Maui	3,381	$112,716,317	$262,533,841
	Lanai	0	$53,732	$1,343
	Molokai	1	$42,071	$72,109
	Kahoolawe	-	-	-
	Oahu	3,040	$200,942,259	$192,907,591
	Kauai	107	$5,854,742	$6,397,147
	Niihau	0	-	$1,045
Puerto Rico	Puerto Rico	4,210	$65,880,224	$115,224,881
	Culebra	11	$148,502	$281,559
	Vieques	0	$94,075	$9,591
USVI	Saint Croix	278	$18,021,883	$21,008,945
	Saint John	3	$527,814	$314,496
	Saint Thomas	59	$3,319,769	$3,539,519

Expected annual benefits by sublocation, for population, averted direct damages to infrastructure and indirect economic disruption.

Table S3.

Location	Sublocation	Benthic habitat data: Minimum mapping unit	Benthic habitat data: Data source	Shoreline data source
American Samoa	Tutuila	1 acre	Anderson, 2004a	NOAA, 2002d
	Ofu and Olosega	1 acre	Anderson, 2004a	NOAA, 2002a
	Tau	1 acre	Anderson, 2004a	NOAA, 2002a
Northern Mariana Islands	Saipan	1 acre	Anderson, 2004c	NOAA, 2002b
	Tinian	1 acre	Anderson, 2004c	NOAA, 2002c
Guam	Guam	1 acre	Anderson, 2004b	NOAA, 2003
Florida	Dry Tortugas	<1 acre	FFWCC-FWRI, 2016	NOAA, 2015
	Key West	<1 acre	FFWCC-FWRI, 2016	NOAA, 2015
	Florida Keys	<1 acre	FFWCC-FWRI, 2016	NOAA, 2015
	Miami	<1 acre	FFWCC-FWRI, 2016	NOAA, 2015
	Palm Beach	<1 acre	FFWCC-FWRI, 2016	NOAA, 2015
Hawaii	Island of Hawaii	1 acre	Anderson, 2007	State of Hawaii, 1997
	Maui	1 acre	Anderson, 2007	State of Hawaii, 1997
	Lanai	1 acre	Anderson, 2007	State of Hawaii, 1997
	Molokai	1 acre	Anderson, 2007	State of Hawaii, 1997
	Kahoolawe	1 acre	Anderson, 2007	State of Hawaii, 1997
	Kauai	1 acre	Anderson, 2007	State of Hawaii, 1997
	Niihau	1 acre	Anderson, 2007	State of Hawaii, 1997
	Oahu	1 acre	Anderson, 2007	State of Hawaii, 1997
Puerto Rico	Isla de Puerto Rico	1 acre	NOAA, 2001a	NOAA, 2015
	Isla de Culebra	1 acre	NOAA, 2001a	NOAA, 2015
	Isla de Vieques	1 acre	NOAA, 2001a	NOAA, 2015
US Virgin Islands	Saint Croix	1 acre	NOAA, 2001b	NOAA, 2015
	Saint John	1,000 m^2	Zitello and others, 2009	NOAA, 2015
	Saint Thomas	1 acre	NOAA, 2001c	NOAA, 2015

Benthic habitat and shoreline datasets' sources and resolution.

Table S4.

Coral coverage (%)	Wave friction coefficient (f_w)	Current and infragravity wave friction coefficient (c_f)
None (sand)	0.10	0.01
0–10	0.15	0.07
10–50	0.30	0.10
50–90	0.45	0.13
90–100	0.60	0.15

Wave and current friction coefficients for different percentages of coral cover as determined from benthic habitat maps.

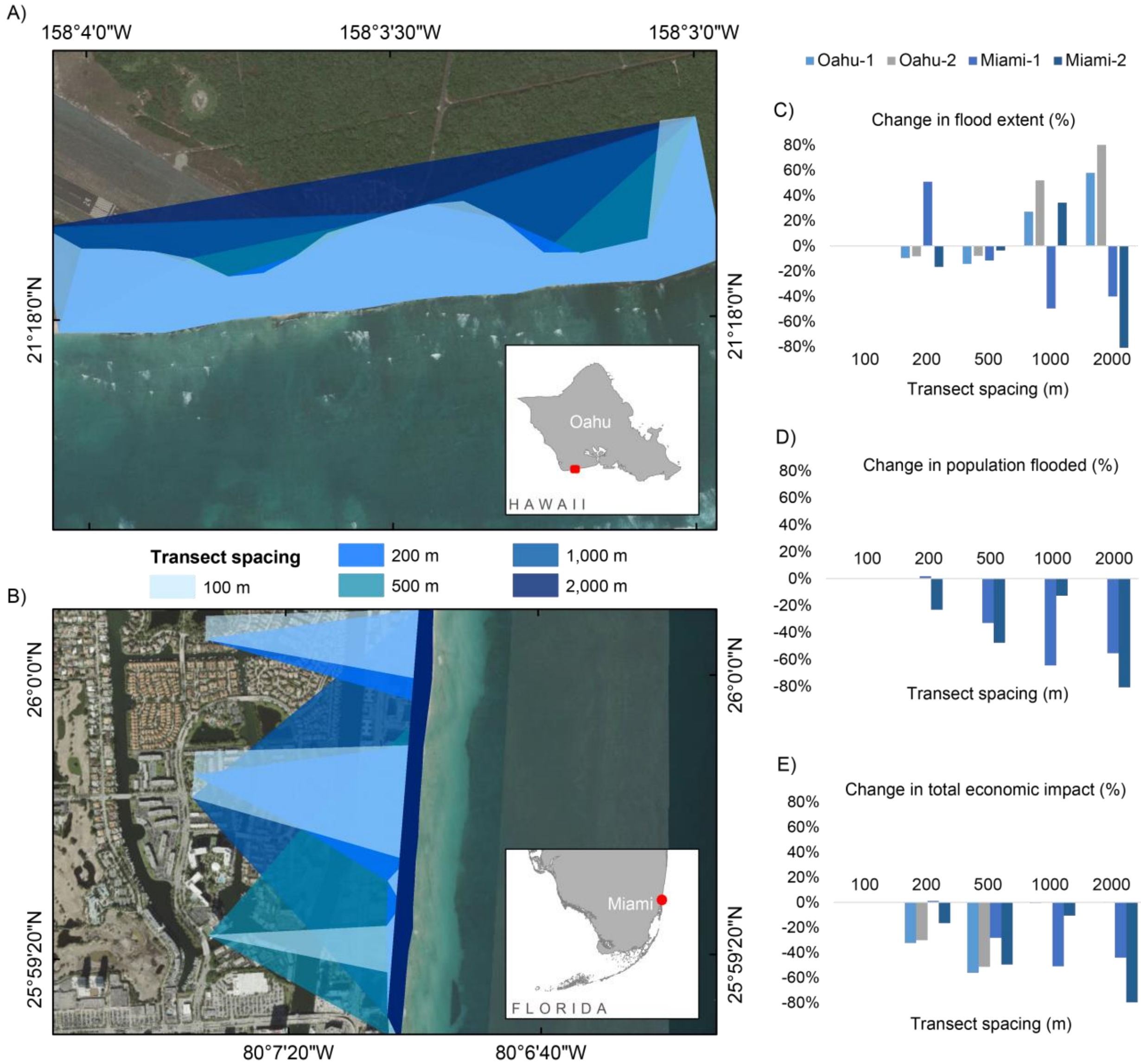
Supplementary Discussion 1

The sensitivity of the results to flood model alongshore transect spacing was evaluated for two end-member geomorphologies: Miami (flat mainland and barrier island; characteristic of 14% of the study area) and Oahu (steep, high island; characteristic of 86% of the study area). Supplementary Figure 4 demonstrates the differences in flood extent for different transect spacing from 100 m (used in the study) to 200 m, 500 m, 1000 m, and 2000 m for these two end-members.

The results indicate that for low-lying coastal zones, like Miami (Supplementary Figure 4-A), larger transect spacing leads to underestimation of the flood risk, as spacing does not capture low areas in the coastal topography that are the initiation points of inland flooding. However, for more complex and steeper coastal zones, like on Oahu (Supplementary Figure 4-B), larger transect spacing (as used in previous global models) leads to overestimation of flooding because the flood extent is interpolated across large areas between transects that would not be flooded due to topographic highs. In term of people flooded, direct damages to buildings, and indirect economic disruption are also influenced by the transect spacing (Supplementary Figures 4-C, D, E). The distribution of socio-economic exposure is sensitive to definition of the flood zones, and for larger transect spacing greater than 500 m, becomes imprecise because low-lying sections of coastline are not captured in the modeled flood extents.

This comparison indicates that a lower resolution in the flood mapping leads to reduced accuracy in both geographies (overestimating/underestimating depending on the type of coastal geomorphology) across the flood risk metrics. Therefore, the most accurate results are generated using the highest possible spatial resolution data, as this accounts for more of the complexity of the coastal zone in terms of topographic features and the distribution of socioeconomic exposure. The hydrodynamic modeling and spatial analysis presented in this manuscript are at a higher resolution than any other previous national-scale coastal flood mapping and any other published valuation of the risk reduction service of any coastal ecosystem.

Fig. S4.



Comparison of flood effects of different transect spacing in two distinct coastal morphologies. The coast of Oahu (A) is characterized by steep, complex coastal topography. The coast of Miami (B) is characterized by low-lying coastal zones and barrier islands. Large transect spacing overestimates flood extent steep, complex coastal topography by integrating across coastal high points that would not be flooded (C) and underestimates flooding low-lying coastal zones and barrier islands by not capturing low areas in the coastal dunes from which inland flooding occurs. The resulting population affected (D) and total economic impact (E) is a misrepresentation of the risk (and the risk reduction benefits of the reefs), with differences up to 80% with respect to the higher resolution 100 m transect spacing. The satellite images were sourced from “World_Imagery” from ESRI with transparency added in ArcGIS.