APPENDICES

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Appendix A Study sites, site codes, regions and, protection level. Habitat type, S&G: Spur and Grove; Protection level, NTZ: No-take zone, MPA: marine protected area. Date of survey is month and year(s).

Site name	Site code	Habitat type	Depth (m)	Date of survey	Latitude	Longitude	Protection level	MR year
Mesoamerican Barrier, Mexico								
Cancún	GH	S & G	12	Jul 12	21.02544	-86.7713	none	
Cozumel North	PB	S & G	10	Jul 12	20.47188	-86.9815	NTZ	1996
Akumal	XA	S & G	15	Jul 12	20.42689	-87.2860	none	
Cozumel South	CR	S & G	15	Jul 12	20.31961	-87.0266	NTZ	1996
Chinchorro North	BCN	S & G	15	Jul 12	18.74867	-87.3476	MPA	1996
Chinchorro Central	BCC	S & G	15	Jul 12	18.57457	-87.4198	MPA	1996
Chinchorro South	BCS	S & G	15	Jul 12	18.41008	-87.4169	MPA	1966
Mesoamerican Barrier, Belize								
Bacalar Chico	BC	S & G	12-15	May 10/12	18.16282	-87.82222	NTZ	1996
Mexico Rocks	MR	S & G	12-15	May 10/12	17.98782	-87.90382	none	
Tackle Box	TB	S & G	12-15	May 10/12	17.91056	-87.95083	none	
Hol Chan	HC	S & G	12-15	May 10/12	17.86343	-87.97238	NTZ	1987
Gallows	GA	S & G	12-15	May 10/12	17.49592	-88.04255	none	
Calabash Caye	CA	S & G	12-15	May 10/12	17.26147	-87.81970	none	
Half Moon Caye	HM	S & G	12-15	May 10/12	17.20560	-87.54679	NTZ	1982
Alligator Caye	AL	S & G	12-15	May 10/12	17.19660	-88.05115	none	
Tobacco Caye	TO	S & G	12-15	May 10/12	16.91911	-88.04757	none	
South Water Caye	SW	S & G	12-15	May 10/12	16.81346	-88.07756	MPA	1996
Middle Caye	MC	S & G	12-15	May 10/12	16.73703	-87.80536	MPA	1993
South Middle Caye	SM	S & G	12-15	May 10/12	16.72875	-87.82867	MPA	1993
Pampion Caye	PO	S & G	12-15	May 10/12	16.37310	-88.08913	none	
Ranguana Caye	RA	S & G	12-15	May 10/12	16.28501	-88.15031	none	
Southwest Caye	ST	S & G	12-15	May 10/12	16.11247	-88.27107	none	
Nicholas Caye	NI	S & G	12-15	May 10/12	16.11230	-88.25586	MPA	2003
Dry Tortugas, USA	LG	S & G	12	Jun 12	24.68508	-82.91050	NTZ	1992
Bay of Pigs, Cuba								
Cueva Peces	CP	Slope	10-12	Jun 10/12	22.16627	-81.13827	none	
Punta Perdiz	PZ	Slope	10-12	Jun 10/12	22.11003	-81.11626	none	
Ebano	EB	Slope	10-12	Jun 10	22.07914	-81.07599	none	
Brinco	BR	Slope	10-12	Jun 12	22.06939	-81.05588	none	
Bacunayagua, Cuba	BC	Slope	10-12	Jun 12	23.14653	-81.66664	none	
Jardines de la Reina, Cuba								
El Peruano	EP	Slope	10-12	Jun 11	20.84411	-79.02166	NTZ	1996
Pipin	PP	S & G	12-15	Jun 11	20.82586	-78.98026	NTZ	1996
Anclita	AN	Slope	10-12	Jun 11	20.78697	-78.94317	NTZ	1996
Cueva Pulpo	CF	Slope	10-12	Jun 11	20.75266	-78.83634	NTZ	1996
Abaco, Bahamas								
Guana Cay	GC	S & G	10-12	Jul 11/12	26.70967	-77.15408	none	
Fowls Cay	FC	Slope	10	Jul 11/12	26.63717	-77.03848	NTZ	2009
Man o' War	MW	S & G	10-12	Jul 11/12	26.62122	-77.00550	none	
Pelican Cay	PC	Slope	10	Jul 11/12	26.39783	-76.98850	NTZ	1972
Little Harbor	LH	S & G	10-12	Jul 11/12	26.32390	-76.99160	none	
Rocky Point	RP	Slope	10-12	Jul 11/12	25.99661	-77.40092	Remote	

Appendix B Fish trophic guilds, species taxonomic information, and allometric parameters used to calculate biomass.

Trophic Group	Family	Common Name	Species Name	a	b
Apex predator	Carangidae	Greater Amberjack	*Seriola dumerili*	0.0325	2.870
Apex predator	Carangidae	Almaco Jack	*Seriola rivoliana*	0.0122	2.957
Apex predator	Carcharhinidae	Silky Shark	*Carcharhinus falsiformis*	0.0101	3.060
Apex predator	Carcharhinidae	Blacktip Shark	*Carcharhinus limbatus*	0.0061	3.010
Apex predator	Carcharhinidae	Reef Shark	*Carcharhinus perezi*	0.0271	3.000
Apex predator	Carcharhinidae	Lemon shark	*Negaprion brevirostris*	0.0053	3.160
Apex predator	Elopidae	Tarpon	*Megalops atlanticus*	0.0120	2.984
Apex predator	Lutjanidae	Cubera Snapper	*Lutjanus cyanopterus*	0.0152	3.060
Apex predator	Muraenidae	Green Moray	*Gymnothorax funebris*	0.0041	2.856
Apex predator	Rhincodontidae	Nurse Shark	*Ginglymostoma cirratum*	0.0105	2.892
Apex predator	Scombridae	Cero	*Scomberomorus regalis*	0.0202	2.800
Apex predator	Serranidae	Black Grouper	*Mycteroperca bonaci*	0.0082	3.140
Apex predator	Serranidae	Yellowmouth Grouper	*Mycteroperca interstitialis*	0.0141	3.000
Apex predator	Serranidae	Tiger Grouper	*Mycteroperca tigris*	0.0094	3.120
Apex predator	Serranidae	Yellowfin Grouper	*Mycteroperca venenosa*	0.0122	3.000
Apex predator	Sphyraenidade	Great Barracuda	*Sphyraena barracuda*	0.0070	2.972
Pisc/Invertivore	Aulostomidae	Trumpetfish	*Aulostomus maculatus*	0.0040	2.866
Pisc/Invertivore	Belonidae	Houndfish	*Tylosurus crocodilus*	0.0008	3.205
Pisc/Invertivore	Bothidae	Peacock Flounder	*Bothus lunatus*	0.0098	3.189
Pisc/Invertivore	Carangidae	Bar Jack	*Carangoides ruber*	0.0180	2.990
Pisc/Invertivore	Carangidae	Blue Runner	*Caranx crysos*	0.0318	2.949
Pisc/Invertivore	Carangidae	Crevalle Jack	*Caranx hippos*	0.0329	2.855
Pisc/Invertivore	Carangidae	Horse Eye Jack	*Caranx latus*	0.0186	2.856
Pisc/Invertivore	Carangidae	Palometa	*Trachinotus goodei*	0.0204	3.000
Pisc/Invertivore	Carangidae	Yellow Jack	*Caranx bartholomaei*	0.0259	2.908
Pisc/Invertivore	Centropomidae	Common Snook	*Centropomus undecimalis*	0.0104	2.910
Pisc/Invertivore	Dasyatidae	Southern Stingray	*Dasyatis americana*	0.0739	2.810
Pisc/Invertivore	Haemulidae	Sailors Choice	*Haemulon parra*	0.0199	2.993
Pisc/Invertivore	Haemulidae	White Grunt	*Haemulon plumieri*	0.0259	3.000
Pisc/Invertivore	Lutjanidae	Mutton Snapper	*Lutjanus analis*	0.0146	3.034
Pisc/Invertivore	Lutjanidae	Schoolmaster	*Lutjanus apodus*	0.0189	3.000
Pisc/Invertivore	Lutjanidae	Gray Snapper	*Lutjanus griseus*	0.0240	2.910
Pisc/Invertivore	Lutjanidae	Dog Snapper	*Lutjanus jocu*	0.0198	2.960
Pisc/Invertivore	Lutjanidae	Mahogany Snapper	*Lutjanus mahogoni*	0.0428	2.719
Pisc/Invertivore	Lutjanidae	Lane Snapper	*Lutjanus synagris*	0.0216	2.917
Pisc/Invertivore	Lutjanidae	Yellowtail Snapper	*Ocyurus chrysurus*	0.0314	2.793
Pisc/Invertivore	Scombridae	King Mackerel	*Scomberomorus caballa*	0.0091	2.960
Pisc/Invertivore	Scorpinadae	Lionfish	*Pterois volitans*	0.0050	3.291
Pisc/Invertivore	Serranidae	Graysby	*Cephalopholis cruentata*	0.0121	3.082
Pisc/Invertivore	Serranidae	Coney	*Cephalopholis fulva*	0.0188	2.973
Pisc/Invertivore	Serranidae	Rock Hind	*Epinephelus adscensionis*	0.0125	3.224
Pisc/Invertivore	Serranidae	Red Hind	*Epinephelus guttatus*	0.0084	3.100
Pisc/Invertivore	Serranidae	Jewfish	*Epinephelus itajara*	0.0131	3.056
Pisc/Invertivore	Serranidae	Red Grouper	*Epinephelus morio*	0.0162	2.990
Pisc/Invertivore	Serranidae	Nassau Grouper	*Epinephelus striatus*	0.0065	3.229
Pisc/Invertivore	Serranidae	Greater Soapfish	*Rypticus saponaceus*	0.0010	1.000
Pisc/Invertivore	Serranidae	Shy Hamlet	*Hypoplectrus guttavarius*	0.0090	3.040
Pisc/Invertivore	Serranidae	Indigo Hamlet	*Hypoplectrus indigo*	0.0110	3.182
Pisc/Invertivore	Serranidae	Black Hamlet	*Hypoplectrus nigricans*	0.0110	3.182
Pisc/Invertivore	Serranidae	Barred Hamlet	*Hypoplectrus puella*	0.0090	3.040

Pisc/Invertivore	Serranidae	Butter Hamlet	*Hypoplectrus unicolor*	0.0090	3.040
Pisc/Invertivore	Sphyraenidade	Southern Sennet	*Sphyraena picudilla*	0.0067	2.942
Macroinvertivore	Balistadae	Queen Triggerfish	*Balistes vetula*	0.0354	2.900
Macroinvertivore	Balistadae	Ocean Triggerfish	*Canthidermis sufflamen*	0.0217	3.000
Macroinvertivore	Carangidae	Permit	*Trachinotus falcatus*	0.0301	2.958
Macroinvertivore	Echeneidae	Sharksucker	*Echeneis naucrates*	0.0010	3.290
Macroinvertivore	Ephippidae	Atlantic Spadefish	*Chaetodipterus faber*	0.0530	2.952
Macroinvertivore	Gerreidae	Yellowfin Mojarra	*Gerres cinereus*	0.0184	3.084
Macroinvertivore	Haemulidae	Black Margate	*Anisotremus surinamensis*	0.0233	3.010
Macroinvertivore	Haemulidae	Porkfish	*Anisotremus virginicus*	0.0148	3.167
Macroinvertivore	Haemulidae	White Margate	*Haemulon album*	0.0144	3.070
Macroinvertivore	Haemulidae	Tomtate	*Haemulon aurolineatum*	0.0120	3.100
Macroinvertivore	Haemulidae	Caesar Grunt	*Haemulon carbonarium*	0.0147	3.056
Macroinvertivore	Haemulidae	Smallmouth Grunt	*Haemulon chrysargyreum*	0.0106	3.047
Macroinvertivore	Haemulidae	French Grunt	*Haemulon flavolineatum*	0.0232	3.000
Macroinvertivore	Haemulidae	Spanish Grunt	*Haemulon macrostomum*	0.0176	3.060
Macroinvertivore	Haemulidae	Cottonwick	*Haemulon melanurum*	0.0226	2.953
Macroinvertivore	Haemulidae	Bluestriped Grunt	*Haemulon sciurus*	0.0194	2.999
Macroinvertivore	Haemulidae	Striped Grunt	*Haemulon striatum*	0.0175	3.099
Macroinvertivore	Holocentridae	Squirrelfish	*Holocentrus adscensionis*	0.0216	3.000
Macroinvertivore	Holocentridae	Longspine Squirrelfish	*Holocentrus rufus*	0.0170	3.000
Macroinvertivore	Holocentridae	Blackbar Soldierfish	*Myripristis jacobus*	0.1110	2.720
Macroinvertivore	Holocentridae	Longjaw Squirrelfish	*Neoniphon marianus*	0.0215	3.000
Macroinvertivore	Labridae	Spanish Hogfish	*Bodianus rufus*	0.0145	3.053
Macroinvertivore	Labridae	Slippery Dick	*Halichoeres bivittatus*	0.0105	3.093
Macroinvertivore	Labridae	Yellowhead Wrasse	*Halichoeres garnoti*	0.0052	3.375
Macroinvertivore	Labridae	Clown Wrasse	*Halichoeres maculipinna*	0.0028	3.693
Macroinvertivore	Labridae	Rainbow Wrasse	*Halichoeres pictus*	0.0052	3.375
Macroinvertivore	Labridae	Puddingwife	*Halichoeres radiatus*	0.0131	3.038
Macroinvertivore	Labridae	Hogfish	*Lachnolaimus maximus*	0.0237	2.950
Macroinvertivore	Labridae	Bluehead	*Thalassoma bifasciatum*	0.0101	3.040
Macroinvertivore	Malacanthidae	Sand Tilefish	*Malacanthus plumieri*	0.0001	2.680
Macroinvertivore	Myliobatidae	Spotted Eagle Ray	*Aetobatus narinari*	0.0059	3.130
Macroinvertivore	Ostracidae	Honeycomb Cowfish	*Acanthostracion polygonius*	0.0178	3.083
Macroinvertivore	Pomacanthidae	Blue Angelfish	*Holacanthus bermudensis*	0.0319	2.899
Macroinvertivore	Pomacanthidae	Queen Angelfish	*Holacanthus ciliaris*	0.0337	2.900
Macroinvertivore	Priacanthidae	Glasseye Snapper	*Heteropriacanthus cruentatus*	0.0188	3.000
Macroinvertivore	Serranidae	Harlequin Bass	*Serranus tigrinus*	0.0145	3.048
Macroinvertivore	Sparidae	Saucereye Porgy	*Calamus calamus*	0.0125	3.180
Macroinvertivore	Sparidae	Sheepshead Porgy	*Calamus penna*	0.0764	2.666
Macroinvertivore	Tetraodontidae	Bandtail Puffer	*Sphoeroides spengleri*	0.0235	3.050
Microinvertivore	Chaetodontidae	Foureye Butterflyfish	*Chaetodon capistratus*	0.0220	3.190
Microinvertivore	Chaetodontidae	Spotfin Butterflyfish	*Chaetodon ocellatus*	0.0318	2.984
Microinvertivore	Chaetodontidae	Banded Butterflyfish	*Chaetodon striatus*	0.0220	3.140
Microinvertivore	Gobiidae	Neon Goby	*Elacatinus oceanops*	0.0080	3.137
Microinvertivore	Grammatidae	Fairy Basslet	*Gramma loreto*	0.0001	1.111
Microinvertivore	Grammatidae	Blackcap Basslet	*Gramma melacara*	0.0001	1.111
Microinvertivore	Monacanthidae	Whitespotted Filefish	*Cantherhines macrocerus*	0.0561	2.653
Microinvertivore	Mullidae	Yellow Goatfish	*Mulloidichthys martinicus*	0.0110	3.092
Microinvertivore	Mullidae	Spotted Goatfish	*Pseudupeneus maculatus*	0.0150	3.157
Microinvertivore	Sciaenidae	Jackknife Fish	*Equetus lanceolatus*	0.0011	3.844
Microinvertivore	Sciaenidae	Spotted Drum	*Equetus punctatus*	0.0153	3.062
Planktivore	Labridae	Creole Wrasse	*Clepticus parrae*	0.0145	3.053
Planktivore	Pomacentridae	Blue Chromis	*Chromis cyanea*	0.0188	3.000
Planktivore	Pomacentridae	Brown Chromis	*Chromis multilineata*	0.0262	2.753
Large Omnivore	Balistadae	Black Durgon	*Melichthys niger*	0.0217	3.000

Large Omnivore	Pomacanthidae	Rock Beauty	*Holacanthus tricolor*	0.0203	3.126
Large Omnivore	Pomacanthidae	Gray Angelfish	*Pomacanthus arcuatus*	0.0203	3.126
Large Omnivore	Pomacanthidae	French Angelfish	*Pomacanthus paru*	0.0203	3.126
Small Omnivore	Monacanthidae	Scrawled Filefish	*Aluterus scriptus*	0.0022	3.000
Small Omnivore	Monacanthidae	Orangespotted Filefish	*Cantherhines pullus*	0.0684	2.563
Small Omnivore	Pomacentridae	Sergeant Major	*Abudefduf saxatilis*	0.0227	3.142
Small Omnivore	Pomacentridae	Dusky Damselfish	*Stegastes adustus*	0.0384	3.010
Small Omnivore	Pomacentridae	Beaugregory	*Stegastes leucostictus*	0.0303	2.887
Small Omnivore	Pomacentridae	Threespot Damselfish	*Stegastes planifrons*	0.0379	2.857
Small Omnivore	Pomacentridae	Cocoa Damselfish	*Stegastes variabilis*	0.0324	2.836
Small Omnivore	Tetraodontidae	Sharpnose Puffer	*Canthigaster rostrata*	0.0323	2.953
Herbivore	Acanthuridae	Ocean Surgeonfish	*Acanthurus bahianus*	0.0236	2.975
Herbivore	Acanthuridae	Doctorfish	*Acanthurus chirurgus*	0.0225	3.000
Herbivore	Acanthuridae	Blue Tang	*Acanthurus coeruleus*	0.0305	3.000
Herbivore	Blennidae	Redlip Blenny	*Ophioblennius atlanticus*	0.0324	2.379
Herbivore	Kyphosidae	Bermuda Chub	*Kyphosus saltatrix*	0.0174	3.080
Herbivore	Pomacentridae	Yellowtail Damselfish	*Microspathodon chrysurus*	0.0239	3.082
Herbivore	Pomacentridae	Longfin Damselfish	*Stegastes diencaeus*	0.0353	2.896
Herbivore	Pomacentridae	Bicolor Damselfish	*Stegastes partitus*	0.0182	3.152
Herbivore	Scaridae	Midnight Parrotfish	*Scarus coelestinus*	0.0153	3.062
Herbivore	Scaridae	Blue Parrotfish	*Scarus coeruleus*	0.0124	3.111
Herbivore	Scaridae	Rainbow Parrotfish	*Scarus guacamaia*	0.0155	3.063
Herbivore	Scaridae	Striped Parrotfish	*Scarus iserti*	0.0158	3.052
Herbivore	Scaridae	Princess Parrotfish	*Scarus taeniopterus*	0.0177	3.000
Herbivore	Scaridae	Queen parrotfish	*Scarus vetula*	0.0158	3.052
Herbivore	Scaridae	Greenblotch Parrotfish	*Sparisoma atomarium*	0.0122	3.028
Herbivore	Scaridae	Redband Parrotfish	*Sparisoma aurofrenatum*	0.0129	3.110
Herbivore	Scaridae	Redtail Parrotfish	*Sparisoma chrysopterum*	0.0135	3.100
Herbivore	Scaridae	Bucktooth Parrotfish	*Sparisoma radians*	0.0179	3.035
Herbivore	Scaridae	Redfin Parrotfish	*Sparisoma rubripinne*	0.0194	3.000
Herbivore	Scaridae	Stoplight Parrotfish	*Sparisoma viride*	0.0250	2.921

Appendix C Summary of preliminary, anthropogenic, physical, biotic, and management-related predictors used in the analysis. For a detailed description of each variable see Appendix D.

Variable name	**Range**	**Units**	**Source**
Anthropogenic			
Coastal Development in 50km	0-26470	light pixels	Suomi NPP satellite [a]
Humans within 50 km	54-67140	#	World Gridded Population [b]
Humans of closest town	0-628300	#	Country census
Distance to population centers	1.6-115.8	km	Calculated in ArcGIS 10
Cultivated land within 50 km	0-3917	km^2	Global Land Cover 2000[c]
Physical			
Net primary productivity	203-1610	mg C m^{-2} day^{-1}	Aqua MODIS
Sea surface temperature (SST)	26.0-29.3	ºC	AHVRR Pathfinder v5.2
Minimum SST	20.8-26.5	ºC	AHVRR Pathfinder v5.2
Wave exposure (log)	3.9-7.9	J m^{-3}	(Chollett et al. 2012)
Depth	10-16	meters	In situ measurements
Reef structural complexity	1.5-5	#	In situ estimations
Distance to deep water	0.03-32.9	km	NOAA bathymetry charts
Distance to tide channels	0.4-6.0	km	Calculated in ArcGIS 10
Distance to mangrove	0.34-31.9	km	Calculated in ArcGIS 10
Reef area within 5 km	0.1-25.9	km^2	Global Coral Reef 2010[d]
Reef area within 10 km	0.4-43.1	km^2	Global Coral Reef 2010
Biotic			
Mangrove perimeter in 5 km	0-175.6	km	Global Mangrove 2011[e]
Mangrove perimeter in 10 km	0-406.10	km	Global Mangrove 2011
Live coral cover	1.5-31.6	%	In situ measurements/video
Macroalgae cover	6.2-71.2	%	In situ measurements/video
Gorgonian cover	0-17.2	%	In situ measurements/video
Fish biomass (lower trophic)	3.5-441.0	g m^{-2}	In situ measurements
Management regime			
Protection level	None, MPA, NTZ	categorical	Reef Base
Reserve size	7.8-2170	km^2	Reef Base
Reserve age	3-40	years	Reef Base
Poaching level	low, high	categorical	Reef Base, Interviews

a Suomi NPP satellite global at 750 m resolution available at NASA Earth Observatory (Black Marble)
b Gridded Population of the World V.3 at 0.25 degree resolution estimated for 2010
c Global Land Cover 2000 database
d Global Distribution of Coral Reef 2010 database from Ocean Data Viewer UNEP-WCMC
e Global Distribution of Mangroves USGS 2011 database from the Ocean Data Viewer UNEP-WCMC

Appendix D Detailed description of covariates

Human population density

We considered three measures of human effects based on population size: 1) humans within 50 km (maximum number of people that occurred within 50-km radius of each site); 2) number of humans in the nearest population center (indicator of spatially immediate human pressure); and 3) distance to nearest population centers (indicator of long-distance effects, calculated from each site to the center of nearest population settlements). We chose 50 km as radius for the first measured variable because it is a reasonable range of anthropogenic influence on Caribbean reefs (Mora, 2008). Projection estimates of human population counts for the year 2010 were obtained from the Gridded Population of the World V.3 at 0.25 degree resolution (SEDAC, 2010) and calculated in ArcGIS v10.0.

Coastal Development

This variable quantified the use of electrical power measured as the intensity of the Earth's city lights at night within 50 km radius of each site. Power infrastructure can be used as a proxy of coastal development which is a good surrogate for fishing pressure (Sanderson et al. 2002). Light intensity was calculated as the sum of pixel values that corresponded to city and town lights within the interest area. We used the high resolution (750 m) composite map of the world assembled from data acquired by the Suomi NPP satellite global available at NASA Earth Observatory (http://earthobservatory.nasa.gov/Features/NightLights/page3.php). All calculations were performed in ArcGIS v10.0.

Cultivated land

We quantified the area of cultivated land that occurred within a 50 km radius of each reef site. The raster data for this variable was obtained from the Global Land Cover 2000 database (GLC 2003). Specifically, we used the regional dataset (North and Central America) that depicts the spatial distribution of 29 different land attributes for the year 2000 as calculated from satellite images at 1 km resolution. Cultivated land could be a surrogate of terrestrial run-offs with potential effects on macroalgae cover when herbivory is reduced (McCook 1999). Additionally sediment derived from agriculture may alter predator-prey interactions in coral reef fish and compromise planktivores feeding efficiency (Wenger et al. 2013). Spatial analyses were performed in ArcGIS v10.

Marine Reserve size, age, and poaching level

In this study we only considered marine reserves where fishing was not allowed, at least in theory (i.e. no-take areas). We assessed three variables that together describe some degree of protection effectiveness for reef sites inside marine reserves (Mora et al. 2006). These variables were reserve size, years since the establishment (reserve age) and poaching level. Reserve size and age can positively influence fish communities, as in general, older and larger reserves tend to accumulate relative more fish biomass than younger and smaller reserves (Côté et al. 2001, Halpern 2003, Claudet et al. 2008, Babcock et al. 2010). In contrast, poaching can directly affect fish abundance and undermine the protection efforts particularly when reserves are small (Kritzer 2004). Poaching levels inside the reserve was classified as "low" or "high" based on interviews with park managers and regular users such as dive shops (method modified from Mora et al. 2006). We assumed that poaching inevitable exist in each reserve, thus a range of low to high was established based on a 5 point scale for which 1-2 was low while 3-5 was high.

Reef Area

Reef areas within 5 km and 10 km radius of each site was calculated from the Global Distribution of Coral Reefs (2010) database as available at the Ocean Data Viewer United Nations Environment Program's World Conservation Monitoring Centre (UNEP-WCMC) (http://data.unep-wcmc.org/datasets/13). This database represents the global distribution of warm water coral reefs compiled mostly from the Millennium Coral Reef Mapping Project validated and un-validated maps as well as other sources acquired by UNEP-WCMC. Reef areas within the interest region were calculated in ArcGIS v10.0.

Reef structural complexity

For each transect set we visually estimated structural reef complexity on a scale of 0-5, where 0 was given to reefs with no vertical relief; 1, low and sparse relief; 2, low but widespread relief; 3, moderately complex relief; 4, very complex relief with numerous caves and fissures; and 5, reefs with exceptionally complex habitats, with numerous caves and overhangs (Polunin and Roberts 1993). This topographic measure provided an assessment of reef complexity at the seascape level which is relevant to large and medium-sized fish (Polunin and Roberts 1993, Wilson et al. 2007). To minimize estimation subjectivity among observers, at least two divers estimated reef structural complexity for each transect set and the average was calculated to be used in the models. We evaluated the accuracy of the estimations among observers by comparing the standard deviations (SD) among transects per site and found that SDs were 0-0.7 in all cases, meaning that average estimation differences were never over 1 unit.

Mangrove Perimeter

Mangrove abundance was quantified as the perimeter covered by mangrove within 5 km and 10 km radius of each site. Estimates of Caribbean mangrove distribution were obtained from the Global Distribution of Mangroves USGS (2011) database as available at the Ocean Data Viewer UNEP-WCMC (http://data.unep-wcmc.org/datasets/21). This database depicts the distributions of global mangroves based on Global Land Survey data and Landsat images. Landsat images (30 m resolution) were interpreted using unsupervised and supervised digital image classification techniques. Each image was atmospherically corrected, ground truth and validated with existing maps and databases.

Net primary productivity

We calculated mean oceanic net primary productivity (mg C m^{-2} day^{-1}) for each site between 2002 and 2012 using remote-sensing. This was obtained from Aqua MODIS satellite monthly data combined in the vertical generalized production model (Behrenfeld and Falkowski 1997) at a spatial resolution of 0.0833º (Oregon State University 2013). We used the mean of the last ten years period because primary productivity is inherently variable in time and established predatory communities may respond better to long term trends in primary productivity than to survey year or monthly mean values. Calculations were performed in ArcGIS 10.0.

Sea surface temperature

We used AHVRR Pathfinder Version 5.2 (PFV5.2) satellite data obtained from the US National Oceanographic Data Center and GHRSST (NOAA 2013). The PFV5.2 data are an updated version of the Pathfinder Version 5.0 and 5.1 collections described in Casey et al. (2010). We calculated average monthly sea surface temperature (SST, 2002-2011) for each source 4 km^2 grid cell that corresponded to each reef site. We also calculated mean minimum monthly SST by selecting the lowest monthly average temperature per year to compute an average across years. Mean minimum monthly SST could be a better predictor of physiological constrains of some fish predator species (Jennings et al. 2008, Nadon et al. 2012). We used mean temperature of nine years because it may represent better the temperature regimen these top consumers experience overtime. All calculations were performed in ArcGIS 10.0.

Wave exposure

The log of wind driven wave exposure (J m^{-3}) was extracted in ArchGIS 10.0 from the wave stress map for the Caribbean basin built by Chollett *et al*. (2012) and available at (http://www.marinespatialecologylab.org/wp-content/uploads/2010/11/PECS1.png). This index does not include the influence of tides or swells, which are not generated by local wind, and it is an approximation of wave patterns in shallow areas (Chollett et al. 2012). Wave exposure has been a good predictor of spatial variation in reef building corals such as *Orbicella* sp. (former *Montastrea* sp.) (Chollett and Mumby 2012) and can partially explain beta diversity patterns of benthic communities (Harborne et al. 2011). Wave exposure may also directly affect the biomass and diversity of tropical reef fish (Friedlander et al. 2003) and the distribution and abundance of temperate reef fish by compromising swimming abilities (Fulton and Bellwood 2004). Alternatively, by modifying the distribution of foundation species like corals, wave exposure could affect fish species that depend on them. The detailed description of the wave exposure calculations and assumptions can be found in Chollett & Mumby (2012).

Benthic cover

Percent cover data of benthic communities by categories (i.e. coral by species, algae by genus or functional groups, gorgonians, sponges, and other) were measured at each site using point intercepts in 6-8 transect lines (10 m long) (Lang et al. 2010) and/or in 6-8 video transects (50 m long) (Carleton and Done 1995). Point intercept transects (PITs) were used at the Belize sites, while both PITs and video transects were used at the rest of the sites. Both methods provided similar accuracy and results in estimating benthic cover categories in our study. Each benthic transect corresponded to a fish transect set. To estimate percent cover, 100 points per transect was used in PITs (Lang et al. 2010), while ~600 points were extracted from each video transect (Carleton and Done 1995). As model predictors we only used live coral, fleshy algae, and gorgonian cover as they provide physical structure that may affect small and medium size fish predators (Alvarez-Filip et al. 2011).

References

See references in Appendix K

Appendix E: Table E1 Spearman's rank (r_s) order correlation matrix for response and explanatory variables. Bold values are correlations $r_s > 0.50$. Upper matrix panel are correlations within marine reserves. Lower matrix corresponds to values for all sites. Number codes are: apex predator (1), piscivore-invertivore (2), herbivore (3), omnivore (4), invertivore (5), planktivore (6), mangrove within 5 km (7), mangrove within 10 km (8), coral cover (9), algae cover (10), gorgonian cover (11), net primary productivity (12), sea surface temperature (13), minimum sea surface temperature (14), wave exposure (15), depth (16), reef structural complexity (17), distance to deep water (18), distance to channels (19), distance to mangrove (20), reef area within 5 km (21), reef area within 10 km (22), coastal development within 50 km (23), number of humans within 50 km (24), number of humans in the closest town (25), minimum distance to closest town (26), area of cultivate land within 50 km (27), reserve age (28), reserve size (29). Note that reserve age and size are only applicable to sites within reserves.

Appendix E: Table E1

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
1		0.38	0.02	0.10	0.10	0.05	0.29	0.25	0.07	0.12	0.16	0.29	0.11	-0.12	-0.16	-0.04	0.26	-0.08	0.12	-0.33	-0.04	0.03	-0.40	-0.39	-0.36	0.39	-0.49	0.08	0.32
2	0.35		0.26	0.31	0.42	0.18	0.03	-0.03	-0.02	-0.06	0.07	0.10	-0.04	-0.06	-0.35	0.08	0.21	-0.27	0.28	-0.12	0.10	0.14	-0.24	-0.30	-0.28	0.32	-0.19	0.16	0.46
3	0.16	0.36		0.02	0.22	0.08	-0.16	-0.20	0.00	-0.46	0.07	-0.19	**-0.50**	-0.36	-0.09	-0.39	0.31	0.15	0.28	0.05	-0.40	-0.24	-0.06	-0.25	0.04	-0.12	-0.15	0.20	-0.23
4	0.07	0.24	0.18		0.29	0.33	0.06	0.00	0.06	-0.14	-0.17	-0.18	0.14	0.34	-0.41	0.35	-0.01	-0.54	0.29	-0.14	0.00	-0.10	0.22	0.17	0.11	-0.03	0.15	0.07	0.34
5	0.18	0.37	0.35	0.25		0.31	-0.16	-0.21	0.03	-0.24	0.04	-0.15	-0.14	0.18	-0.37	0.10	0.07	-0.30	0.33	0.00	0.14	0.12	-0.02	-0.08	-0.19	0.14	-0.03	-0.08	0.26
6	0.06	0.25	0.16	0.28	0.22		-0.01	-0.03	0.24	-0.07	-0.05	-0.21	0.07	0.23	-0.13	0.19	0.21	-0.30	0.15	-0.10	-0.04	-0.05	0.10	0.11	0.02	-0.08	0.11	0.01	-0.03
7	0.21	0.05	-0.03	-0.02	-0.05	-0.11		**0.97**	**0.52**	0.38	0.14	0.46	0.61	-0.27	-0.21	0.04	0.02	0.08	-0.30	-0.89	-0.32	-0.38	-0.44	-0.30	0.00	0.24	-0.32	-0.04	0.28
8	0.15	0.04	-0.01	-0.05	-0.10	-0.08	**0.93**		**0.53**	0.43	0.13	0.47	0.67	-0.28	-0.14	-0.01	-0.07	0.19	-0.47	**-0.79**	-0.35	-0.39	-0.42	-0.27	0.01	0.15	-0.27	-0.13	0.19
9	-0.09	-0.07	-0.15	0.03	-0.04	0.05	0.21	0.26		-0.02	-0.08	0.00	0.38	0.04	-0.24	0.06	0.28	-0.07	-0.25	**-0.58**	-0.18	-0.21	-0.31	-0.01	-0.12	0.08	-0.22	-0.30	-0.01
10	-0.13	-0.20	-0.29	-0.03	-0.16	-0.19	0.19	0.06	-0.10		-0.06	**0.50**	**0.59**	0.12	0.21	0.22	-0.12	0.03	**-0.50**	-0.27	0.16	0.17	-0.17	-0.10	-0.09	0.16	0.05	0.07	0.17
11	0.14	0.05	0.07	-0.02	0.08	0.04	0.08	0.00	-0.20	0.02		0.48	-0.17	-0.44	0.00	-0.22	-0.26	0.38	0.18	-0.04	0.05	0.17	**-0.53**	**-0.67**	-0.40	0.47	-0.43	0.05	0.29
12	0.04	-0.04	-0.22	0.05	-0.02	-0.07	0.04	-0.02	0.17	0.31	0.14		0.43	-0.25	0.27	0.06	-0.25	0.24	-0.17	-0.28	0.24	0.41	**-0.64**	**-0.71**	-0.46	0.66	-0.38	0.42	**0.55**
13	-0.26	-0.32	-0.37	0.04	-0.23	-0.08	-0.10	0.00	0.31	0.17	-0.23	0.29		0.38	0.06	0.44	-0.17	-0.30	-0.45	-0.47	0.17	0.08	-0.13	0.10	-0.08	0.17	0.05	-0.02	0.38
14	-0.28	-0.27	-0.35	0.11	-0.10	0.00	-0.17	-0.13	0.27	0.14	-0.26	0.18	**0.61**		-0.01	**0.71**	0.08	-0.79	0.08	0.07	0.50	0.36	0.39	**0.59**	-0.07	-0.03	0.30	-0.08	0.20
15	0.00	-0.10	0.01	-0.20	-0.10	-0.23	0.00	-0.15	-0.29	0.24	0.25	-0.17	-0.28	-0.26		-0.20	-0.26	0.36	-0.13	0.40	0.08	0.21	0.03	0.08	0.00	-0.05	0.00	0.22	-0.38
16	-0.12	-0.17	-0.35	0.15	-0.05	0.04	0.00	-0.15	0.10	0.27	-0.06	0.14	0.32	0.48	0.00		0.05	-0.65	-0.03	-0.11	0.52	0.39	0.21	0.28	-0.02	0.15	0.38	0.11	0.45
17	0.28	0.37	0.25	-0.02	0.11	0.29	0.13	0.15	0.22	-0.33	0.00	-0.19	-0.21	-0.27	-0.20	-0.15		-0.34	0.12	-0.34	-0.05	0.03	-0.22	-0.05	-0.25	0.15	-0.31	0.09	-0.10
18	0.11	-0.02	0.14	-0.18	-0.08	-0.28	0.28	0.21	-0.10	0.15	0.27	-0.02	-0.33	**-0.50**	0.49	-0.18	-0.07		-0.41	0.19	-0.38	-0.25	-0.22	-0.35	0.13	-0.18	-0.10	-0.16	-0.48
19	0.06	0.06	0.14	0.00	0.04	-0.17	0.07	0.04	-0.18	-0.02	0.16	-0.29	0.03	0.06	0.14	-0.20	-0.11	0.14		0.12	0.07	0.08	0.06	-0.14	-0.14	0.26	-0.27	0.37	0.29
20	-0.08	0.12	0.06	-0.04	0.01	0.18	-0.41	-0.35	-0.17	-0.17	-0.06	-0.28	-0.26	-0.17	0.07	-0.08	0.10	-0.28	-0.10		0.22	0.29	0.48	0.25	0.16	-0.33	0.41	0.07	-0.33
21	-0.14	-0.22	-0.37	0.00	-0.01	-0.08	-0.09	-0.26	0.08	0.33	0.10	0.42	0.28	0.48	0.05	**0.56**	-0.19	-0.14	-0.04	-0.20		**0.91**	-0.14	0.03	-0.52	**0.57**	0.06	0.01	0.46
22	-0.08	-0.09	-0.23	-0.06	0.01	-0.03	-0.11	-0.24	0.09	0.23	0.12	0.26	0.05	0.31	0.13	0.32	0.00	-0.12	0.15	-0.04	**0.83**		-0.33	-0.23	-0.68	**0.66**	-0.08	0.18	0.45
23	-0.23	-0.16	0.10	0.08	-0.01	0.08	-0.29	-0.20	-0.21	-0.10	-0.14	-0.24	-0.04	-0.07	-0.09	0.13	-0.18	0.06	-0.15	0.05	-0.11	-0.25		**0.79**	**0.81**	**-0.81**	**0.76**	0.04	-0.42
24	-0.23	-0.17	-0.09	0.07	0.00	0.08	-0.30	-0.17	0.07	-0.11	-0.39	-0.10	0.26	0.19	-0.24	0.01	-0.06	-0.41	-0.46	0.11	-0.13	-0.27	0.47		**0.57**	**-0.65**	**0.61**	-0.32	-0.42
25	-0.28	-0.25	-0.01	-0.01	-0.15	0.01	-0.04	0.09	-0.01	-0.05	-0.27	-0.17	0.16	-0.06	-0.13	0.02	-0.14	-0.02	-0.37	-0.09	-0.24	-0.41	**0.76**	**0.72**		**-0.86**	**0.70**	0.10	-0.49
26	0.05	-0.05	-0.20	0.08	0.03	0.01	-0.08	-0.18	0.13	0.08	0.28	0.45	0.43	0.39	-0.15	0.33	-0.01	-0.17	0.21	-0.40	**0.68**	**0.51**	-0.28	-0.28	-0.39		**-0.65**	0.17	**0.72**
27	-0.34	-0.13	-0.06	0.05	-0.01	0.11	-0.30	-0.11	0.07	-0.05	-0.36	-0.01	0.16	0.19	-0.35	0.08	-0.16	-0.35	**-0.50**	0.22	-0.19	-0.29	**0.52**	**0.62**	**0.63**	-0.43		0.05	-0.24
28																													0.29

Appendix E: Table E2 Covariate selection procedure for closely related variables for each predator group based on AIC_c (AIC corrected for small samples). $wAIC_c$, AIC_c weigths; Pr(>|z|) significance level from the generalized linear models; CoastDev50km, coastal development within 50 km; PopDen50km, number of humans within 50 km; PopDenclstowns, number of humans in the closest population center; CultLand50km, area of cultivated land within 50 km; DistPop, minimum distance to nearest population center; SSTmin, average monthly minimum sea surface temperature; SST, average sea surface temperature; ReefArea5km(10km), reef area within 5 and 10 km; MangrvPer5km(10km), mangrove perimeter within 5 and 10 km.

All Sites	Predators			Apex predators			Pisc-Invertivores		
Covariate	AICc	wAICc	Pr(>|z|)	AIC_c	$wAIC_c$	Pr(>|z|)	AIC_c	$wAIC_c$	Pr(>|z|)
CoastDev50km	670.4	**1**	***	767.6	**1**	***	634.5	**0.97**	***
PopDen50km	684.3	0	***	791.1	0	***	641.4	0.03	***
PopDenclstowns	710.7	0	***	819.5	0	***	661.8	0	**
CulLand50km	711.1	0	***	798.9	0	***	666.0	0	*
DistPop	725.2	0	ns	842.1	0	ns	669.3	0	ns
SSTmin	686.8	**0.96**	***	812.2	**0.93**	***	641.0	**0.68**	***
SST	693.4	0.04	***	817.4	0.07	***	642.0	0.38	***
ReefArea5km	713.7	**0.96**	***	835.8	**0.62**	*	658.9	**0.98**	***
ReefArea10km	720.3	0.04	*	836.7	0.38	*	666.2	0.02	.
MangrvPer5km	719.6	**0.79**	*	817.3	**1**	***	668.4	**0.60**	ns
MangrvPer10km	722.3	0.21	.	829.1	0	***	669.3	0.40	ns

Reserves (NTZ)	Predators			Apex predators			Pisc-Invertivores		
Covariate	AICc	wAICc	Pr(>|z|)	AIC_c	$wAIC_c$	Pr(>|z|)	AIC_c	$wAIC_c$	Pr(>|z|)
CoastDev50km	218.7	**0.22**	***	276.6	**0.26**	***	206.3	0.16	***
PopDen50km	216.2	**0.75**	***	280.3	0.04	***	203.2	**0.74**	***
CulLand50km	223.4	0.02	***	274.6	**0.69**	***	212.0	0.01	***
DistPop	225.2	0.01	***	291.1	0	***	207.5	0.09	*
PopDenclstowns	230.3	0	**	294.7	0	***	212.5	0.01	*
SSTmin	239.7	0.51	ns	306.4	0.20	ns	218.1	0.53	ns
SST	239.8	0.49	ns	303.6	0.80	.	218.3	0.38	ns
ReefArea5km	239.2	0.39	ns	306.4	0.49	ns	218.0	0.30	ns
ReefArea10km	240.1	0.61	ns	306.3	0.51	ns	216.3	0.70	ns
MangrvPer5km	239.5	0.60	ns	297.5	**0.77**	**	218.5	0.34	ns
MangrvPer10km	240.3	0.40	ns	299.9	0.23	*	217.2	0.66	ns

*Significance codes: 0 '***' , 0.001 '**' , 0.01 '*' , 0.05 '.', non-significant 'ns'*

Appendix F Analysis and R code to predict total predator biomass in the absence of humans considering all sites as no fishing areas based on the best explanatory model from Table 1. Note that all numerical predictors were standardized and centered before model run. Some predictors were log transformed to improve model fit.

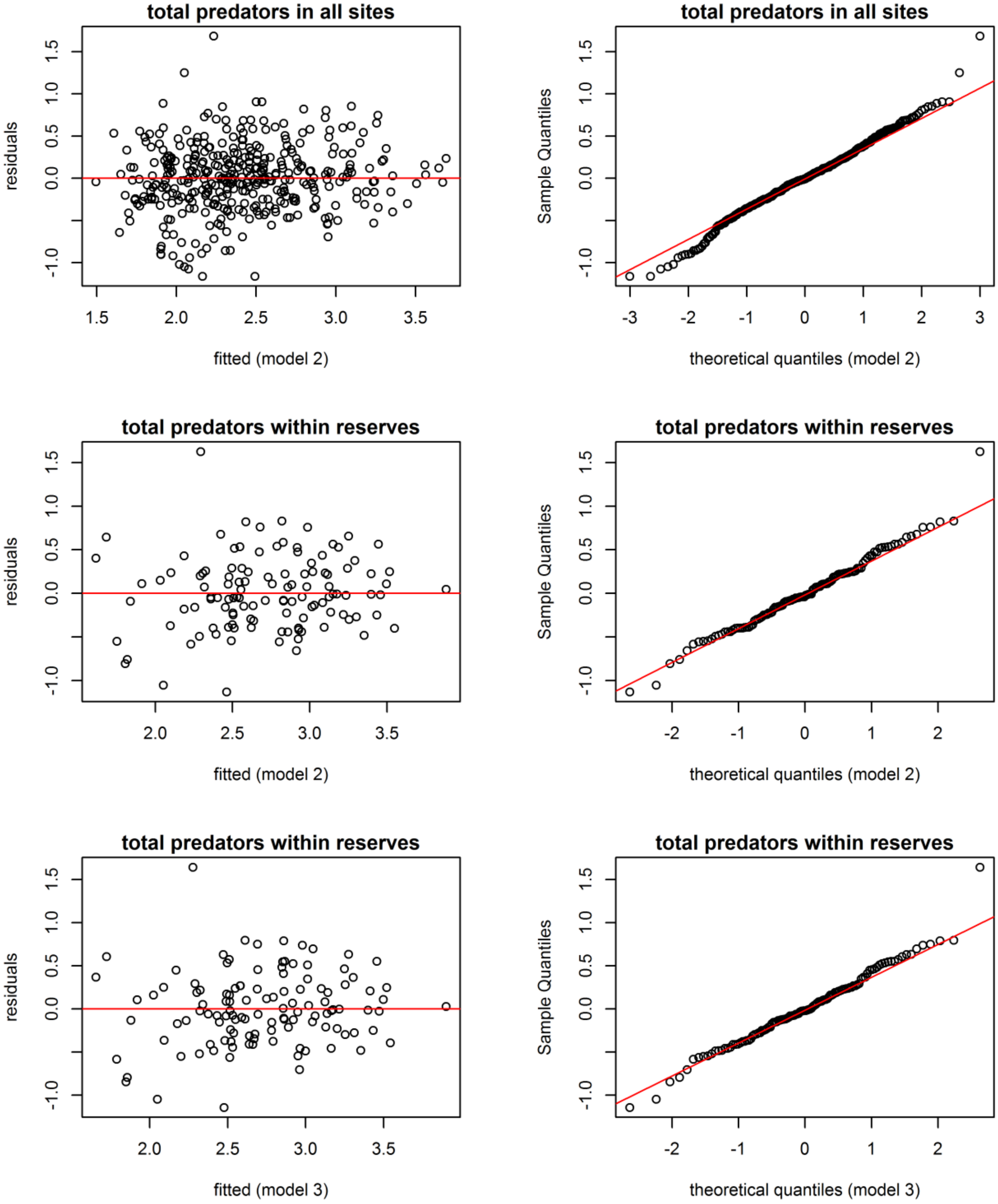
```
# Top model for total predatory fish biomass

modelPR.final <- glmer(log(Predators+1) ~ log(CoastDev50km) + I(SSTmin^2) +
                    Rugosity + Coral + Gorgonian + log(Invertivore) + log(Omnivore) +
                    log(Planktivore) +  log(Herbivore) + Protection.level +
                    (1|Year/Region/Site.Code), na.action=na.omit,
                    Data = fishcoral, family= Gaussian ("log"), nAGQ=1L)
summary (modelPR.final)
```

```
Generalized linear mixed model fit by maximum likelihood (Laplace Approximati
on) [glmerMod]

Family: gaussian ( log )
Formula: Predators.log ~ log(CoastDev50km) + I(SSTmin.s^2) + Rugosity.s +
    Coral.s + Gorgonian.s + scale(Invert.log) + scale(Herbivore.log) +
    scale(Omniv.log) + scale(Planktivore.log) + (1 | Year/Region/Site.Code) +
    Protection.Level
    Data: fishcoral

     AIC      BIC   logLik deviance df.resid
   462.3    525.1   -215.2    430.3      358

Scaled residuals:
    Min      1Q  Median      3Q     Max
-2.7773 -0.5935 -0.0186  0.5598  4.0192

Random effects:
 Groups                  Name        Variance  Std.Dev.
 Site.Code:(Region:Year) (Intercept) 4.769e-03 0.0690604
 Region:Year             (Intercept) 8.772e-07 0.0009366
 Year                    (Intercept) 7.373e-04 0.0271531
 Residual                            1.757e-01 0.4191577
Number of obs: 374, groups: Site.Code:(Region:Year), 62; Region:Year, 14; Yea
r, 3

Fixed effects:
                        Estimate Std. Error t value Pr(>|z|)
(Intercept)             0.847396   0.040077  21.144  < 2e-16 ***
CoastDev50km.s         -0.073770   0.019775  -3.730 0.000191 ***
I(SSTmin.s^2)           0.019078   0.012005   1.589 0.112022
Rugosity.s              0.047850   0.016361   2.925 0.003448 **
Coral.s                -0.026879   0.012604  -2.133 0.032963 *
Gorgonian.s            -0.024912   0.012930  -1.927 0.054013 .
scale(Invert.log)       0.039759   0.010812   3.677 0.000236 ***
scale(Herbivore.log)    0.021963   0.011721   1.874 0.060962 .
scale(Omniv.log)        0.033216   0.010522   3.157 0.001595 **
scale(Planktivore.log)  0.011406   0.011098   1.028 0.304087
Protection.LevelMPA    -0.163262   0.053497  -3.052 0.002275 **
Protection.LevelNTZ     0.004572   0.042879   0.107 0.915090
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

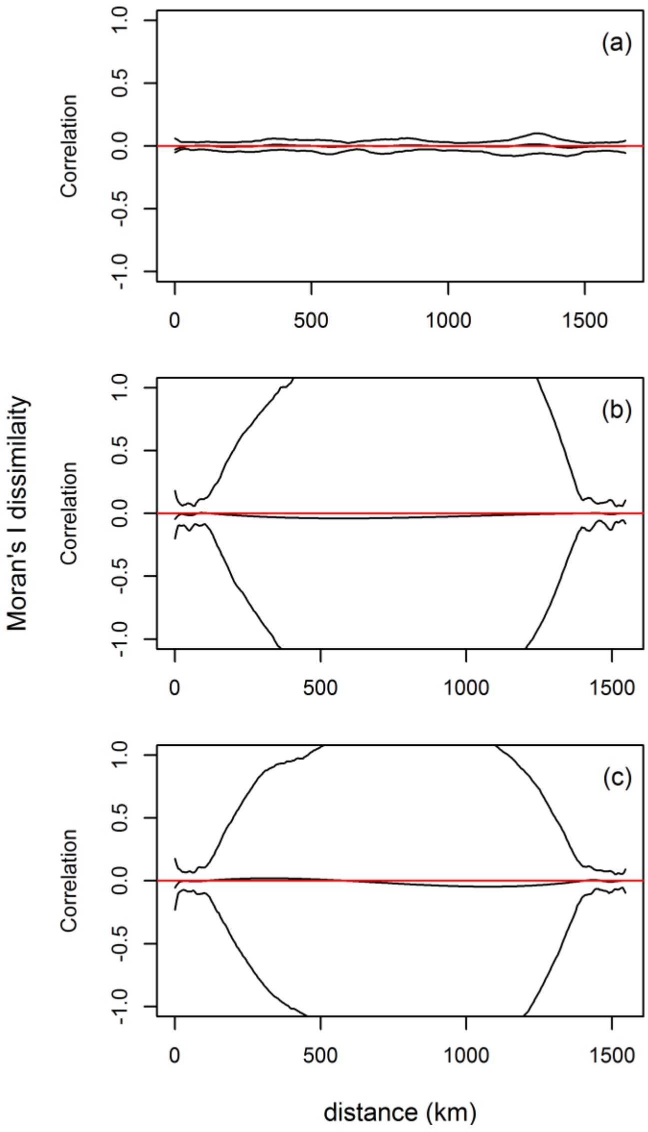
```
#Calculate prediction when coastal development is zero and all sites are NTZ
```

```
prediction <- predict(modelPR.final, newdata = data.frame(
        LightInt50km.s = 0*fishcoral$LightInt50km.s,
        SSTmin.s= fishcoral$SSTmin.s,
        Rugosity.s = fishcoral$Rugosity.s,
        Coral.s= fishcoral$Coral.s,
        Gorgonian.s= fishcoral$Gorgonian.s,
        Invert.log = fishcoral$Invert.log,
        Herbivore.log = fishcoral$Herbivore.log,
        Omniv.log= fishcoral$Omniv.log,
        Planktivore.log = fishcoral$Planktivore.log,
        Protection.Level = recode(fishcoral$Protection.Level,"'none'='NTZ';'MPA'='NTZ'"),
        Site.Code = fishcoral$Site.Code,
        Region= fishcoral$Region,
        Year = fishcoral$Year),
        type ="response", se.fit=TRUE, na.action = na.omit)


#Convert predicted values to biomass values since predator biomass was log10(x+1) transformed

        fishcoral$Predicted.predators=(10^(prediction)-1)
```

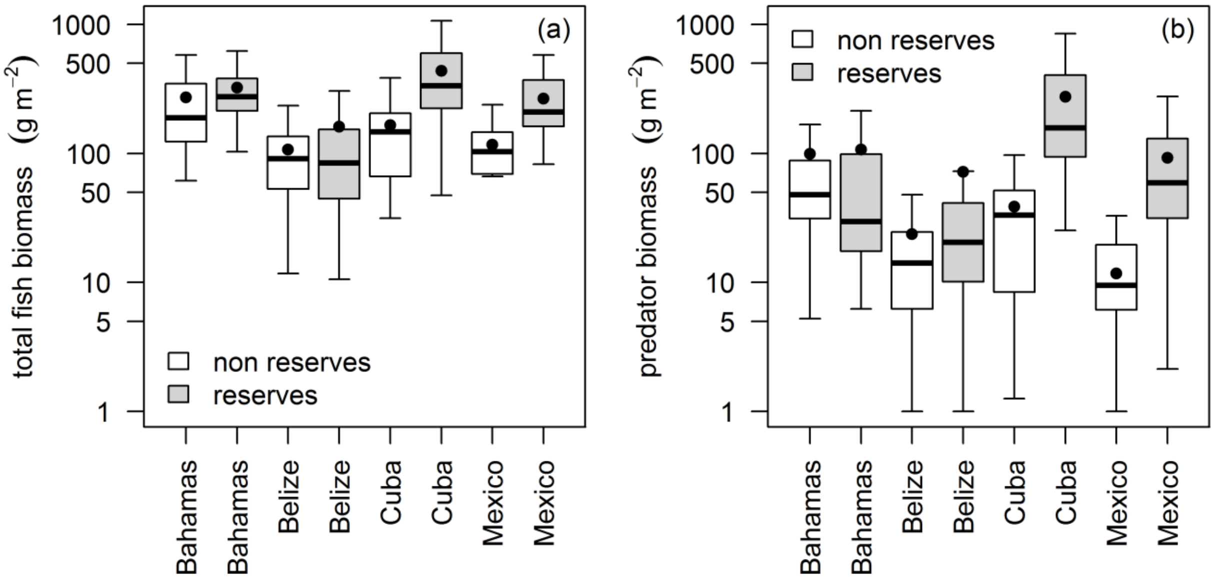
Appendix G Figure G1 Plots of residuals vs. fitted values (left panels) and normal scores of standardized residual deviance (right panels) for the final models (Set A and B) of total predator biomass. The plots for apex predators and piscivore-invertivores are not shown because the patterns are similar to total predators. See Table 1 for model details.



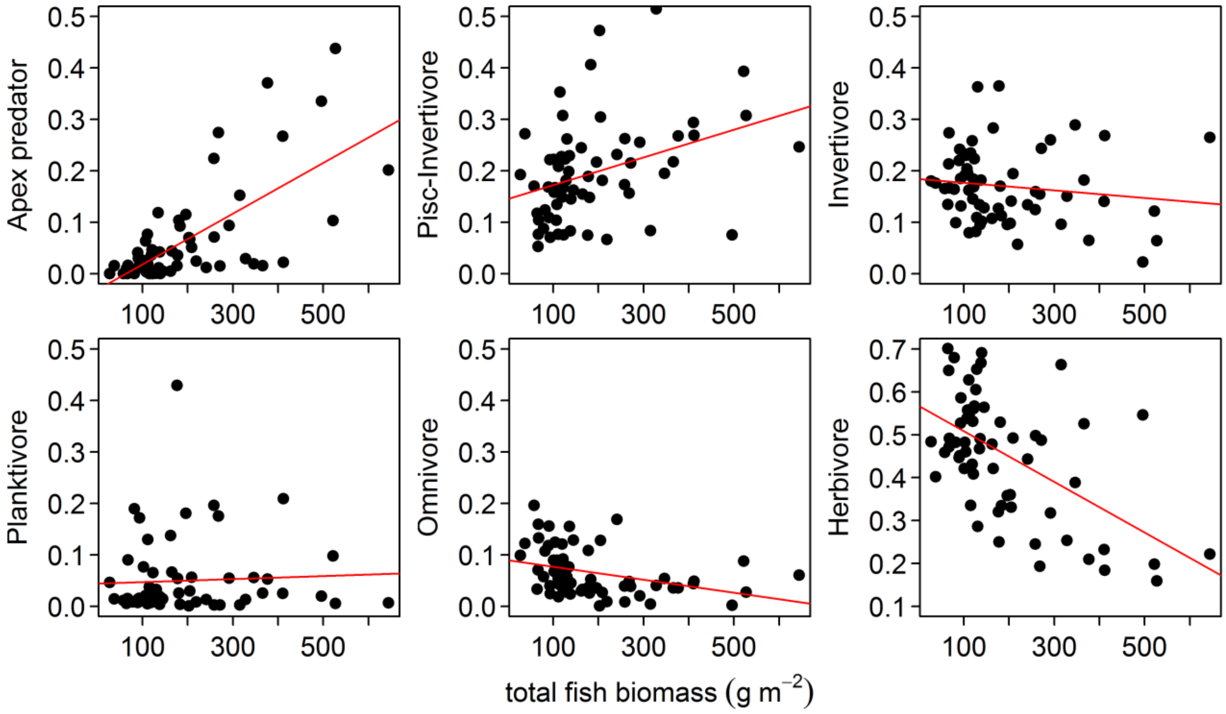
Appendix G Figure G2 Plots of the spline correlogram function against distance. The spline correlogram is based on the residuals of the final models for total predators in all sites (a) and for two selected models within marine reserves (b and c). See Table 1 for models. The plots for apex predators and piscivore-invertivores show similar patterns and are not shown. A 95% pointwise confidence envelope is superimposed.



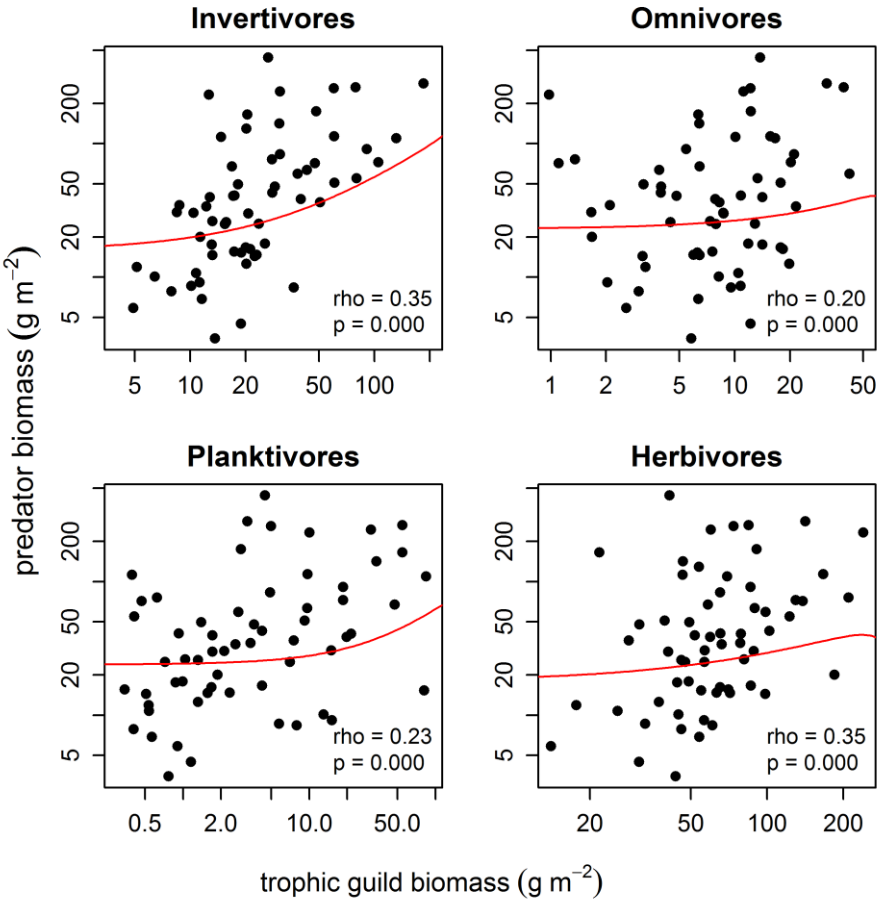
Appendix H: Figure H1 Boxplot of total fish (a) and predator biomass (b) by country and protection level. White boxes are non-reserve whereas grey boxes are reserves. Black points represent the pooled means by site and year of survey for each country. Dry Tortugas is excluded because does not have a non-reserve site.



Appendix H: Figure H2 Scatterplots of the mean proportion of trophic guilds per site and survey year. Red line is the best fit from a linear model. Note that higher total fish biomass is driven by higher proportion of apex predators and piscivore-invertivores, while lower total fish biomass is comprise mostly (> 0.55) of herbivores.



Appendix H: Figure H3 Scatterplots of the mean biomass of predators (apex predator + piscivores-invertivore) and lower trophic guilds across sites. The Spearman's rank correlation coefficient (rho) and the significance probability (p) are shown. Red lines are loess smoothing curve with a span width of 3 in each panel to aid visual interpretation. Axes are in log scale.



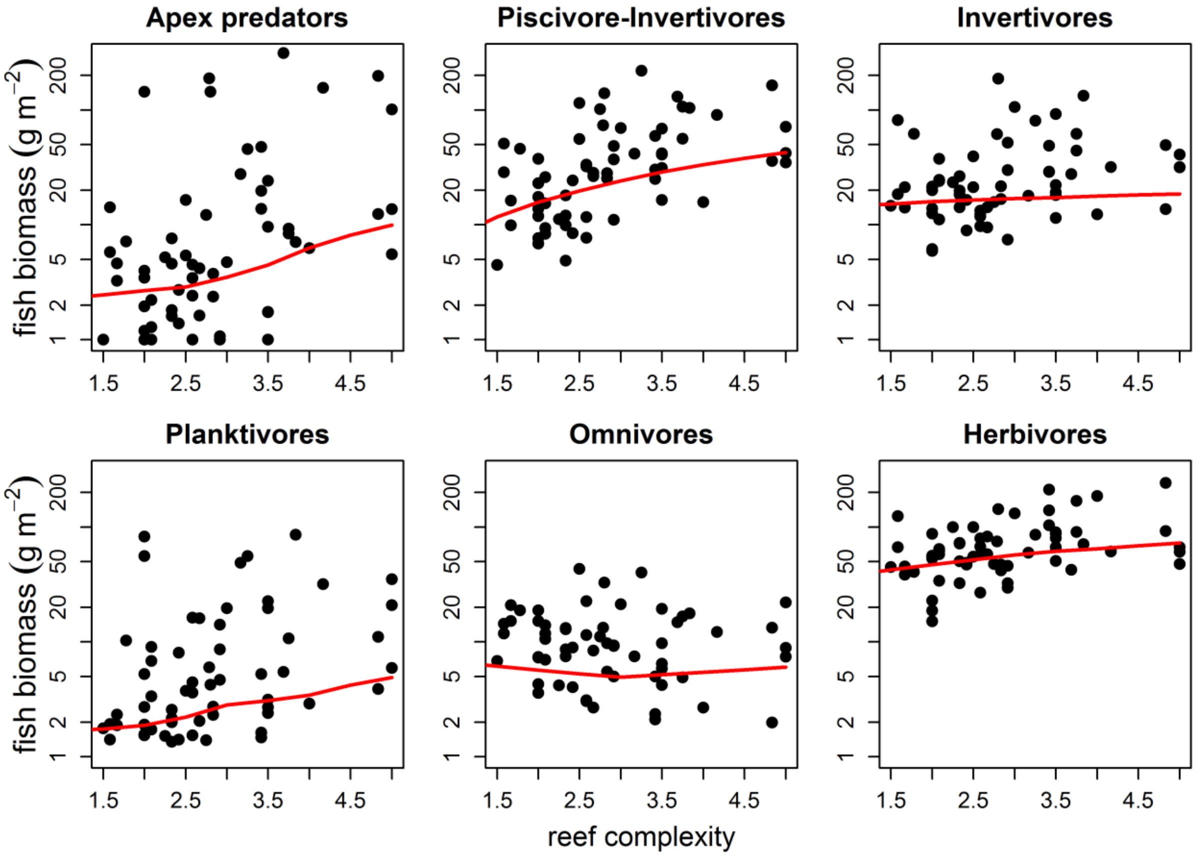
Appendix I Detailed description of reef fish biomass variability

The combined average of total fish biomass in the marine reserves of Abaco, Cuba and Mexico (337 ± 25 g m^{-2}) was 1.6 times higher than in the unprotected reefs of these sub-regions (215 ± 20 g m^{-2}, $p<0.001$). Similarly, the combined predator biomass in reserves of Abaco, Cuba and Mexico (154 ± 22 g m^{-2}) was 2.4 times greater than the combined value of their unprotected sites (65 ± 10 g m^{-2}, $p<0.001$). We found no significant difference in the combined total fish or predator biomass inside and outside marine reserves of Abaco ($p = 0.44$, $p = 0.68$, respectively), or in Belize ($p = 0.78$, $p = 0.94$, respectively). However, reef sites inside the marine reserves of Hol Chan (HC) and Half Moon Caye (HM) had the highest fish and predator biomass within Belize (Fig. 2). Yet the highest total fish biomass found in Belize at HM (212 ± 14 g m^{-2}) was comparable with the combined average of the unprotected sites in the rest of the sub-regions (~215 ± 20 g m^{-2}). The combined total fish biomass for Belize (118 ± 8 g m^{-2}) was 1.8 times lower than in the unprotected sites of Abaco, Cuba and Mexico ($p<0.01$, Fig. 2, Fig. H1). Finally, most sites in the marine reserves of Abaco, Cuba and Mexico had average total fish biomass >200 g m^{-2} and predator biomass >100 g m^{-2} (Fig. 2, Fig. H2).

The proportion trend of trophic groups within the fish assemblages varied across reef sites (Fig. 2, Fig. H2). The proportion of apex predators and piscivore-invertivores increased with increased total fish biomass from 0% to ~22% ($r_s = 0.67$, $p < 0.001$) and from ~15% to ~35% ($r_s = 0.58$, $p < 0.001$), respectively (Fig. H2). In combination, the proportion of predators increased from ~13% to ~55% ($r_s = 0.76$, $p < 0.001$) with increased total fish biomass. Invertivores, planktivores and omnivores did not follow a clear pattern with increased total fish biomass and each group represented less than 20% of the total biomass at most sites. In contrast, the proportional trend of herbivores decreased from ~55% to ~20% ($r_s = -0.58$, $p < 0.001$) with increased total fish biomass (Fig. H2).

The biomass of invertivores, omnivores, planktivores, and herbivores were slightly but significantly and positively correlated with total predator biomass (Fig. H3). This relationship was relatively stronger and less variable for invertivores and herbivores ($r_s = 0.35$, $p = 0.000$), but weaker and more variable for planktivores and herbivores ($r_s = 0.20\text{-}0.23$, $p \sim 0.000$) (Fig. H3).

Appendix J Relationship between reef structural complexity and fish trophic guilds. Red lines are loess smoothing curve with a span width of 3 in each panel to aid visual interpretation. Y axis is in log scale. Reef complexity is described in Appendix D.



Appendix K Detailed discussion of the relationships between predatory fish biomass and cofactors and their potential underlying mechanisms

Ocean productivity had a small positive effect on apex predator biomass. Large predators have been related with quantity and quality of primary production in terrestrial ecosystems (e.g., Serengeti in Africa, Hopcraft et al. 2010). In marine ecosystems, the positive indirect effect of ocean productivity on teleost biomass has been tested theoretically (Jennings et al. 2008) and empirically (Chassot et al. 2010) at global scales, and is probably driven by bottom-up increases of prey populations (Frank et al. 2007). The observed weak connection of apex predators with ocean productivity may not be through increasing reef fish prey, as they did not respond to primary productivity (Fig. 3). Instead, mobile apex predators, such as reef sharks and jacks, may also be feeding upon prey directly linked with ocean productivity via plankton in adjacent oceanic waters (McCauley et al. 2012).

Reef complexity was one of the most important predictors of fish predator biomass. This variable has a strong positive influence on the relative abundance, species richness, and local distribution of small and medium-sized fishes (e.g., 10-30 cm TL) (Wilson et al. 2007, Graham and Nash 2013). As reef complexity increases, refuges become more available to avoid predation and competition (Hixon and Beets 1993). In contrast, less clear is the relationship between landscape reef complexity and the density of large-bodied reef fish (Richards et al. 2012) or reef sharks (Nadon et al. 2012). Large transient predators that actively chase their prey may avoid highly complex environments that reduce hunting efficiency (Hixon and Beets 1993). Conversely, sites with higher structural complexity may attract relative large resident and transient predators that take advantage of greater prey availability (McCauley et al. 2012). Reef tridimensional structure complexity is nonetheless crucial to enhance predatory fish biomass and may be further compromised by the Caribbean-wide reduction of architectural complexity (Alvarez-Filip et al. 2009).

Several physical and biotic cofactors, such as “ocean temperature”, “coral cover”, “gorgonian abundance”, and herbivore and planktivore biomass did not have a significant effect on predator biomass; however, they improved model fit and may be important to support predator biomass within regions. Ocean temperature, for example, showed a weak “unimodal” response on the biomass of piscivore-invertivores. Non-linear relationship between the diversity of pelagic fish predators and temperature has been observed at a global scale (Worm et al. 2005). However, a clear response to temperature by an entire trophic level may be difficult to detect as the response to temperature gradients is species-specific through physiological constraints that affect individual biomass (Jennings et al. 2008, Munday et al. 2008).

Mangrove was a predictor of apex predator biomass, but unexpectedly not of piscivore-invertivores. Reefs associated with mangrove habitats have been reported to support more species, and higher density and biomass of reef fishes, including greater prey biomass for piscivore predators (Nagelkerken et al. 2002, Mumby et al. 2004). Mangroves also provide protection and high-quality nursery grounds for juveniles of top predator teleosts (e.g., *Sphyraena barracuda*, Nagelkerken et al. 2002) and sharks (e.g., *Negaprion brevirostris*, Chapman et al. 2009) that later may migrate as adults to adjacent reef habitats (Mumby et al. 2004). Piscivore-invertivores in our study included several species with strong mangrove association (e.g., most *Lutjanus* spp., see Mumby *et al.* 2004), but other species with a weak connection with mangroves (e.g., *Lutjanus mahogoni,* see Nagelkerken *et al.* 2002) may dilute the average response of the trophic guild. Further research will be needed to identify those species with tight connections with mangrove across our sites, but such endeavor was not objective in this paper.

Lower trophic levels were good predictors of total predator biomass, especially for piscivore-invertivores (Table 1, Fig. 3). We found no evidence of top-down regulation at a regional scale. In fact, the higher the biomass of lower trophic levels, the greater the biomass of predators tended to be. Predator dependence on prey, for example, is common within large reserves of terrestrial savannas and woodland ecosystems (Jhala et al. 2008, Sinclair et al. 2010). Positive associations among reef fish trophic guilds also increase as fishing pressure decreases with protection (Newman et al. 2006, Babcock et al. 2010). Since reef predators are often generalists with opportunistic feeding habits, preying upon several trophic levels including their own, predation pressure may be distributed across levels (Russ and Alcala 2003). Alternatively, subsistence fishing in the Caribbean has simultaneously targeted and depleted all trophic levels potentially overriding predator-prey interactions at regional scale (Hawkins and Roberts 2004, Paddack et al. 2009).

References

Alvarez-Filip, L., N. K. Dulvy, J. A. Gill, I. M. Côté, and A. R. Watkinson. 2009. Flattening of Caribbean coral reefs: region-wide declines in architectural complexity. Proceedings of the Royal Society B: Biological Sciences 276:3019–3025.

Alvarez-Filip, L., J. A. Gill, and N. K. Dulvy. 2011. Complex reef architecture supports more small-bodied fishes and longer food chains on Caribbean reefs. Ecosphere 2:art118.

Babcock, R. C., N. T. Shears, A. C. Alcala, N. S. Barrett, G. J. Edgar, K. D. Lafferty, T. R. McClanahan, and G. R. Russ. 2010. Decadal trends in marine reserves reveal differential rates of change in direct and indirect effects. Proceedings of the National Academy of Sciences 107:18256 –18261.

Behrenfeld, M. J., and P. G. Falkowski. 1997. Photosynthetic rates derived from satellite-based chlorophyll concentration. Limnology and oceanography:1–20.

Carleton, J. H., and T. J. Done. 1995. Quantitative video sampling of coral reef benthos: large-scale application. Coral Reefs 14:35–46.

Casey, K. S., T. B. Brandon, P. Cornillon, and R. Evans. 2010. The past, present, and future of the AVHRR pathfinder SST program. Pages 273–287 *in* V. Barale, J. F. R. Gower, and L. Alberotanza, editors. Oceanography from Space. Springer Netherlands, Dordrecht.

Chapman, D., E. A. Babcock, S. H. Gruber, J. Dibattista, B. Franks, S. Kessel, T. Guttridge, E. K. Pikitch, and K. A. Feldheim. 2009. Long-term natal site-fidelity by immature lemon sharks (*Negaprion brevirostris*) at a subtropical island. Molecular Ecology 18:3500–3507.

Chassot, E., S. Bonhommeau, N. K. Dulvy, F. Mélin, R. Watson, D. Gascuel, and O. Le Pape. 2010. Global marine primary production constrains fisheries catches. Ecology Letters 13:495–505.

Chollett, I., and P. J. Mumby. 2012. Predicting the distribution of Montastraea reefs using wave exposure. Coral Reefs 31:493–503.

Chollett, I., P. J. Mumby, F. E. Müller-Karger, and C. Hu. 2012. Physical environments of the Caribbean Sea. Limnology and Oceanography 57:1233–1244.

Claudet, J., C. W. Osenberg, L. Benedetti-Cecchi, P. Domenici, J.-A. García-Charton, Á. Pérez-Ruzafa, F. Badalamenti, J. Bayle-Sempere, A. Brito, F. Bulleri, J.-M. Culioli, M. Dimech, J. M. Falcón, I. Guala, M. Milazzo, J. Sánchez-Meca, P. J. Somerfield, B. Stobart, F. Vandeperre, C. Valle, and S. Planes. 2008. Marine reserves: size and age do matter. Ecology Letters 11:481–489.

Côté, I. M., I. Mosqueira, and J. D. Reynolds. 2001. Effects of marine reserve characteristics on the protection of fish populations: a meta-analysis. Journal of Fish Biology 59:178–189.

Frank, K. T., B. Petrie, and N. L. Shackell. 2007. The ups and downs of trophic control in continental shelf ecosystems. Trends in Ecology & Evolution 22:236–242.

Friedlander, A. M., E. K. Brown, P. L. Jokiel, W. R. Smith, and K. S. Rodgers. 2003. Effects of habitat, wave exposure, and marine protected area status on coral reef fish assemblages in the Hawaiian archipelago. Coral Reefs 22:291–305.

Fulton, C. J., and D. R. Bellwood. 2004. Wave exposure, swimming performance, and the structure of tropical and temperate reef fish assemblages. Marine Biology 144:429–437.

GLC. 2003. Global Land Cover 2000 Project. http://bioval.jrc.ec.europa.eu/products/glc2000/products.php.

Global Distribution of Mangrove USGS. 2011. Global distribution of mangrove USGS. http://data.unep-wcmc.org/datasets/21.

Graham, N. A. J., and K. L. Nash. 2013. The importance of structural complexity in coral reef ecosystems. Coral Reefs 32:315–326.

Halpern, B. S. 2003. The impact of marine reserves: do reserves work and does reserve size matter? Ecological Applications 13:117–137.

Harborne, A. R., P. J. Mumby, K. Żychaluk, J. D. Hedley, and P. G. Blackwell. 2011. Modeling the beta diversity of coral reefs. Ecology 87:2871–2881.

Hawkins, J. P., and C. M. Roberts. 2004. Effects of artisanal fishing on Caribbean coral reefs. Conservation Biology 18:215–226.

Hixon, M. A., and J. P. Beets. 1993. Predation, prey refuges, and the structure of coral-reef fish assemblages. Ecological Monographs 63:77–101.

Hopcraft, J. G. C., H. Olff, and A. R. E. Sinclair. 2010. Herbivores, resources and risks: alternating regulation along primary environmental gradients in savannas. Trends in Ecology & Evolution 25:119–128.

Jennings, S., F. Mélin, J. L. Blanchard, R. M. Forster, N. K. Dulvy, and R. W. Wilson. 2008. Global-scale predictions of community and ecosystem properties from simple ecological theory. Proceedings of the Royal Society B: Biological Sciences 275:1375–1383.

Jhala, Y. V., R. Gopal, and Q. Qureshi. 2008. Status of tigers, co-predators and prey in India. National Tiger Conservation Authority, Govt., of India, New Delhi and Wildlife Institute of India, Dehradun. TR 2011/003.

Kritzer, J. P. 2004. Effects of noncompliance on the success of alternative designs of marine protected-area networks for conservation and fisheries management. Conservation Biology 18:1021–1031.

Lang, J. C., K. W. Marks, P. A. Kramer, P. Richards Kramer, and R. N. Ginsburg. 2010. AGRRA Protocols version 5.4 Atlantic and Gulf Rapid Reef Assessment Program. University of Miami, Florida.

McCauley, D. J., H. S. Young, R. B. Dunbar, J. A. Estes, B. X. Semmens, and F. Micheli. 2012. Assessing the effects of large mobile predators on ecosystem connectivity. Ecological Applications 22:1711–1717.

McCook, L. J. 1999. Macroalgae, nutrients and phase shifts on coral reefs: scientific issues and management consequences for the Great Barrier Reef. Coral Reefs 18:357–367.

Mora, C., S. Andrèfouët, M. J. Costello, C. Kranenburg, A. Rollo, J. Veron, K. J. Gaston, and R. A. Myers. 2006. Coral reefs and the global network of marine protected areas. Science 312:1750–1751.

Mumby, P. J., A. J. Edwards, J. E. Arias-González, K. C. Lindeman, P. G. Blackwell, A. Gall, M. I. Gorczynska, A. R. Harborne, C. L. Pescod, H. Renken, C. C. C. Wabnitz, and G. Llewellyn. 2004. Mangroves enhance the biomass of coral reef fish communities in the Caribbean. Nature 427:533–536.

Munday, P. L., G. P. Jones, M. S. Pratchett, and A. J. Williams. 2008. Climate change and the future for coral reef fishes. Fish and Fisheries 9:261–285.

Nadon, M. O., J. K. Baum, I. D. Williams, J. M. Mcpherson, B. J. Zgliczynski, B. L. Richards, R. E. Schroeder, and R. E. Brainard. 2012. Re-creating missing population baselines for Pacific reef sharks. Conservation Biology 26:493–503.

Nagelkerken, I., C. M. Roberts, G. van der Velde, M. Dorenbosch, M. C. van Riel, E. C. de la Morinire, and P. H. Nienhuis. 2002. How important are mangroves and seagrass beds for coral-reef fish? The nursery hypothesis tested on an island scale. Marine Ecology Progress Series 244:299–305.

Newman, M. J. H., G. A. Paredes, E. Sala, and J. B. C. Jackson. 2006. Structure of Caribbean coral reef communities across a large gradient of fish biomass. Ecology Letters 9:1216–1227.

NOAA, (National Oceanic and Atmospheric Administration). 2013. The AVHRR Pathfinder Version 5.2 dataset. http://www.nodc.noaa.gov/SatelliteData/pathfinder4km/.

Oregon State University. 2013. Ocean Productivity: Online VGPM Data. http://orca.science.oregonstate.edu/1080.by.2160.monthly.hdf.vgpm.m.chl.m.sst4.php.

Paddack, M. J., J. D. Reynolds, C. Aguilar, R. S. Appeldoorn, J. Beets, E. W. Burkett, P. M. Chittaro, K. Clarke, R. Esteves, A. C. Fonseca, G. E. Forrester, A. M. Friedlander, J. García-Sais, G. González-Sansón, L. K. B. Jordan, D. B. McClellan, M. W. Miller, P. P. Molloy, P. J. Mumby, I. Nagelkerken, M. Nemeth, R. Navas-Camacho, J. Pitt, N. V. C. Polunin, M. C. Reyes-Nivia, D. R. Robertson, A. Rodríguez-Ramírez, E. Salas, S. R. Smith, R. E. Spieler, M. A. Steele, I. D.

Williams, C. L. Wormald, A. R. Watkinson, and I. M. Côté. 2009. Recent region-wide declines in Caribbean reef fish abundance. Current Biology 19:590–595.

Polunin, N. V. C., and C. M. Roberts. 1993. Greater biomass and value of target coral-reef fishes in two small Caribbean marine reserves. Marine Ecology Progress Series 100:177–183.

Richards, B. L., I. D. Williams, O. J. Vetter, and G. J. Williams. 2012. Environmental factors affecting large-bodied coral reef fish assemblages in the mariana archipelago. PLoS ONE 7:e31374.

Russ, G. R., and A. C. Alcala. 2003. Marine reserves: rates and patterns of recovery and decline of predatory fish, 1983-2000. Ecological Applications 13:1553–1565.

Sanderson, E., W., M. Jaitteh, M. Levy A., K. Redford H., A. Wannebo V., and G. Woolmer. 2002. The human footprint and the last of the Wild. BioScience 52:891–904.

Sinclair, A. R. E., K. Metzger, J. S. Brashares, A. Nkwabi, G. Sharam, J. M. Fryxell, J. Terborgh, and J. A. Estes. 2010. Trophic cascades in African savanna: Serengeti as a case study. Trophic cascades: predators, prey and the changing dynamics of nature, Island Press, Washington, DC, USA:255–274.

UNEP-WCMC, WorldFish Centre, WRI, and TNC. 2010. Global distribution of warm-water coral reefs, compiled from multiple sources, including the Millennium Coral Reef Mapping Project. UNEP World Conservation Monitoring Centre. Cambridge (UK). http://data.unep-wcmc.org/datasets/13.

Wenger, A. S., M. I. McCormick, I. M. McLeod, and G. P. Jones. 2013. Suspended sediment alters predator–prey interactions between two coral reef fishes. Coral Reefs 32:369–374.

Wilson, S., N. Graham, and N. Polunin. 2007. Appraisal of visual assessments of habitat complexity and benthic composition on coral reefs. Marine Biology 151:1069–1076.

Worm, B., M. Sandow, A. Oschlies, H. K. Lotze, and R. A. Myers. 2005. Global patterns of predator diversity in the open oceans. Science 309:1365–1369.

Appendix L Estimates of current and potential average biomass (± standard error, se) of predatory reef fishes in the absence of humans (i.e. coastal development) while categorizing every site as a no-take zone (i.e. no fishing). The potential percent lost is shown. Sites with exceptionally high predicted predator biomass are highlighted. Site order follows Fig. 5. For site codes refer to Appendix A.

Sites	Protection level	Current biomass		Predicted biomass		% lost
		mean	se	mean	se	
EB	None	3.5	1.3	81.8	8.7	95.8
NI	MPA	9.5	3.0	205.2	26.8	95.4
XA	None	9.1	4.7	147.0	16.4	93.8
SM	MPA	23.2	16.0	185.7	21.6	87.5
SW	MPA	8.5	2.0	194.0	14.1	95.6
CA	None	16.4	7.9	145.0	20.0	88.7
MR	None	10.7	4.1	119.7	10.1	91.1
BC	NTZ	10.1	3.0	124.7	5.7	91.9
MC	MPA	15.0	5.2	177.3	17.4	91.5
GH	None	14.4	2.9	229.2	33.3	93.7
RA	None	27.8	8.1	196.9	22.9	85.9
AL	None	15.9	2.9	199.1	21.8	92.0
ST	None	16.6	2.8	201.1	17.9	91.7
GA	None	32.8	11.4	287.7	37.1	88.6
HC	NTZ	85.4	67.7	222.5	53.8	61.6
PC	NTZ	88.2	38.4	502.0	76.9	82.4
TO	None	19.8	3.6	199.6	20.8	90.1
CP	None	28.3	7.3	214.9	20.9	86.8
PO	None	41.9	12.7	238.0	30.3	82.4
BCS	MPA	50.9	28.4	299.2	25.0	83.0
PZ	None	35.3	10.8	290.9	41.0	87.9
TB	None	71.9	39.5	295.1	86.6	75.6
MW	None	34.2	8.7	310.3	28.2	89.0
FC	NTZ	125.9	57.2	736.0	182.3	82.9
HM	NTZ	89.7	41.8	408.2	63.0	78.0
PB	NTZ	59.2	18.3	667.3	131.8	91.1
BR	None	67.2	28.4	480.4	38.1	86.0
LH	None	63.2	10.5	520.8	51.2	87.9
GC	None	47.7	7.7	471.3	58.9	89.9
CR	**NTZ**	**83.0**	**35.8**	**890.9**	**116.8**	**90.7**
BA	**None**	**72.3**	**21.7**	**826.7**	**150.1**	**91.3**
LG	NTZ	129.0	52.2	273.6	35.3	52.8
AN	NTZ	90.8	16.2	273.1	49.6	66.7
BCN	**MPA**	**109.3**	**16.3**	**1067.4**	**169.3**	**89.8**
RP	**None**	**268.6**	**73.4**	**1157.8**	**200.8**	**76.8**
EP	NTZ	263.6	77.5	505.8	103.2	47.9
BCC	**MPA**	**174.1**	**35.4**	**1562.0**	**308.5**	**88.9**
PP	NTZ	244.5	58.3	402.2	60.7	39.2
CF	NTZ	441.0	139.4	474.3	92.1	7.0