Electronic Supplementary Material (ESM)

Community-wide scan identifies fish species associated with coral reef services across the Indo-Pacific

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Additional information

Scales of data

Our data were organized at three spatial scales: reef site (n=1824), reef cluster (n=675), and nation/state (n=26).

i) Reef site (the smallest scale, which had an average of 2.6 surveys/transects - hereafter 'reef').

ii) Reef cluster (which had an average of 2.7 +/- 2.6 reef sites). Reefs within 4km of each other were clustered, and we used the centroid to estimate reef cluster-level socio-economic variables as described by Cinner *et al.* (2016) [1].

iii) Nation/state (nation, state, or territory, which had an average of 26 +/- 42 reef clusters). A larger scale in our analysis was 'nation/state', which are jurisdictions that generally correspond to individual nations (but could also include states, territories, overseas regions), within which reef sites and reef clusters were nested for analysis.

Coral reef services

We considered fish biomass and live coral cover as two proxies for coral reef services as support, among many others, food security, shoreline protection and recreational value [2-5]. Fish biomass and coral cover are already monitored at the global scale using visual censuses as well as underwater video surveys (e.g. Reef Life Survey, Catlin Sea Survey) and are highly sensitive to local human activities (e.g. fishing, habitat destruction, pollution) and global climate change [6] and thus, can be considered as key variables for the health and productivity of coral reefs [1, 7, 8].

Fish Biomass

Reef fish biomass estimates were based on instantaneous visual counts from 4,694 surveys collected from 1,824 reefs (Fig. S1). Surveys were carried out using two census methods (belt-transects or distance sampling) and were conducted between 2004 and 2013. On average 2.4 transects (sd=1.32; range: 1-10) were performed on each reef. Within each surveyed area, reef associated fishes were identified to species level, abundance was counted, and total length (TL) estimated.

To make estimates of biomass from these transect-level data comparable among studies, we:

i) Considered only Indo-Pacific reefs and retained families that were consistently included in surveys and were above a minimum size cut-off. Thus, we only retained counts of non-cryptic reef fish species >10cm in total length, that are reef-associated (30 families, 748 species) (Table S1). We did not include sharks as they were often excluded from visual surveys. We calculated total biomass of fishes on each reef using published species-level length-weight relationship parameters or those available on FishBase [39]. When length-weight relationship parameters were not available for a species, we used the parameters for a closely related species or genus.

ii) Depth and habitat were included as environmental variables in the model.

iii) Reef fish biomass estimates were based on instantaneous visual counts using belt-transects or distance sampling. Because several biases were associated with these two methods [9] and the total area of transects changed between locations, we included census method and sampling area as covariates in the model.

Biomass values were calculated at the reef scale and showed a high variability (mean=1,055 $kg.ha^{-1}$; range: 2-25,910 $kg.ha^{-1}$).

Live coral cover

Percent cover of live coral was based on 1,715 point-intercept transects or quadrats collected from 741 reefs (Fig. S2). All surveys were conducted between 2008 and 2013. On average 2.3 transects (sd=1.03; range: 1-4) were performed on each reef. To make estimates of coral cover from these transect-level data comparable among studies, we included depth, habitat and census method (which already different in the sampling area) as covariates in the model (see details in Supplementary Material).

Coral cover values were calculated at the reef scale and showed a high variability (mean=27%; range: 3-94%).

Socioeconomic variables

-Gravity of Human Populations: We used two gravity indices (the cumulative gravity of all cities within 500km and the gravity of the nearest human population) for each of our reefs where we had in situ ecological data because those had the strongest relationships with reef fish biomass as described in Cinner *et al.* (2016) [1].

-Management: For each reef, we determined if it was: i) marine reserve- whether it fell within the borders of a no-take marine reserve and we asked data providers to further classify whether the reserve had high or low levels of compliance; ii) restricted - whether there were active restrictions on gears (e.g. bans on the use of nets, spearguns, or traps) or fishing effort (which could have included areas inside marine protected areas that were not necessarily no take); or iii) fished - regularly fished without effective restrictions. To determine these classifications, we used the expert opinion of the data providers, and validated this with a global database of marine reserve boundaries [10].

-Local Human Population Growth: We created a 100km buffer around each reef cluster and used this to calculate human population within the buffer in 2000 and 2010 based on the Socioeconomic Data and Application Centre (SEDAC) gridded population of the world database. Population growth was the proportional difference between the population in 2000 and 2010. We chose a 100km buffer as a reasonable range at which many key human impacts from population (e.g., land-use and nutrients) might affect reefs [11].

-Human Development Index (HDI): HDI is a summary measure of human development encompassing: a long and healthy life, being knowledgeable, and having a decent standard of living. In cases where HDI values were not available specific to the State (e.g. Florida and Hawaii), we used the national (e.g. USA) HDI value.

-Population Size: For each nation/state, we determined the size of the human population. Data were derived mainly from census reports, the CIA fact book, and Wikipedia.

-Tourism: We examined tourist arrivals relative to the nation/state population size (above). Tourism arrivals were gathered primarily from the World Tourism Organization's Compendium of Tourism Statistics.

-National Reef Fish Landings: Catch data were obtained from the Sea Around Us Project (SAUP) catch database (www.seaaroundus.org), except for Florida, which was not reported separately in the database. We identified 200 reef fish species and taxon groups in the SAUP catch database to define landings in tons/km^2 of reef.

-Voice and Accountability: This metric, from the World Bank survey on governance, reflects the perceptions of the extent to which a country's citizens are able to participate in selecting their government, as well as freedom of expression, freedom of association, and a free media. In cases where governance values were not available specific to the Nation/state (e.g. Florida and Hawaii), we used national (e.g. USA) values.

Environmental variables

-Depth: The depth of reef surveys was grouped into the following categories: <4m, 4-10m, >10m to account for broad differences in reef fish community structure attributable to a number of inter-linked depth-related factors. Categories were necessary to standardize methods used by data providers and were determined by pre-existing categories used by several data providers.

-Habitat: We included the following habitat categories: i) Slope: The reef slope habitat is typically on the ocean side of a reef, where the reef slopes down into deeper water; ii) Crest: The reef crest habitat is the section that joins a reef slope to the reef flat. The zone is typified by high wave energy (i.e. where the waves break) and a change in the angle of the reef from an inclined slope to a horizontal reef flat; iii) Flat: The reef flat habitat is typically horizontal and extends back from the reef crest for 10’s to 100’s of meters; iv) Lagoon / back reef: Lagoonal reef habitats are where the continuous reef flat breaks up into more patchy reef environments sheltered from wave energy. These habitats can be behind barrier / fringing reefs or within atolls. Back reef habitats are similar broken habitats where the wave energy does not typically reach the reefs and thus forms a less continuous 'lagoon style' reef habitat.
For this analysis, we excluded other less prevalent habitat types (channels and banks) and we verified the sites’ habitat information using Google Earth, and site depth information.

-Productivity: We extracted oceanic productivity for each reef following the procedure described by Gove et al. (2013) [12]. We delimited a 100km buffer around each site, we removed shallow waters pixels (those that intersected or were contained within the depth contour of 30m from the General Bathymetric Chart of the Oceans 2014 (http://www.gebco.net/), a global gridded bathymetry dataset) and then calculated the average of monthly chlorophyll-a concentration (proxy for phytoplankton biomass) using data provided at a 4km-resolution by Aqua MODIS (Moderate Resolution Imaging Spectro-radiometer) for years 2005 to 2010 (in hdf format).

Analyses

We used linear mixed models to analyze biomass and live coral cover after checking that both log-transformed variables were normally distributed. For both models, we set site, regional locations and nation/state as random effects to account for the hierarchical nature of the data (i.e. reefs nested in sites, sites nested in regional locations and in nations/states). All continuous covariates were standardized for the analysis and their corresponding Akaike weights were computed to assess their importance (Table S2 & S3).

To check the fit of the linear mixed model, we checked for the representation of actual versus predicted values and we calculated the accuracy of the two models which came to 88% for biomass and 83% for coral cover. To examine homoscedasticity, we checked residuals against fitted values. We checked that the residuals were normally distributed. All analyses were undertaken using R (3.3) statistical packages.

Functional traits to describe fish species.

The 381 candidate fish species were functionally described using six traits extracted from Mouillot et al. (2014) [13]: (1) size, coded using 3 ordered categories: 10-30cm, 30.1-50cm, >50cm ; (2) mobility, coded using 3 ordered categories: sedentary, mobile within a reef and mobile between reefs; (3) period of activity, coded using 3 ordered categories: diurnal, both diurnal and nocturnal, and nocturnal ; (4) schooling, coded using 5 ordered categories: solitary, pairing, or living in small (3-20 individuals), medium (20-50 individuals) or large groups (>50 groups) ; (5) vertical position in the water column, coded using 3 ordered categories: benthic, bentho-pelagic and pelagic; (6) diet, coded using 7 trophic categories: herbivorous-detritivorous, macro-algal browser, invertivorous targeting sessile invertebrates, invertivorous targeting mobile invertebrates, planktivorous, piscivorous, and omnivorous, i.e. fish for which both plant and animal material are important in their diet. Since all traits were categorical, species with identical traits were grouped into functional entities.

Defining presence of species based on abundance threshold.

The community-wide scan (CWS) approach can be adapted for a wide range of taxa from all the ecosystems. The way candidates are tested can be modulated while respecting independence between predicted and explanatory variables (binary variables are a convenient way to test the effect of candidates). More specifically, presence of terrestrial or marine taxa can be determined using any convenient abundance threshold such as a minimum number of individuals, cover rate or biomass.

As an application, we tested two procedures to define presence of reef fish species based on a biomass threshold and compared key species found with those two procedures:

i) the relative intraspecific biomass which defines presence of a species in a community as soon as its biomass reaches upper percentiles of the distribution of biomass of this species over all studied communities. We used the 99^{th} and 95^{th} percentiles (the top 1 and 5%) of the biomass distribution over reef sites as thresholds. This approach is particularly relevant for species widely distributed with normal distribution of biomass while it may not be used for species infrequently encountered or with a skewed biomass distribution.

ii) the relative community biomass which defines presence as soon as the focal species reach a defined minimum percentage of the total biomass of the fish community. Hence, this approach is not affected by biomass distribution among sites. As two thresholds, we tested a contribution of species to total biomass in excess of 1 and 5%, respectively.

Figures and Tables

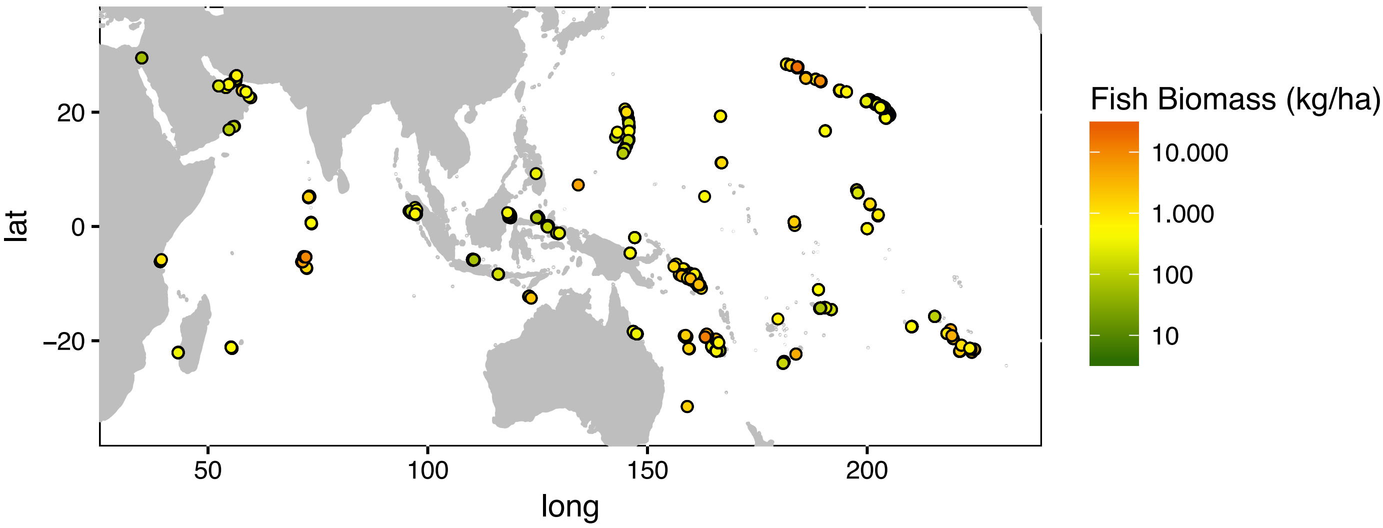

Figure S1. Map of the reef fish biomass observed in 1,824 reefs located in the Indo-Pacific.

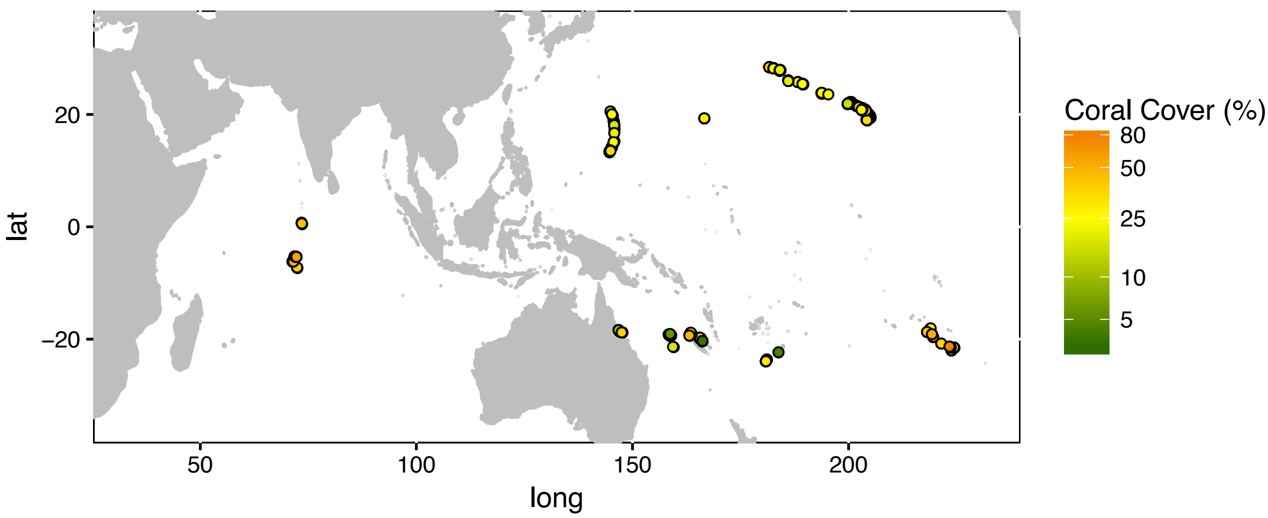

Figure S2. Map of the live coral cover observed in 741 reefs located in the Indo-Pacific. Information on coral cover was not available for all sites at which reef fish biomass was surveyed.

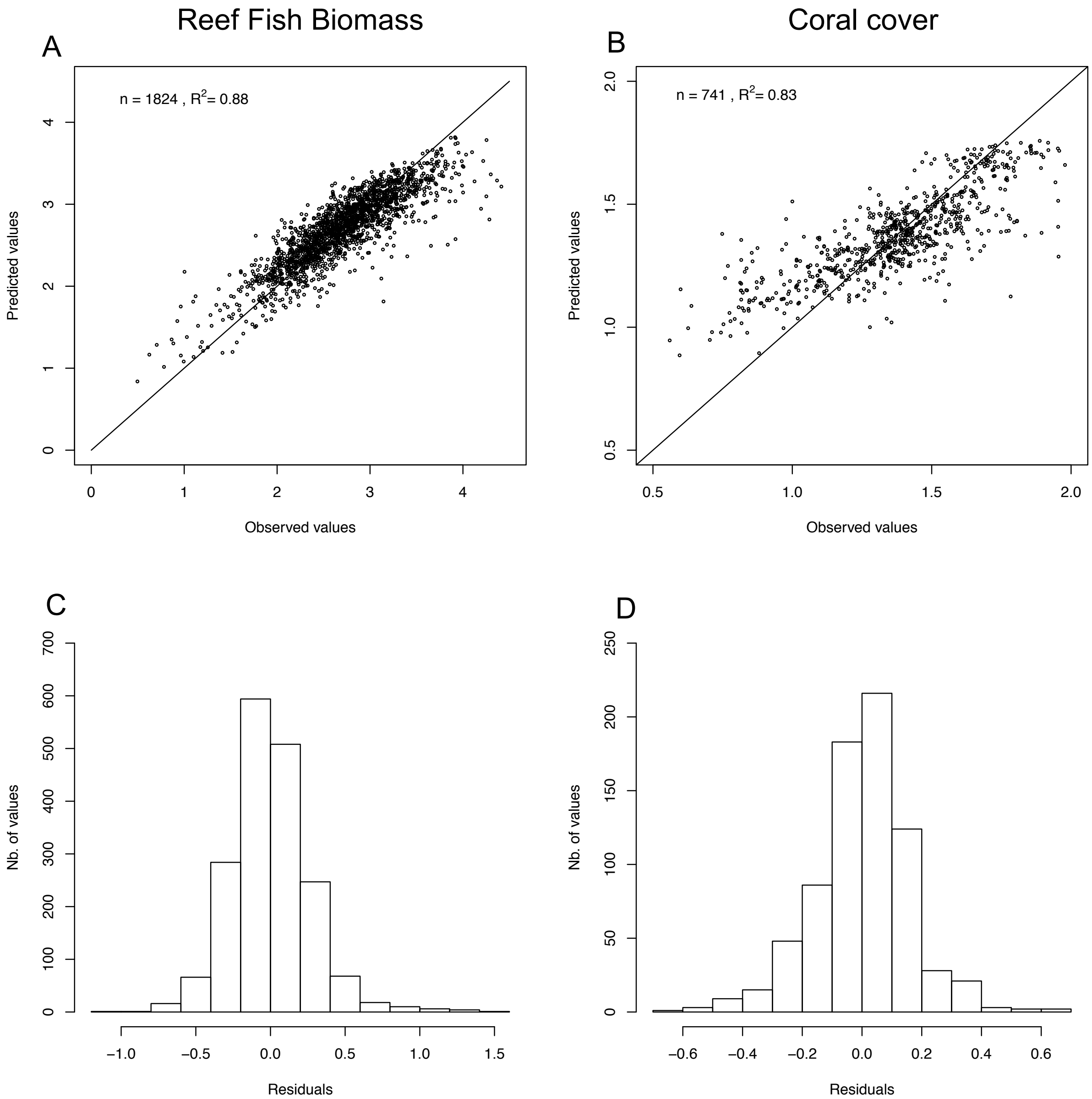

Figure S3. Accuracy and residuals of the two initial models (fish biomass and coral cover). The accuracy of each model is assessed using the Pearson correlation between predicted and observed values which came to 88% for biomass (A) and 83% for coral cover (B). We checked that residuals of the initial model of fish biomass (C) and coral cover (D) were normally distributed.

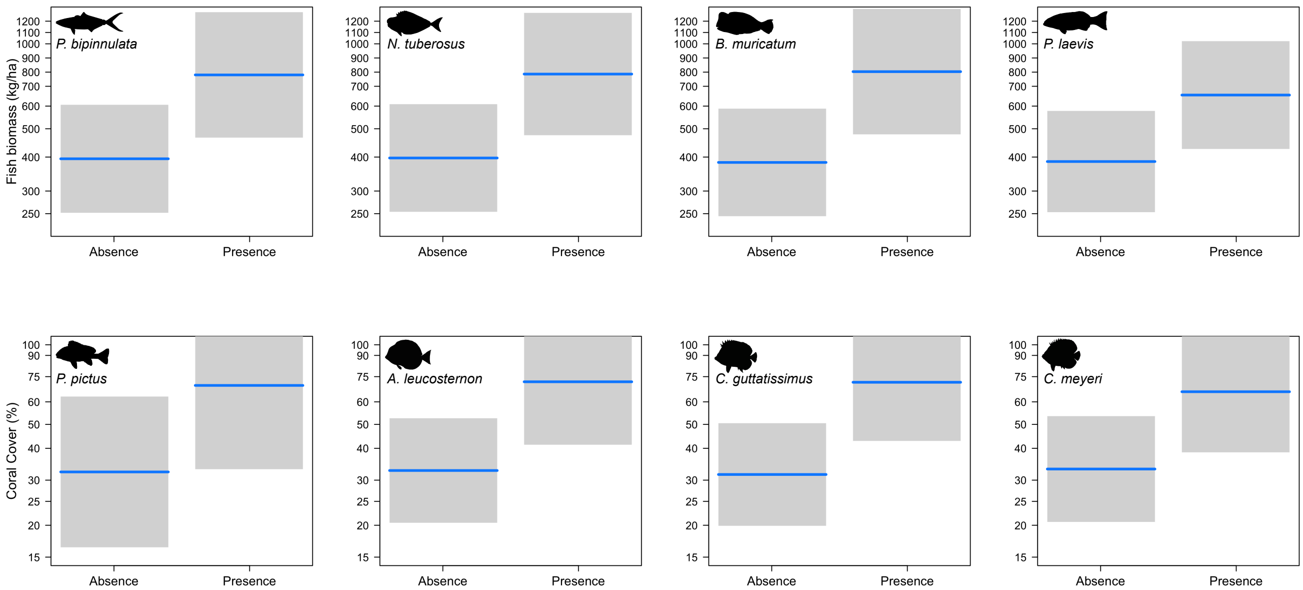

Figure S4. Net effect of the 4 key fish species linked to the highest levels of fish biomass (top) and live coral cover (bottom). We extracted the pure effects of all the key species and determined which were related to the highest levels of biomass and coral cover respectively, using a partial plot from each LMM while the other variables are held constant.

Table S1: List of coral reef fish families included in the study and their common name. Families included are: Acanthuridae, Balistidae, Caesionidae, Carangidae, Chaetodontidae, Cirrhitidae, Diodontidae, Ephippidae, Haemulidae, Holocentridae, Kyphosidae, Labridae, Lethrinidae, Lutjanidae, Monacanthidae, Mullidae, Nemipteridae, Pempheridae, Pinguipedidae, Pomacanthidae, Priacanthidae, Pseudochromidae, Scombridae, Serranidae, Siganidae, Sparidae, Sphyraenidae, Synodontidae, Tetraodontidae, Zanclidae.

Fish family	Common family name	Fish family	Common family name
Acanthuridae	Surgeonfishes	Mullidae	Goatfishes
Balistidae	Triggerfishes	Nemipteridae	Coral Breams
Caesionidae	Fusiliers	Pempheridae	Sweepers
Carangidae	Jacks/Trevallies	Pinguipedidae	Sandperches
Chaetodontidae	Butterflyfishes	Pomacanthidae	Angelfishes
Cirrhitidae	Hawkfishes	Priacanthidae	Bigeyes
Diodontidae	Porcupinefishes	Pseudochromidae	Dottybacks
Ephippidae	Batfishes	Scombridae	Mackerels and Tunas
Haemulidae	Sweetlips	Serranidae	Groupers
Holocentridae	Squirrelfishes, Soldierfishes	Siganidae	Rabbitfishes
Kyphosidae	Drummers	Sparidae	Porgies
Labridae	Wrasses and Parrotfishes	Sphyraenidae	Barracuda
Lethrinidae	Emperors	Synodontidae	Lizardfishes
Lutjanidae	Snappers	Tetradontidae	Puffers
Monacanthidae	Filefishes	Zanclidae	Moorish Idol

Table S2. Relative importance of variables of the fish biomass initial model. The relative importance of each variable is based on the sum of Akaike weights of all the possible models (i.e. all the possible combination of variables) in which the variable is present.

Relative variable importance	
Biodiversity	
Species richness	1
Environmental variables	
Depth	1
Oceanic productivity	1
Habitat	0.94
Socio-economic variables	
Population size	1
Management	1
Tourism	1
HDI	0.72
Reef fish landings	0.71
Gravity of markets	0.66
Voice accountability	0.62
Local population growth	0.39
Gravity of human settlement	0.28
Method	
Sampling area	1
Census method	1

Table S3. Relative importance of variables of the coral cover initial model. The relative importance of each variable is based on the sum of Akaike weights of all the possible models (i.e. all the possible combination of variables) in which the variable is present.

Relative variable importance	
Biodiversity	
Species richness	1
Environmental variables	
Oceanic productivity	1
Habitat	1
Depth	0.56
Socio-economic variables	
Population size	1
Tourism	1
Local population growth	0.85
HDI	0.74
Gravity of markets	0.48
Reef fish landings	0.44
Management	0.41
Voice accountability	0.37
Gravity of human settlement	0.27
Method	
Census method	1

Table S4. Details of key fish species for reef fish biomass. AIC of the initial model M_0 (environment, socio-economics and species richness) provides reference Akaike Information Criterion (AIC M_0). Presence of each species has been added to M_0 as binary variable using occurrence (i.e. presence of at least 1 individual). For each species, number of occurrences, coefficient in the model (Coeff.) and AIC of the model accounting for the species (AIC M1) are reported. Comparisons with reference AIC (AIC M0) are also provided (ΔAIC).

Fish species	Nb of occ.	Coeff.	AIC M1	ΔAIC	AIC M0
Caranx ignobilis	98	0.29	1166.6	54.6	1221.2
Lutjanus bohar	448	0.18	1171.4	49.8	1221.2
Plectropomus laevis	129	0.23	1185.7	35.5	1221.2
Aprion virescens	169	0.18	1189.7	31.5	1221.2
Macolor niger	157	0.2	1189.9	31.3	1221.2
Chlorurus microrhinos	314	0.15	1190	31.2	1221.2
Hipposcarus longiceps	163	0.19	1193	28.2	1221.2
Naso tuberosus	51	0.3	1195.9	25.3	1221.2
Lethrinus atkinsoni	74	0.28	1198.3	22.9	1221.2
Bolbometopon muricatum	38	0.32	1199.9	21.3	1221.2
Cheilinus undulatus	134	0.17	1200	21.2	1221.2
Elagatis bipinnulata	32	0.3	1201.5	19.7	1221.2
Naso hexacanthus	113	0.16	1203.1	18.1	1221.2
Caranx melampygus	286	0.11	1207.1	14.1	1221.2
Scarus altipinnis	181	0.13	1208.5	12.7	1221.2
Naso caesius	31	0.27	1209.2	12	1221.2
Parupeneus crassilabris	55	0.2	1212.3	8.9	1221.2
Naso unicornis	380	0.09	1212.3	8.9	1221.2
Lethrinus olivaceus	79	0.16	1212.8	8.4	1221.2
Macolor macularis	107	0.16	1214.7	6.5	1221.2
Lutjanus gibbus	191	0.12	1215	6.2	1221.2
Gymnosarda unicolor	23	0.24	1215.1	6.1	1221.2
Acanthurus albipectoralis	26	0.23	1215.7	5.5	1221.2
Acanthurus lineatus	282	0.09	1215.8	5.4	1221.2
Scarus rubroviolaceus	367	0.08	1216.6	4.6	1221.2
Acanthurus dussumieri	168	0.1	1217	4.2	1221.2

Table S5. Details of key fish species for live coral cover. AIC of the initial model M_0 (environment, socio-economics and species richness) provides reference Akaike Information Criterion (AIC M_0). Presence of each species has been added to M_0 as binary variable using occurrence (i.e. presence of at least 1 individual). For each species, number of occurrences, coefficient in the model (Coeff.) and AIC of the model accounting for the species (AIC M1) are reported. Comparisons with reference AIC (AIC M0) are also provided (ΔAIC).

Fish species	Nb of occ.	Coeff.	AIC M1	ΔAIC	AIC M0
Chaetodon trifascialis	132	0.22	-106.6	66.4	-40.2
Hemigymnus fasciatus	166	0.17	-82.1	41.9	-40.2
Bodianus loxozonus	35	0.27	-69.1	28.9	-40.2
Zebrasoma scopas	101	0.16	-66.1	25.9	-40.2
Chaetodon guttatissimus	40	0.35	-60.5	20.3	-40.2
Scarus frenatus	158	0.15	-59.1	18.9	-40.2
Chaetodon baronessa	65	0.22	-58.3	18.1	-40.2
Plectorhinchus picus	10	0.33	-55.1	14.9	-40.2
Oxycheilinus unifasciatus	147	0.1	-54.1	13.9	-40.2
Chaetodon meyeri	40	0.29	-54	13.8	-40.2
Chlorurus strongylocephalus	32	0.26	-53.9	13.7	-40.2
Lutjanus gibbus	55	0.16	-53.6	13.4	-40.2
Chaetodon unimaculatus	48	0.16	-52.8	12.6	-40.2
Chaetodon pelewensis	70	0.16	-52.7	12.5	-40.2
Acanthurus leucosternon	44	0.33	-52.6	12.4	-40.2
Ctenochaetus truncatus	36	0.27	-50.6	10.4	-40.2
Chaetodon reticulatus	86	0.18	-50.5	10.3	-40.2
Acanthurus albipectoralis	24	0.2	-49.9	9.7	-40.2
Labrichthys unilineatus	59	0.16	-49.4	9.2	-40.2
Lutjanus bohar	199	0.11	-48.9	8.7	-40.2
Bodianus axillaris	118	0.1	-47.9	7.7	-40.2
Acanthurus thompsoni	88	0.11	-47.3	7.1	-40.2
Scarus chameleon	74	0.11	-47	6.8	-40.2
Paracirrhites nisus	24	0.22	-46.5	6.3	-40.2
Scarus tricolor	31	0.2	-46.2	6	-40.2
Cephalopholis urodeta	145	0.13	-45.2	5	-40.2
Scarus globiceps	76	0.12	-44.7	4.5	-40.2
Cantherhines dumerilii	52	0.11	-44.7	4.5	-40.2

Table S6. Functional traits of key fish species for reef fish biomass and live coral cover. 23, 25 and 3 fish species are significantly related to biomass (BM), live coral cover (CC) or both (BOTH) of those proxies of coral reef services respectively. Each species is described using six traits: (1) size, coded using 3 ordered categories: 10-30cm, 30.1-50cm, >50cm; (2) mobility, coded using 3 ordered categories: sedentary, mobile within a reef and mobile between reefs; (3) period of activity, coded using 3 ordered categories: diurnal, both diurnal and nocturnal, and nocturnal; (4) schooling, coded using 5 ordered categories: solitary, pairing, or living in small (3-20 individuals), medium (20-50 individuals) or large groups (>50 groups); (5) vertical position in the water column, coded using 3 ordered categories: benthic, bentho-pelagic and pelagic; (6) diet, coded using 7 trophic categories: herbivorous-detritivorous (HD), macro-algal herbivorous (HM), invertivorous targeting sessile invertebrates (IS), invertivorous targeting mobile invertebrates (IM), planktivorous (PK), piscivorous (FC), and omnivorous (OM), i.e. fish for which both vegetal and animal material are important in their diet. Several species can have the same functional traits (trait combinations with the same Funct. Entity ID) and thus, represent the same functional entity. In total, 51 key fish species are described, which represent 35 different functional entities with 6 entities common to both fish biomass and coral cover (highlighted in grey).

ES proxy	Fish Species	Size Class	Mobility	Activity	Schooling	Position	Diet	Funct. Entity ID
BM	*Acanthurus dussumieri*	10-30cm	Mob	Day	SmallG	Bottom	HD	6
BM	*Acanthurus lineatus*	10-30cm	Sed	Day	Sol	Bottom	HD	15
BM	*Aprion virescens*	50-153cm	VMob	Both	SmallG	Low	FC	33
BM	*Bolbometopon muricatum*	50-153cm	VMob	Day	MedG	Bottom	IS	35
BM	*Caranx ignobilis*	50-153cm	VMob	Both	Sol	High	FC	34
BM	*Caranx melampygus*	30-50cm	VMob	Both	SmallG	High	FC	25
BM	*Cheilinus undulatus*	50-153cm	Mob	Day	Sol	Bottom	IM	31
BM	*Chlorurus microrhinos*	30-50cm	Mob	Day	SmallG	Bottom	OM	23
BM	*Elagatis bipinnulata*	50-153cm	VMob	Both	MedG	High	FC	32
BM	*Gymnosarda unicolor*	50-153cm	VMob	Both	Sol	High	FC	34
BM	*Hipposcarus longiceps*	10-30cm	Mob	Day	MedG	Bottom	OM	3
BM	*Lethrinus atkinsoni*	10-30cm	VMob	Night	MedG	Bottom	IM	20
BM	*Lethrinus olivaceus*	30-50cm	VMob	Both	Sol	Bottom	FC	26
BM	*Macolor macularis*	10-30cm	Mob	Both	MedG	High	PK	1
BM	*Macolor niger*	30-50cm	Mob	Both	MedG	High	PK	22
BM	*Naso caesius*	30-50cm	VMob	Day	MedG	High	PK	29
BM	*Naso hexacanthus*	30-50cm	VMob	Day	LargeG	High	PK	27
BM	*Naso tuberosus*	30-50cm	VMob	Day	MedG	High	HM	28
BM	*Naso unicornis*	10-30cm	Mob	Day	SmallG	Bottom	HM	7
BM	*Parupeneus crassilabris*	10-30cm	Mob	Day	SmallG	Bottom	IM	8
BM	*Plectropomus laevis*	50-153cm	Mob	Day	Sol	Bottom	FC	30
BM	*Scarus altipinnis*	10-30cm	Mob	Day	LargeG	Bottom	OM	2
BM	*Scarus rubroviolaceus*	30-50cm	Mob	Day	SmallG	Bottom	OM	23
CC	*Acanthurus leucosternon*	10-30cm	VMob	Day	LargeG	Bottom	HD	18
CC	*Acanthurus thompsoni*	10-30cm	VMob	Day	MedG	Low	PK	19
CC	*Bodianus axillaris*	10-30cm	Mob	Day	Sol	Bottom	IM	9
CC	*Bodianus loxozonus*	10-30cm	Mob	Day	Sol	Bottom	IM	9
CC	*Cantherhines dumerilii*	10-30cm	Mob	Day	Pair	Bottom	IS	4
CC	*Cephalopholis urodeta*	10-30cm	Sed	Both	Sol	Bottom	FC	11
CC	*Chaetodon baronessa*	10-30cm	Sed	Day	Pair	Bottom	IS	12
CC	*Chaetodon guttatissimus*	10-30cm	Sed	Day	Pair	Bottom	IS	12
CC	*Chaetodon meyeri*	10-30cm	Sed	Day	Pair	Bottom	IS	12
CC	*Chaetodon pelewensis*	10-30cm	Sed	Day	Pair	Bottom	IS	12
CC	*Chaetodon reticulatus*	10-30cm	Sed	Day	Pair	Low	IS	13
CC	*Chaetodon trifascialis*	10-30cm	Sed	Day	Pair	Bottom	IS	12
CC	*Chaetodon unimaculatus*	10-30cm	Sed	Day	Pair	Bottom	IS	12
CC	*Chlorurus strongylocephalus*	30-50cm	Mob	Day	SmallG	Bottom	OM	23
CC	*Ctenochaetus truncatus*	10-30cm	Sed	Day	SmallG	Bottom	OM	14
CC	*Hemigymnus fasciatus*	10-30cm	Mob	Day	Sol	Bottom	IM	9
CC	*Labrichthys unilineatus*	10-30cm	Sed	Day	Sol	Bottom	IS	17
CC	*Oxycheilinus unifasciatus*	10-30cm	Mob	Day	SmallG	Bottom	FC	5
CC	*Paracirrhites nisus*	10-30cm	Sed	Day	Sol	Bottom	IM	16
CC	*Plectorhinchus picus*	50-153cm	Mob	Day	Sol	Bottom	IM	31
CC	*Scarus chameleon*	10-30cm	Mob	Day	Sol	Bottom	OM	10
CC	*Scarus frenatus*	10-30cm	Mob	Day	Sol	Bottom	OM	10
CC	*Scarus globiceps*	10-30cm	Mob	Day	Sol	Bottom	OM	10
CC	*Scarus tricolor*	10-30cm	Mob	Day	Sol	Bottom	OM	10
CC	*Zebrasoma scopas*	10-30cm	Mob	Day	SmallG	Bottom	HD	6
BOTH	*Acanthurus albipectoralis*	10-30cm	VMob	Day	MedG	Low	PK	19
BOTH	*Lutjanus bohar*	30-50cm	Mob	Night	MedG	Low	FC	24
BOTH	*Lutjanus gibbus*	30-50cm	Mob	Both	MedG	Bottom	IM	21

Table S7. Comparative results of potential key species for fish biomass using relative intra-community (left) and intra-specific (right) biomass to define presence (threshold defined as 1%). AIC of the initial model M_0 provides reference Akaike Information Criterion (AIC M0). Presence of each species has been added to M_0 as binary variable using 2 criteria: i) contribution of species to total biomass higher than 1% and ii) the 99th percentile of the biomass distribution of each species. For each species, number of raw occurrences, number of occurrences meeting the biomass threshold, and AIC of the model accounting for the species (AIC M1) are reported. For clarity, only key species are presented and those that are significantly related to fish biomass under the 2 approaches are highlighted in grey. One species had an AIC lower than M0 but did not exceed the performance criterion (ΔAIC > 4) to be considered as key species (underlined).

INITIAL MODEL (M0): AIC = 1221.2

INTRA-COMMUNITY			
Fish species	Nb of occ.	Nb of occ. (1%)	AIC M1
Caranx ignobilis	98	96	1166.6
Lutjanus bohar	448	332	1185.0
Plectropomus laevis	129	116	1199.3
Chlorurus microrhinos	314	285	1202.3
Bolbometopon muricatum	38	35	1206.1
Naso tuberosus	51	46	1206.6
Macolor niger	157	100	1209.8
Aprion virescens	169	151	1210.9
Hipposcarus longiceps	163	107	1211.5
Naso hexacanthus	113	86	1212.6
Lethrinus atkinsoni	74	58	1213.3
Elagatis bipinnulata	32	28	1214.6
Naso caesius	31	22	1216.7

INTRA-SPECIFIC			
Fish species	Nb of occ.	Nb of occ. (1%)	AIC M1
Caranx ignobilis	98	19	1157.1
Lutjanus gibbus	191	19	1177.5
Macolor niger	157	19	1177.8
Naso hexacanthus	113	19	1183.8
Lethrinus atkinsoni	74	19	1188.2
Bolbometopon muricatum	38	20	1188.4
Hipposcarus longiceps	163	19	1191.6
Scarus altipinnis	181	19	1192.8
Chlorurus microrhinos	314	20	1194
Lutjanus kasmira	202	19	1196
Lutjanus bohar	448	19	1197.3
Plectropomus laevis	129	19	1202.2
Naso tuberosus	51	20	1202.7
Acanthurus blochii	225	19	1202.9
Siganus punctatus	50	19	1203.6
Naso unicornis	380	19	1203.7
Naso caesius	31	19	1204.1
Ctenochaetus striatus	954	19	1205.1
Caranx melampygus	286	19	1205.3
Chlorurus bleekeri	210	19	1206.1
Macolor macularis	107	19	1206.5
Caesio cuning	110	19	1206.7
Chlorurus frontalis	75	19	1206.9
Monotaxis grandoculis	488	19	1206.9
Scarus ghobban	210	19	1208.7
Pterocaesio tile	181	19	1208.9
Acanthurus lineatus	282	19	1208.9
Plectorhinchus orientalis	33	19	1209.4
Elagatis bipinnulata	32	19	1209.9
Naso vlamingii	51	19	1211
Scolopsis ghanam	35	19	1211.2
Lutjanus fulviflamma	107	20	1212.2
Acanthurus xanthopterus	57	20	1212.2
Cheilinus undulatus	134	19	1212.4
Naso brevirostris	155	19	1213.6
Naso lituratus	624	19	1213.6
Parupeneus barberinus	55	20	1213.8
Lethrinus olivaceus	79	23	1213.9
Caesio teres	94	19	1214
Balistoides viridescens	82	19	1214.6
Cetoscarus bicolor	144	19	1214.6
Pterocaesio marri	28	19	1214.9
Scarus rubroviolaceus	367	19	1215.2
Kyphosus vaigiensis	52	19	1215.4
Scarus rivulatus	176	19	1215.5
Epibulus insidiator	428	19	1215.7
Cetoscarus ocellatus	51	19	1215.7
Scarus frenatus	392	19	1215.9
Caesio caerulaurea	55	19	1215.9
Epinephelus polyphekadion	57	21	1216.5
Chaetodon ulietensis	139	19	1216.8
Chlorurus sordidus	1049	19	1216.9
Lutjanus monostigma	84	19	1217
2 < ΔAIC < 4			
Aprion virescens	169	20	1217.9

Table S8. Comparative results of potential key species for fish biomass using relative intra-community (left) and intra-specific (right) biomass to define presence (threshold defined as 5%). AIC of the initial model M_0 provides reference Akaike Information Criterion (AIC M0). Presence of each species has been added to M_0 as binary variable using 2 criteria: i) contribution of species to total biomass higher than 5% and ii) the 95th percentile of the biomass distribution of each species. For each species, number of raw occurrences, number of occurrences meeting the threshold, and AIC of the model accounting for the species (AIC M1) are reported. For clarity, only key species are presented and those that are significantly related to fish biomass under the 2 approaches are highlighted in grey. Some species did not reach the minimal occurrence required and thus could not be tested using the intra-specific approach (asterisk).

INITIAL MODEL (M0): AIC = 1221.2

INTRA-COMMUNITY			
Fish species	Nb of occ.	Nb of occ. (5%)	AIC M1
Caranx ignobilis	98	81	1169.2
Lutjanus bohar	448	238	1186.2
Macolor niger	157	48	1207.1
*Platax teira**	22	8	1207.6
*Lethrinus atkinsoni**	74	38	1209.8
Plectropomus laevis	129	86	1210.1
Naso hexacanthus	113	58	1212.7
*Bolbometopon muricatum**	38	23	1214.5
Chlorurus microrhinos	314	167	1215.1
Lutjanus gibbus	191	72	1215.5
*Chaetodon flavirostris**	58	3	1216.4
*Elagatis bipinnulata**	32	18	1216.9
Hipposcarus longiceps	163	41	1217.2

INTRA-SPECIFIC			
Fish species	Nb of occ.	Nb of occ. (5%)	AIC M1
Lutjanus bohar	448	92	1116.8
Chlorurus microrhinos	314	92	1154.1
Caranx ignobilis	98	92	1156.2
Macolor niger	157	92	1164.1
Hipposcarus longiceps	163	92	1167.3
Monotaxis grandoculis	488	92	1171.2
Naso unicornis	380	92	1183.8
Acanthurus lineatus	282	92	1186.4
Plectropomus laevis	129	92	1186.9
Caranx melampygus	286	92	1191.8
Ctenochaetus striatus	954	92	1193.9
Scarus altipinnis	181	97	1194.7
Lutjanus gibbus	191	92	1198.2
Naso hexacanthus	113	92	1200.1
Aprion virescens	169	92	1201.1
Scarus rubroviolaceus	367	95	1204.9
Cheilinus undulatus	134	92	1205.8
Pterocaesio tile	181	92	1206.8
Lutjanus kasmira	202	92	1207.8
Acanthurus blochii	225	92	1208.5
Cetoscarus bicolor	144	92	1210.7
Macolor macularis	107	96	1210.9
Scarus frenatus	392	92	1211.1
Zanclus cornutus	532	92	1212.2
Chlorurus sordidus	1049	92	1212.2
Heniochus chrysostomus	143	97	1213.6
Naso lituratus	624	92	1213.8
Zebrasoma veliferum	295	93	1213.9
Kyphosus sp.	145	95	1215.2
Cephalopholis argus	570	92	1215.3
Acanthurus dussumieri	168	92	1215.3
Variola louti	139	92	1216.2
Pomacanthus imperator	137	95	1216.5
Scarus niger	447	92	1216.9
Naso brevirostris	155	94	1217.1
Nb occ. > 90 is required to be tested			
*Platax teira**	22	NA	NA
*Lethrinus atkinsoni**	74	NA	NA
*Bolbometopon muricatum**	38	NA	NA
*Chaetodon flavirostris**	58	NA	NA
*Elagatis bipinnulata**	32	NA	NA

Table S9. Comparative results of potential key species for coral cover using relative intra-community (left) and intra-specific (right) biomass to define presence (threshold defined as 1%). AIC of the initial model M_0 provides reference Akaike Information Criterion (AIC M0). Presence of each species has been added to M_0 as binary variable using 2 criteria: i) contribution of species to total biomass higher than 1% and ii) the 99th percentile of the biomass distribution of each species. For each species, number of raw occurrences, number of occurrences meeting the threshold, and AIC of the model accounting for the species (AIC M1) are reported. For clarity, only key species are presented and those that are significantly related to coral cover under the 2 approaches are highlighted in grey. Some species did not reach the minimal occurrence required and thus could not be tested using the intra-specific approach (asterisk), while some species had an AIC lower than M0 but did not exceed the performance criterion (ΔAIC > 4) to be considered as key species (underlined).

INITIAL MODEL (M0): AIC = -40.2							
INTRA-COMMUNITY				**INTRA-SPECIFIC**			
Fish species	Nb of occ.	Nb of occ. (1%)	AIC M1	Fish species	Nb of occ.	Nb of occ. (1%)	AIC M1
Acanthurus albipectoralis	24	15	-59.9	*Epinephelus fuscoguttatus*	11	9	-55.4
Lutjanus bohar	199	172	-57.1	*Naso hexacanthus*	54	8	-53.1
Bodianus loxozonus	35	7	-53.7	*Lutjanus monostigma*	35	8	-50.3
Plectorhinchus picus	10	9	-50.7	*Lutjanus bohar*	199	8	-49.9
Scarus frenatus	158	132	-47.5	*Acanthurus albipectoralis*	24	8	-47.4
Chlorurus strongylocephalus	32	30	-46.9	*Chaetodon reticulatus*	86	8	-47.1
Macolor niger	67	50	-46.6	*Paracirrhites nisus*	24	11	-46.3
Siganus argenteus	20	11	-44.2	*Plectorhinchus picus*	10	8	-46
				Labroides bicolor	26	14	-45.9
				Thalassoma lutescens	214	8	-44.8
				Hemitaurichthys polylepis	22	8	-44.3
				2 < ΔAIC < 4			
				Chlorurus strongylocephalus	32	8	-35.6
				Bodianus loxozonus	35	6	-36.7
				Scarus frenatus	158	8	-37.3
				Macolor niger	67	8	-37.9
				Siganus argenteus	20	8	-38.1

Table S10. Comparative results of potential key species for coral cover using relative intra-community (left) and intra-specific (right) biomass to define presence (threshold defined as 5%). AIC of the initial model M_0 provides reference Akaike Information Criterion (AIC M0). Presence of each species has been added to M_0 as binary variable using 2 criteria: i) contribution of species to total biomass higher than 5% and ii) the 95th percentile of the biomass distribution of each species. For each species, number of raw occurrences, number of occurrences meeting the threshold, and AIC of the model accounting for the species (AIC M1) are reported. For clarity, only key species are presented and those that are significantly related to coral cover under the 2 approaches are highlighted in grey. Some species did not reach the minimum occurrence and thus could not be tested using the intra-specific approach (asterisk).

INITIAL MODEL (M0): AIC = -40.2							
INTRA-COMMUNITY				**INTRA-SPECIFIC**			
Fish species	Nb of occ.	Nb of occ. (5%)	AIC M1	Fish species	Nb of occ.	Nb of occ. (5%)	AIC M1
*Acanthurus albipectoralis**	24	6	-62.7	*Chaetodon trifascialis*	132	42	-71
Lutjanus bohar	199	131	-55.9	*Acanthurus leucosternon*	44	38	-63.7
*Siganus argenteus**	20	4	-52.1	*Chaetodon guttatissimus*	40	40	-60.5
Scarus frenatus	158	60	-50.7	*Zebrasoma scopas*	101	39	-60.4
Macolor niger	67	28	-49.2	*Chaetodon baronessa*	65	44	-58.6
				Hemigymnus fasciatus	166	38	-58.2
				Chaetodon unimaculatus	48	38	-56.6
				Chaetodon meyeri	40	40	-54
				Chaetodon reticulatus	86	38	-52.8
				Scarus frenatus	158	38	-52.4
				Thalassoma lutescens	214	38	-51
				Macolor niger	67	38	-50.3
				Thalassoma hardwicke	123	39	-48.7
				Lutjanus bohar	199	38	-47.1
				Chaetodon pelewensis	70	63	-46.0
				Naso brevirostris	110	39	-45.8
				Lutjanus gibbus	55	38	-44.7
				Sargocentron caudimaculatum	39	38	-44.3
				Nb occ. > 36 is required to be tested			
				*Acanthurus albipectoralis**	24	NA	NA
				*Siganus argenteus**	20	NA	NA

REFERENCES

1 Cinner, J. E., Huchery, C., MacNeil, M. A., Graham, N. A. J., McClanahan, T. R., Maina, J., Maire, E., Kittinger, J. N., Hicks, C. C., Mora, C.*, et al.* 2016 Bright spots among the world's coral reefs. *Nature*. **535**, 416-419. (10.1038/nature18607)

2 Burke, L., Reytar, K., Spalding, M., Perry, A. 2011 *Reefs at risk revisited*.

3 Kittinger, J., Finkbeiner, E., Glazier, E., Crowder, L. 2012 Human dimensions of coral reef social-ecological systems. *Ecology and Society*. **17**,

4 Harris, D. L., Rovere, A., Casella, E., Power, H., Canavesio, R., Collin, A., Pomeroy, A., Webster, J. M., Parravicini, V. 2018 Coral reef structural complexity provides important coastal protection from waves under rising sea levels. *Science Advances*. **4**,

5 McClanahan Timothy, R. 2018 Community biomass and life history benchmarks for coral reef fisheries. *Fish and Fisheries*. **19**, 471-488. (10.1111/faf.12268)

6 Hughes, T. P., Anderson, K. D., Connolly, S. R., Heron, S. F., Kerry, J. T., Lough, J. M., Baird, A. H., Baum, J. K., Berumen, M. L., Bridge, T. C.*, et al.* 2018 Spatial and temporal patterns of mass bleaching of corals in the Anthropocene. *Science*. **359**, 80.

7 Bozec, Y.-M., O'Farrell, S., Bruggemann, J. H., Luckhurst, B. E., Mumby, P. J. 2016 Tradeoffs between fisheries harvest and the resilience of coral reefs. *Proceedings of the National Academy of Sciences of the United States of America*. **113**, 4536-4541. (10.1073/pnas.1601529113)

8 Hughes, T. P., Kerry, J. T., Alvarez-Noriega, M., Alvarez-Romero, J. G., Anderson, K. D., Baird, A. H., Babcock, R. C., Beger, M., Bellwood, D. R., Berkelmans, R.*, et al.* 2017 Global warming and recurrent mass bleaching of corals. *Nature*. **543**, 373-377. (10.1038/nature21707)

9 Usseglio, P. 2015 33 Quantifying reef fishes: bias in observational approaches. *Ecology of fishes on coral reefs*. 270.

10 UNEP-WCMC, I. 2016 The World Database on Protected Areas (WDPA). *ed UNEP-WCMC (Available at: www.protectedplanet.net., Cambridge, UK)*.

11 MacNeil, M. A., Connolly, S. R. 2015 Multi-scale patterns and processes in reef fish abundance. *Ecology of Fishes on Coral Reefs (ed Mora C)*. 116-126.

12 Gove, J. M., Williams, G. J., McManus, M. A., Heron, S. F., Sandin, S. A., Vetter, O. J., Foley, D. G. 2013 Quantifying Climatological Ranges and Anomalies for Pacific Coral Reef Ecosystems. *PLOS ONE*. **8**, e61974. (10.1371/journal.pone.0061974)

13 Mouillot, D., Villeger, S., Parravicini, V., Kulbicki, M., Ernesto Arias-Gonzalez, J., Bender, M., Chabanet, P., Floeter, S. R., Friedlander, A., Vigliola, L.*, et al.* 2014 Functional over-redundancy and high functional vulnerability in global fish faunas on tropical reefs. *Proceedings of the National Academy of Sciences of the United States of America*. **111**, 13757-13762. (10.1073/pnas.1317625111)