Fishing degrades size structure of coral reef fish communities

SUPPORTING INFORMATION

Appendix S1

Explanatory covariate processing

Human covariates

No standard measure of fishing effort was available across all islands sampled, so instead we quantified exploitation pressure using two metrics of broad human impacts on coral reef fish communities. Higher human population densities (Graham et al., 2005; Williams et al., 2011; Cinner et al., 2012; MacNeil et al., 2015; Williams et al., 2015) and greater access to markets (Brewer et al., 2012; Cinner et al., 2012) have been associated with degraded reef fish assemblages, primarily due to increased fishing effort. We extracted 2010 estimates of population density for a 20 km buffer (SEDAC) and divided this by the forereef area (km^2). Following Cinner et al. (2012), we estimated the shortest distance (km) from each site to the provincial capital as a proxy of market access (using ArcGIS).

Environmental covariates

We extracted the average minimum SST (°C) from the National Oceanographic Data Center's Coral Reef Temperature Anomaly Database (CoRTAD) based on AVHRR Pathfinder data on a weekly time-scale between 1982-2008 at a ~4.6 x 4.6 km resolution (http://www.nodc.noaa.gov/SatelliteData/Cortad). Net primary productivity (mg C m^{-2} day^{-1}) was modelled by NOAA CoastWatch based on satellite measurements of photosynthetically available radiation (NASA's SeaWiFS), SST (NOAA's National Climatic Data Center Reynolds Optimally-Interpolated SST), and chlorophyll *a* concentration (NASA Aqua MODIS) estimated every 8 days between 2002-2013 at a ~4.6 x 4.6 km resolution (http://coastwatch.pfeg.noaa.gov/erddap/griddap/erdPPbfp28day.graph). To avoid introducing bias from increased reflectance in shallow waters, we used bathymetry data from the STRM30_plus high-resolution (~1 x 1 km) bathymetry dataset (http://topex.ucsd.edu/WWW_html/srtm30_plus.html) and a focal productivity cell was excluded if any bathymetry cell within its bounds was <30 m depth (Gove et al., 2013). We then estimated the mean SST value and mean productivity value per site by averaging SST or productivity values across the cell that included the site (if not excluded based on depth) and the closest 3 neighbouring cells within 9.3 km of either the shoreline or site that also passed the depth filter.

The extent of coral reef habitat around each site was obtained by merging data from two primary sources, the Millennium Coral Reef Mapping project (data accessed from the University of South Florida Institute for Marine Remote Sensing and through the UNEP World Conservation Monitoring Centre, Andréfouët et al., 2005) and coral maps for Asian Pacific region produced under the "Coral Reef Habitat Map" project by the Japanese Ministry of the Environment (http://coralmap.coremoc.go.jp/sangomap_eng/; accessed 4/28/2011). We merged all non-land geomorphological types mapped in the Millennium data as this classification best matched the known extent of reef habitat based on the fish survey locations. Similarly, we merged all coral and associated habitats mapped in the Coral Reef Habitat Map data to best match the protocol used for the Millennium data. Using these two datasets combined, we calculated the total island reef habitat (<30 m depth) within a 75 km buffer (~17,700 km^2) at each site (*sensu* Mellin et al., 2010). We used the Global Self-consistent, Hierarchical, High-resolution Geography Database (http://www.soest.hawaii.edu/pwessel/gshhg/; Wessel & Smith, 1996) to estimate land area (km^2) within a 75 km buffer at each site.

Finally, we collated *in situ* estimates of structural complexity at each stationary point count. CREP divers assessed structural complexity qualitatively on a scale from 1 (very low) to 5 (very high) between 2010-2011, before switching method and measuring maximum substrate height and proportion of area within substrate height bins in each point count cylinder between 2012-2014 (Williams et al. 2015). We merged both estimates by averaging complexity estimates across all sites for each island that was sampled using both methods (n = 35), and then fitting the relationship between qualitative complexity and maximum substrate height. We used this relationship to convert qualitative complexity values to maximum substrate heights at each 2010-11 site (Williams et al. 2015).

References

Andréfouët S, Muller-Karger FE, Robinson JA, Kranenburg, CJ, Torres-Pulliza, D, Spraggins, SA, Murch, B (2005) Global assessment of modern coral reef extent and diversity for regional science and management applications: a view from space. In: Proceedings of 10th International Coral Reef Symposium (eds Y. Suzuki, T. Nakamori, M. Hidaka, H. Kayanne, B. E. Casareto, K. Nadaoka, H. Yamano, M. Tsuchiya, and K. Yamazato), pp. 1732-1745, Japanese Coral Reef Society, Okinawa, Japan.

Brewer TD, Cinner JE, Fisher R, Green A, Wilson SK (2012) Market access, population density, and socioeconomic development explain diversity and functional group biomass of coral reef fish assemblages. Global Environmental Change, **22**, 399–406.

Cinner JE, Graham NAJ, Huchery C, MacNeil MA (2012) Global effects of local human population density and distance to markets on the condition of coral reef fisheries. Conservation Biology, **27**, 453–458.

Gove JM, Williams GJ, McManus MA, Heron SF, Sandin SA, Vetter OJ, Foley DG (2013) Quantifying climatological ranges and anomalies for Pacific coral reef ecosystems. PloS one, **8**, e61974.

Graham N, Dulvy NK, Jennings S, Polunin N (2005) Size-spectra as indicators of the effects of fishing on coral reef fish assemblages. Coral Reefs, **24**, 118–124.

MacNeil MA, Graham NAJ, Cinner JE et al. (2015) Recovery potential of the world's coral reef fishes. Nature, **520**, 341–344.

Mellin C, Huchery C, Caley MJ, Meekan MG, Bradshaw CJA (2010) Reef size and isolation determine the temporal stability of coral reef fish populations. Ecology, **91**, 3138–3145.

Wessel P, Smith W (1996) A global, self-consistent, hierarchical, high-resolution shoreline database. Journal of Geophysical Research-Solid Earth, **101**, 8741–8743.

Williams ID, Baum JK, Heenan A, Hanson KM, Nadon MO, Brainard RE (2015) Human, oceanographic and habitat drivers of Central and Western Pacific coral reef fish assemblages. PloS one, **10**, e0120516.

Williams ID, Richards BL, Sandin SA et al. (2011) Differences in reef fish assemblages between populated and remote reefs spanning multiple archipelagos across the central and western Pacific. Journal of Marine Biology, **2011**. 14.

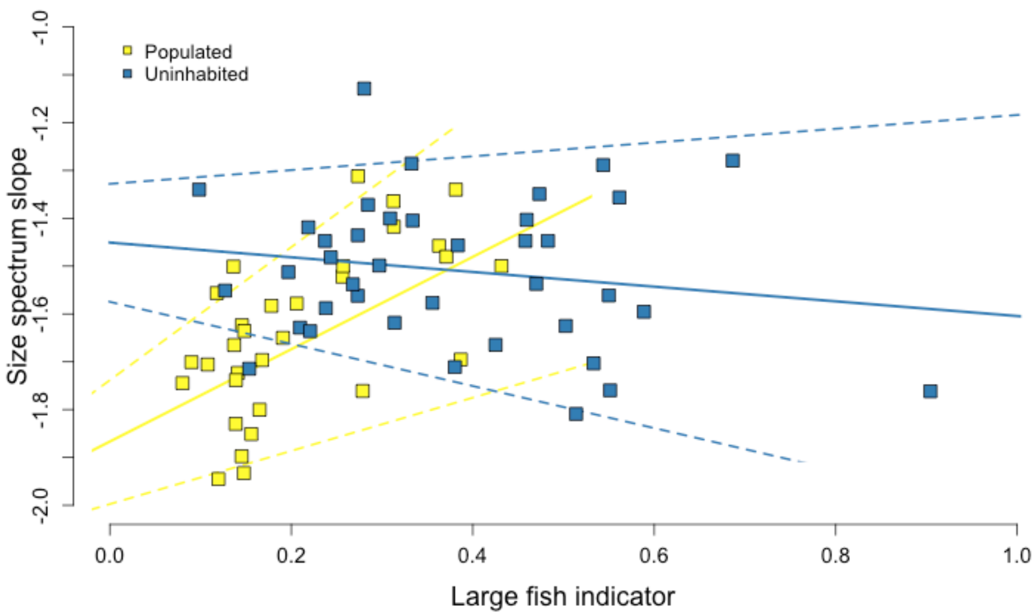

Figure S1. Relationship between size spectra slopes and the LFI at populated (yellow) and uninhabited (blue) reef areas. Linear regression (solid line) and 95% confidence intervals (dashed lines) are parameter estimates from linear mixed effects model with survey year as a random effect.

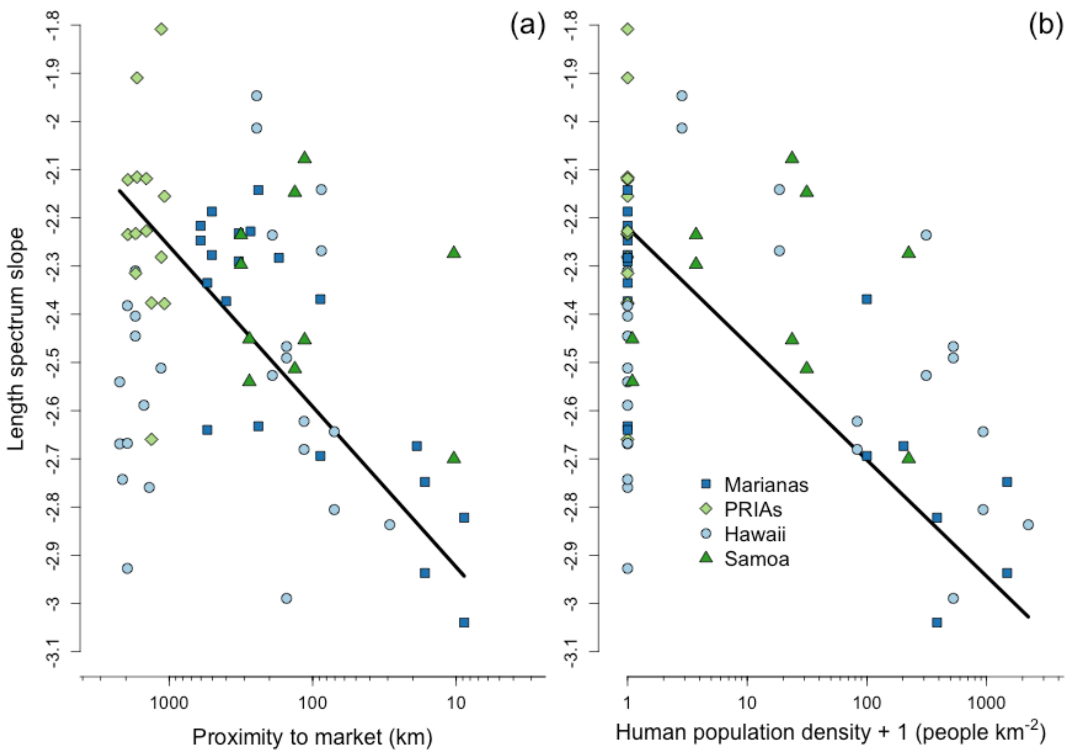

Figure S2. Length spectra slopes across proximity to market (a) and human population density (b). Length spectra relationships are model-averaged predictions across the standardized range of observed log proximity to provincial capital (km) and log human population density per forereef area (km^2) (a, b respectively). Predictions were made across the top model set (ΔAICc < 7) and weighted using model probabilities, while holding all other relevant covariates to their mean observed value (Table S5). Dashed lines are the weighted sample variance at each value of human covariate (though these are indistinguishable here from model predictions). For visualization purposes, we included the observed data as points and coloured by region (dark blue squares = Marianas archipelago; light blue circles = Hawaiian archipelago, light green diamonds = Pacific Remote Island Areas, dark green triangles = American Samoa).

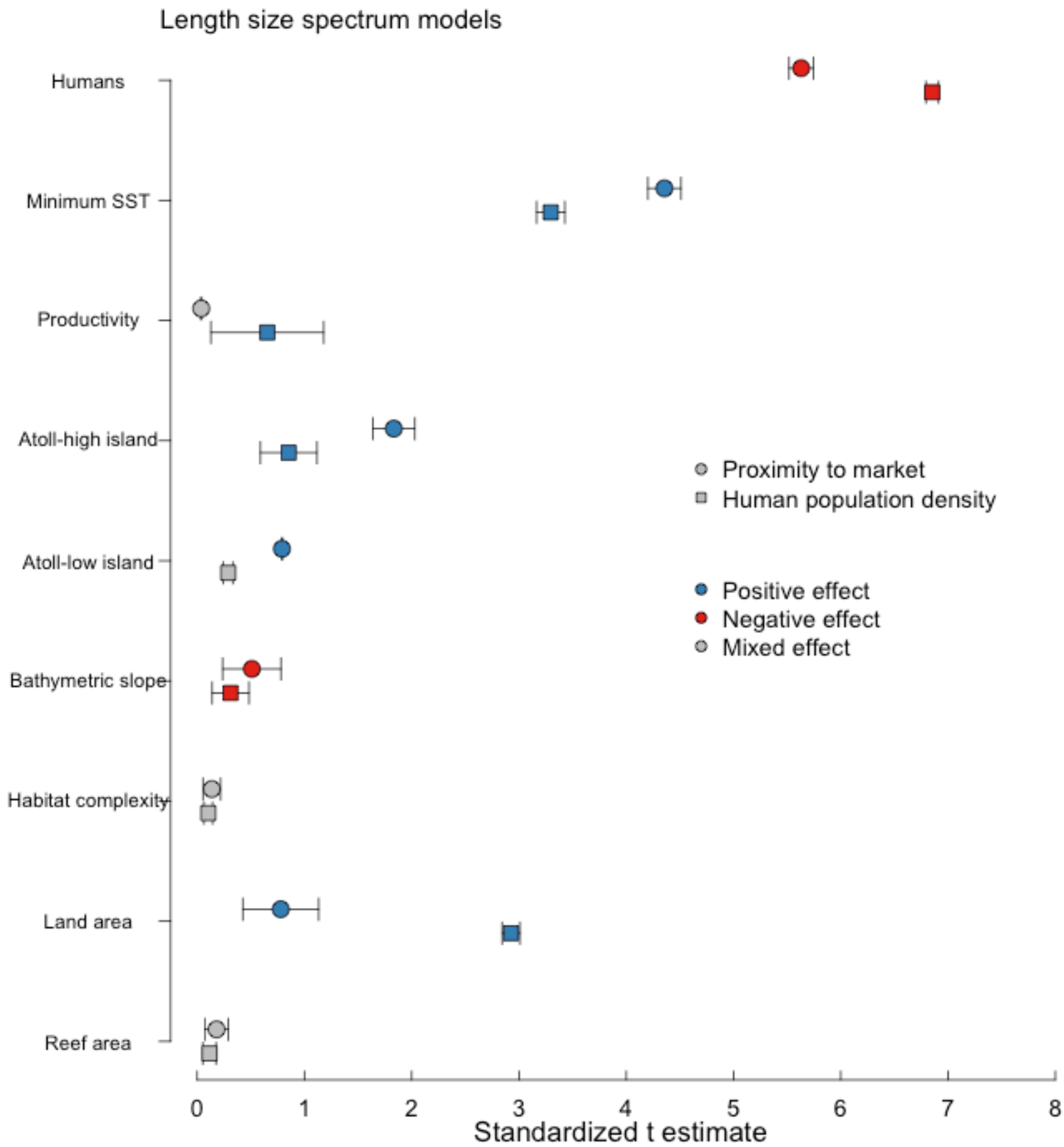

Figure S3. Model parameter estimates for length spectra. Length spectra are for the distance to market (circles) and human population density (squares) full model sets. Points are the weighted absolute t-values for each explanatory covariate, with weighted sample variance as error bars. T-values indicate the magnitude of each covariate effect, and colors indicate the direction of each covariate effect (blue = positive; red = negative; grey = mixed). See Table S5 for further details.