REPORT

The IUCN Red List of Threatened Species: an assessment of coral reef fishes in the US Pacific Islands

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Abstract Widespread declines among many coral reef fisheries have led scientists and managers to become increasingly concerned over the extinction risk facing some species. To aid in assessing the extinction risks facing coral reef fishes, large-scale censuses of the abundance and distribution of individual species are critically important. We use fisheries-independent data collected as part of the NOAA Pacific Reef Assessment and Monitoring Program from 2000 to 2009 to describe the range and density across the US Pacific of coral reef fishes included on The International Union for the Conservation of Nature's (IUCN) 2011 Red List of Threatened Species. Forty-five species, including sharks, rays, groupers, humphead wrasse (*Cheilinus undulatus*), and bumphead parrotfish (*Bolbometopon muricatum*), included on the IUCN List, were recorded in the US Pacific Islands. Most species were generally rare in the US Pacific with the exception of a few species, principally small groupers and reef sharks. The greatest diversity and densities of IUCN-listed fishes were recorded at remote and uninhabited islands of the Pacific Remote Island Areas; in general, lower densities were observed at reefs of inhabited islands. Our findings complement IUCN assessment efforts, emphasize the efficacy of large-scale assessment and monitoring efforts in providing quantitative data on reef fish assemblages, and highlight the importance of protecting populations at remote and uninhabited islands where some species included on the IUCN Red List of Threatened Species can be observed in abundance.

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Introduction

Coral reefs are threatened by a host of human activities. Among these, fishing exerts significant and direct impacts on many coral reef fish assemblages (Jackson et al. 2001; Friedlander and DeMartini 2002; Sandin et al. 2008). Reef fishes have long supported subsistence and artisanal fisheries with the earliest record of fishing of coastal habitats traced back at least 35,000 yrs in the western Pacific (Allen et al. 1989). Today, coral reefs continue to support subsistence fisheries and millions of people depend directly on the harvested resources (Zeller et al. 2006). Financially, coral

reef ecosystems support commercial fisheries estimated to be worth over $5 billion per year (Cesar et al. 2003).

Despite their importance, the complexity of coral reef fisheries provides many challenges for the development of management strategies aimed to maintain sustainable fisheries and other ecosystem services. Coral reef fisheries tend to exploit multiple species (Jennings and Polunin 1996a), with the primary targets oftentimes being large-bodied species such as sharks, groupers, snappers, jacks, parrotfishes, and wrasses (Roberts 1995; Jennings and Kaiser 1998; Pauly et al. 1998; Choat et al. 2006; DeMartini et al. 2008). Further, the life history characteristics of many species render them particularly vulnerable to overexploitation. Many large-bodied species tend to be slow-growing, long-lived, have delayed reproductive development, and some form mass aggregations when they spawn (Choat et al. 2006; Tupper 2007; Sadovy de Mitcheson et al. 2008; Colin 2010). Large-bodied species play a critical role in structuring marine ecosystems (Bascompte et al. 2005; Estes et al. 2011), and severe reductions in their biomass have detrimental ecological and economic effects (Pauly et al. 1998; Jackson et al. 2001; Friedlander and DeMartini 2002; Myers and Worm 2003; Sandin et al. 2008). Therefore, knowing the distribution and relative abundance of these species is of critical importance to the development of effective management strategies.

In 1994, the International Union for Conservation of Nature (IUCN), aided by its Species Survival Commission (SSC), developed and adopted a standardized approach for assessing the extinction risk of species and biodiversity in both terrestrial and aquatic environments. Methods and criteria produced by the SSC were used by the IUCN to categorize Red-listed species (Baillie and Groombridge 1996). In general, assessment criteria incorporate estimates of current and historical population size and geographic range to assign species to one of nine categories of risk. As of 2011, the ICUN Red List categories (in order of descending risk) are extinct, extinct in the wild, critically endangered, endangered, vulnerable, near threatened, least concern, data deficient, and not evaluated. The IUCN Red List of Threatened Species (hereafter IUCN List) has been widely adopted as the basis for identifying species at risk and developing programs to conserve biodiversity (Rodrigues et al. 2006; Mace et al. 2008). Although some assessment criteria used by the United States under the Endangered Species Act (ESA) are similar to those used by the IUCN, the listing process under the ESA incorporates additional criteria and listed species are afforded legal protection administered by either the US Fish and Wildlife Service and the National Oceanic and Atmospheric Administration (National Research Council 1995).

The purpose of this paper is to describe the geographic distribution and density across the US Pacific of shallow-water coral reef fishes included on the 2011 IUCN Red List (across all assessment categories identified above), including the two Indo-Pacific coral reef species identified by NOAA as Species of Concern. We use underwater visual survey data collected as part of the NOAA Pacific Reef Assessment and Monitoring Program (RAMP), a large-scale effort to monitor the status of coral reefs across much of the US Pacific. By design, NOAA Pacific RAMP allocates monitoring effort broadly across space (sampling over 40 islands at least once every 2 yrs) and thus lacks high replication at the within-island scale. As such, the ability to resolve temporal trends is limited to functional group assessments (e.g., total fish biomass) or to long-term changes (e.g., trends over decades), but the power of the sampling lies in the high replication at the island scale for each of these assessments. We provide information on the density of sharks, rays, groupers, the bumphead parrotfish (*Bolbometopon muricatum*), and the humphead wrasse (*Cheilinus undulatus*). Additionally, we compare densities of these species between inhabited and uninhabited US Pacific Islands.

Materials and methods

Study area

Biennial surveys were conducted from 2000 to 2009 at 40 US Pacific Islands as part of the NOAA Pacific RAMP (Table 1; Fig. 1). Sites included islands under US jurisdiction within four geographic regions: American Samoa, the Hawaiian Archipelago, the Mariana Archipelago, and the Pacific Remote Island Areas (PRIA). These islands span much of the central and western Pacific and encompass 3,363 km^2 of shallow-water (<10 fathom) habitat (Rohmann et al. 2005). Islands are exposed to varying levels of anthropogenic disturbance, influenced by their degree of inhabitation and distance from population centers. Some islands, such as Oahu in the Hawaiian Archipelago, Guam in the Mariana Archipelago, and Tutuila in American Samoa are densely populated islands with heavily exploited fisheries resources, while some other islands are remote, uninhabited, and relatively uninfluenced by direct human disturbances (Fig. 1). Islands were classified as either "inhabited" or "uninhabited," based on their respective resident populations and level of fisheries management as described by Williams et al. (2011). In some instances, islands classified as uninhabited had or continue to have small resident populations of <25 people, with two island atolls (Midway and Wake) having populations slightly higher during the survey period (Table 1). Although some islands classified as uninhabited had small resident populations, the level of fisheries exploitation at these islands was considered nonexistent, because residents

of the island during the survey period were caretakers, contract staff, or field researchers, and fishing in surrounding shallow-water habitats was restricted or infrequent. Of the 40 islands and reefs included in this study, 15 islands were classified as inhabited and 25 as uninhabited.

Survey methods

Two underwater survey techniques were used to estimate the density of diurnally active reef fishes. These included towed-diver survey (TDS) and belt transect (BLT) methodologies. All divers collecting data were trained in the identification and size estimation of fishes following protocols outlined by NOAA Pacific RAMP (Richards et al. 2011). Surveys were restricted to the upper forereef slope at depths shallower than 30 m with a majority of surveys conducted at depths of 12–15 m.

The TDS method consisted of a pair of SCUBA divers being towed ∼60 m behind a small boat at a speed of ∼1.5 kts and at depths typically between 10 and 20 m (Richards et al. 2011). Divers maneuvered towboards 1–3 m above the benthos, tallying all fishes ≥50 cm total length (TL) that enter a 10-m wide swath centered on the diver. Fish species were recorded to the finest recognizable taxonomic level (typically species) and size was estimated to the nearest 5 cm TL. Each TDS is 50 min in duration (10, 5-min segments) and covered an average of about 2.2 km of linear habitat (22,000 m² survey area). As such, the TDS method is spatially expansive and results in greater statistical power and higher frequency of encounter than more spatially constrained survey techniques when estimating the density and spatial distribution of rare, large-bodied reef fishes (Richards et al. 2011).

The BLT surveys consisted of a pair of divers conducting three 25-m strip transects, using protocols detailed elsewhere (Friedlander and DeMartini 2002; DeMartini et al. 2008; Friedlander et al. 2010). To summarize, individual fishes were identified to species and length (TL) was estimated to the nearest 5-cm size class. Fish abundance estimates were made by means of two passes for each 25-m transect. The pair of divers surveyed an 8-m width (200 m² area) for individuals ≥20 cm TL on an outward swim, and a 4-m width (100 m² area) for species <20 cm TL on a return swim.

Data analyses

Data from TDS and BLT methods were used to estimate size-specific numerical density for species of interest. Maximum body size of each species, based on published estimates and online sources, was used to determine which of these methods was appropriate for species-specific density estimates (Randall 2005, 2010; Froese and Pauly 2010). Fishes reaching a published maximum TL of 100 cm or greater were classified as large-bodied, and TDS data were used to estimate the density of these species. Fishes reaching a maximum TL <100 cm were classified as smaller-bodied, and BLT data were used to estimate densities of these species. As such, larger-bodied species were assessed using a more spatially expansive method with densities reported as individuals km^{-2}, while smaller-bodied species were sampled using a more comprehensive but spatially constrained method with densities reported as individuals ha^{-1}. Detailed summaries of the mean and maximum size of each species using the results of TDS and BLT surveys are provided at the island level as a series of tables for each region in the Electronic Supplementary Material. To maintain sufficient statistical power, islands with a total survey effort of <9 TDS or <7 BLT were eliminated from the analyses.

Species included in this study were selected based on three factors: (1) inclusion on the 2011 IUCN Red List of Threatened Species (IUCN 2011), (2) biogeographic ranges encompassing the US Pacific Islands confirmed through RAMP surveys, and (3) inhabiting shallow-moderate (<30 m) depth reef habitats. Web-based and published sources were used to identify the geographic ranges and ecological habitats of IUCN-listed species observed in the US Pacific Islands (Myers 1999; Randall 2005, 2010; Froese and Pauly 2010). A list of the 45 species meeting all three factors identified above is presented in Table 2.

Visual estimates of species density collected from TDS and BLT methods were non-normally distributed at both island and regional scales. For abundant species and species groups, region (or island)-specific densities are presented as means with standard errors using all available survey data. However, for statistical comparisons of groups, transforming the data and applying parametric techniques to estimate population parameters, including explicit descriptions of variability, was not practical because of the rarity of many species and zero-inflated nature of the data. Additionally, survey effort for the TDS and BLT methods varied among islands throughout the survey period (Table 1), which complicated simple parametric comparisons of island mean densities. A statistical bootstrapping approach (Efron and Tibshirani 1986; Chernick 2008) was used to evaluate differences in the mean density of fishes between groups of inhabited and uninhabited islands within each region while accounting for the non-normality of the data and to standardize survey effort across islands. The bootstrapping analysis was based on island-specific survey data on density for each species combined over survey years. TDS data were used for large-bodied species and BLT data for smaller-bodied species. Each survey provided an estimate of mean density, and the number of density estimates varied among islands and survey methods (Table 1).

Table 1 Sampling effort for surveys conducted as part of the NOAA Pacific Reef Assessment and Monitoring Program from 2000 to 2009

Region	Island/reef	Reef area (km²)[a]	Cruise visits	Number of TDS (area surveyed, km²)	Number of BLT (area surveyed, ha)[b]
American Samoa	Ofu & Olosega	3.6	4	62 (1.3)	34 (1.0/2.0)
	Tau	3.8	4	50 (1.2)	33 (0.9/1.9)
	Tutuila	35.8	4	122 (2.6)	72 (2.1/4.3)
	Rose	*7.9*	*4*	*60 (1.0)*	*36 (1.0/2.1)*
	Swains	*2.4*	*4*	*42 (0.8)*	*28 (0.8/1.6)*
	American Samoa total			336 (6.9)	203 (6.1/12.2)
Hawaiian Archipelago	Hawaii	193.7	3	74 (1.5)	60 (1.8/3.6)
	Kauai	178.8	3	56 (1.1)	28 (0.8/1.6)
	Lanai	46.3	3	33 (0.8)	18 (0.5/1.0)
	Maui	164.6	3	65 (1.4)	35 (1.0/2.1)
	Molokai	161.6	3	24 (0.6)	13 (0.3/0.7)
	Niihau-Lehua	6.7	3	47 (1.0)	26 (0.7/1.5)
	Oahu	374.8	3	40 (0.8)	19 (0.5/1.1)
	French Frigate	*469.4*	*8*	*62 (1.3)*	*31 (0.9/1.8)*
	Kure	*90.2*	*6*	*49 (0.9)*	*29 (0.8/1.7)*
	Laysan	*26.4*	*6*	*31 (0.5)*	*23 (0.6/1.3)*
	Lisianski	*215.6*	*6*	*71 (1.3)*	*44 (1.3/2.6)*
	Maro	*217.5*	*7*	*82 (1.5)*	*48 (1.4/2.8)*
	Midway	*85.4*	*5*	*47 (0.9)*	*21 (0.6/1.2)*
	Necker	*9.1*	*4*	*12 (0.2)*	*9 (0.2/0.5)*
	Pearl & Hermes	*374.5*	*7*	*78 (1.6)*	*32 (0.9/1.9)*
	Hawaiian Archipelago total			771 (15.5)	436 (13.1/26.2)
Mariana Archipelago	Guam	91.3	4	84 (1.8)	39 (1.1/2.3)
	Rota	12.1	4	44 (0.9)	23 (0.6/1.3)
	Saipan	56.8	4	59 (1.2)	30 (0.9/1.8)
	Tinian	14.7	4	37 (0.8)	19 (0.5/1.1)
	Aguijan	2.6	4	18 (0.4)	8 (0.2/0.4)
	Agrihan	*8.6*	*4*	*34 (0.7)*	*18 (0.5/1.0)*
	Alamagan	*3.2*	*4*	*24 (0.5)*	*11 (0.3/0.6)*
	Asuncion	*0.5*	*4*	*21 (0.4)*	*15 (0.4/0.9)*
	Farallon de Pajaros	*0.8*	*4*	*19 (0.4)*	*13 (0.3/0.7)*
	Guguan	*1.1*	*4*	*18 (0.3)*	*11 (0.3/0.6)*
	Maug	*2.1*	*4*	*44 (0.8)*	*34 (1.0/2.0)*
	Pagan	*11.1*	*4*	*69 (1.3)*	*33 (0.9/1.9)*
	Sarigan	*1.9*	*4*	*22 (0.4)*	*12 (0.3/0.7)*
	Mariana Archipelago total			493 (9.8)	266 (8.0/16.0)
Pacific Remote Island Areas (PRIAs)	Baker	*5.2*	*5*	*29 (0.5)*	*29 (0.8/1.7)*
	Howland	*3*	*5*	*30 (0.7)*	*26 (0.7/1.5)*
	Jarvis	*3*	*5*	*43 (0.8)*	*29 (0.8/1.7)*
	Johnston	*150.1*	*2*	*35 (0.5)*	*7 (0.2/0.4)*
	Kingman	*20.9*	*5*	*53 (0.8)*	*13 (0.3/0.7)*
	Palmyra	*47.2*	*5*	*64 (1.2)*	*39 (1.1/2.3)*
	Wake	*22.9*	*3*	*51 (1.0)*	*36 (1.0/2.1)*
	PRIAs total			305 (5.4)	179 (5.4/10.8)

Uninhabited islands within each region are italicized

TDS towed-diver surveys *BLT* belt transect surveys

[a] Area calculated from shoreline to 10 fathom line (Rohmann et al. 2005)

[b] Survey areas for the BLT were calculated using an 8-m width (200 m² area) for individuals ≥20 cm TL, and a 4-m width (100 m² area) for species <20 cm TL

To create a bootstrap replicate, a sample of density estimates was drawn randomly with replacement for each island from the total pool of estimates for the island (Table 1). Bootstrap sample sizes were 9 surveys for TDS and 7 surveys for BLT. Within each region, island-specific bootstrap means were assigned to one of two habitation categories—inhabited and uninhabited islands. Within each region, the average bootstrap density was computed over all inhabited islands in the region and similarly for the uninhabited islands, and the difference between the two averages was calculated.

The statistical resampling across all islands was completed 10,000 times, generating species-specific bootstrap statistical distributions of density within each region for each habitation stratum and the differences in average density between the habitation strata. In each case, 95 % confidence intervals for mean density using the appropriate bootstrap distribution by calculating the 2.5 and 97.5 % and setting them as the lower and upper 95 % limits, respectively.

Regional differences in density for each species between inhabited or uninhabited island groups were determined by subtracting mean densities at inhabited islands from the mean densities of uninhabited island groups. Positive mean differences denoted that uninhabited island groups yielded a higher mean density of fishes while negative mean differences denoted that an uninhabited island group yielded a lower mean density of fishes than their inhabited counterparts. Significant differences in regional means were estimated by calculating the number of times that subsampled values differed between regional groups (either positive or negative), expressing the quantile range of the distribution of results (e.g., 0, 0.001, 0.01, 0.05, 0.25, 0.5, 0.75, 0.95, 0.99, 0.999, and 1.0 quantiles). If $\geq$95 % of the distribution of data (positive or negative) fell within the quantile range, it was deemed significant and the corresponding level of significance was assigned ($<$0.05, $<$0.01, or $<$0.001). Analyses were conducted using R version 2.15.1 (The R Foundation for Statistical Computing 2012).
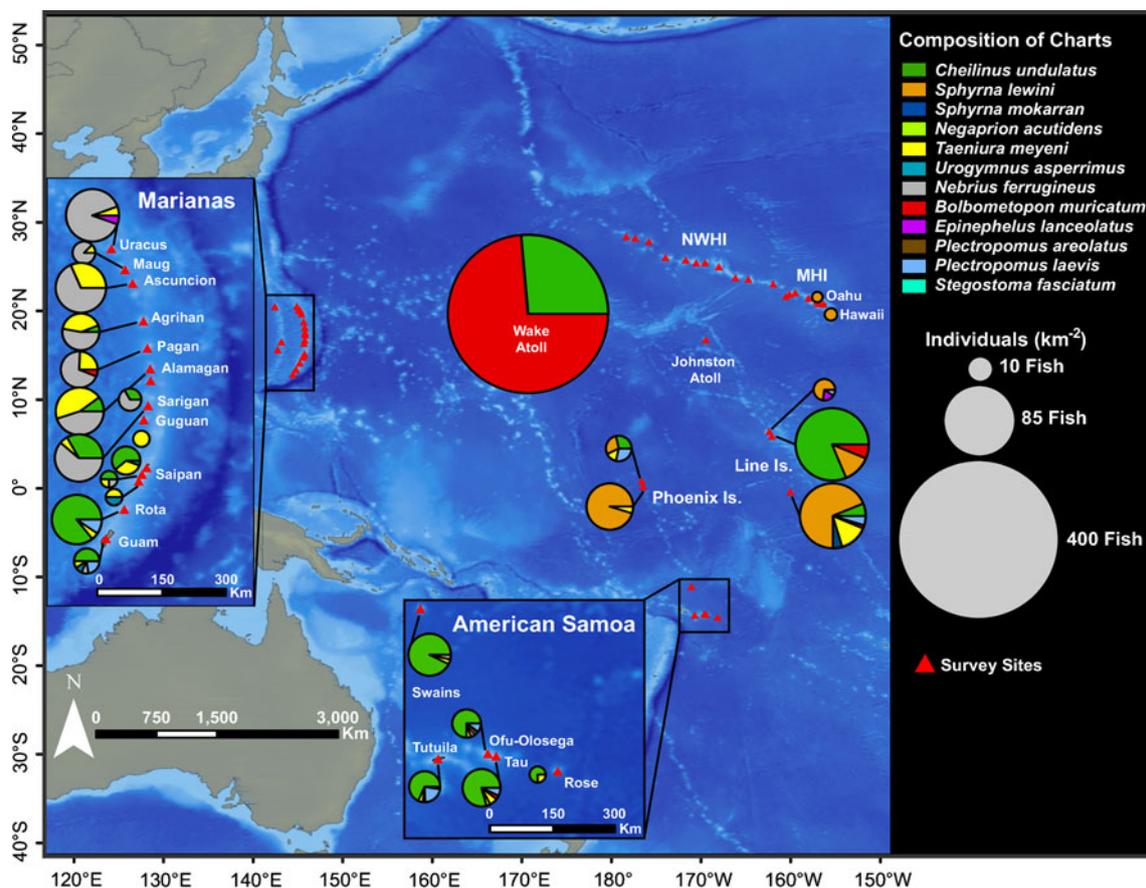

Fig. 1 Chart of the US Pacific Islands identifying islands surveyed as part of the NOAA Pacific RAMP. Figure identifies the total mean density of IUCN Red-listed species facing the greatest threat of extinction (2011 IUCN Red List Categories: endangered and threatened). Data are based on towed-diver surveys conducted from 2000 to 2009. Mean densities of fishes are indicated by *pie diagrams*; the size of individual pies is proportional to the number of individuals observed km^{-2}

Table 2 Fish species included on the 2011 IUCN Red List of Threatened Species observed in the US Pacific Islands during BLT and TDS completed on a biennial or annual basis from 2000 to 2009

Family	Species	Ecological information[a]					IUCN assessment[b]		
		Max length (cm TL)	Depth range (m)	Habitat[c]	Observed region[d]	Published range[d]	Status[e]	Years	Trend
Ginglymostomatidae	*Nebrius ferrugineus*	320	1–70	RA	A, M, P	A, M, P	VU	2003	Decreasing
Stegostomatidae	*Stegostoma fasciatum*	235	0–63	RA	A	A, M, P	VU	2003	Decreasing
Carcharhinidae	*Carcharhinus amblyrhynchos*	255	0–1,000	RA, O	A, H, M, P	A, H, M, P	NT	2005	Unknown
	C. galapagensis	370	0–286	RA	A, H, P	A, H, P	NT	2003	Unknown
	C. melanopterus	200	20–75	RA	A, M, P	A, H, M, P	NT	2005	Decreasing
	Galeocerdo cuvier	750	0–371	B, O	H, P	A, H, M, P	NT	2005	Unknown
	Negaprion acutidens	380	0–92	RA	A	A, M, P	VU	2003	Decreasing
	Triaenodon obesus	213	1–330	RA	A, H, M, P	A, H, M, P	NT	2005	Unknown
Sphyrnidae	*Sphyrna lewini*	430	0–512	PO, O	H, P	A, H, M, P	EN	2007	Unknown
	S. mokarran	610	1–300	PO, O	P	A, H, M, P	EN	2007	Decreasing
Dasyatidae	*Taeniura meyeni*	330	0–500	RA	A, M, P	A, M, P	VU	2006	Unknown
	Urogymnus asperrimus	147		RA	M	M	VU	2005	Unknown
Myliobatidae	*Aetobatus narinari*	330	1–80	RA	A, H, M, P	A, H, M, P	NT	2006	Decreasing
Mobulidae	*Manta alfredi*	910[f]	0–120	RA, O	H, P	A, H, M, P	VU	2011	Unknown
Serranidae	*Aethaloperca rogaa*	60	1–60	RA	M, P	M	DD	2008	Unknown
	Anyperodon leucogrammicus	65	1–80	RA	A	A, M, P	LC	2008	Unknown
	Cephalopholis argus	60	1–40	RA	A, H, M, P	A, H, M, P	LC	2008	Stable
	C. leopardus	24	1–40	RA	A, M, P	A, M, P	LC	2008	Unknown
	C. miniata	45	2–150	RA	A, M, P	A, M, P	LC	2008	Decreasing
	C. sexmaculata	50	6–150	RA	A, M, P	A, M, P	LC	2008	Decreasing
	C. sonnerati	57	10–150	RA	M	A, M, P	LC	2008	Stable
	C. spiloparaea	30	15–108	RA	A, P	A, M, P	LC	2008	Unknown
	C. urodeta	28	1–60	RA	A, M, P	A, M, P	LC	2008	Unknown
	Epinephelus fasciatus	40	4–160	RA	A, M, P	A, M, P	LC	2008	Decreasing
	E. hexagonatus	27.5	0–30	RA	A, M, P	A, M, P	LC	2008	Stable
	E. howlandi	55	1–37	RA	A, M, P	A, M, P	LC	2008	Unknown
	E. lanceolatus	270	4–100	RA	M, P	A, H, M, P	VU	2006	Decreasing
	E. macrospilos	51	1–30	RA	P	A, P	LC	2008	Unknown
	E. maculatus	60.5	2–100	RA	A, M	A, M, P	LC	2008	Decreasing
	E. melanostigma	35	0–30	RA	A, M, P	A, M, P	DD	2008	Unknown
	E. merra	31	0–50	RA	A, M, P	A, M, P	LC	2008	Stable
	E. polyphekadion	90	1–46	RA, O	A, M, P	A, M, P	NT	2006	Decreasing
	E. retouti	50	20–220	RA	P	A, M, P	DD	2008	Unknown
	E. spilotoceps	35	0–30	RA	A, P	A, P	LC	2008	Unknown
	E. tauvina	75	1–300	RA, O	A, M, P	A, M, P	DD	2008	Unknown
	Gracila albomarginata	40	6–120	RA	A, M, P	A, M, P	DD	2008	Unknown
	Hyporthodus quernus	122	20–380	B	H	H	NT	2004	Unknown
	Plectropomus areolatus	73	1–20	RA	A	A, M, P	VU	2008	Decreasing
	P. laevis	125	4–100	RA	A, M, P	A, M, P	VU	2008	Decreasing
	P. leopardus	120	3–100	RA, O	A	M	NT	2004	Decreasing
	Variola albimarginata	65	4–200	RA	A, M	A, M	LC	2008	Decreasing
	V. louti	83	3–250	RA	A, M, P	A, M, P	LC	2008	Stable
Chaetodontidae	*Chaetodon flavocoronatus*	12	36–75	RA	M	M	VU	1996	Needs updating
Labridae	*Cheilinus undulatus*[g]	229	1–100	RA	A, M, P	A, M, P	EN	2004	Decreasing

Table 2 continued

Family	Species	Ecological information[a]					IUCN assessment[b]		
		Max length (cm TL)	Depth range (m)	Habitat[c]	Observed region[d]	Published range[d]	Status[e]	Years	Trend
Scaridae	*Bolbometopon muricatum*[g]	130	1–30	RA	A, M, P	A, M, P	VU	2007	Decreasing

[a] FishBase served as the source for ecological information

[b] IUCN assessment information is based on the 2011 IUCN Red List of Threatened Species

[c] *B* Benthopelagic, *O* Oceanodromous, *PO* Pelagic-oceanic, *RA* Reef-associated

[d] *A* American Samoa, *H* Hawaiian Archipelago, *M* Mariana Archipelago, *P* Pacific Remote Island Areas

[e] *NT* near threatened, *VU* Vulnerable, *EN* Endangered, *DD* data deficient, *LC* least concern

[f] Disk width

[g] NOAA species of concern

Results

IUCN-listed species in the US Pacific Islands

Forty-five species representing 11 families of fishes included on the IUCN List were observed during RAMP surveys (Table 2). Of the species observed, more than 25 % (13 species) are categorized by the IUCN as endangered or vulnerable, the two highest extinction risk categories observed in this assessment. The humphead wrasse, scalloped hammerhead (*Sphyrna lewini*), and great hammerhead (*Sphyrna mokarran*) are the only three species observed during this study that are listed as endangered and are considered to face the greatest risk of extinction. The humphead wrasse is one of two Indo-Pacific coral reef fishes also listed as a NOAA Species of Concern.

Groupers (Serranidae) accounted for more than 60 % (28 species) of the IUCN-listed species encountered during RAMP surveys. However, only 3 of the groupers observed are listed as vulnerable, the second highest risk of extinction. These include the giant grouper (*Epinephelus lanceolatus*), squaretail coral grouper (*Plectropomus areolatus*), and black saddled coral grouper (*P. laevis*). Three additional groupers observed during surveys are assigned to the near-threatened category and considered to be close to qualifying or likely to qualify for one of the threatened categories in the near future. These include the camouflage grouper (*Epinephelus polyphekadion*), Hawaiian grouper (*Hyporthodus* [*Epinephelus*] *quernus*), and the leopard coral grouper (*Plectropomus leopardus*). The remaining 22 grouper species represent 49 % of the IUCN-listed species encountered during RAMP surveys and are assigned to the least concern and data-deficient categories.

Sharks and rays from the subclass Elasmobranchii accounted for the second greatest proportion (31 %) of IUCN-listed species encountered during surveys. Of the 14 species of Elasmobranchs, nearly half (6 species) are requiem sharks (Carcharhinidae), with the lemon shark (*Negaprion acutidens*) being the only reef shark listed as vulnerable. The two species of hammerhead sharks are listed as endangered, and the remaining sharks and rays observed during surveys are listed as vulnerable (4 species) or near threatened (2 species). A complete list of all 45 IUCN-listed species observed during RAMP surveys is included in Table 2. Additionally, the results from the TDS and BLT surveys are summarized in a series of tables included in Electronic Supplementary Material identifying the mean and maximum size of each species observed at each island during this assessment.

Regional and island trends

At the regional level, the greatest number of IUCN-listed species (39 species) was observed in the PRIA, while the smallest number of species (12 species) was observed in the Hawaiian Archipelago. At the island level, the greatest number of IUCN-listed species was observed at Howland Island (PRIA) with 26 species, followed by Jarvis Island (25 species), Palmyra Atoll (24 species), and Baker Island (20 species), all located within the PRIA. Tutuila, the largest and most densely populated island in American Samoa, was the only non-PRIA island with more than 20 IUCN-listed species observed (21 species). Few species have ranges extending to all four geographic regions. These broad-ranging species included gray reef sharks (*Carcharhinus amblyrhynchos*, near threatened), whitetip reef sharks (*Triaenodon obesus*, near threatened), spotted eagle rays (*Aetobatus narinari*, near threatened), and the peacock hind (*Cephalopholis argus*, least concern). The peacock hind's distribution includes the inhabited islands of the Hawaiian Archipelago following its deliberate introduction from the Society Islands in 1956 (Randall 1987).

Density of large-bodied species

Total mean density of large-bodied species varied greatly at the regional and island levels (Table 3). The greatest densities of IUCN-listed species were observed in the

PRIA where the overall mean was 33 individuals km^{-2} (SE 21). In contrast, the lowest density of IUCN-listed species was observed in American Samoa, that is, two individuals km^{-2} (SE 1). In the Hawaiian Archipelago and Mariana Archipelago, IUCN-listed species were observed in densities less than a third of those in the PRIA with total mean density of IUCN-listed species being seven individuals km^{-2} (SE 3) and nine individuals km^{-2} (SE 5) observed, respectively.

Considerable differences in the mean density of IUCN-listed species were observed between inhabited and uninhabited islands of the Hawaiian and Mariana Archipelagoes (Table 3). The mean density of IUCN-listed species (all species pooled) was fivefold greater at uninhabited islands within the two archipelagoes. Of the 11 IUCN-listed species observed in the Hawaiian Archipelago during TDS, 4 were recorded at significantly greater ($p < 0.01$) densities at uninhabited islands. Those were the gray reef shark, Galapagos shark (*Carcharhinus galapagensis*), whitetip reef shark, and Hawaiian grouper all of which are listed as near threatened.

In the Mariana Archipelago, 3 IUCN-listed species were observed in significantly greater ($p < 0.001$) densities at uninhabited islands: the tawny nurse shark (*Nebrius ferrugineus*, near threatened), gray reef shark, and whitetip reef shark. The humphead wrasse was the only IUCN-listed species and NOAA Species of Concern observed in significantly greater ($p < 0.05$) density at inhabited islands in the Mariana Archipelago with 14 individuals observed km^{-2} (95 % CI 5, 27) compared to 4 individuals observed km^{-2} (95 % CI 1, 9) at uninhabited islands within the archipelago. In American Samoa, no significant difference in the mean density of IUCN-listed species was observed between inhabited and uninhabited islands.

Density of high-risk, large-bodied species

In general, high-risk species listed as endangered or vulnerable were uncommon, with the exception of tawny nurse sharks, blotched fantail rays (*Taeniura meyeni*), scalloped hammerhead shark, and humphead wrasse (Fig., 1). Tawny nurse sharks and blotched fantail rays were most frequently observed at uninhabited islands of the Mariana Archipelago, with a mean density of 0.16 individuals km^{-2} (95 % CI 0.10, 0.22) and 0.06 individuals km^{-2} (95 % CI 0.02, 0.12), respectively. Scalloped hammerhead sharks were rare throughout all islands but observed in the greatest density in the PRIA at 0.16 individuals km^{-2} (95 % CI 0, 0.46).

Humphead wrasse was the most widely distributed high-risk species that included all regions except the Hawaiian Archipelago. The greatest densities of humphead wrasse were observed in the PRIA, with a regional mean of 0.26 individuals observed km^{-2} (95 % CI 0.14, 0.42). Within the PRIA, the greatest density was recorded at Wake Atoll with 114 individuals observed km^{-2} (SE 15). Palmyra Atoll had the second greatest density with 63 individuals observed km^{-2} (SE 13). Humphead wrasse was also recorded at the southern islands of the Mariana Archipelago and throughout American Samoa. In the Mariana Archipelago, Rota Island had the greatest density of humphead wrasse with 40 individuals observed km^{-2} (SE 10). Humphead wrasse was also observed at all of the islands in American Samoa with the greatest density observed at Swains Island [29 individuals km^{-2} (SE 7)].

Bumphead parrotfish (vulnerable), one of two Indo-Pacific coral reef species listed as a NOAA Species of Concern, were rare or absent in the US Pacific Islands except for at Wake Atoll where their mean density was 297 individuals km^{-2} (SE 96). Bumphead Parrotfish were also observed at Palmyra Atoll but only at a fraction of what was observed at Wake Atoll, where a mean five fish km^{-2} (SE 4) was observed. Other sightings of the bumphead parrotfish included Pagan Island (Mariana Archipelago), with two individuals observed, and at Tau and Tutuila (American Samoa), where a single individual was observed at each location.

Density of small-bodied species

Small-bodied grouper species reaching a maximum TL of <100 cm accounted for a majority (23 species) of the IUCN-listed species encountered. The yellow-crowned butterflyfish (*Chaetodon flavocoronatus*, vulnerable) was the only other small-bodied included on the IUCN List and recorded in the US Pacific Islands. In general, small-bodied IUCN-listed species were rare, and mean densities varied at both the regional and island level. Most species were infrequently recorded while a few others were observed in great densities (Table 4).

At the regional level, the highest mean densities of IUCN-listed grouper species were observed in the PRIA with 28 individuals observed ha^{-1} (SE 12). Grouper densities in American Samoa and the Mariana Archipelago were a little more than half of those observed in the PRIA, with mean densities equal to 23 individuals ha^{-1} (SE 12) and 17 individuals ha^{-1} (SE 10), respectively.

Significant differences in the density of small-bodied grouper species were observed between inhabited and uninhabited islands (Table 4). In American Samoa, five of the 22 IUCN-listed grouper species recorded in the archipelago were observed in significantly greater densities at uninhabited islands. The yellow-edged lyretail grouper (*Variola louti*, least concern) was the only grouper species observed at significantly greater ($p < 0.05$) densities at inhabited islands with five individuals ha^{-1} (95 % CI 1,

Table 3 Summary results of towed-diver surveys using a resampling approach ($n = 10{,}000$) to evaluate differences (between inhabited and uninhabited regions) in mean densities (individuals km^{-2}) of large-bodied fishes (>50 cm TL) included on the IUCN Red List of Threatened Species observed in the US Pacific Islands from 2000 to 2009

Status[a]	Family	Species	American Samoa		Hawaiian Archipelago		Mariana Archipelago		PRIAs
			Inhabited	Uninhabited	Inhabited	Uninhabited	Inhabited	Uninhabited	Uninhabited
EN	Sphyrnidae	*Sphyrna lewini*	0	0	0.01 ns (0, 0.03)	0	0	0	0.16 (0, 0.46)
		S. mokarran	0	0	0	0	0	0	0.01 (0, 0.02)
	Labridae	*Cheilinus undulatus*[b]	0.14 ns (0.05, 0.03)	0.17 (0.03, 0.33)	–	–	0.14>* (0.05, 0.28)	0.04 (0, 0.09)	0.26 (0.14, 0.42)
VU	Ginglymostomatidae	*Nebrius ferrugineus*	0 ns (0, 0.02)	0 (0, 0.02)	–	–	0<*** (0, 0.03)	0.16 (0.10, 0.22)	0
	Stegostomatidae	*Stegostoma fasciatum*	0 ns (0, 0.01)	0	–	–	0	0	0
	Carcharhinidae	*Negaprion acutidens*	0 ns (0, 0.01)	0	–	–	0	0	0
	Dasyatidae	*Taeniura meyeni*	0.01 ns (0, 0.05)	0 (0, 0.03)	–	–	0.02 ns (0, 0.06)	0.06 (0.02, 0.12)	0.02 (0, 0.05)
		Urogymnus asperrimus	–	–	–	–	0 ns (0, 0.02)	0 (0, 0.01)	–
	Serranidae	*Epinephelus lanceolatus*	0	0	0	0	0 ns (0, 0.02)	0 (0, 0.01)	0
		Plectropomus areolatus	0.19 ns (0, 1.37)	0	–	–	0	0	0
		P. laevis	2.44 ns (0, 7.43)	0	–	–	1.65 ns (0, 5.99)	0	0.95 (0, 3.36)
	Scaridae	*Bolbometopon muricatum*[b]	0.5 ns (0, 3.68)	0	–	–	0 ns	0.15 (0, 1.12)	43.4 (8.52, 124.9)
NT	Carcharhinidae	*Carcharhinus amblyrhynchos*	1.76 ns (0, 5.89)	9.72 (0, 29.03)	1.17<*** (0, 3.40)	21.21 (11.5, 35.6)	0.51<*** (0, 2.73)	82.74 (52, 119)	386.6 (247, 560)
		C. galapagensis	0.14 ns (0, 1.79)	0.39 (0, 2.58)	1.84<** (0, 7.08)	21.61 (6.9, 48.9)	–	–	2.21 (0, 7.52)
		C. melanopterus	3.8 ns (0, 8.96)	4.4 (0, 14.20)	0	0	2.86 ns (0, 7.86)	5.53 (0.46, 16)	20.38 (9.51, 35.24)
		Galeocerdo cuvier	0	0	0 ns (0, 0.55)	0.1	0	0	0.07 (0, 0.51)
		Triaenodon obesus	9.11 ns (1.7, 18)	17.27 (4.6, 34.9)	2.82<*** (0, 8.41)	23.83 (15.1, 33.2)	7.14<*** (1.1, 16)	57.39 (42, 74.1)	53.07 (29.8, 87.54)
	Myliobatidae	*Aetobatus narinari*	4.58 ns (0, 12.36)	0.99 (0, 5.25)	5.78 ns (1.4, 12)	8.67 (2.3, 16.97)	4.27 ns (0, 11.4)	2.37 (0.45, 4.98)	17.61 (7.11, 30.96)
	Mobulidae	*Manta alfredi*	0	0	1.12 ns (0, 3.15)	3.17 (0, 8.81)	0	0	23.14 (4.70, 62.6)
	Serranidae	*Hyporthodus quernus*	–	–	0<*** (2.2, 13.5)	7.21	–	–	–
		Plectropomus leopardus	0.34 ns (0, 2.38)	0	–	–	0	0	–
	Total	All taxa pooled	2.06 ns (0.3, 5.2)	2.69 (0.40, 6.57)	1.21<** (0.1, 3.3)	7.80 (3.46, 14.3)	1.78<** (0.3, 4.3)	9.19 (5.66, 13.7)	32.89 (17.88, 56)

Note that units for mean densities can be converted to individuals ha^{-1} by dividing by 100

Islands are grouped by region and population status (Inhabited vs. Uninhabited). Values are mean density km^{-2} with lower and upper 95 % confidence intervals identified in parentheses Confidence intervals were omitted for species where the resampled mean abundance was equal to 0. Regions outside of the biogeographic range of a species are identified with a dash. Regional island groups with significantly higher resampled abundance values are identified with a < or > sign

Significance is given as: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; and *ns* not significant

[a] 2011 IUCN red list categories: *EN* endangered, *VU* vulnerable, *NT* near threatened

[b] NOAA Species of Concern

Table 4 Summary results of belt transect surveys using a resampling approach ($n = 10,000$) to evaluate differences in mean densities (individuals ha^{-1}) included on the IUCN Red List of Threatened Species observed in the US Pacific Islands from 2000 to 2009

Status[a]	Family	Species	American Samoa		Hawaiian Archipelgo		Mariana Archipelago		PRIAs
			Inhabited	Uninhabited	Inhabited	Uninhabited	Inhabited	Uninhabited	
VU	Serranidae	Epinephelus polyphekadion	0	0	–	–	0.21 ns (0, 0.89)	0	0.97 (0, 2.72)
	Chaetodontidae	Chaetodon flavocoronatus	–	–	–	–	0.91 ns (0, 4.76)	0	–
LC	Serranidae	Anyperodon leucogrammicus	0	0	–	–	0	0	0
		Cephalopholis argus	61.45<* (36.9, 88.5)	109.56 (73.8, 147.1)	21.76>*** (13.7, 32)	0.64 (0, 1.32)	0.89<*** (0, 2.68)	38.92 (27.51, 52.11)	98.6 (78.4, 119.5)
		C. leopardus	1.28<*** (0, 4.76)	46.47 (13.1, 109.5)	–	–	1.13 ns (0, 4.17)	0.23 (0, 0.79)	2.63 (0, 6.46)
		C. miniata	0	0	–	–	0 ns	0.24 (0, 0.93)	126.88 (91.2, 165.9)
		C. sexmaculata	0	0	–	–	0 ns	0.71 (0, 1.72)	0.24 (0, 1.02)
		C. sonnerati	0	0	–	–	0 ns	0.16 (0, 0.79)	0
		C. spiloparaea	2.57 ns (0, 11.90)	1.22 (0, 4.76)	–	–	0	0	1.31 (0, 3.74)
		C. urodeta	212.42<* (150.7, 280)	323.39 (222, 425)	–	–	138.21<*** (98.2, 181)	339.92 (285, 398)	190.06 (129, 257)
		Epinephelus fasciatus	2.89 ns (0, 12.69)	0	–	–	2.57<*** (0, 7.74)	22.11 (10, 36.5)	75.28 (25.9, 142.6)
		E. hexagonatus	0.66 ns (0, 3.17)	1.58 (0, 7.14)	–	–	1.35<** (0, 4.17)	13.27 (5.03, 23.54)	1.94 (0, 4.59)
		E. howlandi	0.65 ns (0, 3.17)	0.46 (0, 2.38)	–	–	0 ns	0.27 (0, 1.06)	1.13 (0, 2.38)
		E. macrospilos	0	0	–	–		–	0.61 (0, 1.70)
		E. maculatus	0.08 ns (0, 0.79)	0	–	–	0 ns	0.31 (0, 1.19)	0
		E. merra	0.82 ns (0, 4.76)	0.99 (0, 3.57)	–	–	0.22 ns (0, 1.19)	0.29 (0, 1.19)	3.07 (0.34, 6.80)
		E. spilotoceps	0 ns	1.22 (0, 4.76)	–	–	–	–	1.89 (0, 4.42)
		Variola albimarginata	0	0	–	–	0	0	–
		V. louti	5.11>* (0.79, 11.90)	0	–	–	2.65<** (0, 6.55)	11.51 (5.95, 18.51)	6.74 (3.06, 11.05)
DD	Serranidae	Aethaloperca rogaa	–	–	–	–	0.1 ns	0.16	3.69

Table 4 continued

Status[a]	Family	Species	American Samoa		Hawaiian Archipelgo		Mariana Archipelago		PRIAs
			Inhabited	Uninhabited	Inhabited	Uninhabited	Inhabited	Uninhabited	
					–	–	(0, 0.60)	(0, 0.53)	(0.34, 8.16)
		Epinephelus melanostigma	0.24<* (0, 1.59)	3.39 (0, 9.52)	–	–	0 ns	0.91 (0, 2.25)	3.17 (0.68, 6.13)
		E. retouti	0	0	–	–	0	0	1.32 (0, 3.74)
		E. tauvina	0 ns	0.35 (0, 1.79)	–	–	0 ns	0.21 (0, 0.79)	1.86 (0, 4.59)
		Gracila albomarginata	1.15<** (0, 3.97)	13.17 (4.76, 23.80)	–	–	0<**	32.51 (1.06, 116.26)	9.88 (4.42, 15.98)
	Total	All grouper species pooled	17.02<* (11.1, 25)	29.52 (18.5, 43.8)	21.76>*** (13, 31.5)	0.64 (0, 1.32)	8.24<*** (5.5, 11.3)	25.65 (18.5, 34.4)	27.96 (17.6, 40.4)

Note that the units for describing densities are different from Table 3 but can be converted to individuals km^{-2} by multiplying by 100

Islands are grouped by region and population status (Inhabited vs. Uninhabited). Values are mean density ha^{-1} with lower and upper 95 % confidence intervals identified in parentheses Confidence intervals were omitted for species where the resampled mean abundance was equal to 0. Regions outside of the biogeographic range of a species are identified with a dash. Regional island groups with significantly higher resampled abundance values are identified with a < or >Impacts of fishing on tropical reef sign

Significance is given as: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; and ns not significant

[a] 2011 IUCN Red List Categories: VU vulnerable, LC least concern, DD data deficient

12); no individuals were recorded at uninhabited islands within the archipelago. In the Mariana Archipelago, 6 of the 22 grouper species were recorded in higher densities at uninhabited islands and no grouper species was more abundant at inhabited islands. In the Hawaiian Archipelago, the nonnative peacock hind was observed at significantly greater ($p < 0.001$) densities at inhabited islands [22 individuals ha^{-1} (95 % CI 14, 32)], likely a persistent consequence of its deliberate introduction into the inhabited main islands (Randall 1987).

The darkfin hind (*Cephalopholis urodeta*, least concern) was the most abundant grouper species overall with the greatest densities (340 individuals ha^{-1}; 95 % CI 285, 399) observed at the uninhabited islands of the Mariana Archipelago. The peacock hind also was abundant in all survey regions, with the greatest densities observed at the uninhabited islands of American Samoa [110 individuals ha^{-1} (95 % CI 74, 147)]. The coral hind (*Cephalopholis miniata*, least concern) and the blacktip grouper (*Epinephelus fasciatus*, least concern) were abundant in the PRIA with 127 individuals ha^{-1} (95 % CI 91, 166) and 75 individuals ha^{-1} (95 % CI 26, 143) observed, respectively. These same species were rare or not observed at the inhabited islands of the American Samoa and Mariana Archipelagoes.

Density of high-risk, small-bodied species

The camouflage grouper (*Epinephelus polyphekadion*) and the yellow-crowned butterflyfish were the only two small-bodied species listed as vulnerable, the second-highest risk category included in this study. Camouflage grouper were most abundant in the PRIA [1 individual ha^{-1} (95 % CI 0, 3). The yellow-crowned butterflyfish, typically observed at depths greater than 30 m in the Mariana Archipelago, was recorded at a single site and depth less than 30 m.

Discussion

Overexploitation is generally considered the primary threat facing coral reef fishes (Friedlander and DeMartini 2002; Reynolds et al. 2002, 2005; Dulvy et al. 2003; DeMartini et al. 2008). Although there are no documented cases of global marine fish extinctions, marked declines have occurred in several species, some of which are considered to be extinct at local or regional scales (Dulvy et al. 2003). Growing concerns over the status of many species led the IUCN to evaluate the conservation status of 1,326 species of marine fishes, 45 of which were recorded in the US Pacific Islands as part of the RAMP. Our aim was to complement IUCN evaluation efforts by providing the first large-scale assessment of IUCN-listed species in the tropical US Pacific Islands. Data included in this study are

substantial, representing 9 yrs of survey effort, including 40 islands spanning a large portion of the tropical Pacific. From these efforts, three key findings emerge: (1) the diversity and density of IUCN-listed species in the US Pacific Islands varied across individual islands and at a regional scale; (2) mean densities significantly differed between uninhabited and inhabited islands—densities were greater in uninhabited versus inhabited regions in 78 % of 23 total cases for which data were available; and (3) IUCN-listed species were most diverse and abundant in the remote and uninhabited PRIA. Threats to these IUCN-listed species continue to include their limited distributions, popularity among fisheries, life history characteristics, and remote regional occurrence (Morris et al. 2000; Sadovy et al. 2003; Donaldson and Dulvy 2004; Sadovy 2005; Sadovy and Domeier 2005).

Widely distributed species are thought to face reduced risks of extinction compared to species with restricted ranges (Hawkins et al. 2000). Large-scale exploitation reduces population densities of a species which can lead to localized extirpations and an overall range reduction (Roberts 1995). Species with clumped population distributions and/or species that form spawning aggregations at specific and predictable times and locations are more susceptible to large-scale exploitation. In the US Pacific islands, most IUCN-listed species have patchy distributions (Tables 3, 4; Fig. 1). These heterogeneous distribution patterns were not restricted to species facing the greatest extinction risk but applied to most species regardless of their IUCN List categorization. Species with low levels of abundance or disparate populations are less resistant and resilient to perturbations and have a diminished capacity to recolonize locally extirpated populations (Cooper and Mangel 1999). These findings suggest that nearly all IUCN-listed species recorded in the US Pacific Islands may be vulnerable to large-scale exploitation or perturbations and face a greater risk of local extinction compared to species with less clumped population distributions.

Most of the IUCN-listed fish species are targets for subsistence, recreational, or commercial fisheries (Morris et al. 2000; Donaldson and Sadovy 2001; Sadovy et al. 2003; Donaldson and Dulvy 2004; Robbins et al. 2006). Some species such as bumphead parrotfish might be especially vulnerable because they are also considered trophy bycatch within multi-species fisheries, thus leading to rapid and little documented rates of population decline (Dulvy et al. 2003; Dulvy and Polunin 2004). Sharks, groupers, humphead wrasse, and bumphead parrotfish accounted for more than 80 % of the IUCN-listed species observed in the US Pacific islands during RAMP surveys. These species are important in structuring fish and benthic communities through their roles as influential competitors and predators on coral reefs (Roberts 1995; Bascompte

et al. 2005; Estes et al. 2011). We did not observe most conspicuous large-bodied species of sharks and groupers except at remote and uninhabited islands (Tables 3, 4; Fig. 1). Large-bodied highly mobile species such as sharks showed the greatest differences in abundance between inhabited and uninhabited islands in the Hawaiian and Mariana Archipelagoes. Significant differences in the mean density of small-bodied grouper species were also observed, although less often. The reason for these differences is unknown, but the pattern has been documented in many marine ecosystems where fishing down large-bodied species has been followed by the exploitation of smaller-bodied species (Roberts 1995; Jennings and Polunin 1996a, b; Pauly et al. 1998; Friedlander and DeMartini 2002; DeMartini et al. 2008). Importantly, there were similarities in the density patterns of these species regardless of category of extinction risk—each of the high-risk, low-risk, and data-deficient species of concern identified by IUCN showed vulnerability to exploitation as evidenced by regional comparisons of density between inhabited and uninhabited islands (Tables 3, 4).

Furthermore, we documented only three instances where greater densities of IUCN-listed species were observed at inhabited islands. These differences were most likely attributed to: (1) persistent results of deliberate introductions of the species to inhabited islands, as is the case for the peacock grouper in the Hawaiian Archipelago (Randall 1987), (2) lack of suitable juvenile habitat (e.g., lagoons with branching coral and macroalgae) for humphead wrasse at uninhabited islands of the Mariana Archipelago (Tupper 2007), and (3) lack of suitable adult habitat (e.g., reef passes or lagoons) for the yellow-edged lyretail grouper at uninhabited islands in American Samoa (Randall and Brock 1960; Myers 1999). Despite some species-specific differences, the life history characteristics common among a majority of the IUCN-listed species recorded during surveys make them particularly vulnerable to overexploitation. These characteristics include slow growth, long life span, late sexual maturation, group spawning, low replenishment rates, and low natural abundance (Reynolds et al. 2002; Sadovy and Cheung 2003; Tupper 2007; Sadovy de Mitcheson et al. 2008). These life history characteristics, combined with the Pacific-wide declines of many of these species, reinforce the importance of large-scale assessments and conservation efforts.

Underwater visual census (UVC) methods are common tools used to characterize coral reef fish assemblages (Friedlander and DeMartini 2002; DeMartini et al. 2008; Sandin et al. 2008; Williams et al. 2011). Although these methods do not provide age-based demographic data used in modern stock assessments, they provide quantitative estimates of species density, size structure, and frequency of occurrence. A key advantage of UVC methods is that

they are fishery independent and nondestructive. This is especially important when assessing species affected by overexploitation or while working in protected areas.

Recent conservation efforts in the tropical Pacific have formally protected many of the uninhabited islands of the US Pacific, including Papahānaumokuākea (Northwestern Hawaiian Islands), Pacific Remote Islands, Marianas Trench (including many of the uninhabited islands of the Mariana Archipelago), and Rose Atoll Marine National Monuments. Such management measures should afford many of species of concern with a refuge from fishing in perpetuity. Further, the remote, uninhabited islands provide an opportunity to estimate baselines and are among the few remaining "pristine" systems where IUCN-listed species can be observed in abundance. As such, these reefs provide an unprecedented opportunity for scientists and managers to examine ecosystem function and the ecology of IUCN-listed species in the absence of direct human-caused disturbances. The knowledge gained by studying these undisturbed systems can be used to identify spawning aggregations, essential fish habitat, fish behavior, and other ecological processes that can be applied to the development recovery strategies and ecosystem-based management plans, including those for sustainable fisheries in inhabited islands.

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