Spawning potential surveys in Solomon Islands' Western Province

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Summary

Since 2014, the World Wide Fund for Nature has worked with local fishing communities around Ghizo Island, in the Western Province of Solomon Islands to assess the status of the reef fish stocks and inform sustainable management. This article describes the results of their catch sampling programme and the assessments completed. A following article will describe how these data have informed the development of a system of four minimum size limits that could make reef fish catches sustainable. A relatively new methodology, length-based spawning potential ratio (LBSPR) assessment, successfully estimated the spawning potential ratio (SPR) of stocks, thereby providing an indication of whether they are likely to decline, increase or remain stable. Prior to this study, size at maturity had been estimated for only four reef fish species in Solomon Islands and no stocks had been assessed. Between February 2014 and June 2018 this project measured 8476 fish from 290 species, enabling the size at maturity of 63 species to be estimated and 61 species assessed, comprising ~84% of the sampled catch by number.

The assemblage of small- and medium-bodied reef fish around Ghizo Island appears to be less depleted than estimated by parallel studies in Palau and Fiji. The average SPR of around ~35% is currently within the target range (30–40%) used internationally as a proxy for the level likely to produce maximum sustainable yields, although we also found evidence of localised depletions of some species by night-time spearfishing. These results need to be interpreted within the context of a lack of any effective management of reef fish, and our inability to assess more highly prized large- bodied serranids, labrids and parrotfish because their prevalence in the catch has already declined. Our study would have been likely to estimate lower levels of spawning potential if we had assessed these larger- bodied species. Without any management, it is likely that the current levels of SPR in small- and medium- bodied species will only be a transitional phase as reef fish stocks in the region continue to be overfished.

Introduction

Globally, the lack of biological information and catch data for reef fish and other small-scale fisheries, has been a long-term challenge for their assessment and management (Andrew et al. 2007; SPC 2015). With the aim of supporting community-based fisheries management around Ghizo Island in Solomon Islands' Western Province, the World Wide Fund for Nature (WWF) has been working with local fishing communities since 2014 to assess the status of reef fish stocks and facilitate the development of sustainable management policies and practices. This article describes the results of the catch sampling programme and the assessments completed through this project. A future article will describe how these data have been used to develop a simple system of size limits that could make reef fish catches sustainable.

In most Pacific Island countries and territories, there are many reef fish species but data on catch trends and biology are insufficient for applying standard methods for assessing trends in biomass (total weight). A relatively new technique, called the length-based spawning potential ratio (LBSPR) assessment, has been developed specifically for fish stocks for which only data on catch size and composition can feasibly be collected (Hordyk et al. 2015a, b; Prince et al. 2015a). By comparing the size composition of catches to the size at which fish mature, the LBSPR methodology estimates the spawning potential ratio (SPR) of a fish population, thus providing an indication of whether those stocks are declining, stable or increasing. Left unfished, fish complete their full life span and complete 100% of their natural reproductive (spawning) potential. Fishing reduces the average life span of fish thus reducing their reproductive, or spawning, potential below natural unfished levels (<100%). SPR is the proportion of the natural unfished spawning potential remaining in a population that is being fished.

The concept of SPR for fished stocks is similar to the human reproductive index (HRI) for human populations, which is the average number of children per couple that survive to adulthood. With 2.1 children surviving through to adulthood, human couples replace themselves and those around them without children, thereby ensuring population stability. An HRI above 2.1 ensures population growth, while

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below that the population declines. Studies from around the world have shown that in marine populations, 20% SPR is the equivalent of the HRI replacement level of 2.1 surviving children per couple; both are pivotal reference points around which populations of humans and fish either increase or decrease. Down to around 20% SPR, fish populations retain the capacity to rebuild their numbers after fishing, although the rate at which stocks can rebuild declines as SPR falls towards 20% (Mace and Sissenwine 1993). Below 20% SPR, the supply of young fish to populations is expected to decline over successive years, while 10% SPR is commonly called 'SPR crash' because populations below this level are likely to decline rapidly towards local extinction.

Methods

The LBSPR assessment methodology compares the size of the fish being caught with the size at which they reach sexual maturity. If fish are all caught before reaching sexual maturity their populations have little spawning potential (i.e. ~0% SPR). On the other hand, with low fishing pressure, fish live close to their natural life spans, enabling them to grow much larger than their size at maturity, with many even attaining the natural average maximum size for their population (L_∞). When this happens, SPR will be close to 100% of the natural unfished level. The LBSPR algorithms enables the information in catch size composition, relative to size at maturity, to be quantified in terms of SPR and the relative fishing pressure on a population: F/M, where F is the rate at which fish are caught ("fishing mortality"), and M is the rate at which fish die due to natural causes ("natural mortality").

The data inputs required for the LBSPR methodology are:

- Catch size composition data that are indicative of the size of the adult fish in a population. If the type of fishing being conducted fails to catch the largest size classes of a fish species, then SPR will be underestimated.
- Estimates of size at maturity, which is defined by L_{50} and L_{95}, the sizes at which 50% and 95%, respectively, of a population become mature.
- The two life history ratios (LHR) that characterise each family and species of fish are:
  - L_m/L_∞ the relative size at maturity, which is L_{50} divided by L_∞; and
  - M/K which is a species' natural rate of mortality (M), divided by the von Bertalanffy growth parameter K, a measure of how quickly each species grows to the average maximum size (L_∞).

The first two of these data inputs need to be measured locally for each species because they vary from place to place; but, the more technically challenging LHR can be estimated generically from the scientific literature because they are shared by families and species across their entire range (Holt 1958; Prince et al. 2015a,b).

For this analysis the algorithms needed to apply the LBSPR methodology were accessed at the freely available website: http://barefootecologist.com.au

Data inputs

Life history ratios

Estimates of LHR used for this assessment (Table 1) were developed through a meta-analysis of all available age, growth and maturity studies for Indo-Pacific reef fish species (Prince et al. in prep).

Table 1. Life history ratios assumed for reef fish families.

Family	M/k	L_m/L_∞
Acanthurid	0.52	0.79
Caesionid	1.28	0.61
Serranid	0.64	0.64
Scarid	0.94	0.65
Labrid	1.43	0.48
Lethrinid	0.87	0.70
Lutjanid	0.75	0.74
Mullid	1.87	0.59
Carangid	1.28	0.61
Siganid	1.65	0.59
Sphyraenid	1.47	0.48

Collection of length and maturity data

Data collection was initiated on 6 February 2014 and this analysis is based on data collected through to 27 June 2018. The majority of catches were sampled in Gizo township by having local fishers bring their catches for inspection, prior to taking them to the market to sell later in the day. Fishers were offered 15 Solomon Island dollars (SBD) per cooler of fish measured (~AUD 2.00), and a top-up of fresh ice afterwards, to assist WWF measure their fish. Researchers were also able to select, and pay market prices for, any samples they wanted to dissect for gonad examination. Fish were identified to the species level and measured in millimetres from the snout to the outer edge of the middle of the tail. Time and method of capture were recorded. Almost all the fish measured were photographed so that pictures could later be matched to data entries, and species identifications could be confirmed. Only a subsample of the most commonly caught species were purchased for gonad inspection.

At the time of sampling, fuel prices were high and there were relatively few outboard motors in the communities so fishers mainly fished from canoes propelled by paddle and sail, and the fish measured in Gizo township were caught relatively close to Ghizo Island. One main source of samples was the fishing village of Saeraghi, located at the northwestern end of Ghizo Island where fishing was mainly with hook and line. The second principle source of samples measured in Gizo was Rarumana, a small island to the east of Ghizo Island where the community primarily spearfished at night.

A third main source of samples were the communities around Nusatuva on Kolombangara Island, several hours by motorboat east of Ghizo Island and too remote for fish to be transported to the market in Gizo. Local fishers from the communities around Nusatuva were periodically asked to catch fish and bring them to Nusatuva to sell to WWF. These fish were caught by either hook-and-line or night-time spearfishing. As these fish were purchased by WWF, almost all were dissected for gonad inspection.

Size at maturity estimation

To the extent possible, fish were opened and their gonads inspected so that they could be macroscopically gauged as immature or mature, male or female, and so that size at maturity could be estimated. We applied a basic protocol developed for general utility across coral reef species, which can be taught to artisanal fishers (Prince et al. 2015b). The primary features for classifying gonads as being are:

- distinct, three-dimensional shape; lobed, and triangular in cross section, for testis, or sausage, tube, or sack-like for ovaries; and
- the length of the gonad is longer than one-third of the length of the body cavity.

Where possible, these macroscopic examinations were used to estimate the proportion of mature fish by size class, and a logistic curve was fitted to estimate L_{50} and L_{95}. Many Indo-Pacific reef fish species exhibit ontogenetic habitat shifts, with juveniles growing up in shallow nursery habitats, such as shallow mangroves, seagrass beds or coral rubble reef flats, and only moving out into the coral reef habitat as they mature (Nakamura et al. 2008; Grol et al. 2011). This behaviour can mean juveniles are rarely found in catches from coral reef habitats, and makes it difficult or impossible to define the transition from 0 to 100% mature, thus preventing the estimation of size at maturity (e.g. Williams et al. 2008; Currey et al. 2013; Moore et al. 2015; Taylor et al. 2018). Caillart et al. (1994) and Prince et al. (2008) suggested turning this difficulty to advantage by using the size of the smallest fish caught in the adult habitat to approximate size at maturity. A recent study completed in Palau by Prince et al. (in prep.) demonstrates how this can be done by converting the left-hand side of the catch length-frequency histogram into a cumulative frequency curve, as the 50th percentile of that curve approximates histological estimates of size at maturity. Using this principle, we fitted logistic curves to the left-hand side of the main mode in the length-frequency histograms, and in this way developed alternative estimates of L_{50} and L_{95}. Where our inspection of a species' gonads revealed a high and trendless proportion of each size class that were mature, causing the macroscopically derived size at maturity curve to be poorly defined, or entirely undefined, we preferred these length-based estimates of size at maturity.

Results

Data collection

Some 8476 fish from 290 species were in the database we analysed, evidence of the remarkably diverse reef fish fauna of the region. With such diversity, sample sizes for most species were relatively small, with n >1000 only being achieved for one species (*Lutjanus gibbus*). Sample sizes were n = 300–1000 for 4 species, n = 100–300 for 16 species, and n = 30–100 for 40 species.

Catch composition of different fishing methods

A total of 4071 fish from 197 species were sampled from catches by night-time spearfishers, and 4405 fish from 200 species from hook-and-line catches.

By number of fish, the hook-and-line catch (Table 2) was dominated by just seven species comprising ~52% of the catch; two snappers *Lutjanus gibbus* (~27%) and *L. bohar* (~3%), 5 species of emperor *Lethrinus lentjan* (~7%), *L. erythropterus* (~5%), *L. obsoletus* (~4%), *L. xanthochilus* (~3%) and *L. microdon* (~3%).

In contrast, the spearfishing catch (Table 2) was more heterogeneous, with a similar 52% of the catch comprising 12 species; goatfishes *Parupeneus barberinus* (~9%) and *Mulloidichthys vanicolensis* (~2%), surgeonfishes *Acanthurus nigricauda* (~8%) and *A. lineatus* (~7%), parrotfishes *Hipposcarus longiceps* (~4%), *Scarus dimidiatus* (~3%), *S. niger* (~2%) and *S. psittacus* (~2%), rabbitfishes *Siganus doliatus* (~4%) and *S. argenteus* (~3%), as well as the fusilier *Caesio caerulaurea* (3.4%), the snapper *Lutjanus gibbus* (2.85%) and humpnosed bigeye seabream *Monotaxis grandoculis* (2.38%).

Regional differences

The catch composition was only subtly different between the two main sampling locations. Larger-bodied predatory species of snappers and groupers, such as *Lutjanus malabaricus*, *L. argentimaculatus*, *Plectropomus aerolatus, Epinephelus coioides, E. fuscoguttatus* and *E. polyphekadion*, were more commonly sampled at Nusatuva, although still relatively rarely, suggesting the fish in that area, which is farther from the market, have been somewhat less impacted by fishing than fishing grounds closer to the market around Ghizo Island. We cannot, however, exclude differences in habitat which could also contribute to this subtle difference.

Table 2. The 30 most frequently sampled reef fish species caught by spearfishing (left) and hook-and-line (right), and the relative importance of each species (in percentage of the total number of individuals caught) for each fishing method.

Spearfishing n = 4071		Hook-and-line n = 4405	
Species	% of total number of fish caught	Species	% of total number of fish caught
Parupeneus barberinus	9.24	*Lutjanus gibbus*	26.88
Acanthurus nigricauda	8.33	*Lethrinus lentjan*	6.72
Acanthurus lineatus	6.63	*Lethrinus erythropterus*	4.93
Hipposcarus longiceps	4.42	*Lethrinus obsoletus*	4.15
Siganus doliatus	3.76	*Lethrinus xanthochilus*	3.75
Caesio caerulaurea	3.39	*Lutjanus bohar*	3.13
Scarus dimidiatus	3.37	*Lethrinus microdon*	2.57
Siganus argenteus	3.02	*Caesio cuning*	2.29
Lutjanus gibbus	2.85	*Selar boops*	2.11
Monotaxis heterodon	2.38	*Sphyraena forsteri*	2.11
Mulloidichthys vanicolensis	1.87	*Lethrinus atkinsoni*	1.98
Scarus niger	1.74	*Lutjanus monostigma*	1.88
Scarus psittacus	1.72	*Lutjanus rufolineatus*	1.75
Monotaxis grandoculis	1.67	*Lutjanus semicinctus*	1.50
Acanthurus xanthopterus	1.65	*Lethrinus olivaceus*	1.43
Scarus quoyi	1.65	*Lethrinus erythracanthus*	1.34
Scarus rivulatus	1.60	*Lutjanus malabaricus*	1.32
Parupeneus crassilabris	1.25	*Myripristis pralinia*	1.23
Lethrinus erythropterus	1.23	*Lutjanus kasmira*	1.20
Naso vlamingii	1.13	*Monotaxis grandoculis*	1.04
Naso lituratus	1.11	*Lethrinus ornatus*	1.02
Scarus ghobban	1.11	*Lutjanus quinquelineatus*	0.77
Siganus punctatus	1.06	*Lutjanus fulvus*	0.75
Choerodon anchorago	1.03	*Lethrinus rubrioperculatus*	0.73
Siganus puellus	1.03	*Myripristis berndti*	0.68
Parupeneus cyclostomus	1.01	*Pristipomoides multidens*	0.68
Caesio lunaris	0.98	*Epinephelus fasciatus*	0.64
Lethrinus obsoletus	0.96	*Lethrinus harak*	0.64
Chlorurus bleekeri	0.86	*Lethrinus semicinctus*	0.61
Cephalopholis cyanostigma	0.84	*Lutjanus argentimaculatus*	0.61

Size at maturity estimates

Size at maturity was estimated for the 61 most frequently sampled species. Table 3 provides the estimated size at maturity parameters derived, where possible, with macroscopic inspection of gonads, and with the length-based approach. Our preferred estimate used for LBSPR assessment is shown in bold. For many species, both techniques produced similar estimates, which enhanced our confidence in those estimates.

There apparently are only four pre-existing size at maturity estimates for reef fish in Solomon Islands: 1) *Bolbometopon muricatum* by Hamilton et al. (2008), 2) *Hipposcarus* *longiceps* (Brett Taylor, B.M. Australian Institute of Marine Science, pers. comm.), 3) *Thalassoma lunare* by Ackerman (2004), and 4) *Scarus ghobban* by Sabetian (2010). Two of these previous estimates are for species for which we estimated size at maturity and were made using samples collected around Ghizo Island, thus enabling a direct comparison. The size at maturity estimate of 260 mm for *H. longiceps* produced with microscopic techniques by Taylor (unpubl.) is very close to our preferred length-based estimate of 249 mm. However, our length-based estimate of 217 mm for *S. ghobban*, which was based on a sample of just 55 individuals, is much smaller than the 260 mm estimated microscopically by Sabetian (2010). In this case, we preferred the Sabetian estimate for our LBSPR assessment.

LBSPR assessments

The multiplicity of small samples sizes presents a challenge for the application of the LBSPR methodology. Ideally, sample sizes greater than 1000 individuals would always be available for analysis so that the largest individuals in each population are fully represented (Hordyk et al. 2015b). The LBSPR method is strongly influenced by the size of the largest fish in a sample, relative to the average maximum size inferred from the size at maturity and the ratio L_m/L_∞. The largest individuals in a population are always the rarest, meaning there is a high chance that small samples will fail to fully represent them. Statistical studies show that sample sizes of 1000 are required to ensure that the largest individuals are fully represented (Erzini 1990). Under-representation of the largest size classes results in downwardly biased estimates of SPR, and upwardly biased estimates of *F/M*. In the real world of reef fish assessment, sample sizes greater than 1000 individuals are extremely difficult to accumulate, and it is necessary to use whatever data are available. During the development of LBSPR, simulation testing with much smaller sample sizes (n>30) demonstrated that indicative assessments (i.e. heavily fished, moderately fished or lightly fished) could often be derived with smaller sample sizes (Hordyk et al. 2015b). While our previous experience applying the methodology to reef fish (Prince et al. 2015b, 2018) has shown that sample sizes of ~100 individuals, which coherently describe the mode of adult fish, produce robust indicative results. Experiences replicated by Babcock et al. (2018) and Hommik et al. (2020) who applied the technique to samples of reef fish as small as ~60 individuals. Although estimates of SPR are expected to increase marginally, and *F/M* to decrease slightly, if sample sizes can be subsequently enlarged (Hordyk et al. 2015b).

In this context, and confronting a multiplicity of small samples, we applied the LBSPR methodology to all species, with ~30 individuals, and samples sizes as small as n = 23 being analysed. Quality control criteria were subsequently applied to the results with the aim of culling the least reliable assessments. In our other applications of LBSPR to reef fish assemblages (Prince et al. 2015b, 2019) we have observed coherent patterns arising from the aggregate of multiple assessments, and this was our hope here, that while the individual assessments based on small sample sizes may not be particularly accurate or reliable in themselves, together they might still contribute to a coherent bigger picture of the status of the reef fish resource in Solomon Islands' Western Province.

Site differences in LBSPR assessments

Sample sizes were considered large enough for only three species to make it potentially worthwhile to assess the two sampling locations – Gizo and Nusatuva – separately, to determine if any difference could be detected (*Acanthurus nigricauda* n = 340 and 150, *Lethrinus erythropterus* n = 83 and 175, *Lutjanus gibbus* n = 970 and 330). Only in the case of *Lutjanus gibbus*, with the largest samples, was a difference detected that approached significance, with the estimated confidence intervals overlapping but not with the average estimates. As expected, the Nusatuva sample looked to have the lower fishing pressure, producing a higher estimate of SPR (0.86 cf. 0.62) and lower estimate of *F/M* (0.15 cf. 0.50).

Aggregated LBSPR assessments

Given the inability to detect a significant difference between sampling locations, and the general context of small sample sizes, all species samples were aggregated across both sites for the purpose of our assessments. The length data and size at maturity estimates (Table 3) were used along with estimates of life history ratios (Table 1) to make LBSPR assessments for 61 species (Fig. 1).

Across all assessments conducted, the estimated average SPR was 0.41 (SD = 0.24, n = 61, range = 0.03–1.0) and the average relative fishing mortality (*F/M*) was 2.32 (SD = 1.49, n = 43, range = 0.32–5.0). The confidence intervals computed around many of the estimates were very wide, indicating many are imprecise and relatively uninformed by the data; predictably so, in the context of the many small sample sizes.

Two forms of quality control were used to identify the more reliable assessments and to cull the least reliable:

1. Medium quality assessments were selected on the basis of their estimated 95% confidence intervals around the SPR estimate being <0.5; and
2. The highest quality assessments were selected on the basis of their estimated 95% confidence intervals around the SPR estimate being <0.5, and their samples size being n >100.

After applying the former criterion 43 species with medium and highest quality assessments were left in the sub-sample producing an average SPR estimate of 0.33 (SD = 0.16, n = 43, range = 0.03–0.77; solid line in Fig. 1) and an average *F/M* = 2.32 (SD = 1.49, n = 43, range = 0.32–5.0).

Table 3. Estimated size at maturity parameters (r = steepness; L_{50} = size class at which 50% are mature; L_{95} = size class at which 95% are mature; n = number of species examined for maturity) estimated through dissection and macroscopic staging and/or analysis of the left-hand side of the main mode in the length-frequency histogram. The preferred estimates used in the assessment of each species are shown in bold.

Species	Macroscopic				Length-based			
	r	L_{50}	L_{95}	n	r	L_{50}	L_{95}	n
Acanthurus lineatus	0.26	172	185	59	0.19	**162**	**178**	270
Acanthurus nigricauda	0.14	**180**	**200**	244	0.10	184	215	313
Acanthurus xanthopterus	0.03	**322**	**450**	27	0.06	245	300	67
Caesio caerulaurea					0.22	166	180	156
Caesio cuning	0.10	**165**	**195**	94	0.30	158	168	112
Caesio lunaris					0.12	188	215	40
Carangoides plagiotaenia	0.013	**217**	**450**	21	0.03	208	300	28
Cephalopholis cyanostigma					0.25	216	228	40
Chlorurus bleekeri	0.10	**207**	**237**	45	0.33	200	209	51
Choerodon anchorago	0.11	**247**	**275**	13	0.05	204	260	48
Epinephelus corallicola					0.06	267	315	24
Epinephelus fasciatus					0.48	180	186	28
Epinephelus ongus	0.02	300	450	27	0.15	**215**	**235**	39
Epinephelus polyphekadion					0.03	329	420	22
Hipposcarus longiceps	0.04	260	340	95	0.05	**250**	**310**	180
Lethrinus atkinsoni					0.07	**206**	**250**	115
Lethrinus erythracanthus	0.03	**287**	**380**	30	0.07	218	260	67
Lethrinus erythropterus	0.08	**171**	**238**	213	0.09	206	238	267
Lethrinus harak					0.15	193	215	36
Lethrinus lentjan	0.12	223	250	121	0.12	**220**	**280**	317
Lethrinus microdon	0.08	237	275	99	0.06	**288**	**340**	127
Lethrinus obsoletus	0.21	**224**	**238**	99	0.29	232	242	222
Lethrinus olivaceus	0.02	373	510	52	0.03	**404**	**510**	65
Lethrinus ornatus					0.13	195	220	57
Lethrinus rubrioperculatus	0.03	222	275	15	0.09	**195**	**230**	48
Lethrinus semicinctus	0.71	176	180	5	0.79	**180**	**184**	27
Lethrinus xanthochilus	0.02	**358**	**500**	134	0.03	252	375	183
Lutjanus biguttatus					0.47	155	161	22
Lutjanus bohar	0.02	**267**	**390**	67	0.05	186	245	147
Lutjanus ehrenbergii	0.08	**213**	**238**	17	0.47	211	217	27
Lutjanus fulvus					0.27	182	194	60
Lutjanus gibbus	0.06	198	245	520	0.07	**209**	**250**	1294
Lutjanus kasmira					0.13	174	195	58
Lutjanus malabaricus	0.04	325	410	55	0.09	**462**	**500**	58
Lutjanus monostigma					0.08	234	275	97
Lutjanus quinquelineatus					0.42	181	188	34
Lutjanus rufolineatus	0.05	174	235	38	0.16	**175**	**195**	74
Lutjanus semicinctus	0.10	**216**	**247**	24	0.82	205	209	87
Monotaxis grandoculis	0.17	**201**	**220**	41	0.10	165	195	114
Monotaxis heterodon					0.10	161	194	103
Mulloidichthys vanicolensis	0.49	189	195	22	0.12	**178**	**202**	76
Naso lituratus	0.04	198	275	13	0.08	**171**	**210**	46
Naso vlamingii					0.11	177	230	47
Parupeneus barberinus	0.90	250	290	78	0.15	**176**	**195**	386
Parupeneus crassilabris					0.22	162	175	51
Parupeneus cyclostomus	0.35	197	260	19	0.12	**194**	**220**	43
Parupeneus multifasciatus					0.42	162	169	31
Plectropomus aerolatus	0.17	**341**	**360**	21	0.45	303	310	31
Scarus dimidiatus					0.11	190	218	140
Scarus ghobban	1.47	187	190	51	0.08	**217**	**255**	55
Scarus niger	0.55	160	166	11	0.20	**206**	**220**	71
Scarus oviceps					0.16	190	210	31
Scarus psittacus	0.12	186	195	52	0.12	**186**	**210**	71
Scarus quoyi	0.05	**201**	**260**	59	0.19	185	200	67
Scarus rivulatus					0.07	208	250	80
Selar boops					0.26	183	195	93
Siganus argenteus	0.05	**193**	**210**	87	0.12	174	200	123
Siganus canaliculatus					0.07	197	240	26
Siganus doliatus	0.12	**158**	**182**	79	0.14	166	188	157
Siganus lineatus	0.08	**213**	**325**	13	0.07	214	260	29
Siganus puellus	0.05	220	275	21	0.11	**173**	**200**	47
Siganus punctatus	0.06	**236**	**290**	29	0.18	204	220	49
Sphyraena forsteri					0.06	386	438	101

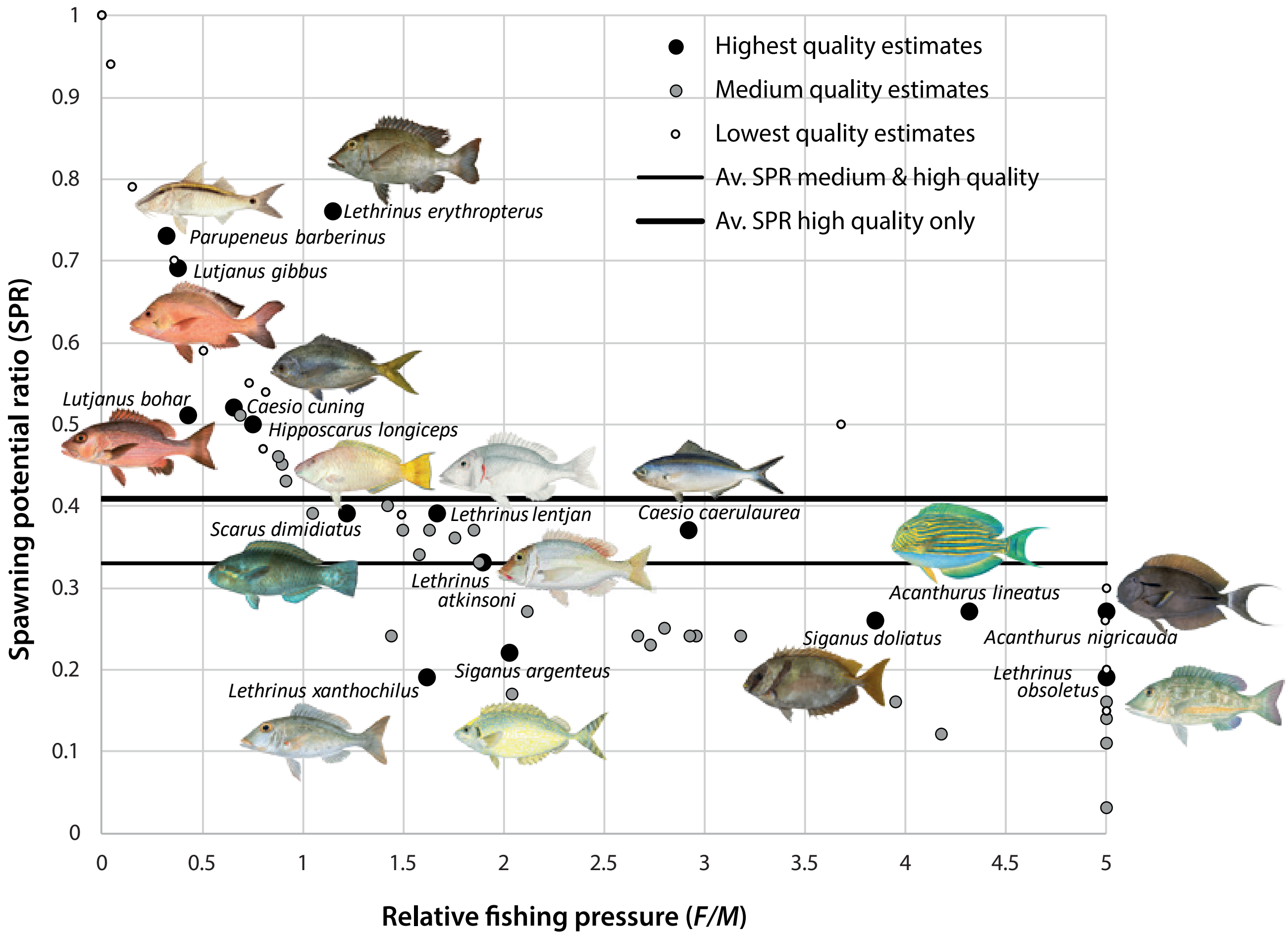

Figure 1. The results of all 61 assessments with estimates of relative fishing pressure (*F/M*) plotted along the x-axis and spawning potential (SPR) plotted up the y-axis. Highest quality assessments plotted as large black circles and identified with species names, medium quality assessments plotted as un-named medium-sized grey circles, and lowest quality assessments as un-named small points. Average SPR of highest quality assessments shown as a dashed line. Average SPR of highest and medium quality assessments shown as a solid line. Note that the maximum F/M has been constrained to a value of 5.

Applying the latter criteria left 16 species highest quality assessments in the subsample (Table 4) producing an average SPR = 0.41 (SD = 0.19, n = 16, range = 0.15–0.76; dashed line in Fig. 1) and an average *F/M* = 2.08 (SD = 1.64, n = 16, range = 0.32–5.0).

Comparison of average SPR for hook-and-line-caught species (SPR = 0.35 SD = 0.20, n = 17) and night-time spearfished species (SPR = 0.32 SD = 0.14, n = 30) revealed little difference in status between these two subsets of species.

Discussion

The stability and homogeneity of the estimates of average SPR across the subsamples of assessments helps to build a level of confidence that in aggregate these assessments present a coherent bigger picture of the portion of the reef fish assemblage we have been able to assess. The average SPR of ~35% is within the range (30–40%) used internationally as a proxy for the fishing level likely to produce maximum sustainable yield (MSY). A level considerably higher than that produced for similar assemblages of reef fish species in parallel studies (Prince et al. 2015b and 2019) conducted in Fiji (19% SPR across 29 species) and Palau (12% SPR across 12 species). Significantly, although the estimated average relative fishing pressure (*F/M*>2) is, by international standards, approximately double the level expected to produce MSY. There is also some interesting variation around these average estimates.

Several groups of small-bodied species emerged as apparently being particularly prone to localised depletion by night-time spearfishers. Our samples of these species came mainly from the catch of night-time spearfishers operating very locally around the small island of Rarumana just to the east of Gizo town. Their representative, who brought their catches to us for sampling, was very forthright about his concern that they were experiencing localised depletion of their fishing ground, and that this was driving his divers to

Table 4. Assessment results of the 16 assessments considered of highest quality, listed in order of descending spawning potential ratio (SPR) estimate; estimated SPR 95% confidence intervals <0.5 and samples size n >100. Results in terms of SPR and relative fishing pressure (*F/M*) along with estimated 95% confidence intervals (CI) around those estimates. Note the maximum estimate of *F/M* has been constrained to a value of 5.

Species	L_{50}	L_{95}	L_{∞}	n - Length comp.	n - L_{50}	SPR	SPR CI	*F/M*	*F/M* CI
Parupeneus barberinus	176	195	298	386	386	0.73	0.6–0.86	0.32	0.09–0.55
Lutjanus gibbus	209	250	282	1300	1300	0.69	0.61–0.77	0.38	0.23–0.53
Lutjanus bohar	300	320	405	151	67	0.51	0.3–0.73	0.43	0.12–0.74
Caesio cuning	165	195	270	113	113	0.52	0.31–0.73	0.66	0.09–1.23
Hipposcarus longiceps	249	320	383	181	181	0.5	0.35–0.65	0.75	0.29–1.21
Lethrinus erythropterus	170	238	243	267	213	0.76	0.64–0.87	1.15	0.23–2.07
Scarus dimidiatus	190	218	292	140	140	0.39	0.28–0.49	1.22	0.66–1.78
Lethrinus xanthochilus	358	500	512	183	134	0.19	0.09–0.29	1.62	0.78–2.46
Lethrinus lentjan	220	280	314	314	314	0.39	0.31–0.48	1.67	0.95–2.39
Lethrinus atkinsoni	206	250	294	115	115	0.33	0.19–0.48	1.9	0.48–3.32
Siganus argenteus	193	200	327	123	86	0.22	0.13–0.32	2.03	0.98–3.08
Caesio caerulaurea	166	180	272	156	156	0.37	0.12–0.62	2.92	0–6.33
Siganus doliatus	158	182	268	157	73	0.26	0.20–0.33	3.85	2.08–5.62
Acanthurus lineatus	162	178	205	270	270	0.27	0.19–0.34	4.32	2.47–6.17
Acanthurus nigricauda	180	220	228	342	244	0.27	0.14–0.4	5	2.04–9.44
Lethrinus obsoletus	224	242	320	222	99	0.19	0.13–0.25	5	4.47–11.37

expand their operations into neighbouring fishing grounds and creating conflict with those other communities. All six assessed species of rabbitfish (*Siganus argenteus, S. canaliculatus, S. doliatus, S. lineatus, S. puellus, S. punctatus*) produced similarly low SPR estimates (SPR = 0.22–0.26). This suite of species has long been recognised as being particularly prone to depletion despite their small body size, a factor normally expected to save species from early targeting in the process of fishing down food webs (Pauly et al. 1998). Johannes (1978) described localised aggregations of rabbitfish being sequentially extinguished around Palau during the 1970s, and attributed it to their being shallow water species that formed predictable spawning aggregations, which were easily and heavily targeted. In our assessments, a group of shallow-living, small-bodied surgeonfish (*Acanthurus lineatus*, *A. nigricauda*, *A. xanthopterus*) targeted by night-time spearfishers also produced relatively low SPR estimates (0.17–0.27) as did a group of small parrotfish (*Scarus ghobban, S. niger*, *S. oviceps*, *S. quoyi*) (SPR = 0.24–0.27); however, SPR estimates of several other parrotfish species were higher: *S. dimidiatus* (0.39), *Chlorurus bleekeri* (0.39), *S. psittacus* (0.46) and *Hipposcarus longiceps* (0.5). Despite these exceptions, there still emerges from our results a pattern of heavy localised impacts resulting from night-time spearfishing around Rarumana.

On the other hand, some of the most abundant species in our sampling regime, which consequently tended to produce the highest quality assessments, were estimated to still be relatively lightly exploited (Table 4 and Fig. 1); for example, the long-finned emperor (*Lethrinus erytheropterus* SPR = 0.77; *F/M* = 1.15), the dash-and-dot goatfish (*Parupeneus barberinus* SPR = 0.74; *F/M* = 0.32) and the humpback snapper (*Lutjanus gibbus* SPR = 0.69: *F/M* = 0.38). These species are apparently less prone to the heavy localised pressure of night-time spearfishing due to being mainly caught by hook-and-line (e.g. *L. erytheropterus* and *L. gibbus*) and/or occupying a broad range of depths (e.g. *L. gibbus* and *P. barberinus*).

The broader picture presented here of a moderately exploited assemblage of medium- and small-bodied species must be qualified by drawing attention to the almost complete absence from our samples of all the largest-bodied serranids, labrids and parrotfish. Species that at some time in the past would have dominated landings. Hamilton et al. (2016) documented the depletion of the largest-bodied parrotfish *Bolbometopon muricatum* through this region. Hamilton and Matawai (2006) described the depletion of the squaretail coral grouper, *Plectropomus aerolatus*, around Papua New Guinea by the live fish trade. A fishery that undoubtedly also depleted all the most valuable large-bodied grouper species throughout the Western Province. The rarity of these species in our samples has prevented us from assessing their status. There can be little doubt that if we had been able to accumulate sufficient samples of these depleted larger-bodied species, our average estimates of SPR would have been much lower, and *F/M* even higher than the average estimates we have produced.

With unmanaged fishing pressure across the region, there can be no doubt that these depleted and unassessed highly prized, larger-bodied species continue to be overfished. As time passes and those more preferred larger-bodied species become even scarcer, fishing pressure previously directed almost entirely at the most preferred bigger species, will increasingly target the assemblage of smaller and medium-bodied species we could assess. Adding to that process of fishing down the food web, as the region develops, is population growth, rising demand for income from fishing to purchase consumer goods, and growing access to better fishing equipment and fish markets. So, we can be certain that fishing pressure on the species assemblage we assessed is going to continue intensifying. The relatively high levels of SPR we estimated, are unlikely to be stable, instead they most probably represent a transitional state the assemblage is passing through as it continues to be fished down. This interpretation of our results is consistent with the high average level of relative fishing pressure we estimated (>2) twice the level likely to produce high sustainable yields. As well as with the much lower levels of SPR we have observed for this assemblage of species in Fiji and Palau where there has been better access to larger fish markets for some time (Prince et al. 2015b and 2019). In this context, and without any improvement to management, we would expect a repeat of this study in five years to find lower levels of SPR in the species we have assessed, and for some of them to have joined a growing list of species that are no longer possible to assess because sample sizes are too small.

Conclusion

This study adds to those of Prince et al. (2015b and 2019) and Babcock et al. (2018) in illustrating the cost-effective utility of the LBSPR methodology for assessing reef fish stocks and for informing the development of management guidelines. Previous to this study, size at maturity had been estimated for only four species of reef fish in Solomon Islands and there were no quantitative estimates of stock status and fishing pressure. Through this project, 63 estimates of reef fish size at maturity were developed, and the status of 61 species assessed, accounting for ~84% of the sampled catch by number.

This study provides a snapshot of the overfishing of reef fish in Solomon Islands' Western Province and parallels observations reported from across other Pacific Island countries (e.g. Newton et al. 2007; Sadovy 2005; Sadovy de Mitcheson et al. 2013) and, indeed, the entire tropical Indo-Pacific region (McClanahan 2011). The picture emerging from these assessments is of the reef fish stocks around Ghizo Island being more lightly fished and less depleted than parallel studies (Prince et al. 2015b and 2019) suggest for Fiji and Palau. The average SPR of around ~35% is within the target range (30–40%) often used internationally as a proxy for the fishing level likely to produce maximum sustainable yields; although we also estimated fishing pressure at double the level likely to be sustainable, and found evidence of localised depletions of some species being driven by night-time spearfishing. These results need to be appreciated in the context of the current lack of any effective fisheries management that has already permitted the depletion of all the most highly prized and largest-bodied serranids, labrids and parrotfish. Their depletion prevented us from sampling enough of those species to make an assessment possible. If we had been able to assess those larger-bodied species, we would inevitably have estimated much lower levels of SPR and higher relative fishing pressure than the averages we have produced. The relatively high levels of SPR we estimated for the assemblage of small- and medium-bodied species are unlikely to be sustainable given the context and our estimates of high fishing pressure. In the absence of effective management, we expect the reef fish food web in the region to continue being fished down.

Acknowledgements

Our heartfelt thanks and acknowledgement to all the dedicated WWF staff, past and present, who assisted with this project: Zeldalyn Hilly, Richard Makini, Salome Topo, Dudley Marau, Dafisha Aleziru, Piokera Holland, Tingo Leve, Sara Martin, Jessica Rutherford. Solomon Islands spawning potential surveys have been financially supported by the Australian government through the Australian NGO Cooperation Program (ANCP), Simplot Australia via their seafood brand John West, and WWF Australia and WWF Netherlands supporters.

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