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Length Based Assessment of the Spawning Potential of Reef Fish from iQoliqoli Cokovata in Macuata

A Case study from Fiji

Prepared by

Biospherics

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WWF-PACIFIC VISION
It is our mission to ensure that the richness and resilience of our Pacific island ecosystems are managed and conserved in harmony with the aspirations and sustainable development needs of our people.

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Summary

Coastal fisheries are of crucial importance to coastal communities, both for family sustenance, and as a source of income. Nationally it has been estimated that Fijian inshore fisheries annually land approximately 2300-3500 tonnes of seafood, earning Fiji approximately $FJD12-16 million but producing a total economic benefit of up to $FJD47.5 million to Fiji. Over recent decades, in Fiji and across all the Pacific island nations, concern has been mounting about the sustainability of coastal marine resources and its implication for both biodiversity and food security. A recent workshop of the Secretariat of the Pacific Community on coastal fisheries estimated that because of rapid population growth, within 15 years Pacific communities will need an extra 115,000 tonnes of fish annually, but that declining local stocks threaten to widen the gap between local supply of fish and demand. That workshop concluded that one of the main barriers to improving the management of coastal fisheries was a lack of relevant data, analysis and knowledge to inform management at all levels, and that existing methods for assessing stocks were ineffective for the small-scale coastal fisheries of the Pacific.

This report describes the application of a new technique for assessing the status of reef fish stocks, the iqoliqoli cokovata fishery in Macuata. The fishery covers an area of 2,041 square km on the central north coast of Vanua Levu and is utilized for subsistence by 24 villages and until recently approximately 400 commercial permit holders as well. The metric of reproduction assessed is called spawning potential (SPR) and is based on the concept that without fishing a fish population can complete 100% of its natural potential for spawning, but that fishing reduces a population's SPR, because on average fish get caught before completing their natural life span. From comparative studies, we know that down to around 30% of SPR, fish populations retain the ability to rebound from fishing and rebuild populations to the carrying capacity of the reef. Around 20% of SPR populations have the ability to stabilize but not rebuild. Below this level, long-term ongoing decline to local extinction is expected.

Our data collection program in Macuata was implemented with initial training workshops held in Naduri in October 2014 and in Naquma in March 2015. In discussion with community participants, an agreed list of 20 important species was developed to prioritize sampling. Through until May 2016, a team of 12 community members measured 5,226 fish, from 33 reefs across the iqoliqoli. With these data we have been able to develop initial stock assessments for five species; kasala (*Epinephelus polyphekadion*), batisai (*Plectropomus areolatus*), rawarawa/ulavi (*Scarus rivulatus*), nuqa (*Siganus vermiculatus*), and taea (*Lutjanus gibbus*).

Consistent with the accounts given to us by community members, our results show that kasala (SPR=11%) and batisai (SPR=18%) are being fished very heavily; about 4-5 times the level that would maximize the sustainable yields, and already have levels of spawning potential below that needed to stabilize their populations (SPR = 20%). The smaller bodied species rawarawa/ulavi, nuqa and taea are assessed as being fished more lightly and having higher levels of spawning potential.

Rawarawa/ulavi (SPR=26%) and nuqa (SPR=31%) are approaching the critical level of SPR = 20%, while taea (SPR=52%) are assessed as being fished relatively lightly and still have relatively high levels of spawning potential. However the recent doubling of the price for taea in the Labasa market, suggests the status of this species is going to decline. In other countries, as more preferred large bodied species decline in abundance and availability, taea have become increasingly important and are increasingly targeted by fishers and buyers to make up the shortfall. This process of fishing down the species assemblage from big-bodied highly preferred species, to less preferred smaller species is occurring in Macuata Province.

These results confirm that Fiji is facing the same crisis of sustainability with its reef fish, as are other Pacific island nations. If Fiji does not significantly reform its management of fisheries, we can confidently predict that all the most valuable food fish species will be depleted to extremely low levels and become insignificant for livelihoods and subsistence, and locally extinct through all but the most remote parts of Fiji. Without implementing significant change to the management of these coastal resources, Fiji's current enjoyment of the larger groupers, parrotfish, wrasse and snapper is coming to an end, and Fijians will have to accept a future of catching and eating fewer and smaller types of fish. A future in which much less reliance can be placed on reef fish for livelihoods and subsistence.

The simplest and most effective way of stabilizing the current situation and beginning to rebuild depleted stocks of reef fish will be to reform the existing system of minimum size limits, so that all the main reef fish species are protected until they have completed a minimum of 20% of their spawning potential. Consistent with the widely accepted principals of change management, reform should occur in small steps; starting within an initial trial of a new minimum size limit for just one or two species in Macuata. Proceeding slowly in 'bite-size chunks' towards the goal of reform will allow Fijians to perceive for themselves the improvement to fish stocks that change can bring, and so build a ground-swell of support for implementing more size limits. A top-down imposition of new minimum size limits for many species at the same time, will risk the intended reforms becoming just regulations stranded on paper that never get implemented in reality.

The stakes are high for the future of Fijians, and Fiji needs to get this right.

Introduction

Coastal fisheries are of crucial importance to Fijian coastal communities both for family sustenance, and as a source of income. Nationally it has been estimated that Fijian inshore fisheries annually land approximately 2300-3500 tonnes of seafood, earning approximately $FJD12-16 million, but producing a total economic benefit up to $FJD47.5 million to Fiji. A study, conducted in 1993 by Rawlinson *et al.* (1994), of rural communities on Viti Levu found that over 50% of households reported at least one family member fishing, and 15% of respondents reported fishing themselves. Of the 50% of households who fished, 68% subsisted by fishing and 32% depended on fishing for their livelihood. In total, some 16% of households reported selling marine products, with 8.8% indicating it was their main source of income, and 4.4% saying it was their sole source of income.

Rawlinson *et al.* (1994) reported that coastal and remote communities reported fishing to be even more important than these averages suggest. This was borne out by a study by Kuster *et al.* (2005) of the remote island of Ono-i-Lau in 1982 and 2002; which found that coastal seafood was the main source of protein, and estimated that over the two decades studied, consumption had remained around 365 – 380 grams/per day/per person, with finfish comprising 76% of the seafood eaten. These older studies are supported by a recent study of the impact of Tropical Cyclone Winston on communities on Vanua Levu (Chaston Radway *et al.* 2016) which found that prior to the cyclone, 36-100% of households depended on coastal fisheries for subsistence, and 32-100% depended on fisheries for livelihoods. Before the cyclone, most people living in coastal villages ate fresh fish at least six times a week.

In recent decades across Fiji and the other Pacific islands, concern has been mounting about the sustainability of coastal fisheries and its implication for both biodiversity and food security. A recent workshop of the Secretariat of the Pacific Community (SPC) on coastal fisheries estimated that because of rapid population growth, within 15 years Pacific communities will need an extra 115,000 tonnes of fish annually, but that declining local stocks is widening the gap between local supply of fish and demand (SPC 2015). That workshop concluded that one of the main barriers to improving the management of coastal fisheries was a lack of relevant data, analysis, and knowledge to inform management at all levels, and that existing methods for assessing stocks were ineffective for the small-scale coastal fisheries of the Pacific. More broadly, it has been estimated that worldwide, less than 10% of fish stocks can be assessed with standard methods of assessment (Andrews *et al.* 2007) and the SPC workshop called for new methodologies to be developed and implemented.

This report describes the application of a new technique for assessing the status of reef fish stocks, in the iqoliqoli Cokovata fishery of Macuata. The fishery covers an area of 2,041 square km on the central north coast of Vanua Levu and is utilized for subsistence by 24 villages (seven in Sasa, 15 in Macuata, and two in Tamonibuca), and until recently approximately 400 commercial fishery permit holders as well.

The newly developed stock assessment technique compares the size of fish in a population, to the size at which they start breeding (the size of maturity) to estimate the population's capacity to reproduce (called spawning in fish), as well as a relative measure of how heavily the population is being fished. The metric of reproduction being measured is called spawning potential (SPR) and is based on the concept that a fish population can complete 100% of its natural potential for spawning when there is no fishing. Fishing reduces a population's SPR below the natural 100% level, because on average fish are caught before completing their natural life span. From comparative studies we know that down to around 30% of SPR fish populations retain the ability to rebound from fishing and rebuild populations to the carrying capacity of the reef (Mace & Sissenwine 1993). Around 20% of SPR fish populations can still stabilize under fishing pressure, but are unable to rebuild over time, as there is only enough spawning potential to replace the existing adults, but not enough to grow the population. This level (20% SPR) is equivalent to when human populations have on average 2.1 surviving children per couple, sufficient to replace existing adults (including those who have no children) and stabilize populations but not sufficient to grow a population. This level of SPR is called the 'replacement level' because it is sufficient to replace existing adults. Below 20% SPR we expect long-term declines in populations to occur because the fish are not allowed to fulfill enough of their potential for reproduction, before being caught, to replace themselves.

The metric of fishing pressure estimated is denoted as 'F/M' because it is the ratio of the mortality caused by fishing pressure (F) and the rate of mortality suffered by fish from natural causes (M) i.e. being eaten by other fish, dying from disease etc. Again from comparative studies it is known that, if fish are only caught as adults, when these two rates of mortality are almost equal (i.e. F/M = 0.8 – 1.0), sustainable catches are optimized (Zhou *et al.* 2012). Levels of F/M above this are indicative of overfishing and result in foregone catch and low economic efficiency, and if high enough, stocks declining into eventual extinction. However, if immature fish are caught along with adults these reference points are lower, so that levels of F/M less than 0.8 – 1.0 can cause overfishing. On the other hand, if fisheries are prevented from catching fish until they are larger than the size of maturity, with enforced minimum size limits or gear restrictions, much higher levels of F/M can then be sustained.

Methods

The technical basis of the newly developed length based SPR assessment methodology (LB-SPR) being implemented in Macuata, is described in technical detail by Hordyk *et al.* (2014a & b) and Prince *et al.* (2014). For brevity and clarity it will not be detailed here.

In brief, each type of fish can be characterized by two ratios called Life History Ratios, which determine the size structure of fish population. The first ratio '*M/k'* compares longevity or natural mortality (*M*) of a fish species, with how quickly each type of fish grows to maximum size (*k*). The second life history ratio, 'L_m/L_∞', is the size at which a fish reaches sexual maturity (L_m) relative to the average maximum size that type of fish could achieve without fishing (L_∞). The size of maturity is estimated by determining the size at which 50% of a species has become mature and so is denoted as 'L50' in this report, while 'L_∞'is also called the 'asymptotic size' because it is the size at which fish growth slows to very low levels i.e. it approaches an asymptote. For brevity, that terminology is generally used through this report.

The technique uses newly developed algorithms (Hordyk *et al.* 2014a) to analyze the size composition of a fish population of fish to estimate spawning potential (SPR) and relative fishing pressure (F/M). At the risk of over-simplifying, the new technique works by mathematically comparing the size composition of catches to the local size of maturity. Basically if few fish reach the size of maturity (L_m), then logically very little spawning (SPR) can be occurring; however if many fish achieve the average maximum size for that population (L_∞), close to 100% of the natural spawning potential is occurring.

Two types of data are collected; the length of fish measured from end to end through the middle of the body (Figure 1) and whether the fish is an adult or immature, along with the gender if it can be determined (Figure 2).

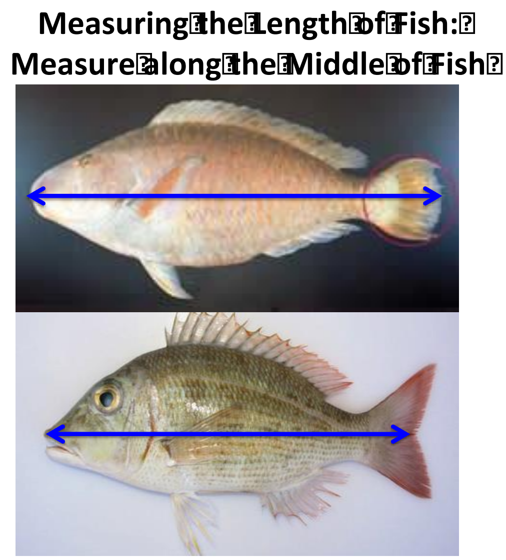

Figure 1: lllustration of the measurement of fish length.

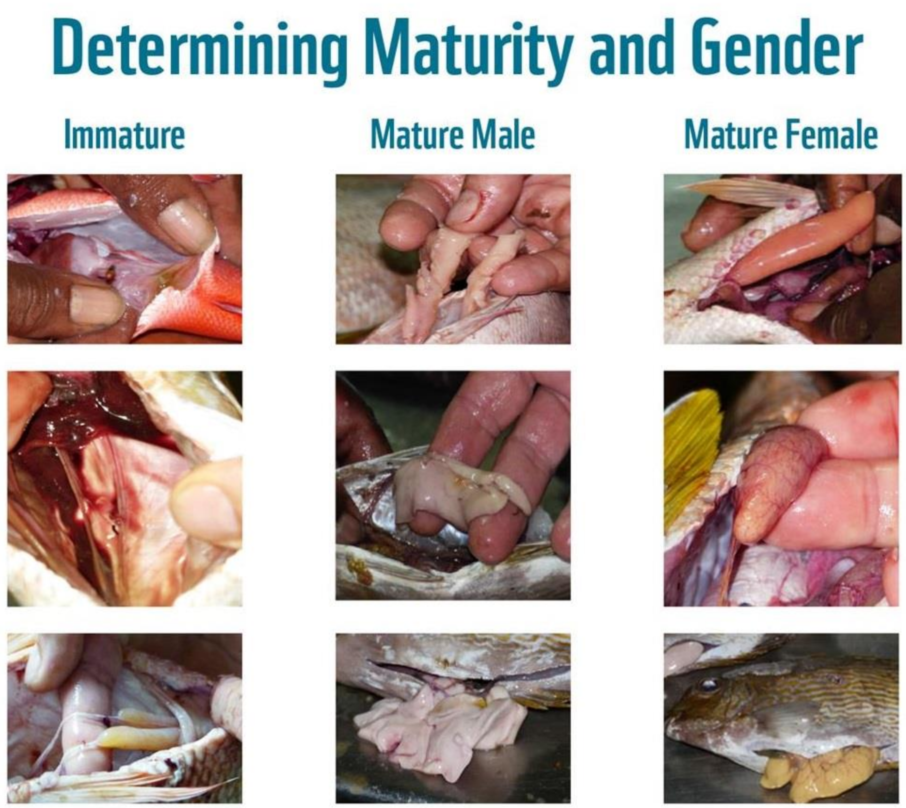

Figure 2: Illustration of how the maturity and gender of fish is determined.

The conceptual basis of this approach and the scientific techniques used are logical and simple so that communities can be trained to collect the data needed through programs of citizen science. The process we find allows the communities to see and understand what has been happening to their local fish stocks, and to perceive the need for new forms of management. The methodology begins with providing training workshops for community members who then collect the data for analysis.

In Macuata the data collection program was implemented with initial training workshops held in Naduri in October 2014, and a follow up workshop in Naquma in March 2015. During the workshops, breakout groups we asked to list the species of fish they had observed changing the most, and which species they considered most important to their communities. These lists were used to develop an agreed list of species for sampling (Table 2). The Naduri workshop participants chose the parrotfish (locally called Rawarawa) to be assessed because of its importance for food and also because the participants perceived its abundance is declining rapidly. When we identified the species, we found it to be just male *Scarus rivulatus* and that community members use the name ulavi for female *S. rivulatus*. Consequently, we collected and combined data for both rawarawa and ulavi. Taea (*Lutjanus gibbus*) was not initially chosen by the workshop participants, but because of its known importance in other countries, we requested that the community representatives place it on the list to facilitate cross-country comparisons in the future.

Naduri List of Species
Nuqa - *Siganus vermiculatus*
Kalia/nono - *Bolbometopon muricatum*
Lele - *Naso unicornis*
Banito - *Caranx sexfasciatus*
Kasala - *Epinephelus polyphekadion*
Soisoi - *Epinephelus coioides*
Donu tuimuri/loia/lola damur - *Plectropomus laevis*
Batisai - *Plectropomus areolatus*
Kawango – *Lethrinus nebulosus*
Sirisiriwai - *Kyphosus bigibbus*
Sabutu - *Lethrhinus obsoletus / Lethrinus harak*
Bici - *Plectorhincus albovittatus*
Walu - Scomberomorus *commerson*
Kava - *Ellochelon vaigiensis*
Kanace - *Moolgarda engeli*
Rawarawa - *Scarus rivulatus*
O'o – *Cetoscarus ocellatus*
Mama / mu - *Monotaxis grandoculis*
Tevulu - *Symphorus nematophorus*
Taea - *Lutjanus gibbus*

Table 1: List of species agreed for data collection by participants at the Naduri training and initiation workshop.

Through until May 2016, a team of 12 community measurers, measured a total of 5,226 fish, from 33 locations across the iqoliqoli Cokovata. With the data collected to date it has been possible to develop stock assessments for five species; Kasala - *Epinephelus polyphekadion*, Batisai - *Plectropomus areolatus*, Rawarawa/Ulavi – *S. rivulatus,* Nuqa - *Siganus vermiculatus,* Taea – *L. gibbus.*

All the fish species within any taxonomic family share virtually the same life history ratios; so through systematically studying the scientific literature we have been able to develop estimates of the life history ratios needed for LB-SPR assessment of all the main species of reef fish. The estimates of the life history ratios (M/k & L_m/L_∞) for these five species used in this study are tabulated below (Table 4).

Fishing Location	n	Fishing Location	n
Baravi kei Niurua	24	Niqaniqa	63
Cakaba	12	Nukunuku	91
Cakau Lase	131	Rama	67
Cakau Levu	127	Raviravi	65
Drama	64	Sese	63
Ketei Lewa	762	Tadraniu	1
Macuata-i-wai	13	Talailau	196
Nacula	9	Teteba	9
Naiseva	21	Tuavucu	287
Nakalou	22	Utulei	215
Nalase	46	Vaturova	8
Nalumi	132	Yalava	53
Namama	178	Yamotu ni dri	9
Namoli	21	Yamotuinaibuka	42
Naqumu	105	Yamotuniogo	21
Nasea	33	Yawea	44
Natualevu	572	(blank)	1717
		Grand Total	**5225**

Table 2: List of the 33 fishing locations from which fish were measured and the number (n) of fish measured from each site; the names Nakalou, Naqumu, Nasea, Raviravi and Yalava refer to fishing occurring adjacent to villages of that name, while the remainder are reef names.

Species	Total
Rawarawa/Ulavi - Scarus rivulatus	1079
Lele - Naso unicornis	953
Batisai - Plectropomus areolatus	689
Sabutu - Lethrinus obsoletus	464
Kasala - Epinephelus polyphekadion	395
Nuqa - Siganus vermiculatus	366
Taea - Lutjanus gibbus	253
Donu - Plectropomus laevis	183
Ulurua - Cetoscarus ocellatus	103
Kawago - Lethrinus nebulosus	151
Sabutu - Lethrinus harak	76
Mama - Monotaxis grandoculis	73

Table 3: List of the 12 most common species sampled and the number of fish sampled (n) for each species.

Species	Fijian Name	*M/k*	*Lm/L∞*
Epinephelus polyphekadion	***Kasala***	0.7	0.61
Plectropomus areolatus	***Batisai***	0.91	0.61
Scarus rivulatus	***Rawarawa/Ulavi***	0.61	0.66
Siganus vermiculatus	***Nuqa***	1.98	0.52
Lutjanus gibbus	***Taea***	0.51	0.75

Table 4: Estimates of life history ratios (M/k and L_m/L_∞) used as input parameters to assess five species of reef fish in the Macuata iqoliqoli Cokovata fishery.

LB-SPR Assessments

Kasala – *Epinephelus polyphekadion*

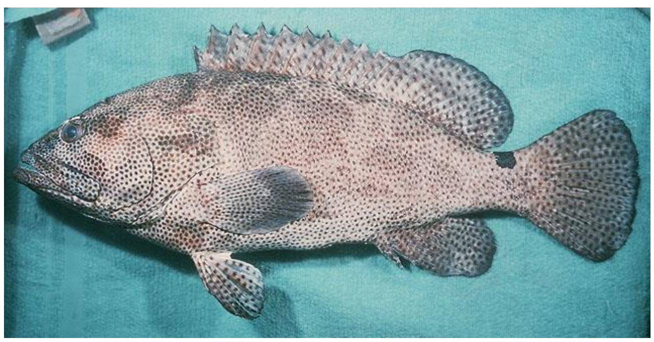

Figure 3: Kasala – *E. polyphekadion*

To date, 395 kasala (*E. polyphekadion*) have been measured by the community observers allowing estimates to be made of size at 50% maturity = 35cm and 95% maturity = 46cm (Figure 4 & Table 5). Using the assumed relative size of maturity (L_m/L_∞= 0.61; Table 4) and the estimate of L50 = 35cm, it can be estimated that the growth of kasala asymptotes (slows to zero) at an average maximum size of 57.4 cm. The length frequency histogram plotted with the data collected has a modal length of 35-40cm, and maximum length ~ 55cm (Figure 5 & Table 4). With these input parameters and length frequency data, the LB-SPR assessment model estimates that this specie becomes vulnerable to fishing around the size it matures (Figure 4) and that currently it is being fished very heavily (F/M = 4.9); about 5 times more heavily than the level expected to produce the maximum sustainable yield. Consequently the population's current level of spawning potential is just 11%; around half the replacement level (SPR = 20%) needed to stabilize the population even without allowing for the population to rebuild (Table 5).

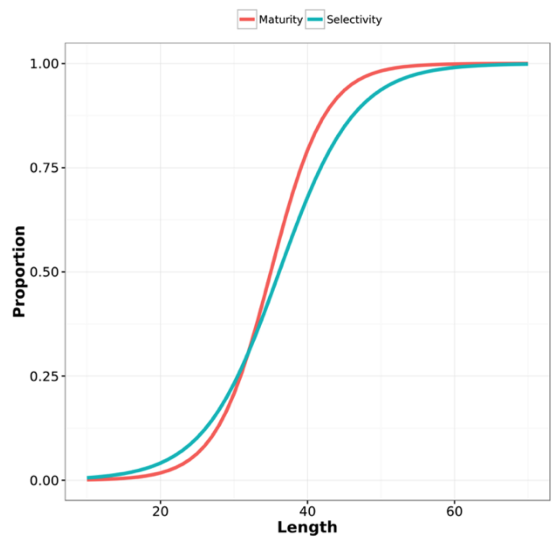

Figure 4: Red line: the proportion of kasala (*E. polyphekadion*) mature by length (cm) estimated directly from the data collected by the community observers.
Blue line: the proportion of kasala vulnerable to capture by length (cm) as estimated by the LB-SPR assessment model.

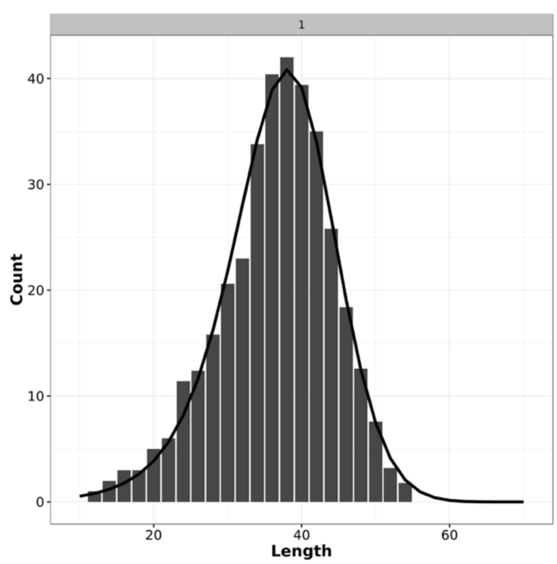

Figure 5: Black bars: the length (cm) frequency histogram of the kasala (*E. polyphekadion*) catch measured by community observers. Black line: the length (cm) frequency histogram fitted to the data by the LB-SPR assessment model.

SPR %	SL50	SL95	F/M	MK	Linf	L50	L95
11	36.1	51.26	4.9	0.7	57.4	35	46
0.07 – 0.15	32.8 – 39.4	46.4 – 56.1	3.1 – 6.6				

Table 5: Tabulated input parameters and assessment results for kasala (*E. polyphekadion*). Input parameters: size of maturity (L50, L95) as plotted by the red line in Figure 4, and estimate of the life history ratio *M/k* (MK). Model generated estimates: spawning potential (SPR%), size of selectivity (SL50, SL95) as plotted by the blue line in Figure 4, relative fishing pressure (F/M) and asymptotic size (Linf). The estimated 95% confidence intervals around the estimates of spawning potential, selectivity and relative fishing pressure are shown below the estimates.

Batisai – *Plectropomus areolatus*

Figure 6 : Batisai – *Plectropomus areolatus*

To date, 689 batisai (*P. areolatus*) have been measured by the community observers allowing estimates to be made of size at 50% maturity = 36cm and 95% maturity = 42cm (Figure 7 & Table 6). Using the assumed relative size of maturity (L_m/L_∞ = 0.61; Table 4) and the estimate of L50 = 36cm it can be estimated that the growth of batisai asymptotes (slows to zero) at an average maximum size of 61 cm (Table 6). The length frequency histogram plotted with the data collected has a modal length of ~40cm, and maximum length <60cm (Figure 8 & Table 6). With these input parameters and length frequency data, the LB-SPR assessment model estimates that this species becomes vulnerable to fishing around the same size maturity, but that full maturity is achieved before they become fully selected by the fishery (Figure 7) Currently it is being fished very heavily (F/M = 4.4); about 4 times greater than the level expected to produce the maximum sustainable yield. Consequently the population's current level of spawning potential is just 18%; below the replacement level (SPR=20%) needed to stabilize the population without allowing for the population to rebuild (Table 6).

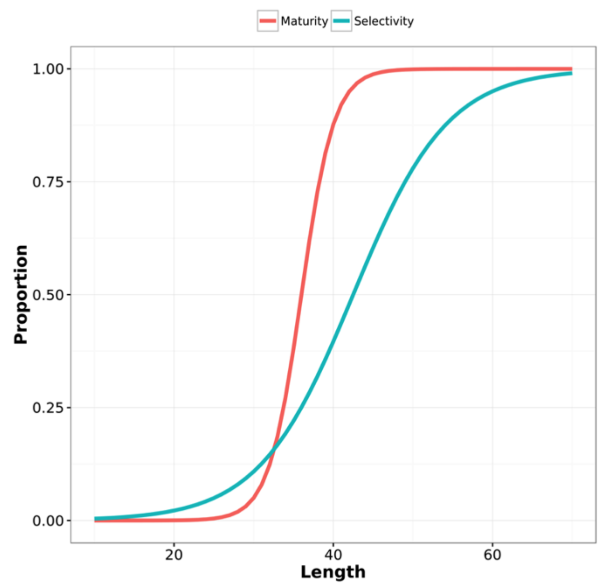

Figure 7: Red line: the proportion of batisai – (*P. areolatus*) mature by length (cm) estimated directly from the data collected by the community observers. Blue line: the proportion of batisai vulnerable to capture by length (cm) as estimated by the LB-SPR assessment model.

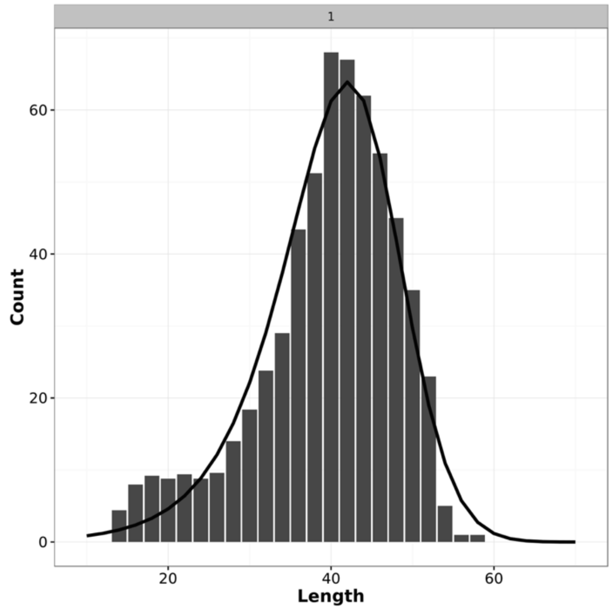

Figure 8: Black bars: the length (cm) frequency histogram of the batisai – (*P. areolatus*) catch measured by community observers. Black line: the length (cm) frequency histogram fitted to the data by the LB-SPR assessment model.

SPR	SL50	SL95	F/M	MK	Linf	L50	L95
18	42.5	60	4.41	0.91	61	36	42
0.13–0.23	39.9–45.1	56.5–63.4	3.1–5.7				

Table 6: Tabulated input parameters and assessment results for batisai – (*P. areolatus*). Input parameters: size of maturity (L50, L95) as plotted by the red line in Figure 7, and estimate of the life history ratio *M/k* (MK). Model generated estimates: spawning potential (SPR%), size of selectivity (SL50, SL95) as plotted by the blue line in Figure 7, relative fishing pressure (F/M) and asymptotic size (Linf). The estimated 95% confidence intervals around the estimates of spawning potential, selectivity and relative fishing pressure are shown below the estimates.

Ulavi / Rawarawa – *Scarus rivulatus*

Figure 9: A picture of rawarawa – male *Scarus rivulatus*

Figure 10: A picture of ulavi – female *Scarus rivulatus*

To date, 1079 rawarawa and ulavi (*S. rivulatus*) have been measured by the community observers allowing estimates to be made of size at 50% maturity = 27cm and 95% maturity = 38cm (Figure 11 & Table 7). Using the assumed relative size of maturity (L_m/L_∞ = 0.66; Table 4) and the estimate of L50 = 27cm it can be estimated that the growth of rawarawa/ulavi asymptotes at an average maximum size of 41 cm (Table 7). The length frequency histogram plotted with the data collected has a modal length of ~30cm, and maximum length <50cm (Figure 12 & Table 7). With these input parameters and length frequency data, the LB-SPR assessment model estimates that this species becomes vulnerable to fishing above the size maturity (Figure 11) and that currently it is being fished about one and half times more heavily than is likely to produce the maximum sustainable yield (F/M = 1.55). The population's current level of spawning potential is estimated to be around 26%; slightly above the replacement level (SPR=20%) needed to stabilize the population (Table 7).

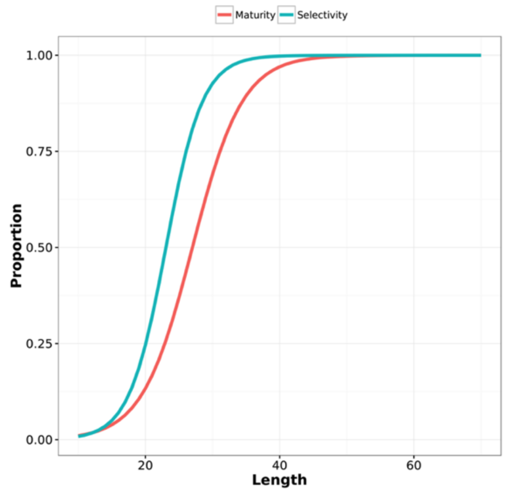

Figure 11: Red line: the proportion of rawarawa/ulavi – (***S. rivulatus***) mature by length (cm) estimated directly from the data collected by the community observers. Blue line: the proportion of rawarawa/ulavi vulnerable to capture by length (cm) as estimated by the LB-SPR assessment model.

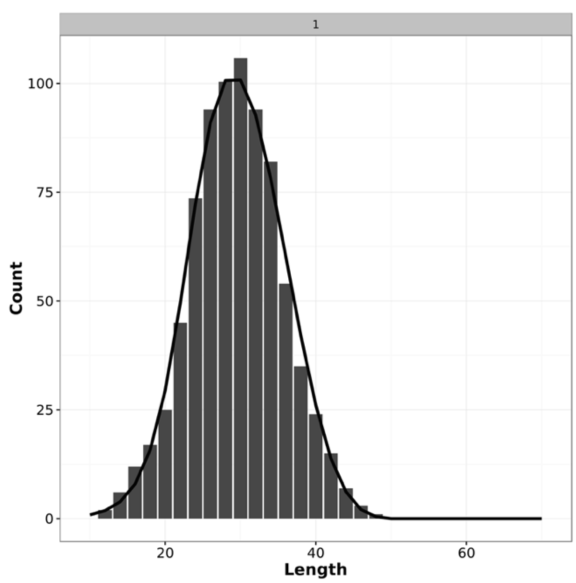

Figure 12: Black bars: the length (cm) frequency histogram of the rawarawa/ulavi – (*S. rivulatus*) catch measured by community observers. Black line: the length (cm) frequency histogram fitted to the data by the LB-SPR assessment model.

SPR	SL50	SL95	F/M	MK	Linf	L50	L95
26	23.1	31.1	1.55	0.61	40.9	27	38
0.22 - 0.3	21.9 - 24.2	29.1 - 33.1	1.23 - 1.87				

Table 7: Tabulated input parameters and assessment results for rawarawa/ulavi – (*S. rivulatus*). Input parameters: size of maturity (L50, L95) as plotted by the red line in Figure 11, and estimate of the life history ratio M/k (MK). Model generated estimates: spawning potential (SPR%), size of selectivity (SL50, SL95) as plotted by the blue line in Figure 11, relative fishing pressure (F/M) and asymptotic size (Linf). The estimated 95% confidence intervals around the estimates of spawning potential, selectivity and relative fishing pressure are shown below the estimates.

Nuqa – *Siganus vermiculatus*

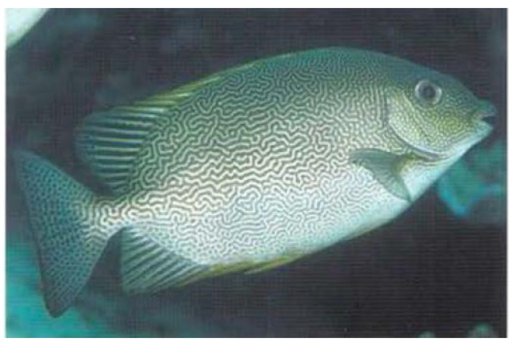

Figure 13: Nuqa – *Siganus vermiculatus.*

To date, 366 nuqa (*S. vermiculatus*) have been measured by the community observers allowing estimates to be made of size at 50% maturity = 24cm and 95% maturity = 31cm (Figure 14 & Table 8). Using the assumed relative size of maturity (L_m/L_∞ = 0.52; Table 4) and the estimate of L50 = 24cm, it can be estimated that the growth of nuqa asymptotes at an average maximum size of 46 cm (Table 8). The length frequency histogram plotted with the data collected has a modal length of 25-30cm, and maximum length <40cm (Figure 15 & Table 8). With these input parameters and length frequency data, the LB-SPR assessment model estimates that this species becomes vulnerable to being caught around the size maturity (Figure

14) and that currently it is being fished about one and half times more heavily than is likely to produce the maximum sustainable yield (F/M = 1.39). The population's current level of spawning potential is estimated to be around 31%; slightly above the replacement level (SPR=20%) needed to stabilize the population (Table 8).

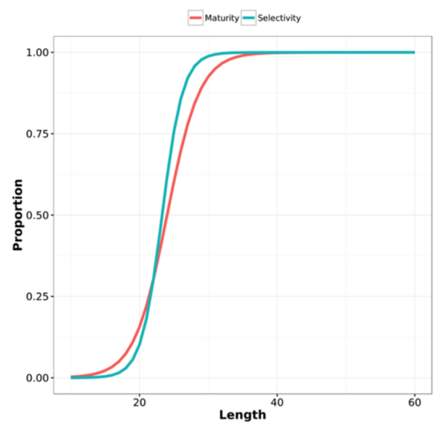

Figure 13: Red line: the proportion of nuqa – (*Siganus vermiculatus*) mature by length (cm) estimated directly from the data collected by the community observers. Blue line: the proportion of nuqa vulnerable to capture by length (cm) as estimated by the LB-SPR assessment model.

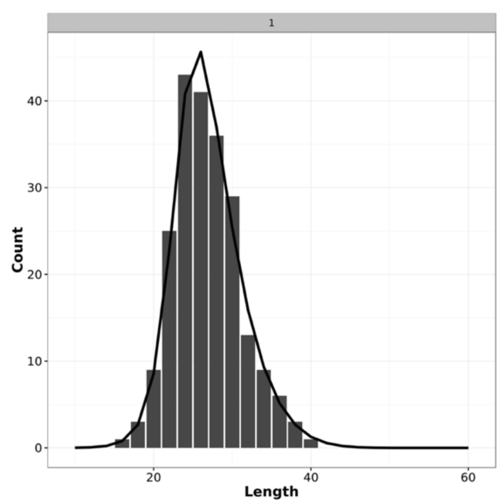

Figure 14: Black bars: the length (cm) frequency histogram of the nuqa – (*S. vermiculatus*) catch measured by community observers. Black line: the length (cm) frequency histogram fitted to the data by the LB-SPR assessment model.

SPR	SL50	SL95	F/M	MK	Linf	L50	L95
31	23.3	27.7	1.39	1.98	46.2	24	31
0.23 – 0.39	22.1 – 24.5	25.7 – 29.8	0.86 – 1.92				

Table 8: Tabulated input parameters and assessment results for nuqa – (*S. vermiculatus*). Input parameters: size of maturity (L50, L95) as plotted by the red line in Figure 13, and estimate of the life history ratio M/k (MK). Model generated estimates: spawning potential (SPR%), size of selectivity (SL50, SL95) as plotted by the blue line in Figure 13, relative fishing pressure (F/M) and asymptotic size (Linf). The estimated 95% confidence intervals around the estimates of spawning potential, selectivity and relative fishing pressure are shown below the estimates.

Taea – *Lutjanus gibbus*

Figure 15: Taea – *Lutjanus gibbus.*

To date, 253 taea (*L. gibbus*) have been measured by the community observers allowing estimates to be made of size at 50% maturity = 27cm and 95% maturity = 32cm (Figure 16 & Table 9). Using the assumed relative size of maturity (L_m/L_∞ = 0.75; Table 4) and the estimate of L50 = 27cm it can be estimated that the growth of taea asymptotes at an average maximum size of 36 cm (Table 9). The length frequency histogram plotted with the data collected has a modal length of about 30cm, and maximum length a little larger than 40cm (Figure 17 & Table 9). With these input parameters and length frequency data the LB-SPR assessment model estimates that this species becomes vulnerable to being caught below the size maturity (Figure 16) and that currently relative fished pressure is F/M = 0.71, around, or even slightly below the level likely to produce the maximum sustainable yield (F/M = 0.8 – 1.0). The population's current level of spawning potential is estimated to be around 52%; suggesting that until now the species has been relatively lightly exploited (Table 9).

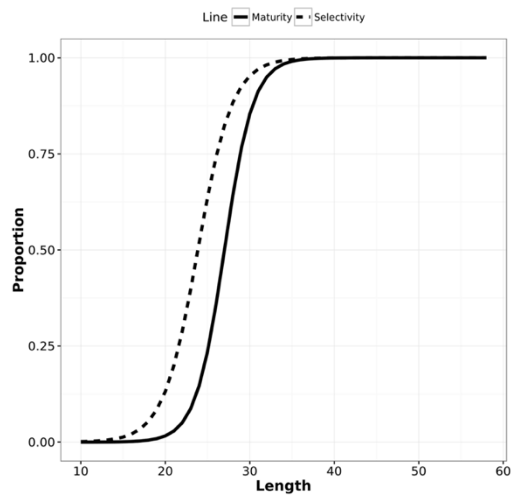

Figure 16: Solid black line: the proportion of taea – (*L. gibbus*) mature by length (cm) estimated directly from the data collected by the community observers. Broken black line: the proportion of taea vulnerable to capture by length (cm) as estimated by the LB-SPR assessment model.

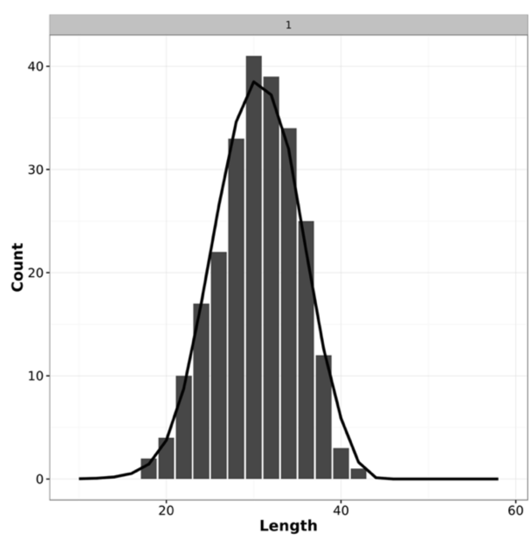

Figure 17: Black bars: the length (cm) frequency histogram of the taea – (*L. gibbus*) catch measured by community observers. Black line: the length (cm) frequency histogram fitted to the data by the LB-SPR assessment model.

SPR	SL50	SL95	F/M	MK	Linf	L50	L95
0.52	24.4	31	0.71	0.51	36	27	32
0.33 - 0.71	21.7 - 27.2	26.2 - 35.7	0.15 - 1.27				

Table 9: Tabulated input parameters and assessment results for taea – (*L. gibbus*). Input parameters: size of maturity (L50, L95) as plotted by the red line in Figure 13, and estimate of the life history ratio M/k (MK). Model generated estimates: spawning potential (SPR%), size of selectivity (SL50, SL95) as plotted by the blue line in Figure 13, relative fishing pressure (F/M) and asymptotic size (Linf). The estimated 95% confidence intervals around the estimates of spawning potential, selectivity and relative fishing pressure are shown below the estimates.

Discussion

Results of this Study

Hordyk *et al* (2014b) analyzed the performance of the LB-SPR technique under different circumstances and found that assessments of SPR require sample sizes of around 1,000 to become completely robust. This is the sample size around which length frequency histograms tend to take on the characteristic smooth uni-modal appearance that fish populations are expected to have. When the histograms have this shape the LB-SPR fitting routine can most accurately fit the measured size structure. Until that stage, the addition of extra data can continue changing the shape of the length frequency histogram being assessed, and in consequence change the result of the assessment. In addition, the few largest individuals in a sample have a disproportionate effect on the estimation of SPR and F/M. The largest individuals are naturally rare in any population; so until sample sizes reach n ~ 1,000 the largest individuals are often under-represented in a sample.

As a consequence, estimates of SPR produced with small samples sizes tend to be 5-10% lower than actual, and estimates of F/M slightly higher than actual levels. With the exception of rawarawa/ulavi – (*S. rivulatus*) for which we now have a sample size n=1,079; all our other samples sizes are still considerably smaller than the ideal of n~1,000. Our sample of batisai (*P. areolatus*) n= 689 is the next largest while the sample of taea (*L. gibbus*) with n= 253 is the smallest sample we have analyzed. In this context we should expect these results to change slightly as our data is improved by more sampling.

Notwithstanding the above, our experience to date in other places, watching how assessments improve with additional data, leads us to be confident, that even if not yet exact, these preliminary assessments are already strongly indicative of the current status of these stocks in Macuata. Our confidence is bolstered by the fact that our results are also entirely consistent with the anecdotal accounts provided by the participating community members during our initiating workshop in Naduri in October 2014. Also by the fact that taken together, these 5 assessments are internally consistent with each other, and what we know about the depletion of these species in other locations.

These results suggest that kasala (*E. polyphekadion*) and batisai (*P. areolatus*) are being fished very heavily, about 4-5 times more heavily than what would maximize sustainable yields, and already have levels of spawning potential below that required to replace the current adult population and keep it stable. This complements accounts given to us by community members who told us that it has become rare to see these species in any number, or of a good size, during the day-time, and that seasonal spawning aggregations have become very small, and in many places have stopped occurring, suggesting small populations are already going locally extinct. Our results suggest that without improved management to increase the spawning potential of these species, they are headed towards extreme depletion and eventual local extinction.

On the other hand the smaller bodied species we assessed; rawarawa/ulavi (*S. rivulatus*) SPR = 26% & F/M = 1.55, nuqa (*Siganus vermiculatus*) SPR = 30% & F/M =

1.39, taea (*L. gibbus*) SPR = 52% & F/M = 0.71, as being fished more lightly than the two grouper species, and still having higher levels of spawning potential. This is to be expected; smaller species are generally less preferred, and not targeted as heavily as the larger species. In addition, the larger species mature at much larger sizes and so their juveniles tend to be vulnerable to fishing for longer before they become adults. In some cases few individuals even reach maturity.

Although the assessments for all three of the smaller species suggest spawning potential levels that are to some extent higher than the level at which they can barely replace and sustain themselves (SPR = 20%), there is really no room for complacency here. Firstly, we need to be aware that this form of assessment looks backward and indicates the fishing pressure these species have experienced over their entire lives (i.e. the previous 5-10 years). From the accounts of community members it seems clear that things are changing fast and that fishing pressure is rapidly intensifying. As the availability of the bigger species declines, we expect targeting of these smaller species to keep intensifying. In this situation the spawning potential we estimate for these species is not some stable longer-term level from which we might draw a little comfort for above the replacement level (SPR = 20%). Rather they are just a recent point along a declining trend that for rawarawa/ulavi (*S. rivulatus*) and nuqa (*Siganus vermiculatus*) is already dangerously close to where the adults will become unable to replace themselves, and an even more rapid decline in abundance is expected to begin as the supply of new young fish declines.

The case of rawarawa and ulavi (*S. rivulatus*) is of particular interest; community members only indicated their concern about rawarawa becoming scarce, and apparently had no immediate concern for ulavi, which they considered a different type of parrotfish. This study found that ulavi are the smaller females of *S. rivulatus*, which like all parrotfish transition into males (rawarawa) as they grow. So in noting that the rawarawa are become rare, the community is in fact observing that fewer *S. rivulatus* are surviving the smaller female (ulavi) stage of their life, to become the larger male rawarawa. What they were telling us, without knowing it at the time is that the larger males are now scarce, most likely as much due to the overfishing of the female ulavi, as the fishing of the male rawarawa. All of which is entirely consistent with our assessment that fishing pressure is too high to be sustainable, and spawning potential is declining towards the bare minimum needed just to replace the existing adults.

The plight of rawarawa also provides a poignant anecdote illustrating the extent to which reef fish abundance has already declined in Macuata. Community members at the initiating workshop in Naduri, October 2014, explained to us that the name rawarawa translates into English as ‘easy-easy’, and that in the past this species was what young boys practiced spearfishing on because it was so easy to find and spear. We were able to draw rye laughter from the workshop participants by then referring to this species as ‘now-not-so-easy’.

Taea is also of some specific interest. The community partners at the Naduri workshop did not consider this species to be of major importance to them, or of any concern at that point in time. It was only prioritized for sampling because we specifically requested that. The community’s own qualitative assessment of this species has been confirmed by our results which suggest that fishing pressure on this species has been relatively low (F/M =0.71) and spawning potential relatively high (SPR = 52%). The reason we requested they gather data on this species was because our own observation is that in Pacific countries where the more preferred larger species of grouper, parrotfish, wrasse and snappers have already almost vanished from reefs and catches, this species becomes extremely important; until it in turn is also depleted. While our results confirm that this species has, until now, been relatively lightly targeted, this situation already appears to be changing in response to declining stocks of the preferred larger species in Macuata. We have been told that during the period of this study the price of taea in the Labasa fish market has doubled, suggesting this species is already becoming more important and valuable to local fishers and fish buyers, and that targeting of this species is likely to, or has already, intensified.

The Way Forward

These results confirm that Fiji is facing the same crisis of sustainability with its reef fish, as are other Pacific island nations. If Fiji does not significantly reform its management of these fisheries, it should expect to see all the most valuable commercial and food fish species depleted to extremely low levels, making them insignificant for livelihoods and subsistence, and probably locally extinct through most of Fiji. Without embracing and effectively implementing significant change to the management of these coastal resources, Fiji's current enjoyment of the larger groupers, parrotfish, wrasse and snapper is coming to an end, and Fijians will have to accept a future of catching and eating fewer smaller types of fish, and placing much less reliance on reef fish for livelihoods and subsistence. One only needs to travel through the coastal communities of Indonesia and the Philippines to see what this sort of future looks like. These countries also once had the full fish assemblage that Fiji still enjoys, but today coastal communities in those countries primarily eat species that would be used for bait in Fiji, or purchase their fish supply in tins.

We suggest the simplest and most effective way of stabilizing the current situation and beginning to rebuild depleted stocks of reef fish in Macuata and Fiji more broadly, is to reform the existing system of minimum size limits. Over time this should involve setting minimum size limits for all the most important species at sizes that protect them until they have completed at least 20% of their natural spawning potential. Our studies show that setting minimum size limits at a size that protects 20% of spawning potential will ensure that fish are sustainable even under extremely heavy fishing pressure, and also ensure optimal levels of catch if fishing pressure is managed around optimal levels.

While the long term aim should be to reform the existing system of minimum size limits and set minimum size limits to protect SPR 20% in all the most important species, we caution against moving too rapidly in that direction. Instead, we advise commencing reform with a more limited trial of just one or two species with the communities in Macuata. Our suggestion of beginning reforming with a small limited trial is based on the theory of change management developed by Kotter (2007), as well as our interest in achieving successful implementation for the long term, rather than new regulations on paper that are never properly implemented or enforced. Kotter noted that communities are naturally fearful of, and resistant to, change, and through his studies he observed that successful change processes invariably follow the same series of steps:

1. Establishing a sense of urgency
2. Forming a powerful guiding coalition
3. Creating the right vision for change
4. Communicating for buy-in
5. Empowering action
6. Creating short-term wins
7. Not letting up, and
8. Making change stick

This project in Macuata has been successfully following this approach and is now at step 6; which Kotter noted should involve setting aims in 'bite-size chunks', that are easy to achieve; a manageable number of initiatives that should be completed before starting new ones. This is the context in which we propose trialing a single new minimum size limit in Macuata, so that local communities, provincial government and regional fisheries staff can all gain experience with a successful implementation process, and be rewarded quickly by seeing a first species of fish rapidly improve. Tropical fish grow very quickly around the size of maturity; so that while a size limit implemented to protect SPR 20% will inevitably initially reduce catches for several months, within 6 – 12 months fishers will notice increased catches of that species above the new size limit increase; by 25 - 100%, depending on the species, and the current depletion of that species. In keeping with Kotter's formula for successful change; where we have been involved with this process of reforming minimum size limits in other countries, the fishing communities have quickly seen real benefit from the change, in the form of a rapid recovery and then an increase in catches and catch rates. All round the world fishing communities are practical people and seeing successful change they become motivated and increasingly supportive of implementing further changes. It is for this reason that we strongly advise reforming fisheries management in Fiji with small steps or in 'bite-size chunks'; that can be seen through successfully, before proceeding onto the next step. Over-reaching with broad-scale reform driven from the top-down will be likely to jeopardize community support and remain just on paper, rather than in real implemented change to the amount of fish on the reefs.

With the aim of building support for a broader implementation of effective minimum size limits in Fiji to ensure the sustainability of the vital reef fish, the next phase of this project will continue working with the fishing communities of Macuata, provincial government authorities and Ministry of Fisheries staff to develop and implement a trial of an initial one or two minimum size limits. To support the dialogue that will be needed, the size at maturity data gathered by this project will be used to develop the estimates of minimum size limits for the main species that will protect 20% SPR.

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Over the next 5 years we will accelerate our on-ground conservation and advocacy work, focusing on priority areas where we have the greatest impact and influence.

Building a strong network

We will draw strength from WWF's 50 years of rich history, knowledge and experience, harnessing our network of people around the world.

Walking the talk

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WWF-Pacific (Fiji) partners make an invaluable contribution to our conservation work. We couldn't do without their loyalty, generosity and personal involvement. We will expand the ways in which partners can connect with WWF-Pacific (Fiji), giving them a greater choice of programmes from which they can choose to protect our planet's future.

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Through building influential relationships with business and industry, we will continue to create solutions to address the major threats to our natural environment.

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To stop the degradation of the planet's natural environment and to build a future in which humans live in harmony with nature.

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