# Application of a harvest strategy to resource-limited deepwater snapper fisheries

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*Deepwater snapper fisheries represent an important resource for many Pacific Island countries and territories (PICTs). Artisanal and commercial fishers target deepwater finfish species for local consumption and export. Many of these fisheries were developed in the 1970s in attempts to relieve pressure from shallow-water demersal stocks. However, since the early 2000s, participation has declined, with some fisheries no longer active. With PICTs looking to improve food security, efforts have been made in recent years to re-invigorate deepwater fisheries.*

Effective management of fish stocks requires an accurate estimate of stock status. This is achieved by monitoring and assessing stock levels over time and subsequently controlling harvest rates of the fishery. In PICTs, however, many fisheries remain unassessed due to a lack of data and resources (Costello et al. 2012). This leaves fisheries managers unable to appropriately monitor stocks, thus increasing the risk of overexploitation.

Over the last decade, there has been substantial development of tools for assessing data-poor fisheries (Edwards et al. 2012). These tools have been developed to allow managers to assess fisheries with minimal data or restricted analytical capacity. These methods use a range of data inputs such as catch, effort, length, age and biological data to assess stock status. Data-poor assessment techniques have proven successful, with previously unassessed or overexploited fisheries now sustainably managed (Smith et al. 2014). These improvements, however, have been predominately limited to developed nations.

Implementation of these tools within a harvest strategy management framework represents an exciting opportunity. Harvest strategies involve a series of pre-agreed on decisions that outline how a fishery is to be managed (Dowling et al. 2007). Harvest strategies outline monitoring programmes, stock assessment techniques and management actions that take place based on stock assessment outcomes. By outlining these decisions at the beginning, it becomes a very transparent approach that improves stakeholder engagement. Implementation of harvest strategies has proven successful for many fisheries although it has proven challenging to implement them within a resource-poor context.

With PICTs looking to increase food security, improved utilisation of the full range of available fisheries resources is important. For deepwater snappers, this can be achieved by returning overexploited fisheries to sustainable levels, which will increase their harvest potential, or by developing new fisheries under a sustainable management framework. To achieve this, we applied three data-poor assessments techniques to Tonga's deepwater snapper fishery and outlined how they could be implemented within a harvest strategy framework. We provide appropriate monitoring programmes, assessment techniques and examples of possible harvest control rules. This will not only help improve the management capacity of Tonga's deepwater snapper fishery, but also outline the process for other resource-poor fisheries.

## Tongan deepwater snapper fishery

The Tongan deepwater snapper fishery began in the 1970s after a short developmental phase. Official data collection and monitoring of the fishery began in 1986, which aligned with a vessel building project that supplied 40 vessels to the fishery. After its official commencement in 1986, the fishery quickly expanded with reports of high catch rates. The number of vessels in the fishery peaked at 44 in 1988, which corresponded with a peak in harvest and catch rates (TDFMP 2014). Catch rates and harvests declined soon after. A second peak in harvests occurred in 2000–2002, reaching a maximum of ~230 tonnes (Fig. 1), likely driven by improved fishing technology. After this peak, catch rates declined and the number of vessels participating in the fishery concurrently decreased, with less than 14 vessels currently active in the fishery. Spatial expansion of effort and

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changes in species composition suggests that the fishery may be depleted (Fig. 2).

This fishery uses drop lines, primarily in depths of 100–400 m, to target demersal snappers (Lutjanidae), groupers (Epinephelidae) and emperors (Lethrinidae). Many of these deepwater species are slow-growing, long lived, and are late to mature. As a consequence, they are susceptible to overexploitation. Numerous assessments have been commissioned throughout the lifetime of this fishery. External organisations have undertaken biomass dynamic models to estimate maximum sustainable yield (MSY) for this fishery. However, these estimates have ranged widely from ~60–400 tonnes, with large uncertainty limiting their usefulness. Furthermore, a lack of data collection at the commencement of the fishery and the discontinuous collection of data throughout the duration of the fishery reduces the capacity to reliably estimate the current status of this fishery. With concerns of overexploitation, an improved understanding of the status of this fishery is required.

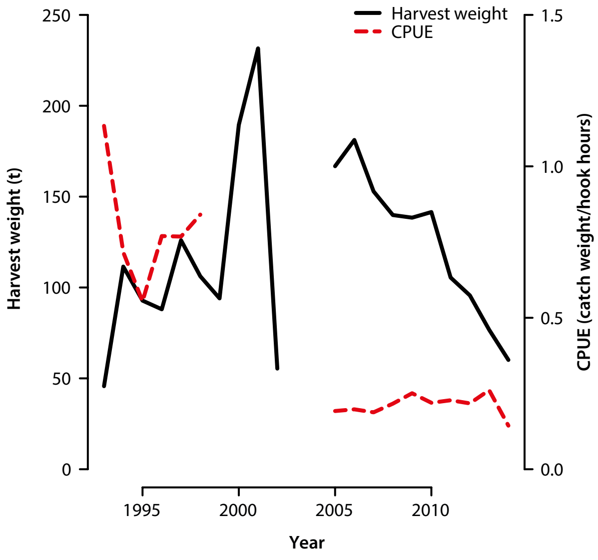

*Figure 1. Total harvest weight (t) of deepwater snapper in Tonga, and the corresponding catch per unit effort from 1993–2014.*

## 1. *Biomass dynamic model for flametail snapper (*Etelis coruscans*)*

Biomass dynamic models use catch and effort data to gain an estimate of MSY – the theoretical maximum amount of catch that can be taken from the stock per year, on average, in the long-term without causing the stock to decline. By harvesting at the rate of MSY, the stock is kept at the point of maximum productivity. To undertake this assessment, an index of population abundance is required, which is used to reflect shifts in stock abundance over time; we used catch rate or catch per unit of effort (CPUE). This requires a monitoring programme that records harvest and effort of all vessels within the fishery and also any factors that influence catchability – factors that will improve fishers' ability to

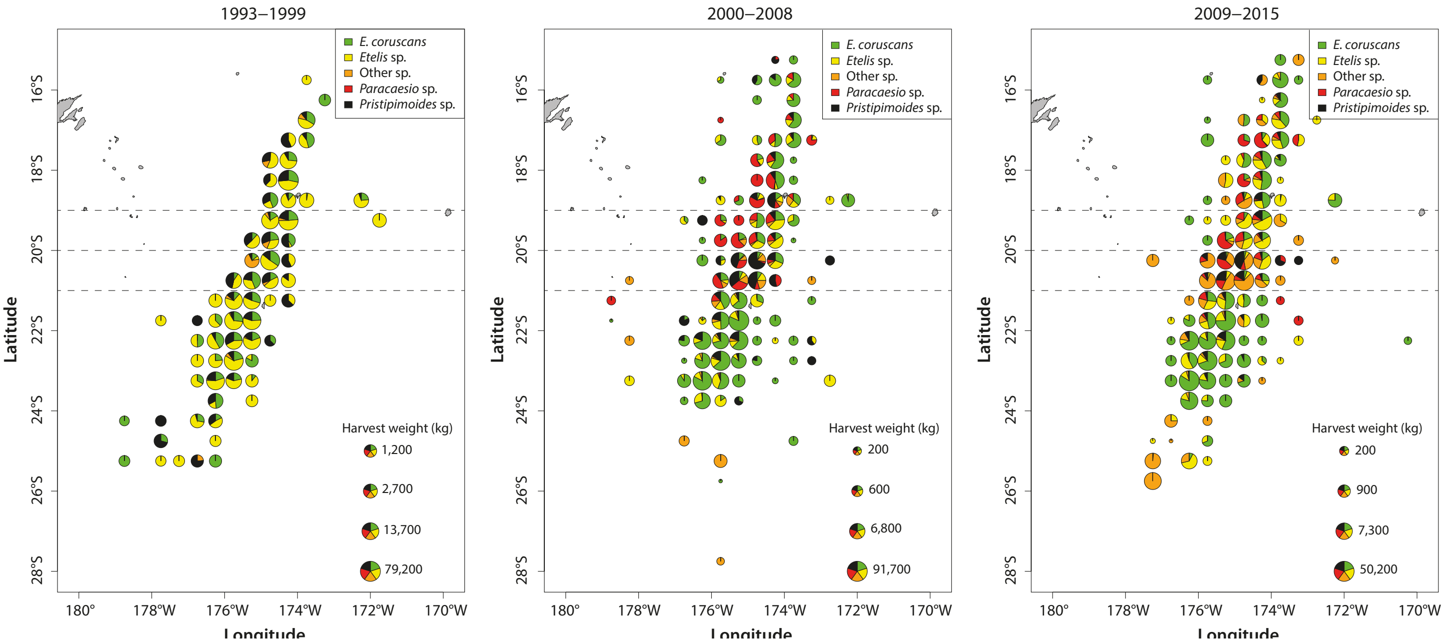

*Figure 2. Shifts in species composition and spatial expansion of effort in the Tongan deepwater snapper fishery at 0.5o resolution. Pie radius size determined by total harvest weight (kg) removed from each grid cell across three time periods (1993–1999, 2000–2008, 2009–2015). Species composition is represented by five clusters designated using k-means clustering analysis.*

harvest fish. To assess the accuracy of CPUE estimates we modelled three different scenarios (Fig. 3):

1. Base model – that included: year, month, depth fished, vessel, region and species composition.
2. Active vessels – base model but only including vessels that completed >15 trips per year.
3. Core area – base model for grid cells (0.5°) that recorded >1 fishing trip every 5 years.

The results of this assessment suggest that the Tongan deepwater snapper fishery is overfished (Fig. 4). Biomass of flametail snapper dropped below where MSY can be achieved ($B_{MSY} = 0.5\ B0$) in 2000 and has remained below that level since then. Flametail snapper stock is currently at 26–36% of 1993 levels (Table 1). Fishing pressure has declined in recent years, leading to increases in biomass from 25–30%, suggesting that flametail snapper is recovering. It must be noted that these results are relative to the stock size in 1993, not a virgin biomass, due to a lack of data collection at the start of the fishery. A lack of data at the commencement of the fishery and discontinuous data collection throughout the lifetime of this fishery limits the accuracy of this assessment. If it is to be used in the future, the monitoring programme must improve in consistency and coverage.

## 2. Length-based indicators

This technique investigates length composition of catch over time to infer stock status (Froese 2004). It looks at trends in the proportion of mature individuals, those within the optimal harvest range ($L_{opt}$), and large individuals (megaspawners), which are assumed to provide a disproportionately large number of recruits to assess stock status (Fig. 5). The aim is to minimise the proportion of juveniles and megaspawners captured and maximise the number of those found within the $L_{opt}$ size range. These goals will minimise the likelihood of overexploitation occurring by ensuring a viable number of adults survive to spawn. To undertake this assessment, a simple monitoring programme that records length frequency of a subsample of catch for a number of indicator species and an estimate of length at maturity for these species is all that is required. The length-frequency distributions of flametail snapper and crimson jobfish (*Pristipimoides filamentosus*) were analysed from 1993–2014. Length data were collected for a large number of

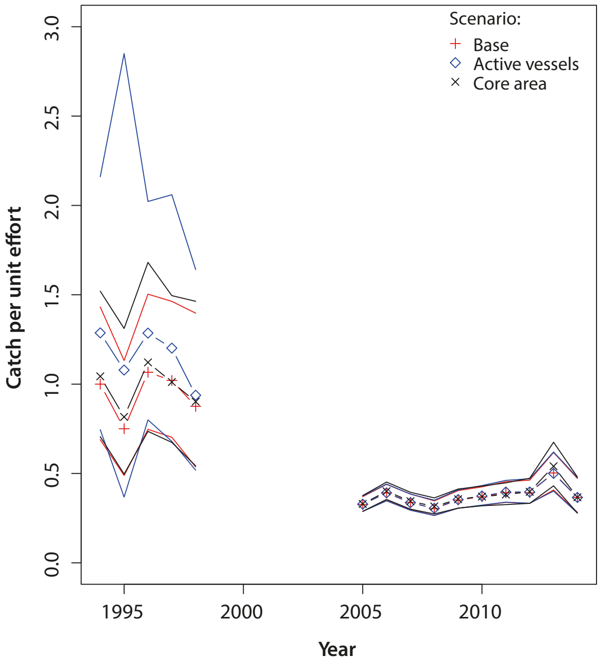

*Figure 3. Estimates of standardised catch per unit effort of flametail snapper calculated using harvest weight for three different scenarios.*

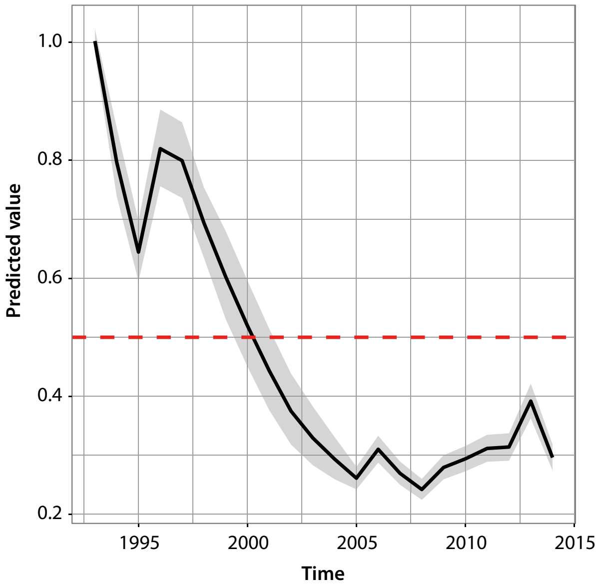

*Figure 4. Predicted stock levels of flametail snapper (E. coruscans) from 1993–2014 estimated from the base biomass dynamic model. Dashed red line denotes $B_{MSY}$ for flametail snapper.*

*Table 1. Biomass dynamic model outputs for all three scenarios of the Tongan deepwater snapper fishery.*

| Scenario | MSY (t) | Biomass at MSY (t) | Harvest rate at MSY | Current (2014) biomass (t) | Current (2014) depletion | Current (2014) harvest rate |
|---|---|---|---|---|---|---|
| Base | 80.3 | 2436.2 | 0.032 | 1438.8 | 0.29 | 0.021 |
| Active vessels | 74.0 | 2151.1 | 0.034 | 1518.8 | 0.36 | 0.019 |
| Core area | 86.6 | 2905.8 | 0.030 | 1527.1 | 0.26 | 0.029 |

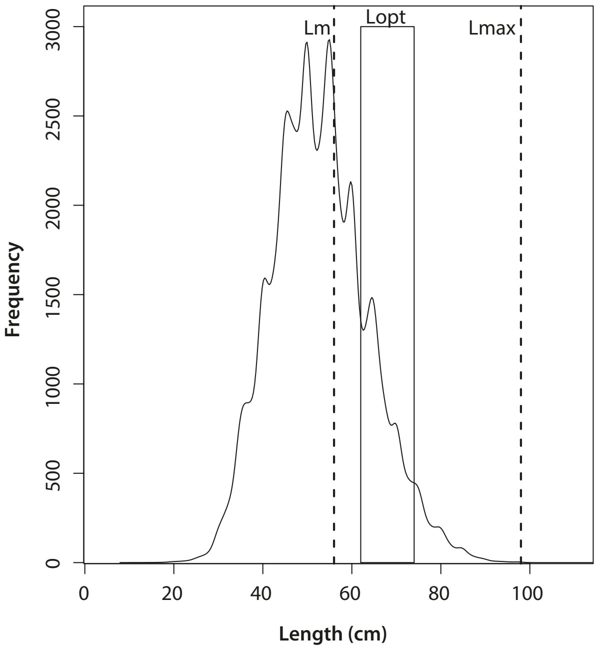

*Figure 5. Length-frequency distribution plot outlining the position of length-based indicators defined by Froese (2004) in a theoretical population.*

species although only adequate samples were gathered for these two species.

The length-frequency distribution of flametail snapper and crimson jobfish from 1993 to 2014 shifted over time. For flametail snapper, a decline in population health from 1993–2002 was apparent where data are available (Fig. 6A). The proportion of mature individuals in catches declined from 60% to 22%. From 2003 onwards, the number of mature individuals has increased gradually from 22% to 38% in 2014. The proportion of megaspawners has remained low since their initial decline from 15% to ~5% from 1993–1996. These results suggest that the depletion of the stock occurred from 1993 to 2002, with a recent recovery from 2005 to 2014. Crimson jobfish seems to have a more stable population with the proportion of mature individuals captured fluctuating at ~80% from 1993 to 2014 (Fig. 6B). This is likely due to a small length at maturity and individuals recruiting to the fishery at larger sizes. This means that crimson jobfish are more resilient to fishing pressure. Despite this, there is evidence of declines in the proportion of megaspawners encountered, declining from 20% to ~5%. Similar to the biomass dynamic model, a lack of data collection at the commencement of the fishery and discontinuous data hinders this assessment. If continued, fisheries should aim to incorporate a number of different indicator species to help capture trends in the fishery.

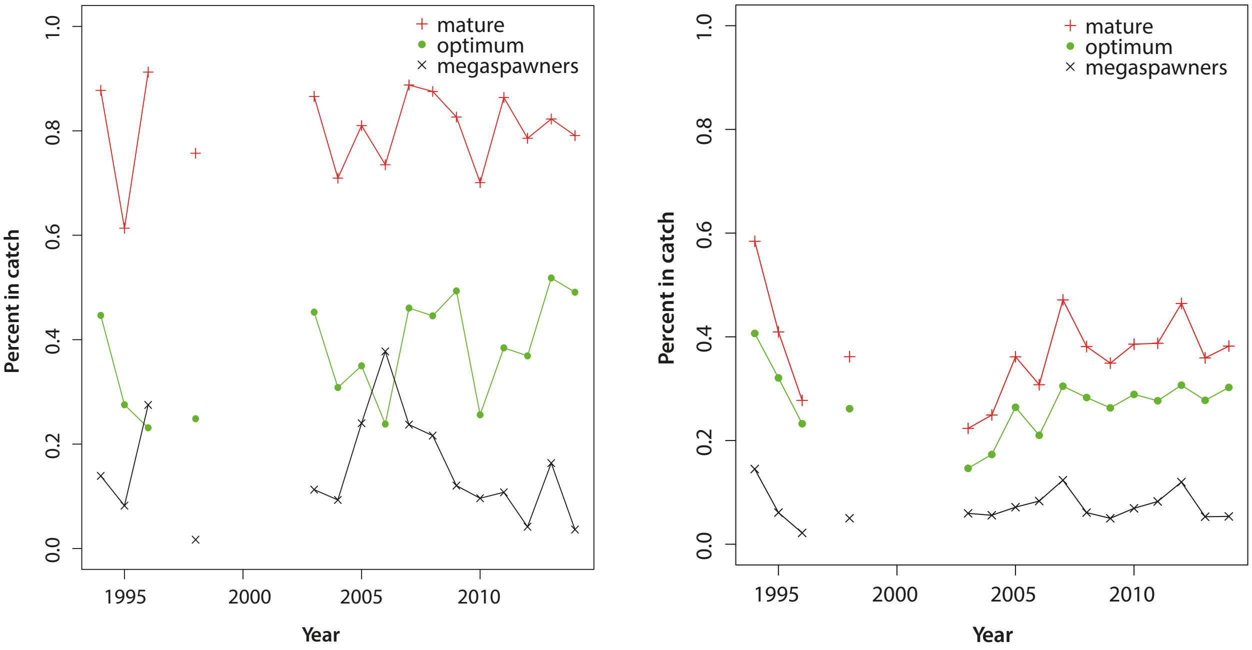

*Figure 6. Length-based population indicators for indicator species from 1994 to 2014. A)* E. coruscans*. B)* P. filamentosus*. No data for 1997 or from 1999 to 2002.*

### 3. *Catch-curve analysis (age-based indicators)*

Catch-curve analysis assesses stock status using age-based indicators over time to estimate fishing mortality. In essence, the more heavily exploited the stock, the fewer old individuals will be present in the population. Similar to the length-based assessment, this technique requires a representative sample of catch to assess its age composition. This was undertaken for flametail snapper in 2012 and 2013.

In 2012, estimates of fishing mortality indicated that flametail snapper were being harvested sustainably. An increase in fishing mortality occurred from 2012 to 2013 suggesting that fishing pressure on flametail snapper may be increasing (Table 2). However, a longer time series of data is required to make robust conclusions. If an increasing trend in fishing mortality was to continue into the future, this would be indicative of increased fishing pressure.

## Management options

Results across each assessment were consistent, providing confidence in the outcomes. Trends for the biomass dynamic model and length-based assessment show that stocks declined from 1993 to 2005. From 2005 onwards, there are signs of recovery, likely due to decreased fishery participation. Although lacking an adequate time scale, estimates of fishing mortality from the catch-curve analysis were similar to those from the biomass dynamic model, providing confidence in its accuracy. Therefore, the Tongan deepwater snapper fishery is likely overfished and not operating at optimal levels. However, current levels of effort seem sustainable and are allowing the fishery to recover.

From these results, harvest control rules (HCR) can be assigned based on the outcomes of each assessment technique to initiate management action (Table 3). These are aimed at maintaining the fishery at a level that

*Table 2. Estimates of total (Z) and fishing (F) mortality for sexed* E. coruscans *in 2012–2013. Estimate of natural mortality (Hoenig 1983) was 0.109 for females and 0.122 for males.*

| | Sample size | Total mortality (Z) | Fishing mortality (F) |
|---|---|---|---|
| Males (2012) | 215 | 0.14 | 0.016 |
| Females (2012) | 274 | 0.13 | 0.021 |
| Males (2013) | 196 | 0.15 | 0.025 |
| Females (2013) | 282 | 0.17 | 0.058 |

*Table 3. Example of decision rule table based on outcomes of each assessment technique. F = fishing mortality, which is an output from catch-curve analysis.*

| Assessment outcome | Decision rule |
|---|---|
| 1. Harvest < $\text{Harvest}_{\text{target}}$<br>2. %mature > $\text{\%mature}_{\text{target}}$<br>3. F < $F_{\text{target}}$ | Maintain or increase quota/effort. |
| 1. $\text{Harvest}_{\text{target}}$ < Harvest < $\text{Harvest}_{\text{threshold}}$<br>2. $\text{\%mature}_{\text{target}}$ > %mature > $\text{\%mature}_{\text{threshold}}$<br>3. $F_{\text{target}} < F < F_{\text{threshold}}$ | Quota/effort should remain constant. Potential for increased data collection/analysis. |
| 1. $\text{Harvest}_{\text{threshold}}$ < Harvest < $\text{Harvest}_{\text{limit}}$<br>2. $\text{\%mature}_{\text{threshold}}$ > %mature > $\text{\%mature}_{\text{limit}}$<br>3. $F_{\text{threshold}} < F < F_{\text{limit}}$ | Decrease quota/effort, e.g.: 0–50%. |
| 1. Harvest > $\text{Harvest}_{\text{limit}}$<br>2. %mature < $\text{\%mature}_{\text{limit}}$<br>3. F > $F_{\text{limit}}$ | Decrease quota/effort substantially, e.g.: 50–100%. |

best achieves the management objectives. Commonly, a three-level system is used whereby target, threshold and limit reference levels are set for each assessment technique to enact HCRs. The goal is to maintain the fishery at the target reference level that will best achieve management objectives. If the threshold level is reached, it suggests that the fishery is under pressure and often triggers an HCR, which requires further assessment or decreased exploitation. If the limit reference level is reached, the fishery is overexploited and action must be taken to return it to more sustainable levels. These levels are designated based on assessment techniques chosen and management objectives of the fishery. For resource-poor fisheries, a precautionary buffer should also be implemented to account for uncertainty within assessment outcomes due to errors associated with these simple methods. As confidence in assessments and fishery responses to management actions improve, this buffer can be reduced.

Based on assessment outcomes, Tonga's fisheries managers should aim to maintain exploitation rates at or below current levels, which would allow stocks to continue their recovery to levels where greater harvests can be sustainably achieved. This will help to achieve management objectives of stock sustainability and ensure food security and maximisation of jobs for Tonga. This could be achieved through actions such as controlling harvest or effort quotas, or restricting the number of fishers entering the fishery.

## Discussion

The ability for PICTs to autonomously manage fisheries resources is paramount to food security and sustainability. This research has outlined several data-poor assessment techniques and how they can be implemented within a harvest strategy framework based on country-specific management objectives. Feedback from Tonga's fishery managers and stakeholders has been positive, with a review currently underway into the management of Tonga's deepwater snapper fishery with cooperation from fishers based on these results. Continued development of harvest strategies applicable to resource-poor fisheries managers must be fostered.

Explicitly outlining monitoring programmes, assessment techniques and subsequent HCRs will aid resource-poor nations in autonomously managing fisheries. By clearly outlining harvest strategies, fisheries can allocate the resources required. The three assessments undertaken represent a subsample of available data-poor techniques that are available. Each requires different data inputs and analysis, provides a variety of options. Length and age-based monitoring programmes can be undertaken simultaneously, streamlining resource use. Furthermore, recent analysis has shown that simple otolith morphometrics can be used to age key deepwater fishery species, eliminating the need for resource-intense laboratory analysis (Williams et al. 2015). These two techniques represent simple assessment techniques that require few resources for monitoring or analysis. In contrast, biomass dynamic model monitoring programmes and subsequent statistical analyses are resource-intensive. As a solution, this assessment may only be undertaken when there are concerns that the fishery is in decline.

## Recommendations

From this exercise we have established several key recommendations for Tonga's deepwater snapper fishery and resource-poor fisheries, which aim to improve management capabilities. Firstly, resources must be clearly identified and allocated. This provides managers with a clear understanding of what options are viable. This includes factors such as funding, number of staff, equipment and analytical expertise. In many cases, only a limited number of individuals will be charged with managing a fishery, limiting sampling and analytical capacity. Second, a clear understanding of the fishery must be obtained. This will help determine which monitoring programmes are feasible, where to focus them and what assessments are most appropriate. For example, for many PICTs there is no centralised port to process catches. This makes it difficult to monitor catch and effort, making catch-based assessment techniques unviable. Logbooks represent a potential solution to this problem. Third, key indicator species should be designated to allow concentration of monitoring resources. Comparison of assessment outcomes across species will provide a better snapshot of the status of the fishery. A range of species should be selected that are commonly caught in the fishery and represent divergent life histories. Data collection and analysis of numerous indicator species would strengthen the accuracy of assessment outcomes for Tonga's deepwater snapper fishery. Fourth, the limitations and uncertainties of assessments and monitoring programs must be addressed and accounted for. This can be achieved by setting reference levels conservatively to reduce the likelihood of overfishing occurring. Lastly, stakeholder engagement is very important. Compliance monitoring is likely to be minimal and fisheries must rely on fishers to abide by management controls. Therefore, consultation is important to maximise compliance and engagement, which will aid in achieving management objectives.

These recommendations provide fishery managers with several key considerations that will aid in managing resource-limited fisheries. Implementation of newly developed data-poor assessment techniques within a harvest strategy represents an exciting opportunity for improved management of many PICT fisheries. However, continued research and development of data-poor assessment techniques and management strategies will play a key role in achieving these goals in future. This article was based on a recent fact sheet published by the SPC that can be found online (Hill et al. 2016).

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## References

Costello C., Ovando D., Hilborn R., Gaines S.D., Deschenes O. and Lester S. 2012. Status and solutions for the world's unassessed fisheries. Science 338:517–520.

Dowling N.A., Smith C.A. and Smith A.D.M. 2007. Finalisation of harvest strategies for AFMA's small fisheries. Australian Fisheries Management Authority. Final report for project 2007/834, Canberra.

Edwards C.T.T., Hillary R.M., Levontin P., Blanchard J.L. and Lorenzon, K. 2012. Fisheries assessment and management: A synthesis of common approaches with special reference to deepwater and data-poor stocks. Reviews in Fisheries Science 20(3):136–153.

Froese R. 2004. Keep it simple: Three indicators to deal with overfishing. Fish and Fisheries 5:86–91.

Hill N.J., Williams A.J., Peatman T., Nicol S.J. and Halafihi T. 2016. Development of a harvest strategy for resource-limited deepwater snapper fisheries. Technical Report, Secretariat of the Pacific Community, Noumea. DOI: 10.13140/RG.2.1.2861.5447.

Hoenig J.M. 1983. Empirical use of longevity data to estimate mortality-rates. Fishery Bulletin 81(4):898–903.

Smith A.D.M., Smith D.C., Haddon M., Knuckey I.A., Sainsbury K.J. and Sloan S.R. 2014. Implementing harvest strategies in Australia: Five years on. ICES Journal of Marine Science 71(2):195–203.

TDFMP. 2014. Tonga Deepwater Fisheries Management Plan 2014–2016. Fisheries Division, Ministry of Agriculture and Food, Forests and Fisheries, European Union ACP Fish II Project, Tonga.

Williams A.J., Newman S.J., Wakefield C.B., Bunel M., Halafihi T., Kaltavara J. and Nicol S.J. 2015. Evaluating the performance of otolith morphometrics in deriving age compositions and mortality rates for assessment of data-poor tropical fisheries. ICES Journal of Marine Science, doi: 10.1093/icesjms/fsv042.