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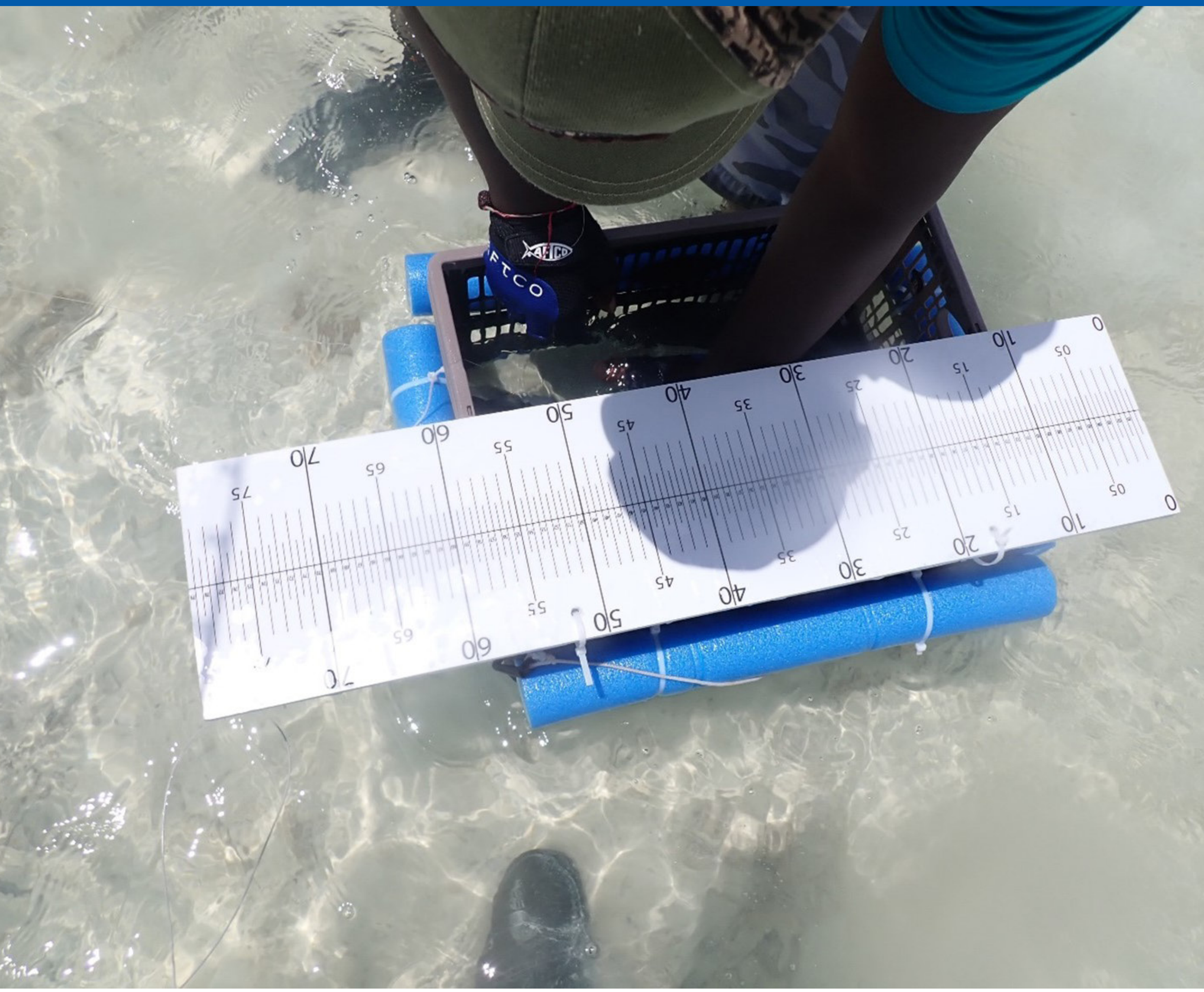

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Stock status of the bonefish, *Albula glossodonta*, in Kiritimati, Kiribati

Hannah Gilchrist,[1] Léonore Page,[1] George Shedrawi,[1]
Sebastien Gislard,[1] Andrew Halford,[1] Max Peter[2]

1 Pacific Community
2. Ministry of Fisheries and Marine Resources Development (MFMRD), Kiribati

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Contents

Summary

Recreational fishing for bonefish, *Albula glossodonta*, in Kiritimati contributes to the island's economy. During COVID-19, this fishery came to a halt due to the lack of flight connections. In 2023, Kiribati's Ministry of Fisheries and Marine Resources Development (MFMRD), requested SPC to assist in assessing the stock status of this fishery to inform management going forwards.

SPC collected data on lengths, weights and maturity of fish, and took samples of otoliths for aging. A trial of mark-and-recapture methods was also conducted to assess suitability of this method for ongoing assessment of bonefish stock status.

Mean fork length of bonefish in Kiritimati is 39.2 cm and mean weight was 929.3g. A length–weight relationship for this species was established alongside von Bertalanffy growth parameters. L_{50} for bonefish in Kirimati is 34.5 cm and L_{∞} is 52.6 cm. The growth coefficient K is 0.243 and maximum predicted age is 12.8 years. The mean size of bonefish in Kiritimati appears to be smaller than elsewhere in the Pacific, this may be due to the low latitude of Kiritimati and warmer tropical waters compared to the locations of other studies, rather than fishing pressure.

A spawning potential ratio of 0.63 indicates that the stock is in good condition, only 23.3% of fish sampled were under the size at maturity (L_{50}).

Garcia et al., 2024 recommended that the fishery remain closed to fishing by the local population as it brings an important source of revenue for Kiritimati. However, they noted that improved monitoring of the recreational fishery, in addition to monitoring of other commercial and subsistence fisheries are needed. Recommendations, in addition to those outlined in the socio-economic assessment of the bonefish fishery (Garcia et al. 2024), are as follows:

1. Creel surveys to monitor the status of other species of importance to food security in Kiritimati are recommended – the status of species of importance to subsistence fisheries is important context to have in making management decisions for food security fisheries and the recreational bonefish fishery alike. As highlighted in Garcia et al. (2024), NGO or university partners could assess incidental catch of bonefish every few years to supplement the creel monitoring programme, independent surveys would remove conflicts associated with monitoring, control and surveillance efforts by the Kiritimati government.

2. Results of both this stock status report, and the results of the socio-economic assessment should be discussed with fishing communities to engage them in decision-making and improve voluntary compliance to regulations.

3. We do not recommend continuing with a mark-and-recapture programme to monitor the status of the bonefish stock due to resources and time required and the appropriateness of the Length-based Spawning Potential Ration (LBSPR) to conduct a stock health assessment.

Acknowledgements

The Pacific Community would like to thank all who participated in the surveys, contributing their time and expertise. SPC is grateful for the financial support of New Zealand's Ministry of Foreign Affairs and Trade and the in-kind contribution of the Kiribati Ministry of Fisheries and Marine Resources Development. The content of this publication does not necessarily reflect the views of the government of New Zealand.

Introduction

Kiritimati atoll is one of Kiribati's line islands (Figure 1). It comprises more than half of Kiribati's total land area and is the largest coral atoll in the world. Fishing is one of the primary livelihoods; 95% of households are involved in fishing activity, mainly for consumption and local sale (Kiribati National Statistics Office ND).

Recreational fishing by tourists also contributes to the atoll's economy. Tourists make up 71% of visitors to Kiritimati (Tourism Authority of Kiribati 2020), many of them arriving from the USA and Australia to engage in fly and spin fishing for bonefish, *Albula glossodonta*. The total direct revenue in Kiritimati from tourism for recreational fishing is estimated to be at least AUD 4.3 million per year (Garcia et al. 2024). This revenue stopped during the COVID-19 pandemic due a closure of the borders in Kiritimati until May 2023.

There is currently no fisheries management plan for the Kiritimati Recreational Fishery, but there are some regulations. These regulations include the Fisheries (Protection of Bonefish of Kiritimati) Regulations 2008 and the Fisheries (Conservation and Management of Coastal Marine Resources) Regulations 2019. The former prohibits the catching, killing and selling of bonefish unless in possession of a tourist fishing permit in Kiritimati. The Fisheries Regulations 2019 prohibit fishing for bonefish three days before and three days after the full moon across all of Kiribati. This national regulation also imposes a minimum fork length of 30 cm. It is unclear if the national legislation is applied to recreational fishers in Kiritimati.

Gillnetting is commonly practiced for subsistence fishing in Kiritimati; bonefish are likely to be caught using this method even without intention. Concerns were expressed that the health of the bonefish stock was threatened by increased pressure on the fishery through incidental subsistence fishing in the absence of tourism during COVID-19.

In 2023, the Ministry of Fisheries and Marine Resources Development (MFMRD) requested support from SPC to assess the health of the bonefish stock to inform the management of this fishery in Kiritimati.

In this report we:

1. Analyse the lengths, weights, ages and maturity of fishes caught through gillnetting, fly and spin fishing to establish key life-history parameters and length-based spawning potential ratio for *A. glossodonta*.

2. Assess the feasibility of mark-and-recapture methods in Kiritimati to continuously monitor the abundance of *A. glossodonta*.

3. Provide some recommendations to MFMRD with regards to the monitoring and management of the bonefish fishery.

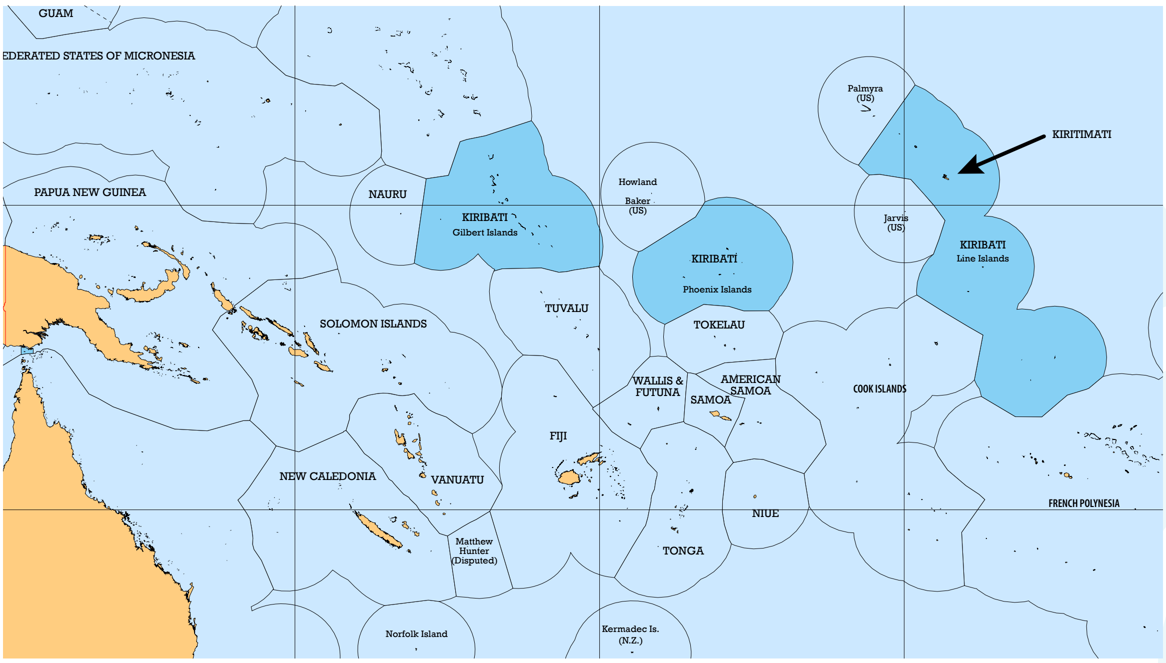

Figure 1. The Pacific Ocean, with the exclusive zone of each of the three island groups in Kiribati (Gilbert, Phoenix and Line) in dark blue.

Methods

Surveys were conducted on Kiritimati in August 2023; mark-and-recapture methods using fly and spin fishing were trialled to explore the feasibility of this approach to stock assessment of the bonefish recreational fishery. These fishing methods were chosen to increase the chances of survival of each fish after capture.

Gillnet fishing was used to capture bonefish for biological sampling purposes. All sampling was carried out inside the lagoon, across different sand flats depending on informal reports from fishing operators.

Creel survey data from Tarawa, Gilbert Islands in 2019 was shared with the authors by the Ministry of Fisheries and Marine Resources Development to allow comparison between bonefish stocks experiencing lighter (Kiritimati) and heavier (Tarawa) fishing pressure.

Biological sampling

Samples in Kiritimati were taken from 339 bonefish over the course of seven days between 27 July and 10 August 2023. For each fish, fin clips, otoliths, muscle samples and gonads were extracted, and length and weight were recorded. While fin clips and muscle samples were not used in this study, they were collected to maximise the use of valuable biological resources. These samples can support additional analyses, such as genetic population structure assessments, species identification (Gislard et al. 2023), toxicology and nutritional content analysis at a later stage.

Maturity

Extraction of gonads and staging were conducted in person. External morphology of gonads was examined, and the fish were subsequently identified either as "mature" or "immature". Images were taken of gonads with their tag numbers for 265 out of 339 fish that were sampled.

Using photos, maturity stages were examined by a second observer to assess consistency in recorded maturity stages made in the field. Images went through two blind reviews whereby all fish were sorted into "mature" or "immature" categories by two different people without being biased by the previously conducted staging, nor length, weight or age data for each fish. When there was disagreement between two observers in the final maturity assessment, a third opinion was sought as a "tie-breaker", this was the final maturity stage selected.

Due to the difficulty encountered in identifying sex from photos of gonad external morphology, we took the decision not to disaggregate analyses by sex.

Aging

Otoliths were extracted from fish caught through gillnetting. Both otoliths were rinsed with 95% ethanol and then put in vials labelled per the tag number for that fish. These were then sent to a contractor, Fish Aging Services, for processing.

Data analysis

Except for calculation of LBSPR and natural mortality, all analyses and charts were done using R version 4.3.2 installed on R-Studio (R Core Team 2023). Graphics were produced using the ggplot2 package (Wickham 2016).

Length and weight parameters

When both weight and length data were available, Fulton's condition factor (K) was calculated using the formula : (W = weight in grams, L = fork length in cm (Lloret et al. 2013; Nash et al. 2006)). Only data within the 2.5th and 97.5th percentiles of K were retained.

Length-frequency distributions were created using the length data with bin sizes of 1 cm. This enabled comparison with previous analyses of bonefish length frequencies in Kiribati (Gislard 2020).

To create a length–weight relationship, a linear model was fitted to the log10-transformed weight and fork length data, allowing for the estimation of the scaling parameters of the curve. Model coefficients, including the slope (b) and intercept (a), along with their confidence intervals, were back transformed to the original scale. The model's fit, given by the allometric equation $W=aL^b$ where W is weight in grams and L is fork length in cm, was evaluated using R^2, and predictions, along with their confidence intervals, were transformed back to the original scale for visualisation.

A two-sample Kolmogorov Smirnov test as conducted on the length distribution data to test for significant difference between length frequencies of bonefish in Kiritimati and Tarawa.

Growth

Kiritimati

We modelled the growth of fish using the von Bertalanffy Growth Function (VBGF). The VBGF, which describes growth as , was fitted to the length and age data sourced from biological samples. Initial parameter estimates for asymptotic length (L_∞), the growth coefficient (K) and hypothetical age at a length of zero (t_0) were obtained using starting values derived from the data. These parameters were refined using a non-linear least squares (NLS) optimisation method, and 95% confidence intervals were calculated.

Maximum age (t_{max}) was estimated using the following formula: .

Tarawa

Using the creel data from Tarawa in 2019, we modelled the growth of fish using the VBGF function applied to a series of length-frequency data through Electronic LEngth Frequency ANalysis (ELEFAN) (Zhou et al. 2022). We used a bin size of 1 cm and a moving average of 3 cm.

Maturity

Kiritimati

To estimate the length at 50% maturity (L_{50}) and 95% maturity (L_{95}) for Kiritimati, maturity and length data were used. A logistic regression model was fitted using the *glm* function with the binomial family and logit link (Prince et al. 2020). The maturity variable was coded as binary (mature = 1, immature = 0) to predict the probability of maturity (*P*) as a function of fork length (*l*). Bootstrap parameter estimates were used to derive 95% confidence intervals for the maturity index using the boot package (Canty and Ripley 2012; Doll and Lauer 2013). The same analysis was performed to find the age at 50% maturity (A_{50}) and age at 95% maturity (A_{95}).

Tarawa

To estimate L_{50} and L_{95} for Tarawa, length-frequency data were analysed using a logistic regression model (Zhou et al. 2022). The cleaned dataset was then binned into 1 cm length intervals. Each bin represented a frequency distribution of fish lengths, with midpoints calculated for each bin. A proportion of maturity was assigned to each length class, assuming a gradual increase in maturity with size. A logistic regression model was fitted to the proportion of maturity as a function of length midpoint using a generalised linear model (GLM) with a binomial distribution where represents the proportion of maturity and and are the estimated coefficients. L_{50} and L_{95} were then calculated as follows:

Mortality

The natural mortality rate (M) of the population was estimated using Then's empirical equation for both Kiritimati and Tarawa data. This equation uses the von Bertalanffy growth coefficient (K), the asymptotic length (L_∞) and the length at 50% maturity (L_{50}) (Then et al. 2015). The equation used was: . This calculation was performed in R using the TropFishR package (Mildenberger et al. 2017), applying *A. glossodonta*'s growth parameters as reported in the results section of this study.

Length-based Spawning Potential Ratio

LBSPR analyses were conducted to evaluate the stock health status of *A. glossodonta* in the Line and Gilbert Islands. The analysis was conducted using R-Shiny application from the iMarine Gateway Virtual Research Environment Stock Monitoring Tool v0.6 developed by the FAO (Taconet et al. 2024). This platform provides resources for length-based fisheries assessments, including the LBSPR method (Hordyk, Ono, Sainsbury, et al. 2015; Hordyk, Ono, Valencia, et al. 2015). LBSPR evaluates stock status by estimating the spawning potential ratio (SPR), which represents the proportion of mature fish capable of spawning in a fished stock compared to an unfished stock. LBSPR is particularly useful for data-limited fisheries, as it requires only a representative sample of the size structure of the fished stock and an understanding of the species' life history.

LBSPR is estimated using length-frequency data and both estimated key life-history parameters asymptotic length (L_{∞}), the ratio of natural mortality (M) to the von Bertalanffy growth coefficient (K), which is shown to be less variable across different stocks and species than just M alone. Other input metrics in lengths at maturity (L_{50} and L_{95}) and the length–weight relationship of the species were estimated from samples collected as part of the mark recapture and gillnetting conducted in Kiritimati, and creel studies in the Gibert group of islands.

Results

Mark-and-recapture

A total of 151 fish were tagged and released over nine days of fishing across 16 sites. Most fish were tagged between 1 and 3 September (95 fish). No recaptured fish were recorded in this time.

Lengths and weights of bonefish

The mean length of bonefish in Kiritimati was 39.75 cm (SE 0.40), ranging from 18.0 cm to 56.4 cm (n=321) (Table 1). When plotted in a length frequency distribution, the modal length class is 42 cm. The length distribution of bonefish in Tarawa is significantly different from those in Kiritimati ($D = 0.43$, $p < 0.001$); the mean length in Tarawa is 36.60 cm (SE 0.10) with a modal length class of 36 cm.

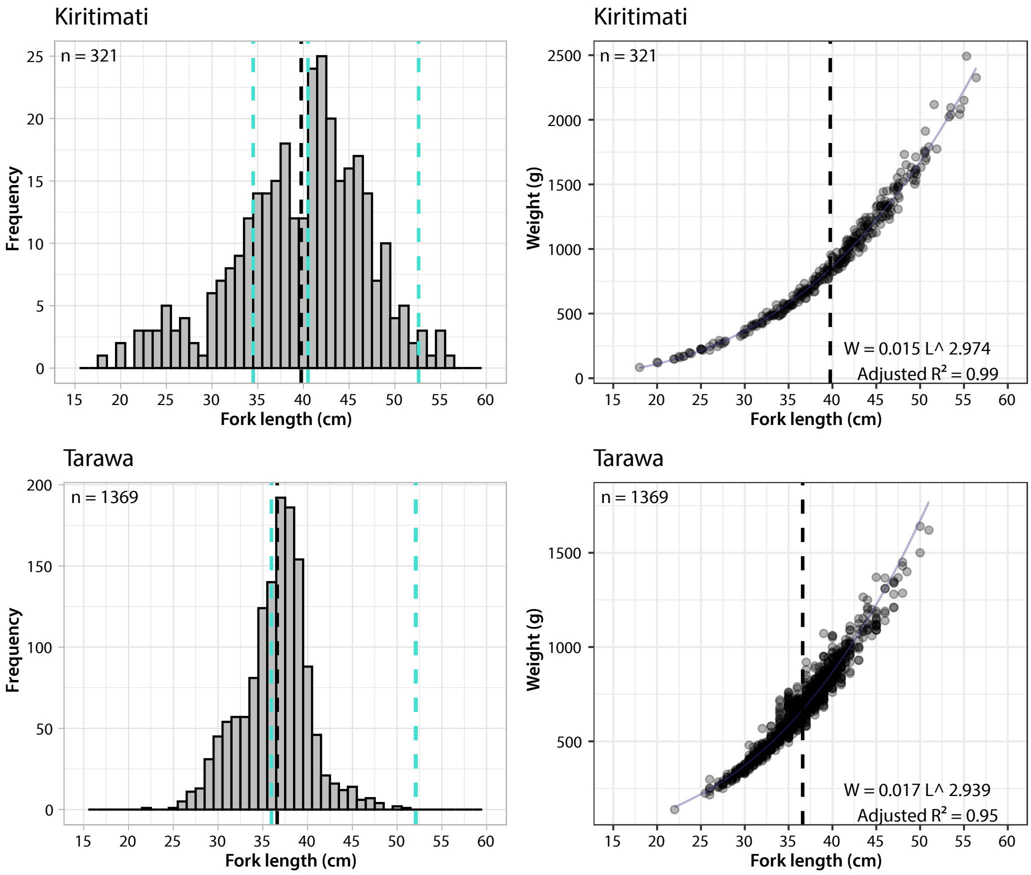

Figure 2. Length frequency distribution of A. glossodonta with 1 cm size bins (left), and length–weight curves (right) for Kiritimati (top) and Tarawa (bottom). Black vertical lines indicate the mean length, blue lines indicate L50, L95 and Linf on the length frequency histograms, values for these lines are noted in Table 1. All lengths are fork lengths in centimetres.

Mean weight of bonefish sampled was 929.3 g (SE 25.3), ranging from 84 g to 2492 g (n = 321).

The length–weight ratio of bonefish in Kiritimati is ($a = 0.015$, $b = 2.97$) with an R^2 value of 0.993 (Figure 2; Table 1).

Growth parameters and size at maturity

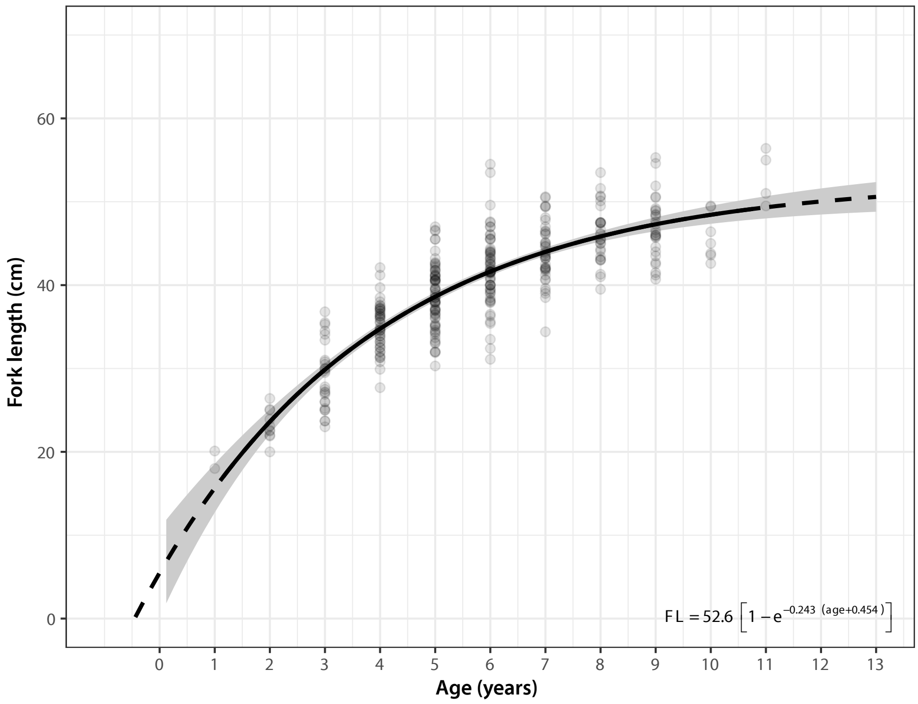

Figure 3. Growth rate of *A. glossodonta* in Kiritimati n = 317. 95% confidence interval is marked in grey, dashed lines indicate predicted values.

Asymptotic fork length (L_{∞}) of bonefish in Kiritimati is 52.6 cm (Figure 4). The growth coefficient K is 0.243, and the hypothetical age at which length is zero (t_0) is 0.454 years. Using these factors, we were able to estimate that the maximum age for bonefish in Kiritimati is 12.8 years.

ELEFAN analysis of length-frequency data in Tarawa indicate that L_{inf} is 52.1 cm and K is 0.7 (Table 1).

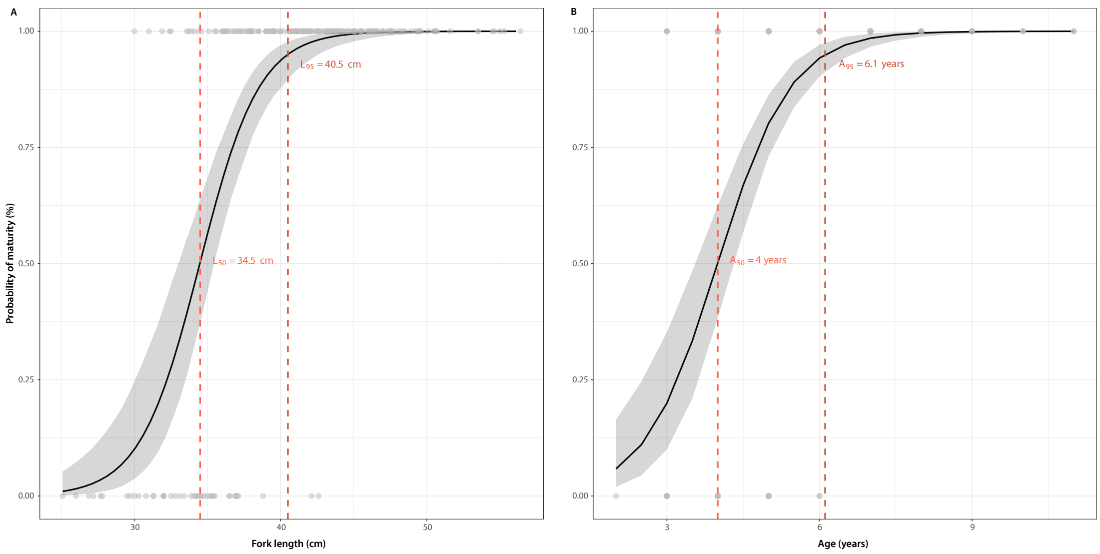

Figure 4. A. Maturity ogive for L50 and L95 from logistic regression for Albula glossodonta in Kiritimati. B. Maturity ogive for A50 and A95 from logistic regression for *Albula glossodonta* in Kiritimati. For both figures, the curved grey area represents the 95% confidence interval. n = 244

In Kiritimati the L_{50} is 34.5 cm and L_{95} is 40.5 cm (Figure 5). Therefore, age at maturity is A_{50} = 4 years and A_{95} = 6.1 years. 21% of fish (67) are below L_{50} and 47% of fish (152) are below L_{95}.

Logistic regression of length frequency data in Tarawa estimates an L_{50} of 37.0 cm and L_{95} of 52.0 cm Table 1). 45% of fish (620) are below L_{50} and 100% (1369) are below L_{95}.

Table 1. Von Bertalanffy growth parameters, mortality and maturity information for A. glossodonta in Kiritimati (2023) and Tarawa (2019). Errors are standard error about the mean.

Island	Mean Length (cm)	Mean Weight (g)	a	b	k	M	L_{50} (cm)	L_{95} (cm)	L_{inf} (cm)
Kiritimati	39.75 ±0.40	929.3 ±25.3	0.015	2.974	0.24	0.37	34.5	40.5	52.6
Tarawa	36.60 ±0.10	688.9 ±5.5	0.017	2.939	0.70	0.86	37.0	52.0	52.1

Length-based Spawning Potential Ratio

The SPR value of 0.63 in Kiritimati indicates that the stock retains 63% of its reproductive capacity compared to an unexploited state (Table 2). This exceeds the typical sustainability thresholds of 20–30%, suggesting the population is not overfished. The fishing mortality rate (F) relative to natural mortality rate (M) (F/M ratio) was 0.83, suggesting moderate fishing pressure.

In contrast, the analysis of data from Tarawa indicates high fishing pressure, with the LBSPR at 19% and a very high F/M ratio of 5.66 (Table 2).

Table 3: Results of the LBSPR analysis for Tarawa in the Gilbert Islands (2019) and Kiritimati (2023).

Island	SPR [%]	F/M
Kiritimati	0.63	0.83
Tarawa	0.19	5.66

Discussion

Stock status of bonefish in Kiritimati and Tarawa

The stock status of bonefish in Kiritimati appears to be healthy and is not currently at risk of overexploitation. Results of the LBSPR analysis give a SPR of 0.63, above an SPR of 0.4 generally indicating good stock status, and well above the threshold of 0.2 needed to replace the population (Froese et al. 2019; Prince and Hordyk 2019). Furthermore, 79% of fish sampled in Kiritimati were over the length at maturity (L_{50}=34.5 cm), with the mean and modal lengths at 39.8 cm and 42.0 cm respectively also above L_{50}.

F/M of 0.83 indicates that there is some fishing mortality. This is in line with the known presence of indicental subsistence catches of bonefish by the local population. However this fishing activity does not seem to threaten the sustainability of the bonefish stock.

In comparison, bonefish in Tarawa have a low SPR of 0.19, and an F/M of 5.66 indicating a heavily expoited fishery. Furthermore, the current size limit (30 cm) in place in the Gilbert islands is smaller than the L_{50} value of 36.0 cm for Tarawa, and all other L_{50} values for *A. glossodonta* in the Pacific region (Table 3).

The contrasting LBSPR results between the two islands emphasise the importance of considering differences in fishing pressure and life-history characteristics when assessing stock health and developing management strategies

Lengths of bonefish in Tarawa are smaller than in Kiritimati. This, in combination with contrasting SPR values, indicates that the difference in length distributions between these two islands may be because of higher fishing pressure in Tarawa.

In Kiritimati, bonefish are mostly targeted by the recreational catch-and-release fishery and legislation dictates that this species cannot be legally caught without a tourist permit. However, low rates of incidental mortality are likely to occur through subsistence fishing activity and predation following catch-and-release. In comparison, in Tarawa bonefish can be caught if they are larger than 30 cm, and are sometimes caught at smaller sizes than this due to the mesh size of gillnets commonly used (Gislard 2020).

However, care should be taken interpreting the SPR results from Tarawa, as both the growth coefficient (k) and L_{95} differ by a large margin from Kirimati (Table 1), and from other known k values around the Pacific region (Table 3). L_{50} and L_{95} values derived from observed maturity in Tarawa, and data from a longer time series, would be needed to confirm suspicions that the differences in observed length distirbutions and SPR values between Tarawa and Kiritimati are in fact as a result of fishing pressures and not inherent differences in the growth of bonefish between these islands.

In Kiritimati, where the stock appears healthy, maintaining the current fishing practices are likely to be sufficient to ensure the long-term sustainability of *A. glossodonta*.

Table 3: Life-history parameters for A. glossodonta in the Pacific region.
Lengths are fork lengths (FL) and measured in cm, "m" denotes males, "f" females and "a" is 'all' combining males and females into one figure. M = natural mortality, K = growth coefficient. *3 years age and ** 7 years age.

Location	Source	Latitude	M	K	L_{50} (FL cm)	L_{∞} (FL cm)
Kiritimati, Kiribati	This study	1.85°N	0.37	0.24	34.5 (a)	52.6
Tarawa, Kiribati	2019 unpublished creel survey data	1.35°N	0.86	0.70	35.97 (a)	52.11
Ka'ūpūlehu Marine Reserve, Hawai'i	(Ristig and Harford 2020)	19.80°N	0.23	0.18	42.5 (a)	67.3
Oahu, Hawai'i	(Donovan et al. 2015)	21.50°N	0.39	0.18	42.35 (a)	67.26
Anaa Atoll, French Polynesia	(Filous et al. 2020)	17.40°S	0.64* 0.001**	0.17	43 (m) 48 (f)	71
Palmyra Atoll, USA	(Friedlander et al. 2008)	5.87°N	0.27	0.3	unavailable	67.28

Feasibility of a Kiritimati mark-and-recapture programme

It was not possible to tag the number of fish required to carry out a stock assessment of *Albula glossodonta* in Kiritimati using mark-and-recapture methods during the time available. Ahead of the work we had anticipated needing to tag at least 500 fish to get a sample large enough to tentatively draw conclusions about total abundance. Nine days were spent tagging fish, during this time 151 were caught and tagged, none were recaptured.

Catching bonefish using fly or spin fishing requires specialised skills. Despite recruiting the assistance of guides and practicing techniques ahead of time, fish were not caught at a high enough rate to mark-and-recapture an adequate sample of the population in the time available.

Successful mark-and-recapture programmes have long-term presence on the ground, multiple tagging instances over time, and awareness campaigns/extensive stakeholder engagement to inform fishers and tourism operators of what to do when a tagged fish is caught (Filous et al. 2020; Zurcher et al. 2007). In this case, without a dedicated project with budget and staff, a mark-and-recapture campaign would be difficult to run, and more expensive and time consuming than other approaches that could be used to inform bonefish management and development of regulations.

Furthermore, the data from mark-and-recapture monitoring alone would not be directly comparable with the fisheries-dependent catch monitoring programmes currently being conducted elsewhere in Kiribati (e.g. Gislard, 2020; Shedrawi et al., 2024). This limits the conclusions that could be drawn about the differences in bonefish stocks between the Gilbert and Line Islands in the long term.

As demonstrated in this report with creel survey data from the Gilbert islands, using fisheries-dependent surveys alongside the LBSPR method can provide valuable insights into stock status, even with limited data, making it a powerful tool for fisheries management. The contrasting results obtained for *A. glossodonta* in Kiritimati and Gilbert Islands demonstrate the importance of employing such methods to assess and monitor fish stocks.

The original motivation behind the assessment was to inform management of the bonefish fishery. This objective has been achieved through this study using a snapshot gillnetting campaign paired with LBSPR analysis. As the LBSPR indicates that the bonefish fishery is in relatively good condition, a second snapshot assessment of stock health would not be needed in Kiritimati unless the legislation for this fishery changes and leads to changes in fishing effort targeting bonefish.

Recommendations

Recommendations by SPC have already been made through the socio-economic assessment of bonefish recreational fishing in Kiritimati, Kiribati (Garcia et al. 2024). Garcia et al., 2024 recommended that the fishery remain closed to fishing by the local population as it brings an important source of revenue for Kiritimati. However, they noted that improved monitoring of the recreational fishery, in addition to monitoring of both commercial and subsistence fisheries are needed. In addition to the recommendations made by Garcia et al.:

1. **Creel surveys to monitor the status of species of importance to food security in Kiritimati are recommended.**

Creel surveys regularly conducted by MFMRD in Kiritimati would allow the monitoring and assessment of other species caught locally for subsistence and sale; status of a wide range of subsistence fisheries is important context to have in deciding whether to open the bonefish fishery to local consumption. Furthermore, directing the department's limited staff time and budget to a creel monitoring programme would allow comparison with fisheries-dependent data being collected in other parts of Kiribati. As bonefish is illegal to catch for subsistence, it is unlikely that government-run surveys would lead to good data; therefore, to understand incidental catch rates of bonefish, an independent study could be conducted by an NGO or academic partner every few years.

2. **The results of both this stock status report, and the results of the socio-economic assessment should be discussed with fishing communities.**

Fishing communities should understand the results of the bonefish fishery assessments. Involving them in the interpretation of results and decision-making to develop any new management strategies for the fishery will improve voluntary compliance with any potential management plans or regulations regardless of the land tenure context in Kiritimati.

3. **The size limit for bonefish in the Gilbert Islands should be reconsidered.**

The current regulation dictates a minimum size limit of 30 cm for bonefish; this is smaller than the estimated size at maturity (L_{50}) in Tarawa and other parts of the Pacific. A limit of at least 36 cm should be considered.

4. **We do not recommend continuing with a mark-and-recapture programme to monitor the status of the bonefish stock.**

Funding for equipment, staff time, awareness campaigns and close management of collected data are needed to carry out a mark-and-recapture programme over the long term; this is a high investment of financial and human resource to understand the stock status of one species. If fishing effort of bonefish changes substantially then another snapshot study, can be done on their stock status with a research permit, drawing on creel survey monitoring done by an independent body.

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Pacific Community
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BP D5 • 98848 NOUMEA CEDEX
NEW-CALEDONIA

Phone : +687 26 20 00
E-mail : cfpinfo@spc.int

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