Stock status evaluation for red swimming crab (*Monomia haanii*) FIP, Dongshan, Fujian Province, China

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April 2023

Abstract / summary

Launched in August 2018, the Fujian Red Swimming Crab (RSC) Fishery Improvement Project (FIP) has continued over five years to address management gaps associated with the RSC trawl and trap fisheries in China. This report describes the stock status analysis conducted as part of the FIP.

The RSC fisheries mainly take place in the Minnan-Taiwan Bank fishing grounds, off the southern area of Fujian Province. The primary gear types targeting crab in this area are single vessel bottom trawls and crab pots/traps. The fisheries operate year round except for the summer fishing moratorium from May to mid August. The peak fishing seasons for the RSC are from August to November for trawlers. However, strong northeast monsoons significantly dampen fishing activity from November to Chinese Spring Festival (usually in January or February), resulting in fewer fishing trips taken during that time period.

The available data for RSC included catch data collected from vessels and biological measurements data from commercial catch. Two types of analysis were conducted based on the available data. The fishery-dependent analysis evaluated the relative fishing efficiency of the fishing fleet by tracking the trends in RSC catch, catch ratio, and catch-per-unit-effort (CPUE) over time. The stock biological status analysis used Length-Based Bayesian (LBB) and Length-Based Spawning Potential Ratio (LBSPR) to evaluate RSC stock status using indicators such as relative fishing mortality (F), relative biomass (B), and spawning potential ratio (SPR). Additional statistical analyses were performed to examine the seasonal and yearly pattern.

The fishery-dependent analysis showed that the RSC was caught in a multispecies fishery, with catch ratios consistently below 0.25. The RSC fishery also has significant seasonality and interannual variations in CPUE according to ANOVA test results, suggesting the fishery efficiency varied among seasons and years.

The stock biological status analysis highlighted that the RSC stock status was at a biologically sustainable level. Specifically, the stock was not overfished and overfishing was not occurring, indicated by low F/M and high B/B_0 values estimated by LBB. LBSPR results suggested that the

RSC stock was lightly fished compared to the sustainable SPR reference level (SPR > 0.3, which was close to the 0.4 reference), and the fishery had further exploitation potential indicated by high stock biomass relative to biomass at MSY level (B/B_{MSY} > 2).

While we conducted data-limited stock assessment for RSC using the best available data, we discovered some flaws and gaps in data for certain years (such as the bi-modal size frequency in 2021). These flaws have resulted in violation of model assumptions, unrealistic selectivity curves, and large uncertainty in estimates. Therefore, the presented stock assessment results will need to be interpreted with caution if used to advise management actions. We attributed these data deficiencies to inconsistent sampling practices throughout the survey period. Finally, we proposed recommendations to improve further data collection efforts to better assess and manage the RSC fishery. These include performing regular seasonal sampling, tracking a fixed group of representative vessels in the commercial fleet, standardizing sample size to achieve unbiased data collection and adequate statistical power, and conducting scientific surveys to collect fishery-independent data.

Background

This report was completed as part of the work plan for the China Fujian Zhangzhou red swimming crab (RSC) bottom trawl & pot/trap FIP. Specifically, it describes progress being made on Action 3: Regular stock assessment. Based on the type and amount of data available, only data-limited methods were applicable for conducting this assessment.

Ocean Outcomes contracted Dr. Ming Sun, a post-doctoral associate and stock assessment scientist at Stonybrook University, to evaluate the stock status of the Fujian red swimming crab (*Monomia haanii,* synonyms *Portunus haanii*) stock using fishery catch and research data collected by the FIP stakeholders, notably Dr. Liu Min and her students at Xiamen University. See Lin et al. 2021 for additional details on data collection methods. The data are fishery dependent and collected from the trawl fishery. Other gears used to harvest this stock are traps and gillnets.

Methods

Data sources

Two types of data were utilized in the stock status evaluation for RSC, including dockside catch data and biological measurements data from the commercial catch. All data were collected by Dr. Liu Min's research team at Xiamen University. The total catch volume, total crab catch volume, and RSC catch volume data were collected from sample trawlers for each trip. The biological measurements included individual body weight, carapace length, sex, and egg conditions. Based on the data available, we performed fishery-dependent analysis and stock status analysis to understand the fishery-dependent status and the stock biological status, respectively.

Fishery-dependent analysis

The fishery-dependent analysis used the vessel-level catch data for the RSC fishery. Since the crabs were sampled from different vessels across the surveyed years, they were deemed not representative of the entire fishing fleet. Hence, it was not possible to determine the total catch for the RSC fishery, which prohibited the use of catch-based stock assessment methods.

Nevertheless, we were able to evaluate the relative fishing efficiency of the fishing fleet by tracking the trend in RSC catch over time. Specifically, we analyzed the monthly distribution and medians of RSC catch for each vessel over the surveyed time period, which served as a proxy of the total RSC yield from the fishery.

We then estimated the "RSC catch ratio" for each month by dividing the RSC catch by total catch for each vessel. This ratio was used to assess the relative importance of RSC for the fleet and was reflective of the temporal trend in RSC catch dominance, given the fishery's multispecies feature (Boenish et al., 2021).

We lastly estimated the RSC catch-per-unit-effort (CPUE) by dividing the RSC catch by the days-at-sea for each vessel. CPUE was considered a reliable indicator of stock relative abundance index, as it excluded the effects of fishing intensity. We compared the estimated RSC CPUE by vessel for each season to examine whether there were significant seasonal and yearly variations in RSC abundance using Analysis of Variance (ANOVA). A Tukey test was also performed to identify the disparities between seasons and years. The four seasons were defined as March to May for spring, June to August for summer, September to November for autumn, and December to February for winter.

Stock biological status

We employed data-limited length-based methods to evaluate the RSC stock biological status. Length-based methods involved analyzing length-frequency data to determine the size structure of the RSC population, which was related to growth, mortality, and spawning capability under the impacts of fishing. We converted the RSC length measurements into length-frequency data with a bin size of 1 cm.

We first examined the RSC size structure for both sexes and females only. Female ratios were calculated for each month and size bin based on the numbers of individuals caught. We hypothesized that patterns in size structure could help us identify potential spawning seasons and seasonal fishing patterns for the RSC fishery.

We then used Length-based Bayesian (LBB) to estimate the biological status. LBB is a recently developed analytical framework that assumes equilibrium conditions and von Bertalanffy growth (Froese et al., 2019). This method only requires length-frequency data collected from the commercial fisheries, making it widely popular in assessing data-limited fisheries. By specifying the fishing selectivity pattern (gear) and prior values, LBB can fit observed and predicted length distributions using the Bayesian Gibbs sampler software JAGS. LBB can estimate a suite of key growth and mortality parameters, including asymptotic length (L_{inf}), relative natural/fishing mortality (*F/M*), and ratios between growth and mortality parameters (*M/K*, *Z/K*). LBB can also estimate a set of stock status indicators, such as current exploited biomass relative to unexploited biomass and biomass corresponding to maximum sustainable yield (B/B_0, B/B_{MSY}). Additionally, LBB can return the relative length at first capture that would maximize catch and biomass (L_c), and estimation of a proxy for the relative biomass capable of producing maximum sustainable yields (L_{opt}). We conducted LBB using the R package "TropFishR" 1.6.0 (Mildenberger et al., 2017).

We lastly estimate the spawning potential ratio (SPR) of the RSC stock using a length-based approach. SPR represents the spawns produced by a fish stock over its lifespan under a specific fishing intensity, relative to the life-long spawns that would have been produced if there were no fishing. SPR would always range from 0 to 1, with 0 representing a stock severely overfished and had almost no spawners left, and 1 representing an unfished stock. SPR can be used as a biological indicator reflecting stock status. In the United States, many fisheries have been using critical SPR threshold as their key management target levels (e.g., the South Atlantic Fishery Management Council and Northeast Fishery Management Council adopted SPR40% as MSY proxies for some fisheries they manage). Traditionally, SPR would be estimated using age-structured data in terms of female ratio, maturity, weight, natural mortality, and most importantly, fishing mortality. To obtain these input data, formal model-based stock assessment is required, which is unrealistic for data-limited fisheries. To make SPR more easily obtainable for data-limited fisheries, Hordyk et al. (2015) have developed a novel data-limited approach, length-based SPR (LBSPR), based on length-frequency data. The method uses maximum likelihood methods to find the values of relative fishing mortality (F/M) and selectivity-at-length that minimize the difference between the observed and the expected length composition of the catch, and calculates the resulting SPR. This approach has been successfully applied to other data-limited fisheries in China (Sun et al., 2018). LBSPR requires primarily length frequency data as input as well as some additional growth parameters such as L_{inf}, *M/K*, and length at 50% and 95% maturity (L_{50} and L_{95}). We conducted LBSPR using the R package "LBSPR" 0.1.6 (Hordyk, 2021).

Results

Fishery-dependent analysis

1. Total RSC catch over time

The distribution and medians of RSC catch for each vessel over the surveyed time period varied by year and month (Fig. 1). We observed the peak median catch values in September 2020. The end of 2019 (December) and early 2020 (January) also demonstrated high RSC catch. RSC catch in early 2019 and throughout the years of 2021 and 2022 were relatively low.

Catches in spring (March to April) were generally lower compared to other seasons. However, we did not observe consistent seasonal patterns over the four years.

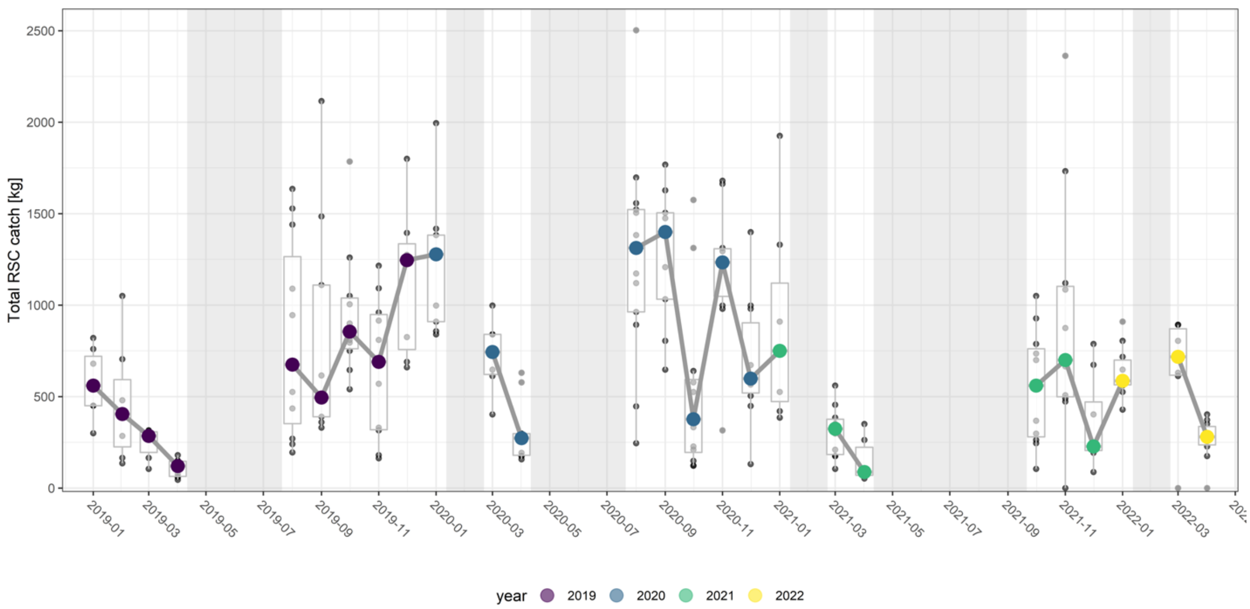

Fig. 1 RSC catch (in kg) over the survey period. Dots represent median values which are colored by year. Grey areas are time periods when no data were collected.

2. RSC catch ratio over time

The distribution and medians of RSC catch ratio for each vessel over the surveyed time period were generally low (Fig. 2). The highest single value was around 0.4 which occurred in January 2020. However, most RSC catch ratio values were below 0.25, and all median values were below 0.2, indicating the RSC was not a single-species fishery. Catch ratios in winter (November to February) were relatively higher than other months. The lowest median catch ratios were observed in spring (March and April).

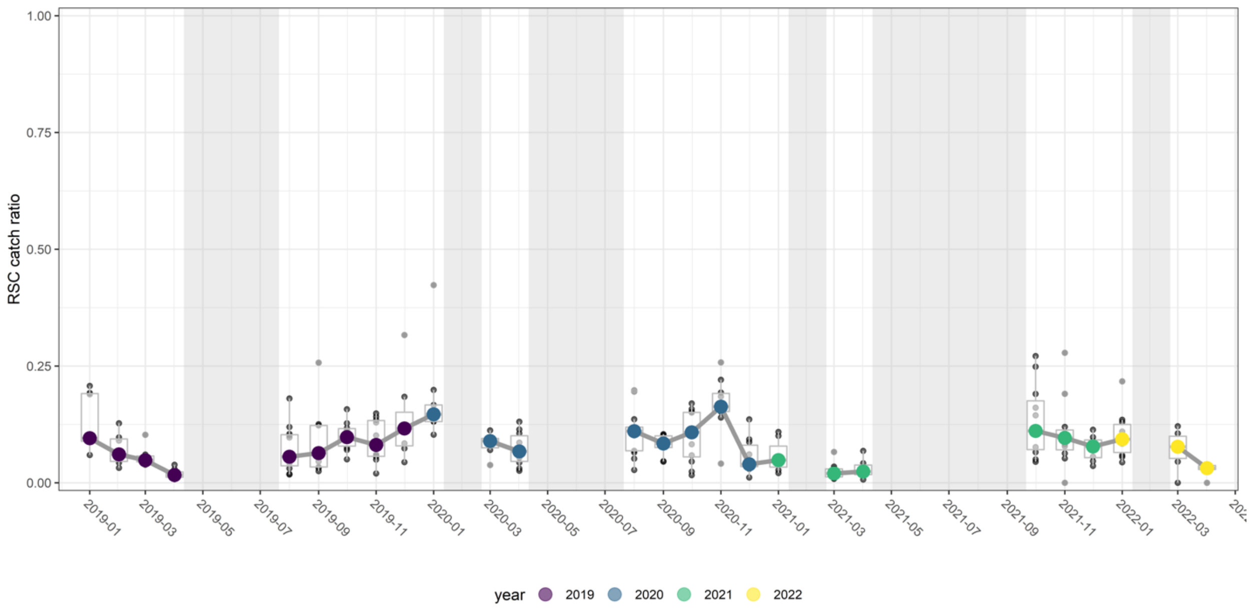

Fig. 2 RSC catch ratio (RSC.catch/total.catch) over the survey period. Dots represent median values which are colored by year. Grey areas are time periods when no data were collected.

3. RSC CPUE over time

The distribution and medians of RSC CPUE for each vessel over the surveyed time period demonstrated substantial temporal variability (Fig. 3). The observed trend in RSC CPUE was synchronous with the trend in RSC catch ratio. The two highest RSC CPUEs were observed in August and November of 2020, while other years (2019, 2021, 2022) had comparatively low CPUEs. The variability for each month was also considerable, indicating inconsistent RSC targeting behavior by vessel over time.

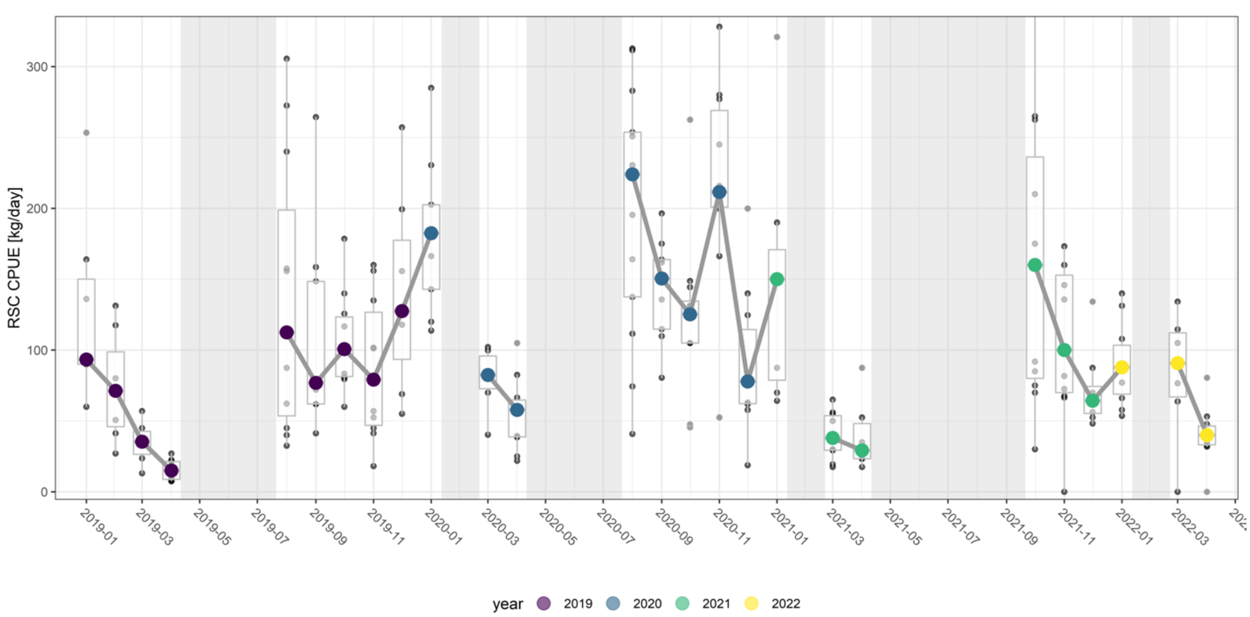

Fig. 3 RSC CPUE (RSC.catch/days.at.sea) over the survey period. Dots represent median values which are colored by year. Grey areas are time periods when no data were collected.

4. Evaluate seasonal effects in CPUE

RSC CPUE exhibited strong seasonal and annual variations over the surveyed time period (Fig. 4 and Table 1). Statistical results indicated that the fishery exhibits some seasonality, with spring CPUE significantly lower than other seasons. Summer CPUE was the highest by both median and mean values, probably due to the rebuilding effects from China's summer fisheries moratorium. However, the rebuilding effects on RSC remained short-term, as CPUE decreased in autumn and winter. It should be noted that the sample size from summer was also the smallest and concentrated in August, suggesting potential sampling bias. ANOVA results highlighted significant CPUE variability by year, with the disparity between 2019 and 2020 being largest. Overall, the RSC fishery showed substantial seasonality and interannual variability.

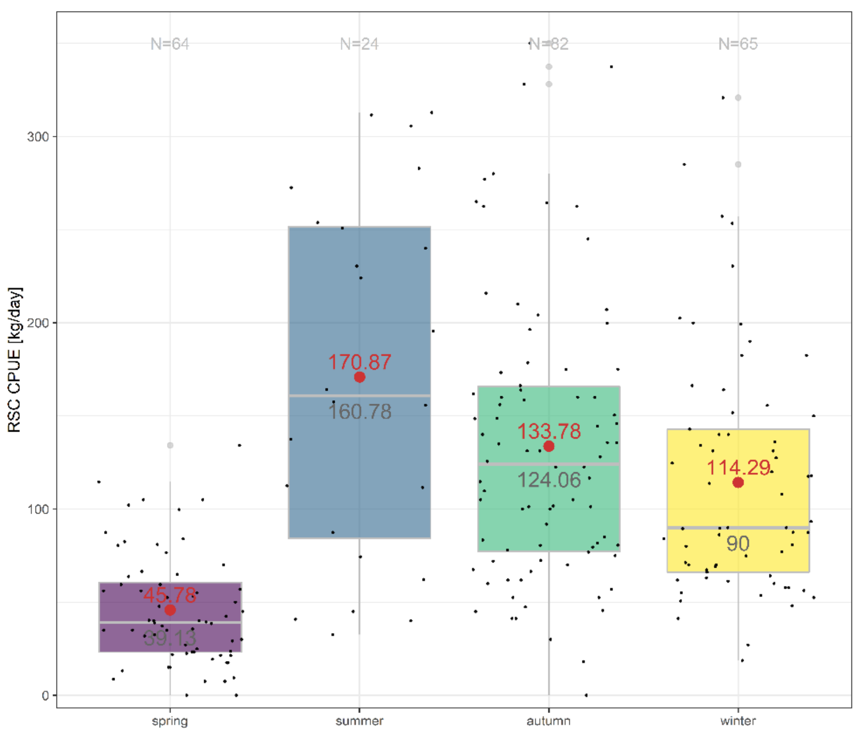

Fig. 4 RSC CPUE (RSC.catch/days.at.sea) aggregated by season over the survey period. Red dots and numbers represent mean values. Grey horizontal lines and numbers represent median values. Sample sizes are demonstrated at the top of the panel.

Table 1. Statistical results of ANOVA and Tukey test. Significant results at 95% confidence interval are marked in red.

Variables	Pr (>F)		Pr (>F)

ANOVA			
Season	≈0.00	Year	≈0.00
Tukey test			
$Season	Pr adj.	$Year	Pr adj.
spring-autumn	≈0.00	2020-2019	≈0.00
summer-autumn	0.06	2021-2019	0.21
winter-autumn	0.25	2022-2019	0.53
summer-spring	≈0.00	2021-2020	0.15
winter-spring	≈0.00	2022-2020	0.26
winter-summer	≈0.00	2022-2021	0.99

Stock biological status

1. Size structure over time

The sampled RSC size structure for both sexes and for female-only data are described via respective length frequency (Fig. 5). The dominant size group for the sex-combined data was between 6-11 cm. Only the data from January and November from 2019 were dominated by smaller size group (3-4 cm), which might point to massive catch of undersized individuals and potential violation of minimum legal size regulations. There were noticeable differences between the size structures of female only and sex-combined data, although the most frequent dominant size groups also mostly fell between 6-11 cm.

Earlier studies identified a peak spawning season in February-April and possibly in August (Lin et al., 2021). However, the structure data suggested potential spawning seasons in January and November, based on the dominant presence of smaller-sized crabs in those months in 2019 and assuming the survey data were unbiased overtime. Furthermore, we did not observe consistent seasonal patterns in size structure over the four years that could be reflected by gradual shifts of dominant size groups over time. This could be due to three reasons. Firstly, sampling duration differed greatly by year (6 months in 2018, 9 months in 2019, 3 months in 2020, and 3 months in 2021), which made the results less comparable. Secondly, the gaps in the sampling months might have masked some temporal patterns. Thirdly, samples collected were from commercial trawl fishing vessels that did not demonstrate consistent catch targeting of RSC.

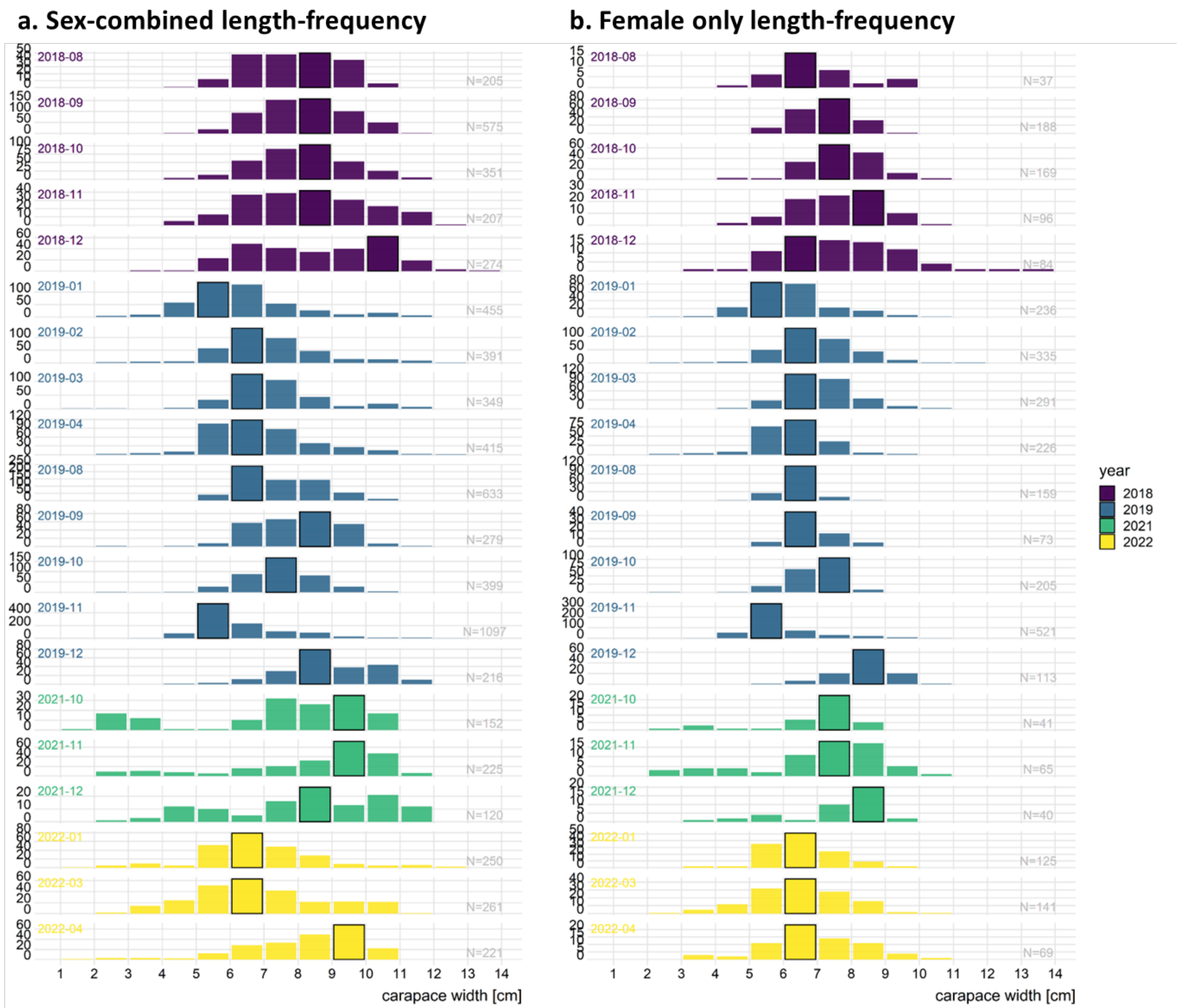

*Fig. 5 The **a) sex-combined** and **b) female only** length-frequency over the survey period. Length-frequency of the sampled month are colored by year. The most frequent size group for each month is marked with a black boundary. Y-axis scales are not consistent by month.*

The female proportion by month and length group showed considerable variability (Fig. 6). The female proportions varied widely over the survey period, ranging from 0.2 to 0.8. The highest female proportions occurred in February and March of 2019. Unfortunately, due to the aforementioned deficiencies in survey data and lack of repetitive sampled months, we could not attribute the occurrence of peaks to any factors. The lowest female proportions showed chaotic patterns as we have observed low values (close to 0.25) in all four seasons. The productive spawner size groups (large proportion of females) were hard to identify due to the highly variable female proportion by length group over time. We did not have sufficient information to attribute such variability to management effects of size limits measures or temporal recruitment dynamics.

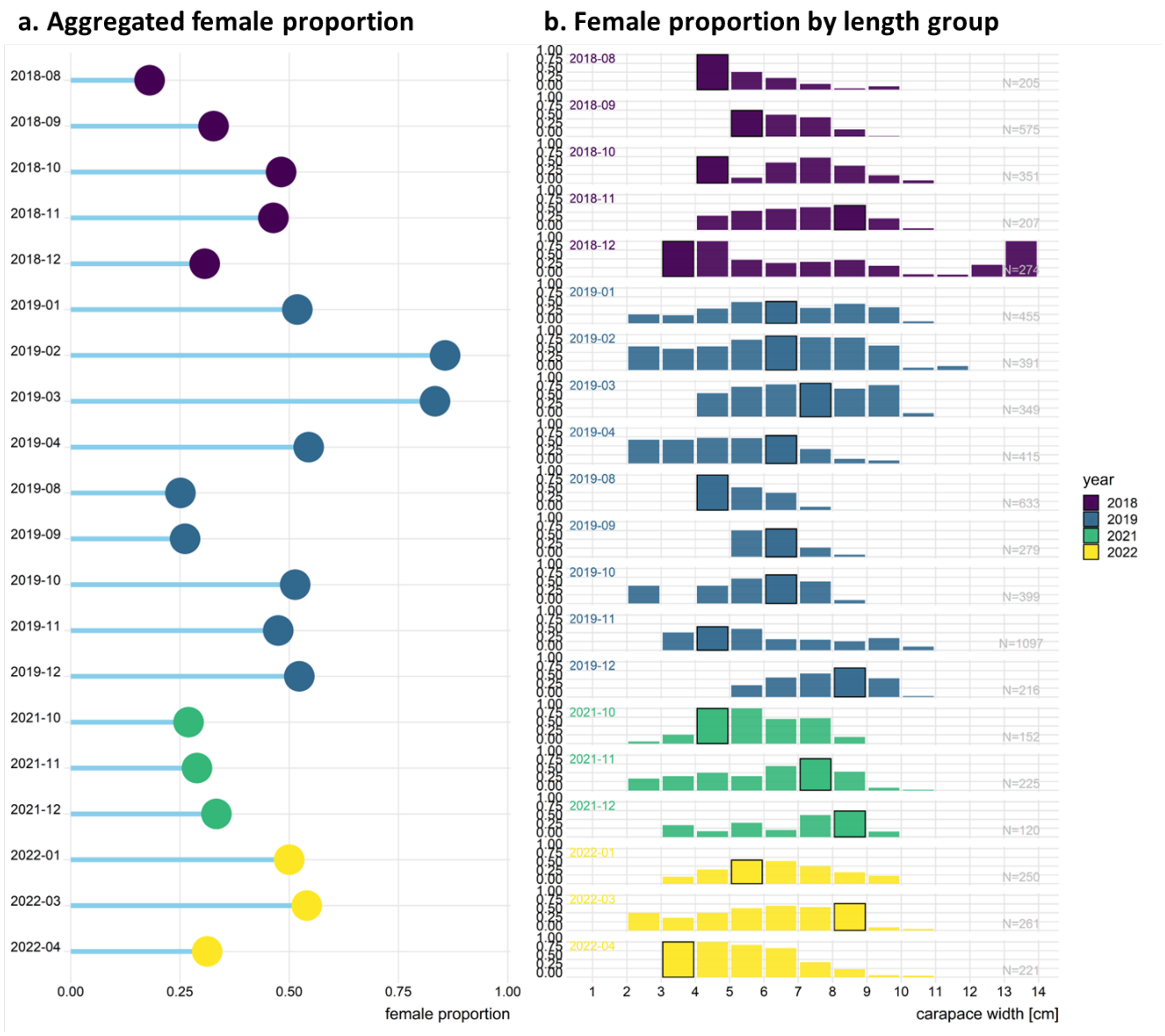

*Fig. 6 The **a) aggregated female proportion by month** and **b) female proportion by length group** over the survey period. The proportion values and length-frequency of the sampled month are represented by colored dots and bars, respectively. The most frequent size group for each month is marked with black boundary. The total sample sizes for both sexes are demonstrated in b).*

2. LBB (Length-based Bayesian) stock status estimates

LBB was used to estimate stock status for each year and all years combined (Table 2). Estimates of size reference did not vary greatly over the survey period, with a relative lower L_{mean} value observed for 2019. L_{mean}/L_{opt} were consistently above 0.9 for other years, indicating the stock was lightly fished compared to the most productive size structure. Variations in growth and mortality parameter estimates were also small. However, we noticed that *M/K* values were often lower than 1.5, an empirical life-history invariant value that has been widely used in many data-limited methods (Jensen et al., 1996), suggesting potential risks in assuming invariant life-history ratios for RSC stock assessment.

For fisheries that lack sufficient data for formal assessment, a fishing mortality rate equal to natural mortality rate (F/M = 1) is often considered a proxy for sustainable fishing intensity at MSY. We found that the *F/M* ratio for RSC remained consistently low throughout the survey period, indicating that fishing pressure was reasonably low (<0.4) and overfishing was not occurring. The most important indicators of RSC stock status estimated by LBB were relative biomass indicators. The estimated B/B_0 was mostly above 0.7 except for 2019, which suggests that the RSC stock was lightly exploited compared to its unfished state. Additionally, the remarkably high B/B_{MSY} estimates (consistently >1.5) indicated that RSC stock size was much larger than the MSY level and has untapped exploitation potential.

Table 2. LBB estimates of size reference, growth and mortality parameters, and stock status. The "all year" results were acquired by running the aggregated data across all years. LBB with only 2021 data was not viable due to too few fully selected length groups.

Estimates	2018	2019	2021	2022	All year
Sample size	1612	4234	497	732	7075
Size reference (unit in cm)					
L_{inf}	12.8	12.7	NA	12.4	13.2
L_{opt}	9.1	8.4	NA	8.8	9
L_{c_opt}	6.7	6.4	NA	6.2	6.3
L_{mean}/L_{opt}	0.97	0.91	NA	0.92	0.95
Growth and mortality parameters					
M/K	1.23	1.5	NA	1.25	1.42
F/K	0.32	0.595	NA	0.15	0.194
Z/K	1.56	2.07	NA	1.42	1.65
F/M	0.26	0.398	NA	0.12	0.14

Stock status					
B/B_0	0.71	0.579	NA	0.84	0.82
B/B_{MSY}	1.9	1.6	NA	2.2	2.3
Y/R’	0.031	0.032	NA	0.017	0.017

*L_{inf} denotes VBGF infinite length. L_{opt} denotes the optimal length is defined as the body length when an unfished age group reaches its maximum biomass. L_c denotes length at first capture. L_{mean} denotes mean length in sample. *M* denotes natural mortality. *K* denotes VBGF growth rate. *F* denotes fishing mortality. *Z* denotes total mortality. B/B_0 denotes current stock biomass relative to unfished biomass. B/B_{MSY} denotes current stock biomass relative to biomass at Maximum Sustainable Yield. *Y/R*’ denotes relative yield-per-recruit.

Catch curves fitted by LBB differed greatly among surveyed years (Fig. 7). The estimated L_{opt} did not vary substantially by year, ranging from 0.65 to 0.7. The fully selected length (peak of the curve) was always slightly lower than L_{opt}, indicating the stock was subject to slight overfishing. The overall shapes of catch curves were also different by year. This could be due to interannual growth variations or inconsistent data quality. The 2021 catch curve did not provide reliable data points for a catch curve model fitting, demonstrated by a quasi bi-modal distribution with two peaks.

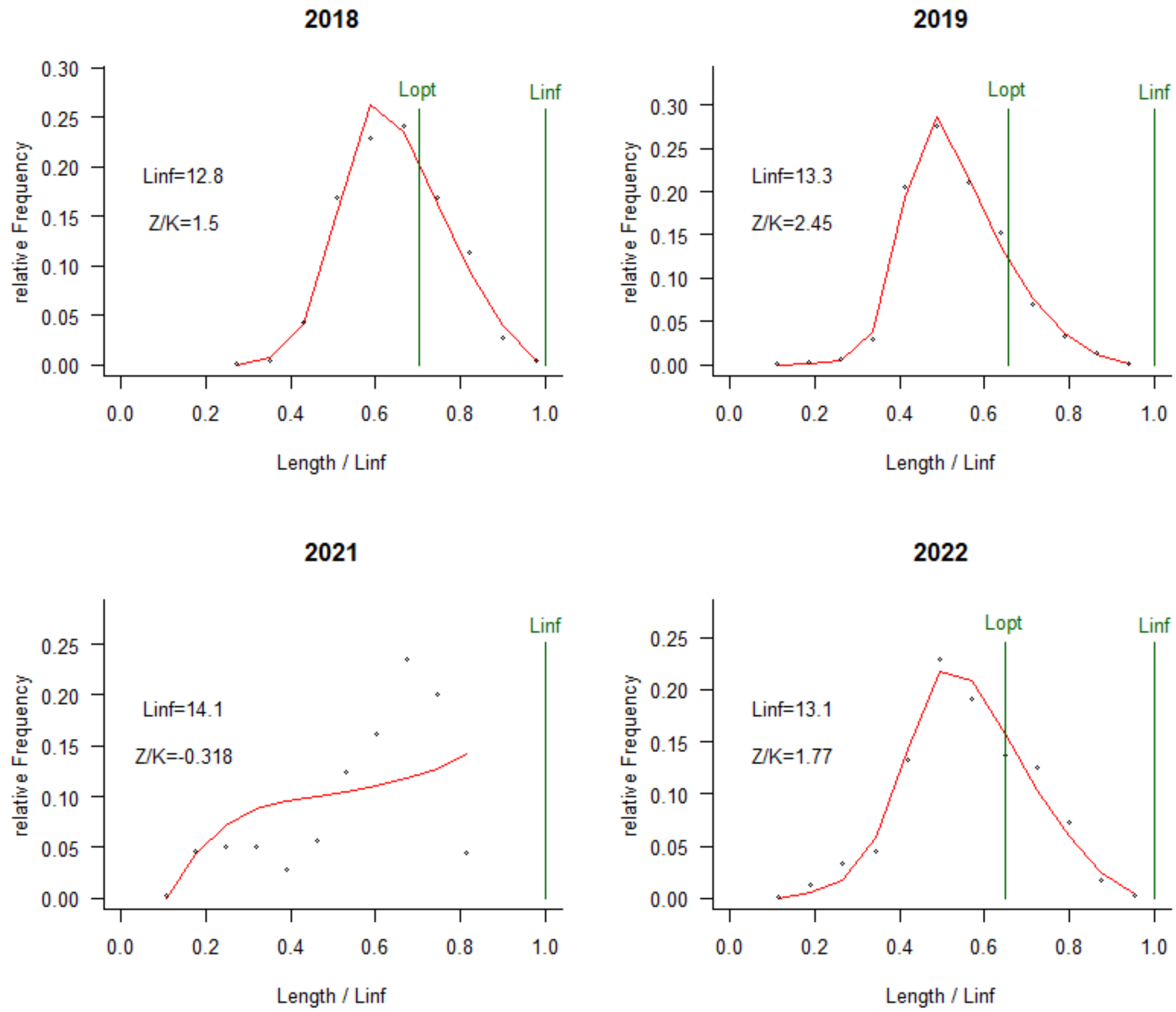

Fig. 7 Catch curves (red) based on the relative length frequency for the surveyed years. Note that the parameters in the 2021 panel were not generated from model estimates.

3. LBSPR (length-based spawning potential ratio) stock status estimates

Input data and priors used for LBSPR were acquired from previous studies (L50=6.3 cm CW and L95=10 cm CW from Lin et al., 2021, Boenish et al., 2021) and LBB estimates (L_{inf}=13.2 cm CW and *M/K*=1.42). Smoothed (Kalman filter and Rauch-Tung-Striebel smoother) and point estimates of SPR, F/M, and selectivity parameters are shown for each year (Table 3).

Overall, SPR values were lower than the classic MSY proxy SPR=0.4 according to the smoothed estimates. This indicates the RSC stock was only slightly overfished and had maintained a fairly productive spawning capacity. However, the *F/M* ratios were quite high (>1.2), which strongly disagreed with the LBB estimates. This was because LBSPR reports the F value for the fully selected size groups, which were quite rare as the fully selected size was larger than 10 cm. Hence, the *F/M* returned by LBSPR could overestimate the fishing mortality at the stock level. Moreover, we noticed the estimated SL50 and SL95 did not match well with previous estimates of 5cm and 7cm CW (Boenish et al, 2021), suggesting potential bias due to model-based uncertainty. The smoothed selectivity curves demonstrated a weak similarity in length pattern to and RSC's maturity ogive, particularly less selective over smaller individuals <10cm CW, suggesting low possibility of recruitment overfishing (Fig. 8).

In contrast, the point estimates for each year demonstrate considerable interannual variation for all estimates. Specifically, the SPR values varied the least among all estimates, ranging between 0.24 and 0.39. The difference in *F/M* values was most significant, displayed by a 6 times difference between the minimum and maximum over the five years. The selectivity parameters were also unrealistic for the year of 2021, which were considerably higher than the values from other years. The 2021 estimates were particularly uncertain, according to their incomparable confidence intervals and unrealistically high *F/M* (Fig. 9).

We argue that the point estimates from LBB will need to be interpreted with caution, due to the flaws in the length structure data. The available length frequency data did not support a plausible model fit catch curve (Fig. 10) due to several issues. First of all, we did not have comparable data volumes for each year, which could not provide consistent statistical power. Additionally, the 2018, 2019, and 2022 length frequency distribution demonstrated a typical catch curve pattern, while the 2019 data fit poorly.

Table 3. Smoothed LBSPR estimates of size selectivity parameters, fishing mortality rate relative to natural mortality rate, and spawning potential ratio. Results are shown for each year.

Year	SL50/cm	SL95/cm	F/M	SPR
Smoothed multi-year estimates				
2018	7.41	10.05	2.65	0.33
2019	7.47	10.19	2.80	0.33
2021	7.73	10.67	3.05	0.33
2022	7.58	10.51	2.90	0.33
Individual point estimate for each year				
2018	6.89	8.72	1.28	0.39
2019	5.47	6.84	1.60	0.24
2021	11.86	17.09	7.21	0.39
2022	6.06	8.87	1.34	0.31

**SL50 and SL95 are the lengths at which 50% and 95% of the fish are vulnerable to the fishery, respectively.*

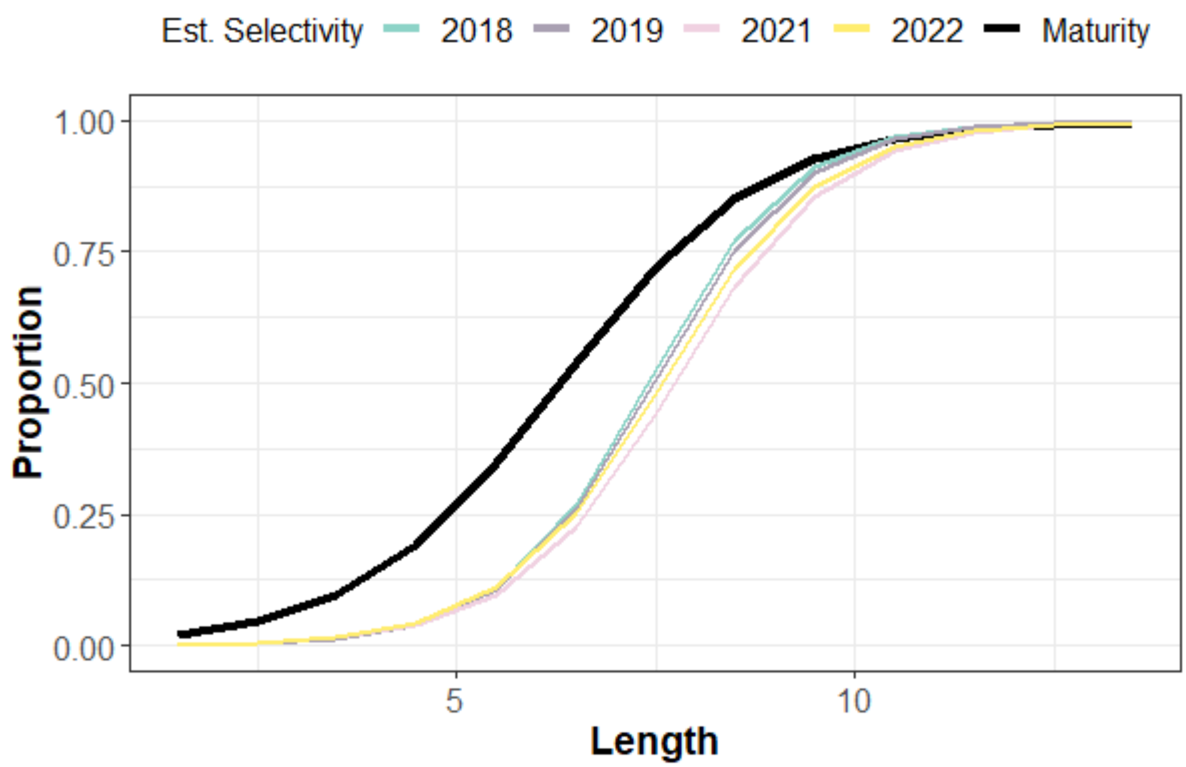

Fig. 8 Estimated selectivity curve for each year and the maturity ogive as reference.

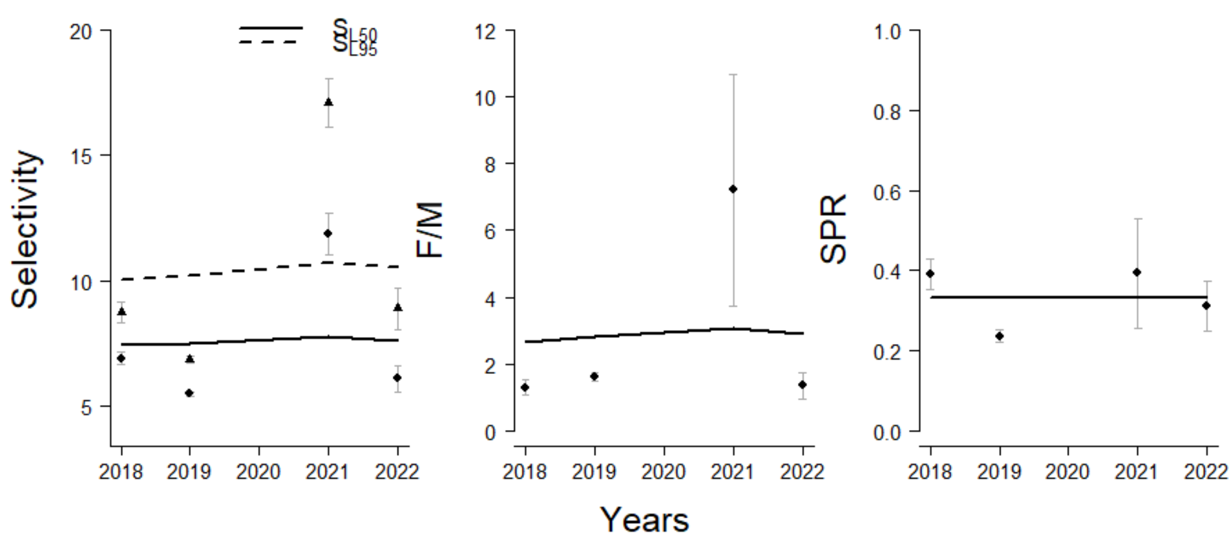

Fig. 9 Interannual variability of the estimated indicators.

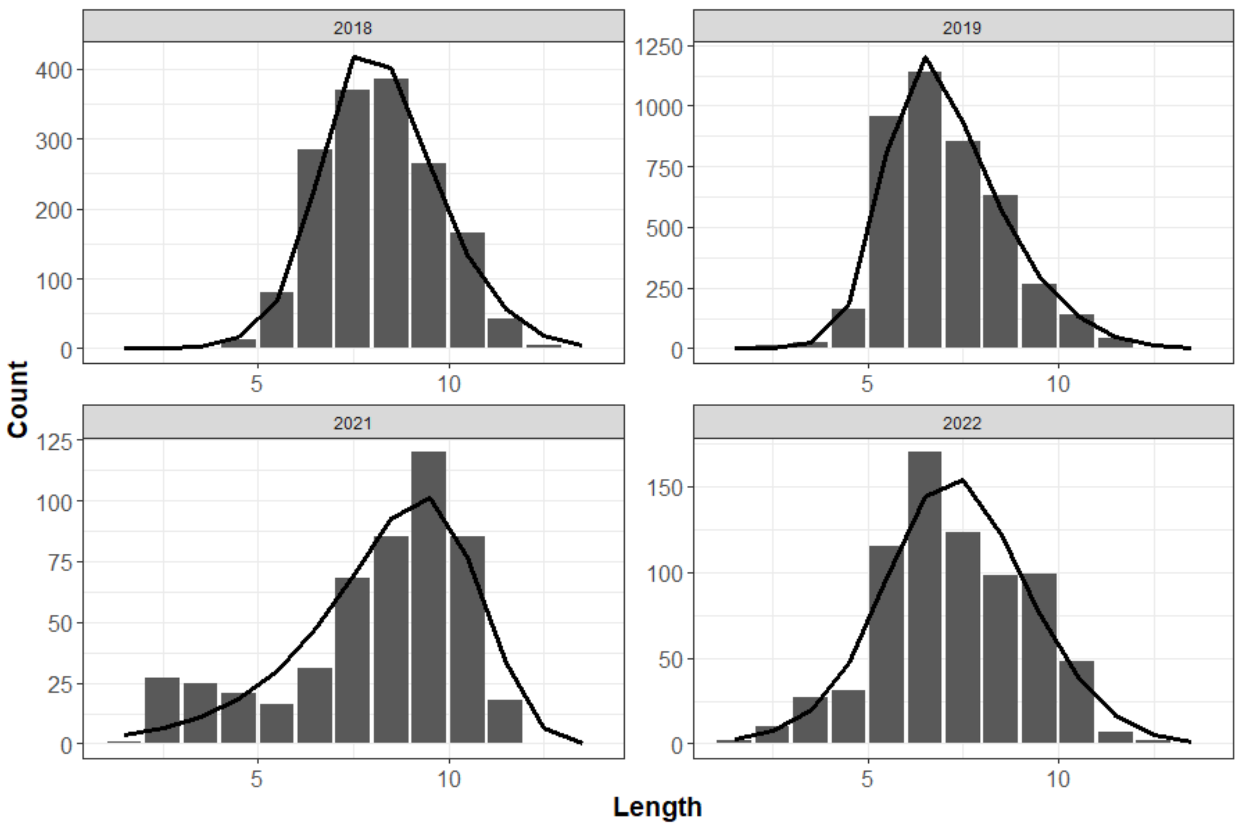

Fig. 10 Length frequency data for each year used for estimating spawning potential ratio.

We further compared the observed (sample) RSC size structure to the simulated sample size structure corresponding to a target SPR of 0.4 (Fig. 11). As the SPR estimate for RSC was close to 0.4, we would expect the observed (sample) size structure should roughly match to the simulated one. However, we found that the sampled data had much fewer smaller crabs (<7 cm CW) and more mid size individuals (9-11 cm). These disparities indicate that the realistic RSC stock suffered relatively high fishing pressure for smaller individuals while larger individuals were fished less intensively. Meanwhile, the RSC stock also lacked adequate mega-spawners (very productive large individuals >11cm).

Several factors could contribute to the unexpected inconsistency between the size structures from sample data and simulation. For example, the RSC stock might possess a weakened recruitment capacity, as the huge amounts of large crabs did not generate many smaller individuals proportionally to their size. Furthermore, sampling bias could result in data issues due to the lack of consistent sampling protocol among the years. The observed disparities could also be due to the inconsistent sampling intensity on juvenile and adult fish, as the fishers tended to sort the crabs by size and land them separately. Size-based conservation measures and regulations could also shape the size structure of the RSC stock, although the compliance level of these measures is believed to be limited. Potential contributory regulations included minimum and maximum legal size, juvenile landing ban, and minimum mesh size.

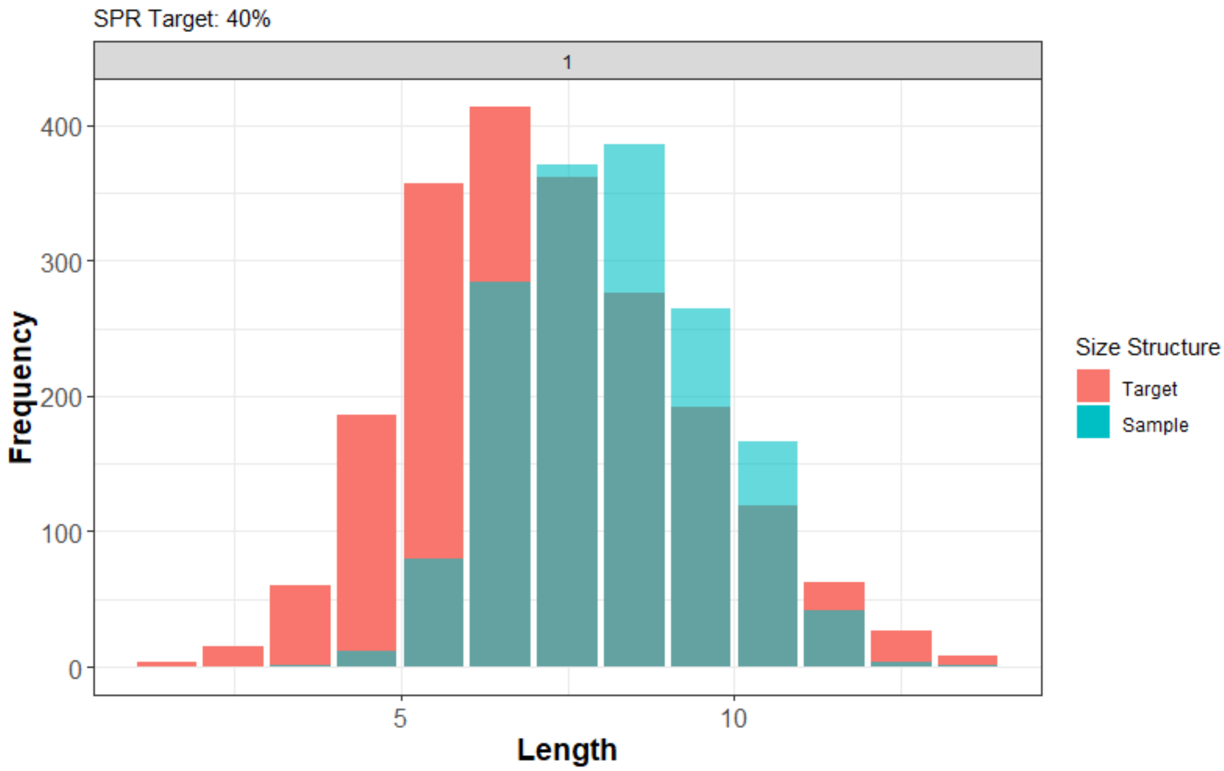

Fig. 11 Comparison between the sampled size structure to target size structure corresponding to SPR=0.4.

Conclusions

Using the dockside catch data and biological measurements data from commercial catch, we conducted fishery-dependent analysis and stock biological status evaluation for the red swimming crab (*Monomia haanii*) fishery in Dongshan, Fujian Province. Our findings revealed that the RSC fishery had a multispecies nature, indicated by a low catch ratio (<0.25), and significant seasonality and interannual variations in CPUE (significant ANOVA results). Specifically, RSC CPUE were significantly lower in spring and the highest in summer. The stock biological status was fairly healthy, with no signs of overfishing occurring or being overfished, as evidenced by low F/M and high B/B_0 values. The RSC stock was lightly fished and maintained a sustainable spawning capacity (SPR > 0.3). The RSC fishery even showed further exploitation potential, as its current biomass was two times of the MSY level (B/B_{MSY}>1.5). However, we observed that the available RSC size structure did not show significant patterns related to temporal recruitment dynamics and was not reflective of the stock structure for a certain year (2021). These challenges could result in larger uncertainty in parameter estimates and even bias. Therefore, we suggest the results should be interpreted with caution.

Recommendations

Based on the conclusions and observed data deficiencies, we proposed several recommendations for future data collection to improve the data quality and consequently support effective fisheries management.

Firstly, we suggest the dockside sampling protocol follows a more consistent timetable. Although we observed significant seasonal variations in RSC CPUE, this observation was still subject to uncertainty due to the lack of comparable data size or repetitive sampling months throughout the surveyed years. Such inconsistency could introduce stronger variations due to yearly effect, which could obscure the true seasonal dynamics. A consistent seasonal survey design is particularly crucial for understanding the fishery-dependent information during the major RSC fishing seasons (summer and autumn). Therefore, we recommend conducting seasonal sampling in specific months with regular intervals to provide seasonal data for each year.

Secondly, we suggest the fishery-dependent data should be sampled from the same group of vessels over time. Currently, data are collected from different fishing vessels each year, which could introduce a vessel effect on the data due to temporal and spatial variations in fishing and targeting behaviors over RSC. Moreover, the survey data only covers the trawler fleets and does not include the cage fleet, which also plays a role in Fujian RSC fisheries. This could cause bias in CPUE and catch ratio estimates, and less representative stock size structure. Therefore, we recommend future fishery-dependent surveys that track a fixed group of representative vessels. The selection of the sampling vessels needs to take into account their gear types, fishing behaviors, and statistical power.

Thirdly, we suggest standardizing the fishery-dependent sample protocol by establishing consistent sample size for each season and size group. The previous sample protocol yielded a substantial amount of catch data and biological measurements for 2018 and 2019, but the 2021 and 2022 data were significantly inadequate. Additionally, smaller crabs were relatively rare in the sample due to onboard sorting procedures by fishers, resulting in truncated RSC length structure and difficulties in identifying fisheries selectivity. To ensure reliable stock status analysis in the future, we recommend conducting statistical power analysis to determine the minimum sample size and ideal sample number for each month/season.

Fourthly, we suggest conducting scientific surveys to collect fishery-independent data as a necessary supplement to the fishery-dependent data. Scientific surveys are designed using statistical approaches to provide representative and unbiased biological data such as relative abundance, density, and size structure. Compared to fishery-dependent data, fishery-independent data can avoid sampling bias from commercial fishing behavior, making them more reflective of the stock status. Furthermore, fishery-independent sampling is not impacted by management actions such as summer moratorium or legal size limits, hence can provide more representative biological samples for the entire stock over space and time.

Conducting fisheries scientific surveys in China can be costly. We recommend that investigators identify representative study areas with optimized survey stations to maximize cost effectiveness. It is also advisable to commission commercial fishing vessels as survey platforms, which can provide experienced crew members and reliably survey gears to guarantee the data quality. Working with fishers can also contribute to the use of empirical knowledge, which can help further optimize survey design in the long term.

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