Caribbean Netherlands Science Institute, St. Eustatius

Spawning Potential Ratio of Ten Reef Associated Fish Species around St. Eustatius from 2012 to 2020

Lisanne van Harten - 01813015

Promotor & supervisor: Kimani Kitson-Walters, Ph.D

Master thesis submitted to Ghent University for the partial fulfilment of the requirements for the degree of **Master of Science in Marine Biological Resources (IMBRSea)**

Academic year: 2019-2020

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30-07-2020

Executive summary

Worldwide, many fish stocks are overfished and coral reefs are declining, including the waters around St. Eustatius. There is little information on the fish stocks around the island, which makes it a data-poor situation. A method has been developed to assess data-poor fisheries with only limited information, this method is based on the Spawning Potential Ratio (SPR). The SPR is the amount of eggs produced by a population under no fishing pressure divided by the amount of eggs produced under a certain fishing pressure. Under sustainable circumstances, the SPR should stay above the replacement level of 20%. If it drops below this threshold, the population will decline.

In this study, the SPR values of ten target species of the St. Eustatius fishery were assessed between 2012 and 2020. The ten species consist of Ocean Surgeonfish (*Acanthurus bahianus*), Doctorfish (*Acanthurus chirurgus*), Blue Tang (*Acanthurus coeruleus*), Queen Triggerfish (*Balistes vetula*), Coney (*Cephalopholis fulva*), Red Hind (*Epinephelus guttatus*), Squirrelfish (*Holocentrus adscensionis*), Yellow Goatfish (*Mulloidichthys martinicus*), Yellowtail Snapper (*Ocyurus chrysurus*) and the Stoplight Parrotfish (*Sparisoma viride*). The purpose of the study is to determine the sustainability of the status of the stocks.

This assessment was performed using the LBSPR package in RStudio. As input, this package requires length frequency data, M/k ratio and the $L_{50}/L\infty$ ratio from every species, where M is the natural mortality, k is the von Bertalanffy growth parameter, L_{50} is the size of maturation and $L\infty$ is the asymptotic length. For the species assessed here, fishery dependent length frequency data from 2012 to 2020 was combined with life history parameters found in literature. Per-species length distributions and graphs of F/M, a measure of fishing mortality relative to natural mortality, and SPR over time were created.

It was concluded that *A. chirurgus, A. coeruleus* and C*. fulva* have an SPR lower than the replacement level, which is an indication of overfishing. With a slightly higher SPR, *A. bahianus, O. chrysurus* and *B. vetula* are expected to be at risk of overfishing. Species with a high SPR are *E. guttatus, S. viride*, *H. adscensionis* and *M. martinicus.* According to the calculation of SPR (in this study), these species seem to be fished in a sustainable way. However, for all ten species assessed in this report, it would be recommended to keep monitoring the SPR and to gather more information on the local life history parameters. As a possible solution for the most overexploited species, escape gaps in the traps are proposed.

Abstract

Many fish stocks and coral reefs around the world are declining. In this study, ten reef associated fish species around St. Eustatius are assessed on their sustainability. These stocks are data-poor and therefore the Length-Based Spawning Potential Ratio (LB-SPR) is used. This is a method that needs limited information in order to judge the sustainability of a stock. The Spawning Potential Ratio is the spawning potential in unfished circumstances divided by the spawning potential under fishing pressure.

Based on the SPR values found in this study, *A. chirurgus, A. coeruleus* and *C. fulva* are assumed to be fished unsustainably, i.e. the fishing pressure is too high for the stock. *Acanthurus bahianus, O. chrysurus* and *B. vetula* have a slightly higher SPR, but are expected to be at risk of overfishing. The SPR values of *E. guttatus, S. viride*, *H. adscensionis* and *M. martinicus* are such that they seem to be fished in a sustainable way. However, for all ten species assessed in this report, it would be recommended to keep monitoring the SPR values in the future in order to maintain or achieve healthy stocks. Furthermore, research on the local life history parameters is highly recommended.

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1. Introduction

Globally, 80 million tonnes of marine animals are caught yearly (Food and Agriculture Organization of the United Nations, 2018). Worldwide, catch numbers have been stable since the 1980s, however, catches in the Western Central Atlantic (FAO area 31) have been increasing since 2004 (Food and Agriculture Organization of the United Nations, 2018). Fish is a healthy food source and in coastal lower-income countries it is often an essential part of the diet (Food and Agriculture Organization of the United Nations, 2018). Globally, the per capita fish consumption is twice as much as it was in the 1960s and the demand for fish is likely to keep increasing due to a growing world population (Food and Agriculture Organization of the United Nations, 2018).

One of the most diverse ecosystems on the planet is coral reefs. Coral reefs serve different purposes, which include providing habitat to a variety of fish species (Spalding, Ravilious, & Green, 2001). Seven percent of all coral reefs worldwide are found in the Caribbean (Spalding et al., 2001). A decline in coral cover of around 80% since 1975 is reported (Jackson, Donovan, Cramer, & Lam, 2014), driven by climate change, ocean acidification, pollution and overfishing (Jackson et al., 2014; Spalding et al., 2001). Healthy coral reefs are essential for healthy fish populations by, for example, providing habitat, food and shelter (Wilson et al., 2017). Meanwhile, the fish species living around the coral reefs are important to keep the coral reefs healthy. For example, by biting or scraping off corals or coralline algae, this makes these fish species bioeroders (Glynn & Manzello, 2015). Bioeroders are important in maintaining the biodiversity of the coral reefs by creating micro-habitats (Hallock, 2015). With the increasing catch numbers in the Western Central Atlantic, it is important to closely monitor the different species that inhabit the coral reefs in order to prevent overfishing and protect both the fish populations and coral reefs.

St. Eustatius is a Dutch Caribbean island of around 21 km², located in the North East of the Caribbean arch (Figure 1). The island is surrounded by the St. Eustatius Marine Park, which was created in 1996 (STENAPA, n.d.). The marine park covers an area of 27.5 km² and consists of a general use zone and two no-take reserves (White, Esteban, & Polino, 2006). In total the two no-take reserves, one in the north and one in the south, take up 4.9 km² (Dutch Caribbean Nature Alliance, n.d.). One type of habitat that occurs in the marine park is coral reefs, either on natural substrates, shipwrecks, or other artificial structures. The St. Eustatius Marine Park is covered by reef-like structures coral reef (4%), gorgonian reef (22%), and dense or diffused patches of reef (7% and 8%, respectively) (Debrot et al., 2014).

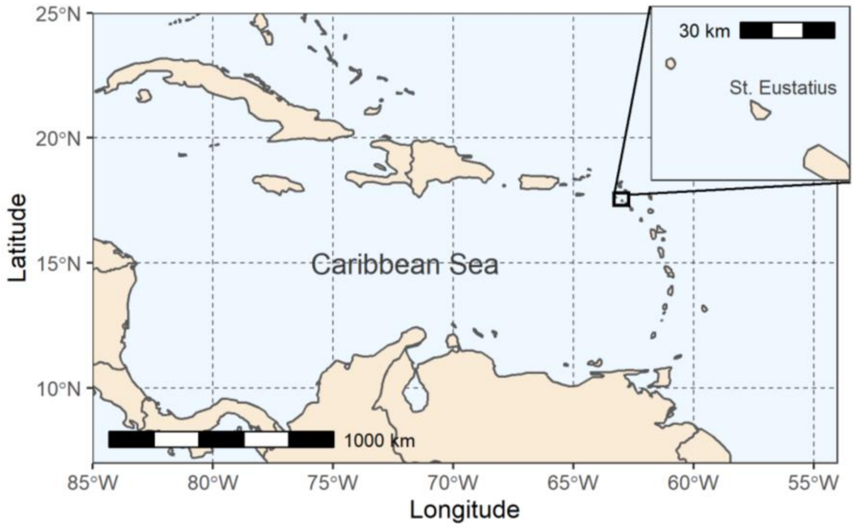


Figure 1: Map of the Caribbean Sea with St. Eustatius magnified in the top-right corner.

The coral reefs around St. Eustatius are declining and this decline can be characterized by a decline in coral coverage and an increase in macroalgal coverage (De Graaf, Piontek, Miller, Brunel, & Nagelkerke, 2015). Other characteristics of coral reef degradation are a decreasing number of predators and parrotfish. According to De Graaf et al. (2015), from 2012 to 2015, the stocks of predators and parrotfish are declining around St. Eustatius, but still maintain a healthy status.

The coral reefs are of major importance to St. Eustatius, since they provide protection against hurricanes and both fishery and tourism substantially contribute to the islands Gross Domestic Product (GDP) (Bervoets, 2010; De Graaf et al., 2015). In total around 10% of the GDP comes indirectly from the corals (Bervoets, 2010). It is therefore important to keep the coral reefs healthy. The most used fishing methods on the island are traps, hook and line, trolling, collecting organisms while scuba diving, and freediving with or without spear. Most reef associated fish species are caught with traps: metal frames with chicken wire, usually with a bag of bait inside to lure the fish in through a funnel-shaped opening (Hawkins, Roberts, Gell, & Dytham, 2007). Different trap and mesh sizes can be used. The traps are known to catch a high variety of fish species (Hawkins et al., 2007; Stevenson & Stuart-Sharkey, 1980). Small boats are used to deploy the traps, which are left in the water for a number of days before retrieval.

According to ICES (2012) the fish stocks around St. Eustatius are categorized as data-poor, which means that conventional stock assessment methods are hard to apply (Hordyk, Loneragan, & Prince, 2015). Hordyk, Ono, Valencia, Loneragan, & Prince (2014) developed the “Length-Based Spawning Potential Ratio” (LB-SPR) method that has few data requirements and is therefore easy to use in data poor fisheries (Hordyk, Loneragan, et al., 2015; Prince, 2003) This method estimates the potential of a population to reproduce based on maximum likelihood methods (Hommik, Fitzgerald, Kelly, & Shephard, 2020; Prince et al., 2019) and can be used to monitor recruitment and recruitment overfishing (Slipke, Martin, Pitlo, & Maceina, 2002). Recruits are the individuals that become available to the fishery and recruitment overfishing takes place when more fish are caught than can be replaced by the new recruits (Nations, n.d.).

The Spawning Potential Ratio (SPR) is the amount of eggs produced under a certain harvesting strategy divided by the amount of eggs produced if the fish stock was unfished (Equation 1) (Walters & Martell, 2004). Following this equation, spawning potential ratios should be 100% in the absence of fishing and

0% in a population without spawning (Prince et al., 2019). The SPR can be used as a biological reference point, which can either be a target or a limit that should be avoided (Smith, Hunt, & Rivard, 1993).

$$SPR = \frac{SSB_F}{SSB_{F=0}} \qquad \textit{Equation 1}$$

An SPR of 20% is considered as the replacement level. This is the level at which fish dying of natural mortality get replaced by new fish. When the SPR drops below 20%, there are not enough fish to replace the fish that die, which means that an SPR of 20% is the minimum SPR under which fish stocks can be maintained (Prince, 2017; Slipke et al., 2002). In this study, an SPR of 20% will therefore be considered as a limit rather than a target.

The LB-SPR method uses length frequency data, the M/k ratio, $L_m/L\infty$ ratio and the F/M ratio. The M/k is the natural mortality (M) divided by the von Bertalanffy growth coefficient (k). L_m stands for the length of first maturity and is divided by the asymptotic length ($L\infty$) and the F/M ratio is the fishing mortality (F) divided by the natural mortality (M). The F/M ratio is calculated from the length frequency data. The ratios of parameters are considered to vary less between species and stocks than the individual parameters and is therefore considered to be more reliable in data-poor situations (Prince, Hordyk, Valencia, Loneragan, & Sainsbury, 2015). If two species have different individual parameters, but the same ratios, the SPR of these two species will be the same (Hordyk, Ono, Sainsbury, Loneragan, & Prince, 2015).

The LB-SPR method assumes that the stock is in equilibrium (Julie K. Nielsen & Andrew C. Seitz, 2017) and that the individuals caught are representative of the population around the island (Nadon, 2019). Another assumption is knife-edge maturation at size L_m and since the model also assumes no variation of length-at-age, this L_m corresponds to a certain age of maturation (x_m) (Hordyk, Ono, et al., 2015). This assumption means that above a certain age/size all individuals contribute to egg production. The simplest model also assumes full selectivity, which means that all size classes are evenly likely to be caught by the fishing gear (Hordyk, Ono, et al., 2015). Full selectivity is highly unrealistic for most fishing gear, therefore some complexity can be added to the model by assuming knife-edge selectivity. This means that all fish larger than the selected size of selectivity are susceptible to fishing and to natural mortality, and all fish smaller than this size are only susceptible to natural mortality (Hordyk, Ono, et al., 2015). The model can be described by the following equation (Equation 2).

$$SPR = \frac{\sum(1-\tilde{L}_x)^{\left(\frac{M}{k\left[\left(\frac{F}{M}\right)+1\right]}\right)} * \tilde{L}_x^b}{\sum(1-\tilde{L}_x)^{\frac{M}{k}} * \tilde{L}_x^b} \qquad \textit{Equation 2}$$

In this equation, $\tilde{L}_x$ is total length, M is natural mortality, k is the von Bertalanffy growth coefficient, F is fishing mortality, and b is an exponent (usually a value close to 3) (Ernawati & Budiarti, 2020).

1.1 Aims and objectives

With worldwide and locally declining coral reefs, it is important to protect the coral reefs and the fish that depend on these coral reefs. Limited information can be found on the status and life history of fish populations around St. Eustatius. Proper management plans are needed, which can only be made after an assessment of the current situation. The Spawning Potential Ratio (SPR) of different reef associated fish species will be assessed in order to be able to judge the status of the stocks and protect the fish species associated with the coral reefs around St. Eustatius.

The species that will be looked at are the Ocean Surgeonfish (*Acanthurus bahianus*), Doctorfish (*Acanthurus chirurgus*), Blue Tang (*Acanthurus coeruleus*), Queen Triggerfish (*Balistes vetula*), Coney (*Cephalopholis fulva*), Red Hind (*Epinephelus guttatus*), Squirrelfish (*Holocentrus adscensionis*), Yellow Goatfish (*Mulloidichthys martinicus*), Yellowtail Snapper (*Ocyurus chrysurus*) and the Stoplight Parrotfish (*Sparisoma viride*). These species are common target species of the St. Eustatius fishery.

This study will assess the SPR of these ten common reef fish species of St. Eustatius over a period of 8 years (from 2012 to 2020) in order to see if the situation of these ten species is sustainable and if there was a change in SPR over time.

2. Material and Methods

2.1 Data collection

2.1.1 Length frequency data

Specimens were collected around the island of St. Eustatius (17° 29' N, 62° 58' W) between January 2012 and May 2020. Fish were caught by different fishers on a total of 336 different fishing trips, mostly using pots (8859 fish in total). Some were collected by freediving or scuba diving (448 fish) and a few were caught with handlines (117 fish) (Annex A – List of gear).

Depending on the species of the fish, the total length or fork length (Annex B – Total length and fork length) was measured to the nearest centimetre onboard the vessels, at the fisheries institute or in the lab of the Caribbean Netherlands Science Institute (CNSI). All species with a sample size of over 200 fish were used in this study (Table 1).

Table 1: Sample size by species and year

Species	Sample size									
	2012	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**Total**
Acanthurus bahianus	55*	83	114	217	37	27	21*	41	28	623
Acanthurus chirurgus	93	123	271	219	22	74	140	76	29	1047
Acanthurus coeruleus	221	258	627	913	149	240	454	275	170	3307
Balistes vetula	22	17	50	86	14	74	43	28	22	356
Canthiderhines macrocerus	8	21	70	256	46	81	107	42	22	653
Cephalopholis fulva	53	25	141	125	25	70	39	72	27	577
Epinephelus guttatus	101	39	215	245	38	209	174	173	66*	1260
Holocentrus adscensionis	64	106	378	271	57	147	214	154	36	1427
Acanthostracion polygonius	154	97	247	302	19	226	294	153	49	1541
Mulloidichthys martinicus	6	6	48	60	5	25	68	16	0*	234
Ocyurus chrysurus	8	11	41	81	10	16*	22	19	2*	210
Sparisoma viride	51	41	47	82	12	37	67	28	24	389

* Were excluded from the model since there was a warning about the final Hessian not being positive definite as mentioned in 2.2 Data analysis).

2.1.2 Life history parameters

To analyze the SPR according to the LB-SPR method, the following life history parameters were needed:

- $L\infty$ The asymptotic length of an unfished population
- L_{50} Length at which 50% of the population is sexually mature
- L_{95} Length at which 95% of the population is sexually mature
- $M/k\ ratio$ Ratio of natural mortality (M) and the Von Bertalanffy growth coefficient (k)

These life history parameters were gathered for all species with more than 200 datapoints. There was no information on these parameters for the specific stocks of St. Eustatius, therefore, a literature review was performed in order to collect all the life history parameters (Table 2). Species were excluded from the analysis if no information on the life history parameters was found, which was the case for *Acanthostracion polygonius* and *Canthiderhines macrocerus*.

In case different studies reported different values for the same life history parameter, the study with the largest sample size was used as input for the analysis. In case of hermaphroditism or sexual dimorphism in size, the female life history parameters were used in the model to determine the SPR. Groupers *C. fulva* and *E. guttatus* and parrotfish *S. viride* are protogynous hermaphrodite (Cardwell & Liley, 1991; Sadovy, Rosario, & Román, 1994; Trott, 2006), which means that these species start their lives as females and later turn into males (Anand & Pillai, 2002). The female life history parameters are used for these species.

Table 2: Life history parameters (in mm)

Species	Life history parameters				References
	L∞	L_{50}	L_{95}	M/k *ratio*	
Acanthurus bahianus	189	160	165*	0.15	(Mutz, 2006); (Hawkins et al., 2007); (Wolfe, 2003)
Acanthurus chirurgus	268	175	180*	0.19**	(Nagelkerken & Faunce, 2007); (Mutz, 2006)
Acanthurus coeruleus	276	145	150	0.17**	(Mutz, 2006); (Hawkins et al., 2007)
Balistes vetula	450	250	280	4.56	(de Albuquerque, Martins, de Oliveira, de Araújo, & Ribeiro, 2011; Munro, 1983b; Rivera-Hernández et al., 2019)
Cephalopholis fulva	377	185	215	0.79	(Burton, Potts, & Carr, 2015; Marques, 2011)
Epinephelus guttatus	393	215	270	0.85	(Sadovy et al., 1994); (Ault, Bohnsack, & Meester, 1998); (Cushion, 2010); (Ault et al., 2002)
Holocentrus adscensionis	265	146	159	3.66	(Munro, 1983a);(Shinozaki-Mendes, Vieira Hazin, De Oliveira, & De Carvalho, 2007)
Mulloidichthys martinicus	300	175	185	4.25	(Munro, 1983a)
Ocyurus chrysurus	484	213	245	1.02	(Trejo-Martínez, Brulé, Mena-Loría, Colás-Marrufo, & Sánchez-Crespo, 2011); (Ault, Smith, Luo, Monaco, & Appeldoorn, 2008); (Ault et al., 2002)
Sparisoma viride	357	205	235	1.03	(Choat, Robertson, Ackerman, & Posada, 2003); (Figuerola, Matos-Caraballo, & Torres, 1998); (Ault et al., 2002)

*Values are estimated based on the steep growth curve of closely related species. It is assumed that there is little difference between L50 and L95, the assumption is based on the parameters found for *A. coeruleus*.

** Mortality rates were adapted from maximum age values (t) from a study by Ault et al. (2002) using $M = \frac{\ln(0.05)}{-t}$, assuming 5% of all individuals survives to maximum age (Alagaraja, 2011).

2.2 Data analysis

Minimum length, maximum length, mean length and standard deviation were calculated for each species, followed by the calculation of the SPR. The SPR was calculated by comparing the size of the catch with the size of maturation. The LB-SPR analysis was performed using the LBSPR package version 0.1.5 (Hordyk, 2019) in RStudio 1.2.5019 (R Core Team, 2018). Hordyk, Ono, Prince, & Walters (2016) described all the steps of finding the SPR by fitting the length frequency data that were used to compose the R script that was used in this study.

The LBSPRfit() function from the LBSPR package (Hordyk, 2019) takes the length frequency data (LB_lengths) and life history parameters (LB_pars) as input. The whole procedure was described by

Mardones & Hordyk (2019). The length frequency data was used to estimate the ratio of fishing mortality and natural mortality (F/M) and selectivity-at-length from the known parameter M/k based on maximum likelihood methods (Hordyk et al., 2014). F/M and selectivity-at-length were then used to calculate SPR using Equation 2 (Hordyk, Ono, et al., 2015).

For each species, all years were used, except if RStudio gave the following warning about a specific year: "The final Hessian is not positive definite." Years with these warnings were taken out of the model (indicated with * in Table 1), since the model could not come up with accurate estimates given the data.

For each species, length frequency distributions per year were created, a mean F/M and mean SPR were calculated and reported with standard deviation as a measure of spread. Firstly, the plotSize() function was used to visually inspected how the model fitted the length frequency data. Secondly, the plotEsts() function was used to visualize the change F/M ratio and the SPR over the years. Lastly, the plotMat() function was used to visualize the selectivity curves of different years and maturation curve of all years combined for each separate species.

3. Results

The total catch consisted of 11764 specimens of 107 different species. For this study, only species with a sample size over 200 and sufficient information on the life history parameters were used. This came down to a total of 9430 specimens distributed over ten different species (Table 1), these ten species in total comprised 80.2% of the total catch. Pictures of all species can be found in Annex C – Pictures of assessed species).

All length frequency data is summarized by dividing it into different species and different years (Figure 2). Each year has a different colour, with the most recent year (2020) on the bottom of the graph and the earliest year (2012) on the top of the graph. The complete shape of the graph shows the length frequency distribution of all years combined. In general, the graphs of species with a bigger sample size approach a normal distribution, whereas species with a smaller sample size show multiple peaks and the catch is thus less normally distributed.

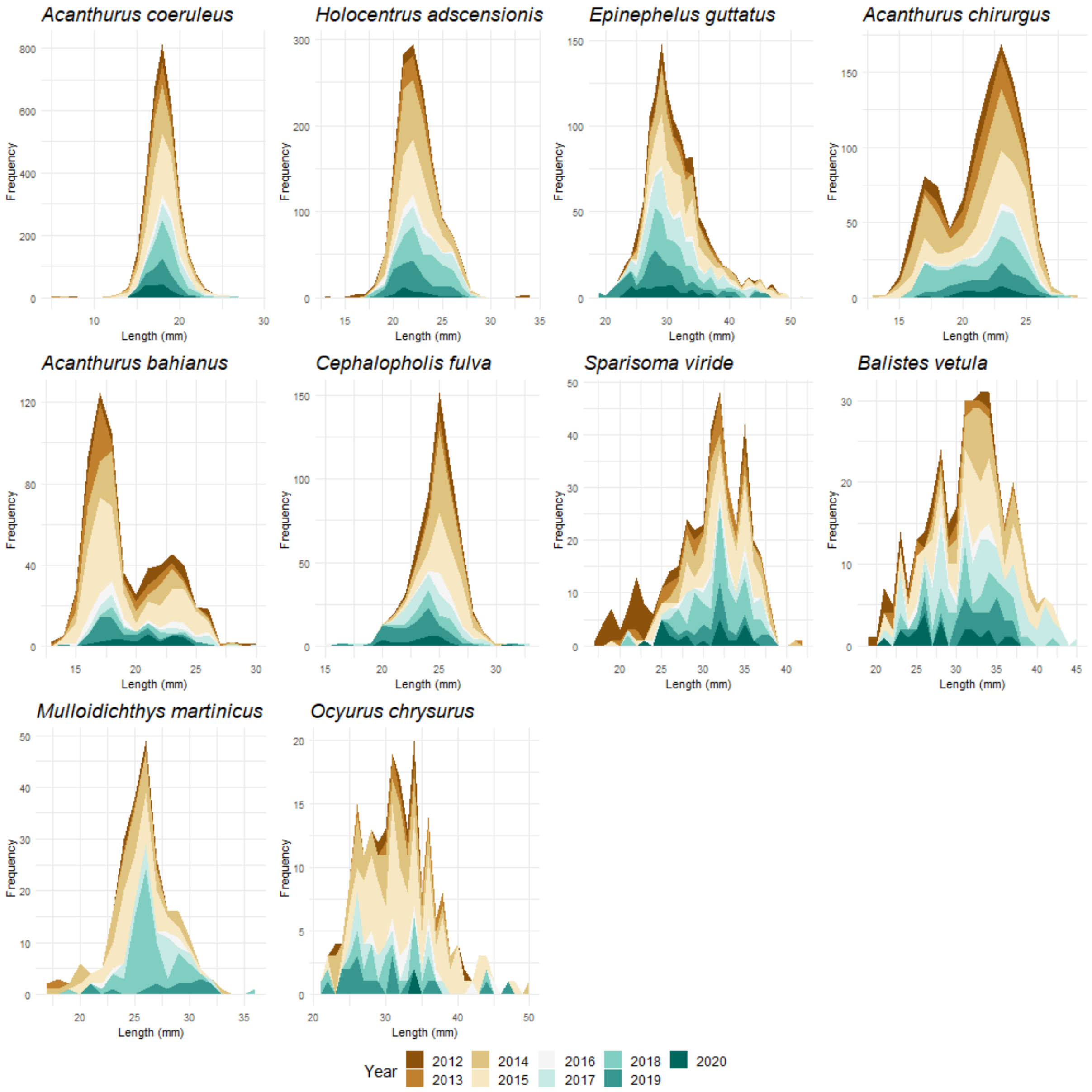


Figure 2: Length frequency distributions of the ten analysed species. Different years are shown in different colours and are stacked upon each other. From left to right, top to bottom, the graphs (species) are ordered from the biggest sample size to smallest sample size.

Length frequency distribution was created for each separate year per species and the model was fit to this distribution (Annex D – Length frequency distribution with fitted LB-SPR model). Next, the model produced a graph that showed the F/M ratio over the period from 2012 to 2020 and a graph that showed the SPR over that same period. In the whole result section, the SPR is given as a proportion of 1 rather than a percentage.

The length distribution of *A. bahianus* ranges from 13 cm to 30 cm FL, with a mean length of 19.2 ± 3.2 cm. The F/M ratio and especially the SPR are highly variable with large 95% confidence intervals and no clear trend (Figure 3a). Over the whole period (2012 to 2020), the mean F/M is 1.11 ± 1.20 and the mean SPR is 0.61 ± 0.30.

The length distribution of *A. chirurgus* - minimum fork length of 13, a maximum of 29 cm and a mean of 21.5 ± 2.9 cm - was found to be very similar to the distribution of *A. bahianus. Acanthurus coeruleus* had a wider range (minimum of 5 cm and maximum of 29 cm). The mean fork length (18.0 cm) and standard deviation (1.9 cm) are, however, similar to the other two *Acanthurus* species. Both the *A. chirurgus* and the *A. coeruleus* have high mean F/M ratio of, respectively, 23.48 ± 18.83 and 38.08 ± 12.41 and a low mean SPR of, respectively, 0.12 ± 0.02 and 0.03 ± 0.01. The high standard deviations indicate a high variability, but no clear trend can be observed in the graphs (Figure 3b & c).

The *B. vetula* had a mean fork length of 31.5 cm and a standard deviation of 5.1 cm and a distribution range from 19 cm to 45 cm. With a mean F/M of 4.00 ± 8.25 and a mean SPR of 0.93 ± 0.11, both the F/M as well as the SPR seem to be stable over time. There are however wide SPR 95% confidence intervals in year 2, 5, 8 and 9 for this species (Figure 3d).

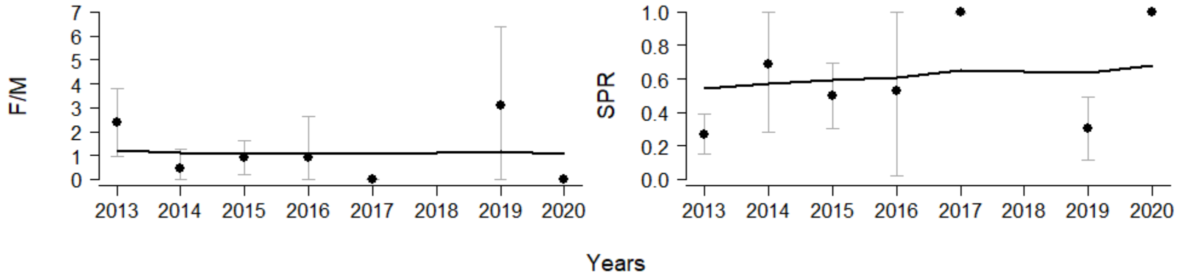
The length distribution of *C. fulva* ranges from 15 cm to 33 cm fork length with a mean of 24.8 cm and a standard deviation of 2.1 cm. The mean F/M is 20.89 ± 20.50 and the mean SPR is 0.14 ± 0.02. The scale of the left graph (F/M graph) is very wide, due to the high values in 2016. Excluding 2016, all values for F/M are between 7.22 and 23.35. The high variability in values for F/M, can also be seen from the standard deviation. However, there doesn't seem to be any detectable trend and the SPR overall seems to be stable (Figure 3e).

The smallest individual of *E. guttatus* caught was 19 cm and the biggest 52 cm. The whole sample had a mean total length of 31.2 cm and a standard deviation of 5.0 cm. The stock status of *E. guttatus* seems to be relatively stable over time with a mean F/M of 0.69 ± 0.22 and a mean SPR of 0.56 ± 0.07. There is no clear downward trend and the 95% confidence intervals of the SPR never show values below 0.2 (Figure 3f).

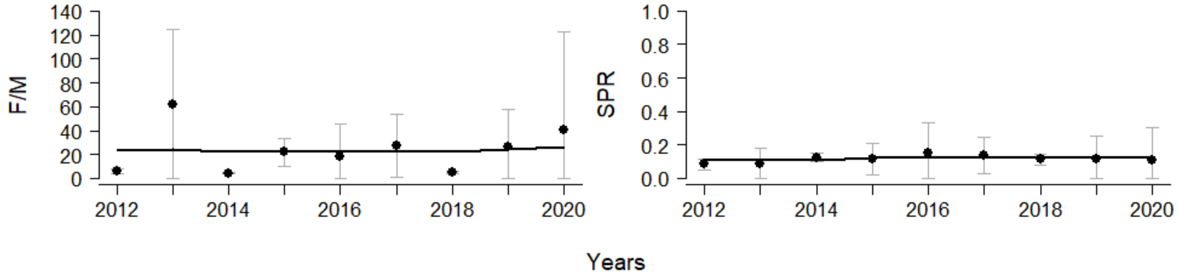
The length distribution of *H. adscensionis* ranges from 13 cm to 34 cm and has a mean fork of 22.4 cm with a standard deviation of 2.2 cm. This species' stock has a mean F/M of 0.10 ± 0.20 and a mean SPR of 0.99 ± 0.02. The F/M line shows a slight downward trend, whereas the SPR seems to be stable over time (Figure 3g).

The minimum length found for *M. martinicus* was 17 cm and the maximum length found was 36 cm. The mean fork length was 25.7 cm and had a standard deviation of 2.9 cm. The stock seems to have a stable F/M and high and stable SPR with respectively a mean of 0.84 ± 1.98 and 0.99 ± 0.02. There is no clear trend and, with exception of the first year (2012), there are small 95% confidence intervals, which never show a SPR of lower than 0.6 (Figure 3h).

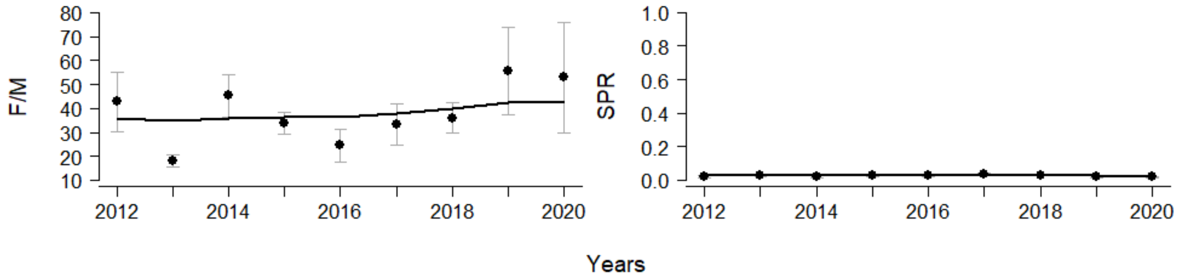
a. *Acanthurus bahianus*



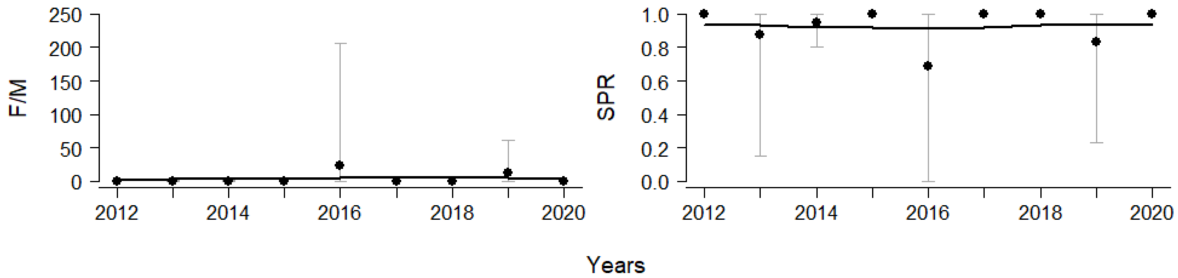
b. *Acanthurus chirurgus*



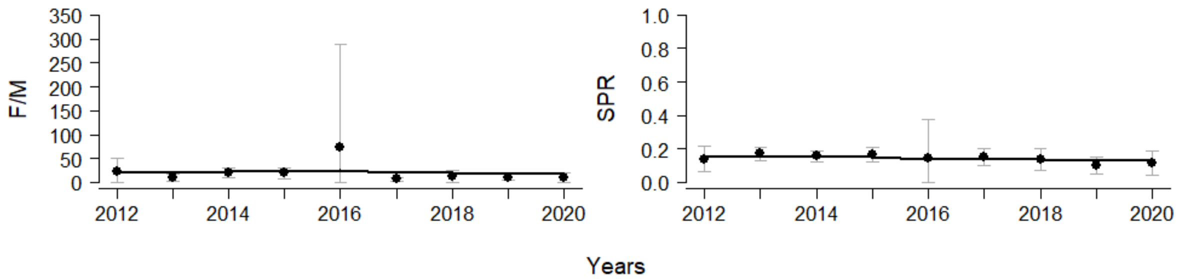
c. *Acanthurus coeruleus*



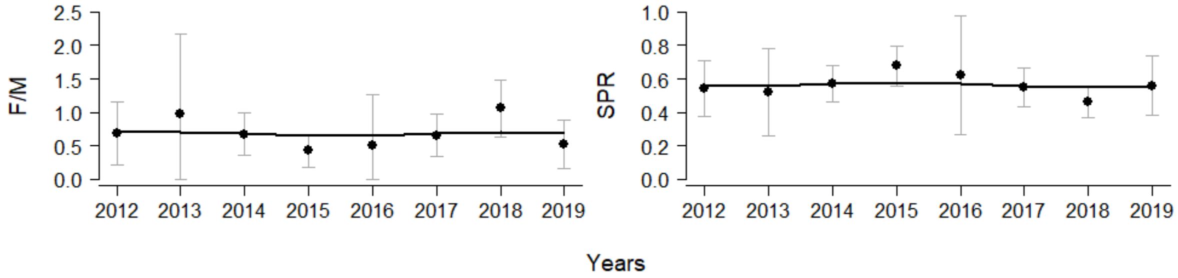
d. *Balistes vetula*



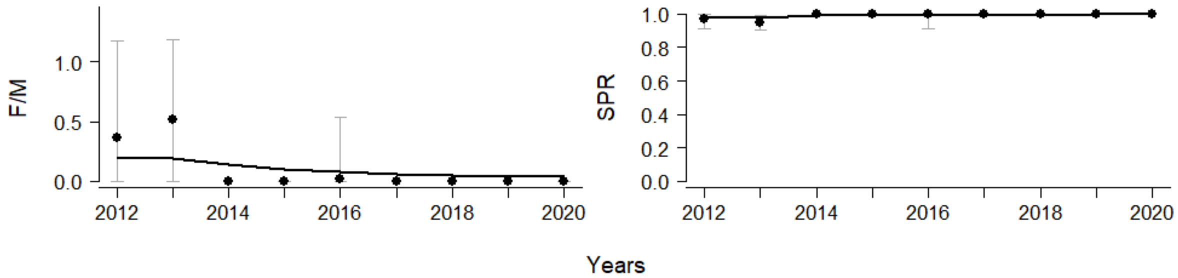
e. *Cephalopholis fulva*



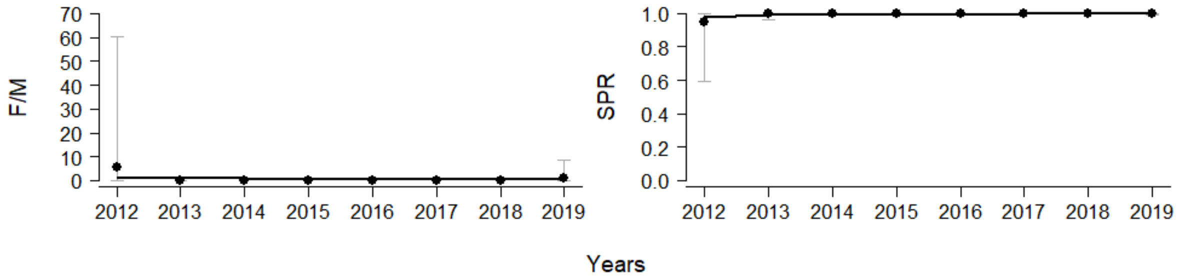
f. *Epinephelus guttatus*



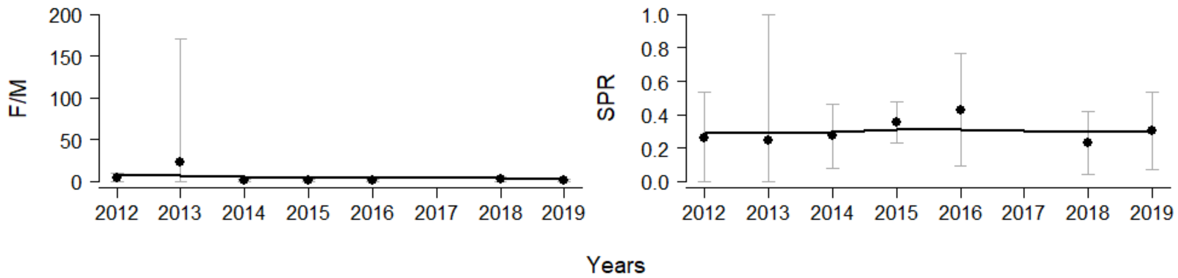
g. *Holocentrus adscensionis*



h. *Mulloidichthys martinicus*



i. *Ocyurus chrysurus*



j. *Sparisoma viride*

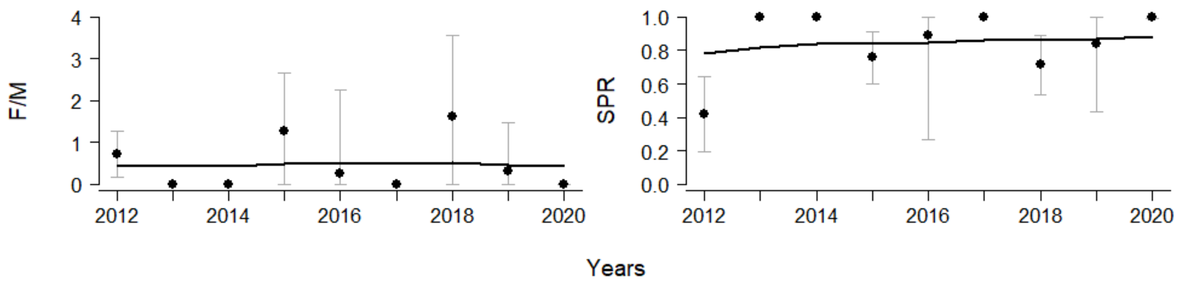


Figure 3: graphs of the F/M ratio and SPR over the years. On the x-axis are the years from 2012 to 2020. For some species, some years were excluded from the analysis as explained in 2.2 Data analysis. The dots represent the estimates of the F/M ratio and the SPR, with in grey bars the 95% confidence intervals. The SPR values are given as a proportion rather than a percentage, an SPR of 1.0 equals an SPR of 100%, e.g. the SPR of an unfished stock.

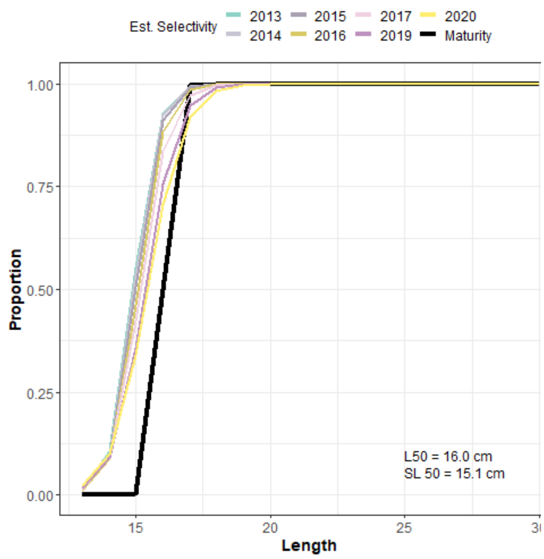
The smallest individual of *O. chrysurus* was caught at 21 cm and the largest at 50 cm. With a mean total length of 31.9 cm and a standard deviation of 5.3 cm, this species had the highest mean length of all species included in this study. The stock had a mean F/M of 5.04 ± 7.99. The F/M in year 2 was 23.06 while in all other years, the F/M was below 4. The means SPR is 0.30 ± 0.07, which seems to be stable over time. However, the 95% confidence intervals are quite wide (Figure 3i). In modelling the F/M and SPR, year 6 and 9 were left out as described in 2.2 Data analysis.

The length distribution of *S. viride* ranges from 17 cm to 42 cm, had a mean of 30.5 cm and a standard deviation of 4.8 cm. Both the F/M and the SPR of *S. viride* seem to be highly variable with wide 95% confidence intervals. The mean F/M is 0.47 ± 0.61 and the mean SPR is 0.85 ± 0.20, but despite the high variability, the confidence intervals of the SPR are never below 0.2 (Figure 3j).

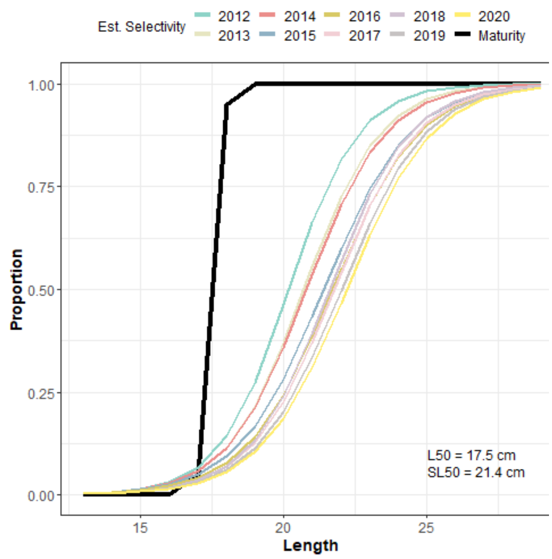
For all species a graph was created that combined the size of maturation and the selectivity-at-size for all different years (Figure 4). The only species with a selectivity curve smaller than the maturation curve is *A. bahianus*, all other species have a selectivity curve larger than the maturation curve. In this report a difference of 5 cm or more between the size of maturation (L50) and mean size of selectivity (SL50) was considered to be a relatively large difference. Species with a difference of more than 5 cm are *B. vetula, C. fulva*, *H. adscensionis, M. martinicus, O. chrysurus* and *S. viride.* The remaining three species (*A. chirurgus, A. coeruleus* and *E. guttatus*) have less than 5 cm difference between the size of maturation and the mean size of selectivity.

A. chirurgus has a standard deviation greater than 4 on the SL50. For this specific species, a pattern was observed. In the first year in which data was gathered, smaller individuals were caught. Every following year, the curve of selectivity moves a little to the right, with the biggest individuals being caught in the last year (2020) (Figure 4b). For *S. viride,* the standard deviation is also greater than 4. The selectivity curves from 2015 to 2020 seem to be quite close together, the first three years, however, are slightly left of the other curves, with 2012 most left and 2014 closest to the rest of the curves (2015 and later) (Figure 4j). The pattern described for *S. viride* can also be seen for *B. vetula* (Figure 4d). For *M. martinicus* the standard deviation was around 2.9 and most of the spread came from the last 4 years (Figure 4h). The selectivity curves from 2012 to 2015 are close together. For the next following 4 years (2016 to 2019), the curve moves a little to the right each year. The last species with a large standard deviation is *O. chrysurus*. For this species, an opposite pattern was detected. The selectivity curve that shows the smallest sizes was from the latest year (2019), every curve to the right shows the selectivity of the next year (Figure 4i). The four remaining species (*A. bahianus, A. coeruleus, E. guttatus* and *H. adscensionis*) have a standard deviation of less than 2 (Figure 4a, c, f & g).

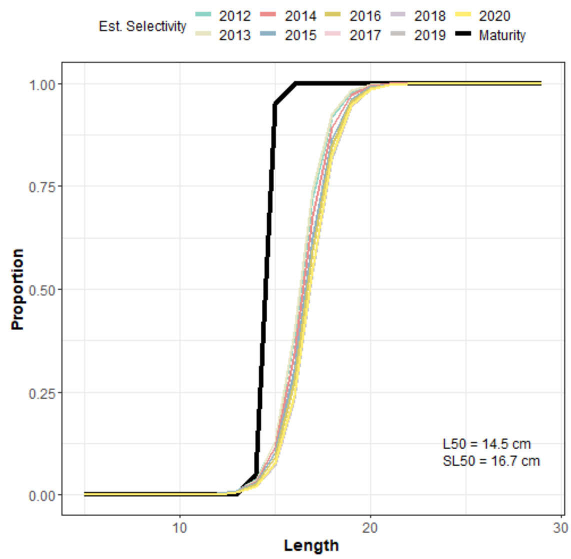
a. *Acanthurus bahianus*



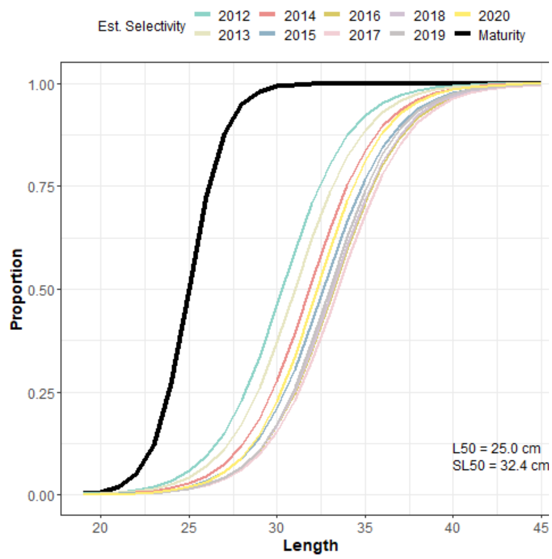
b. *Acanthurus chirurgus*



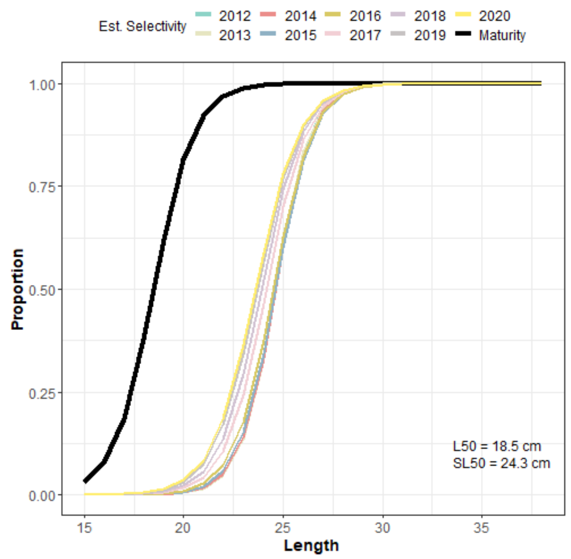
c. *Acanthurus coeruleus*



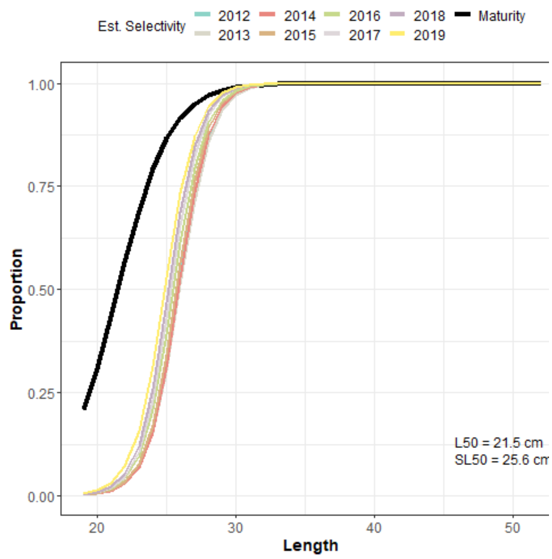
d. *Balistes vetula*



e. *Cephalopholis fulva*



f. *Epinephelus guttatus*



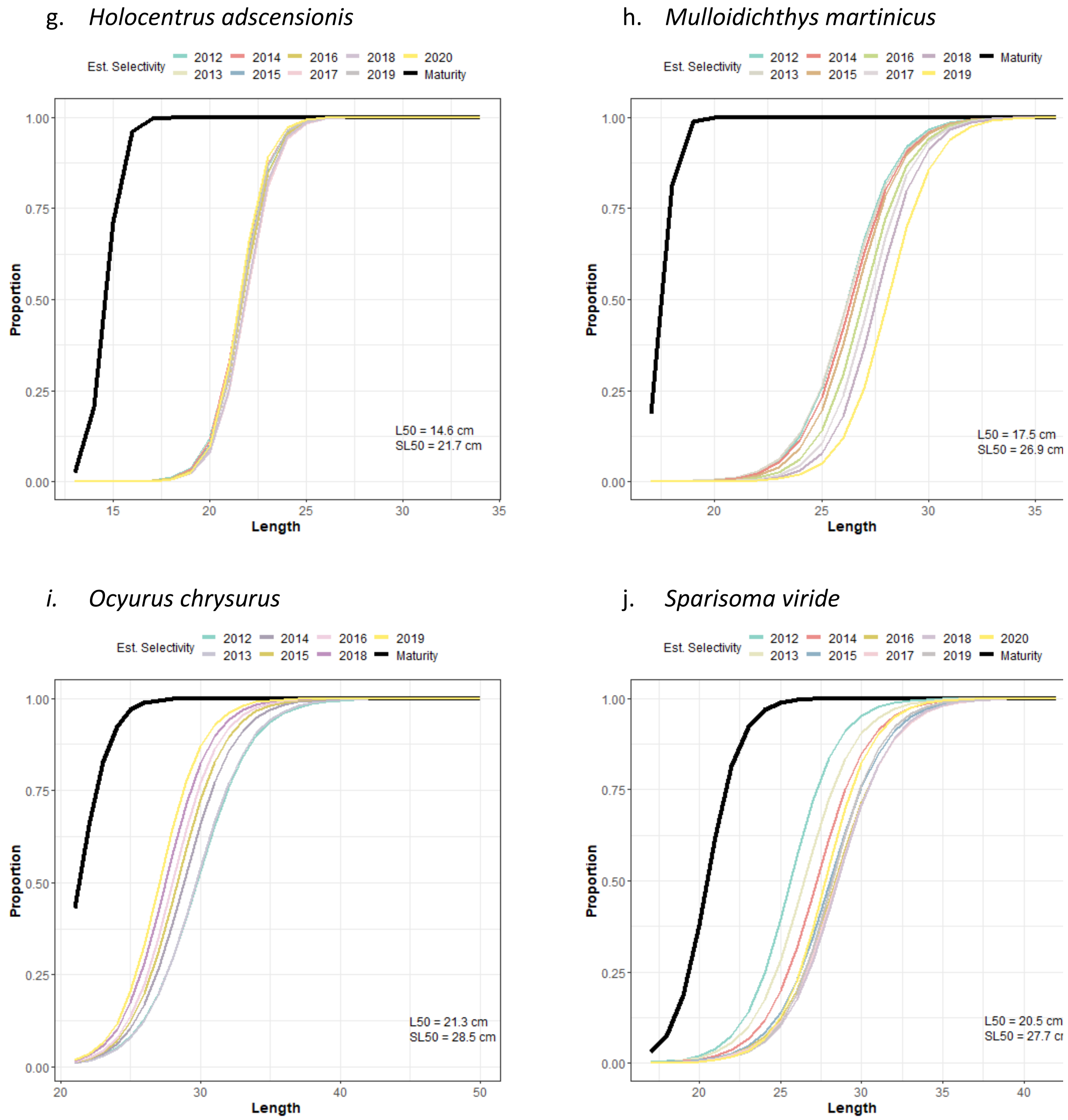


Figure 4: Size at first capture for different years (2012-2020) given in different colours and the size at maturity given in black. Text in bottom right shows the size at which 50% of the population is mature (L50) and the mean size at which 50% of the size class is retained in the fishing gear (SL50). SL50 is calculated over the entire period included in the model.

4. Discussion

4.1 Assumptions of the model

Different assumptions were made regarding the LB-SPR model. First, the model assumes that a stock is in equilibrium. It is hard to be certain of this, but if the stock was not in equilibrium, one would expect to see a pattern in the length distribution (Nadon, 2019)(Annex D – Length frequency distribution with fitted LB-SPR model). In a situation of extreme high recruitment numbers, it would be expected to see a high peak in lower lengths and this peak moving to the right margin of the graph during later years. In the case of a short term high mortality rate caused by fishing, it would be expected that the length of the catch slowly reduces (Nadon, 2019). For most species, the length frequency distribution over the years seems to be stable. However, for species with a smaller sample size (*M. martinicus, O. chrysurus* and *S. viride*), it is harder to judge if the irregularities in the distribution are caused by the stock not being in equilibrium or by the smaller sample size.

Another assumption is that the length data used as input represents the length data of the true population around the island (Nadon, 2019). When, due to different reasons, larger fish are missing from the dataset, the LB-SPR method will overestimate the fishing mortality and therefore underestimate the SPR (Hordyk et al., 2014). One reason for missing large individuals could be the selectivity of the gear, for instance when the selectivity is dome-shaped instead of logistic (Hordyk, Ono, et al., 2015; Rudd, 2017). Another reason could be a decreased catchability for larger fish, for example because they live in different places (Thórarinsson & Jóhannesson, 1997). In this study, there are no obvious irregularities in the length frequency data and for that reason there is no indication that the length data might not be representative of the true population. This observation is supported by the study of Langlois et al. (2015), where length distributions of the catch from traps were compared to fishery independent samples and no biologically significant differences were found between the length distributions.

One of the most important assumptions made in this study is that the life history parameters chosen for the ten species are accurate. The life history parameters for all species were found in literature and based on different areas and therefore different stocks. In case multiple values were found for the same life history parameter, the life history parameters of the studies with the biggest sample size were chosen. Since the fish stocks around St. Eustatius are data-poor, it was not an option to work with life history parameters of the local stocks.

Lastly, there is the assumption of knife-edge maturation at size L_m and knife-edge selectivity. This is unlikely to be completely true, but for the model used in this study, this is a close enough approximation.

4.2 Length frequency distributions

In general, the bigger the sample size, the more normal the length frequency distribution seemed to be (Figure 2) and the better the model seemed to fit the actual length distribution (Annex D – Length frequency distribution with fitted LB-SPR model). The method gets more robust with a sample size over a 1000 length data points, which should be evenly distributed over the time of the study (Hordyk et al., 2014). Based on the sample sizes of this assessment, *A. chirurgus*, *A. coeruleus, E. guttatus* and *H. adscensionis* are most robust.

The mean of the SL50 is calculated using the SL50 of each separate year. The standard deviation associated with this mean gives a measure of spread of different SL50 values in different years. As mentioned in the results, the extent of spread is different for each species. A similar pattern can be seen for the selectivity curves of some different species (Figure 4). The selectivity curve of *A. bahianus* seems to move a little more to the right side of the graph every following year during the whole study period (2012-2020). The same pattern can be observed for *S. viride* and *B. vetula* during the first three years (2012-2015), the selectivity curves from all years from 2015 to 2020 for these species are similar. Since the gear did not change during the period 2012 to 2020, it is expected that this pattern is due to a relatively small sample size of these three species.

4.3 F/M ratio

The F/M ratio must be interpreted carefully since the selectivity of the fishery should also be taken into account. A high F/M value generally means that a big part of the fish stock dies due to fisheries compared to the amount of fish dying due to natural mortality, while a low F/M value generally means that a big part of the stock dies due to natural mortality (Hordyk et al., 2014). However, when a fishery specifically targets the older and bigger individuals, the F/M ratio can be very high, which in this case didn't necessarily mean that the fishery is unsustainable. One species that clearly illustrates that the F/M can be relatively high without lowering the SPR is *M. martinicus*. A mean F/M ratio of 0.84 ± 1.98 is not extremely high. However, it is high in combination with the 99% SPR of *M. martinicus*. The selectivity curves of this species are much larger than the maturation curve, which shows that the fishery mostly targets the bigger individuals. The same counts for very low F/M ratios, which may be due to the fishery catching a lot of younger fish, and thereby affecting the spawning potential and thus the sustainability of the fishery (Hordyk et al., 2014). The three *Acanthurus* species have both a low SPR and a high F/M ratio, this does indicate that a large proportion of the fish stock dies due to fishing efforts.

4.4 M/k ratio

Species with a lower M/k value mature relatively early in life and stop growing after maturation, species with a higher M/k value mature relatively late in life and continue growing throughout their lifespan (Hordyk et al., 2014). In general, when species mature early, the amount of biomass peaks at an early age and a relatively large length (Hordyk, Ono, et al., 2015). Hordyk, Ono, et al. (2015) studied the performance of the LB-SPR method and found that the model is most robust with a M/k over 0.53. This can be explained by the fact that the LB-SPR method relies on detecting the fishing mortality in the right side of the length distribution, e.g. the side with the larger length classes (Hordyk, Ono, et al., 2015). In cases of a low M/k ratio, a fish that just matured is assumed to be similar in size to a fish that matured a longer time ago. This means fish accumulate in the size classes that are only slightly larger than the maturation size, a peak in the length distribution develops (Figure 5a). The model detects that there are not a lot of fish on the right side of this peak and assumes that they are fished away, whereas these length categories are likely to be non-existent (Hordyk, Ono, et al., 2015). For higher M/k ratios, the continuous growing throughout their life creates a peak in the length composition around the smaller size classes. The influence that the M/k ratio has on the length composition is clearly illustrated by Hordyk, Ono, et al. (2015) in Figure 5.

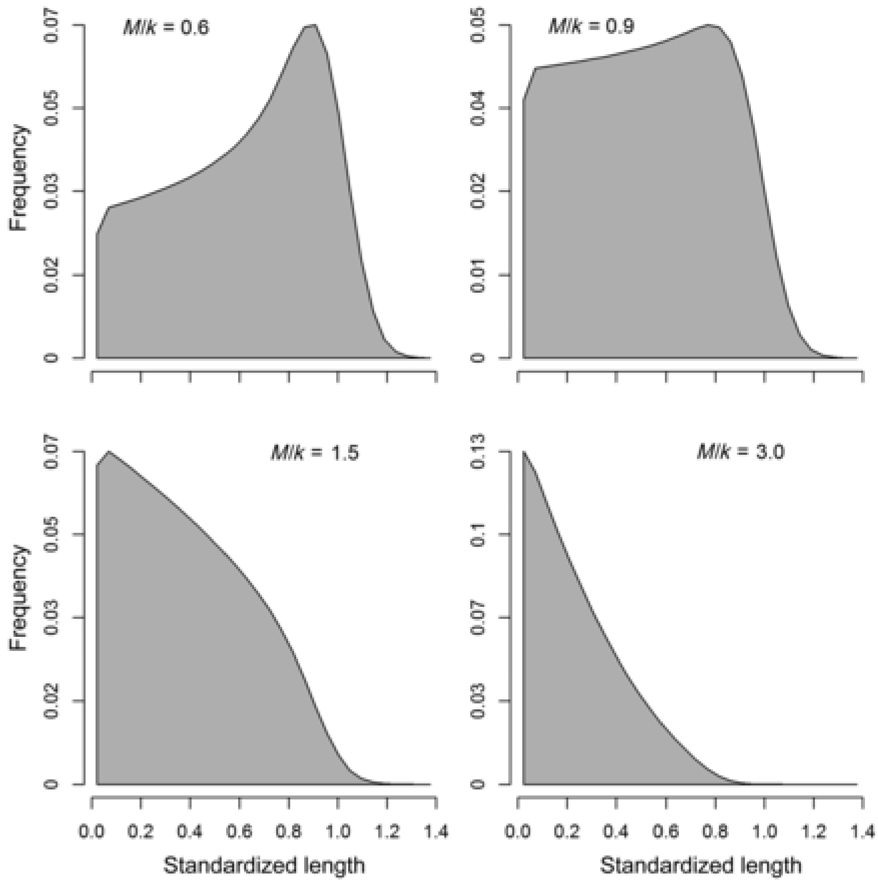


Figure 5: Standardized unfished length frequency composition under different values of M/k. On the x-axis the standardize length and on the y-axis the standardized frequency. The grey area represents the shape of the length frequency distributions. Figure is taken from the paper of Hordyk, Ono, et al. (2015).

From the ten selected species, there are three species with a M/k ratio lower than 0.53, namely *A. coeruleus, A. bahianus* and *A. chirurgus.* The low M/k ratio of these species indicates that they mature and reach their final size relatively early in life, the low M/k ratios of these species are expected to impact the SPR. The SPR values of *A. coeruleus* and *A. chirurgus* were below 20%, the SPR of *A. bahianus* was around 60%. It is unclear if the low SPR values are caused by the limitations of the model or that it is an actual sign of overfishing. In the results, it is mentioned that *A. chirurgus* and *A. coeruleus* have a maturation curve smaller than the selectivity curves. Compared to some of the other species assessed, the difference between the curves is relatively small, this might be a result of the low M/k value. The species stop growing after their maturation, which makes it impossible to catch many fish much bigger than the maturation size. In these cases, this does not need to be a sign of overfishing. In general, stocks with a selectivity curve close to the maturation curve are more prone to overfishing than species that have a selectivity curve at much larger sizes than the maturation curve (Prince, Creech, Madduppa, & Hordyk, 2020).

4.5 Spawning potential ratio

The different species analysed in this study seemed to have completely different SPR values. However, for all species the SPR seemed to be relatively stable with no clear downward trends. In this assessment, an SPR of 20% was considered to be the replacement level and a limit, which means that the SPR of the stocks assessed should never go below 20%. In this study, there are three species with a mean SPR below the 20% replacement level. These species are *A. chirurgus, A. coeruleus* and *C. fulva* (Figure 3).

In the current assessment, *C. fulva* had SPR values below 20% during the whole study period (2012-2020), indicating the species is overfished. De Graaf et al. (2015) also studied the SPR of some of the same stocks assessed in this report and found an SPR of around 0.45, or 45%, for *C. fulva*. This stock was not classified as overfished; however, a risk of overfishing was present. The difference in SPR values could be due to different life history parameters used, which shows the relevance of gaining knowledge on the correct life history parameters of the local stocks.

The SPR of *A. coeruleus* was the absolute lowest with a mean of 0.03 ± 0.01. This is peculiar since it would be expected that the stock would have completely collapsed after at least eight years of extreme overfishing. An SPR this low for several years might not solely be an indication of overfishing, but perhaps also an indication of some flaws in the model or the chosen life history parameters. De Graaf et al. (2015) also considered *A. coeruleus* around St. Eustatius to be overfished, based on an SPR of approximately 0.15, which is considerably higher than the 0.03 calculated in this assessment. The findings of this study and the study by De Graaf et al. (2015) suggest that *A. coeruleus* is indeed overfished. The difference in SPR between the two studies might also be due to a difference in life history parameters used.

The SPR of *A. chirurgus* was 0.12 and therefore higher than the SPR of *A. coeruleus*, but still below the replacement level. De Graaf et al. (2015) found an SPR of approximately 0.25 for *A. chirurgus*. This stock is still considered to be overfished by both this study and the study of De Graaf et al. (2015).

The SPR of *A. bahianus* varies a lot over time and in some years, the lower boundaries of the 95% confidence interval are below the 20% replacement level. As mentioned in the results section, the selectivity curves of *A. bahianus* are lower than the maturation curve. This means that a high proportion of the catch is immature and did not have the chance to reproduce yet. This is likely to be a sign of unsustainable fishing practices. In the assessment of De Graaf et al. (2015), *A. bahianus* is considered to be fished sustainably with an SPR of around 0.7. However, the fact that in this study many fish are caught beneath the maturation size combined with a highly variable SPR, even though the mean is above 20%, warns for the risk of overfishing.

Acanthurus chirurgus, *A. coeruleus* and *A. bahianus* are closely related and all three *Acanthurus* species have low or highly variable SPR values. This is unexpected and could be due to different reasons. One thing these species have in common is the low M/k value which might be of influence on the performance of the model as described in section 4.4 M/k ratio). As reported by De Graaf et al. (2015), all three species had a higher SPR value, which again may be an indication of different life history parameters used.

Ocyurus chrysurus has an SPR of 30%, which is above the replacement level. However, the lower boundaries of the 95% confidence intervals often reach below the replacement level. This means that it is not possible to say with 95% confidence that this stock is harvested sustainably during the whole period. Of all species assessed in this report, *O. chrysurus* had the smallest sample size with only 210 individuals, which is quite small for this type of assessment. It is therefore recommended to gather more data on this species, while being cautious of the possibility that this species is currently being overexploited. The difference between the maturation curve and selectivity curves was relatively big, which means that a large part of the catch was sexually mature and had the possibility to reproduce.

Balistes vetula had a high mean SPR of 93%. In year five there was a wide 95% confidence interval with the lower boundary below the 20% replacement level. This indicates that during the period from 2012 to 2020 this fishery was most likely sustainable, with a small chance of overfishing in 2016. There was a relatively big difference between the maturation curve and the selectivity curves, with the selectivity curves being approximately 7 cm larger. This difference implies that a big proportion of the catch is sexually mature, which makes the species less susceptible to overfishing. However, worldwide this species is classified as “Near Threatened” by the IUCN with a decreasing population trend (Liu et al., 2015). This means that *B. vetula* should be monitored closely in order to recognize changes in local population numbers as quickly as possible.

Epinephelus guttatus had a mean SPR of 56% and the lower 95% confidence interval boundary never reached below the replacement level. This species had a sample size of 1260 animals, which makes the method relatively robust (Hordyk et al., 2014). According to the LB-SPR method, this stock is fished in a sustainable way. This is also the case for the *S. viride* stock. The SPR of this stock varies over time but has a mean of 85% and the 95% confidence interval boundary stays above the replacement level. However, *S. viride* has a much smaller sample size with only 389 individuals split over eight years. This sample size is not large enough to conclude that the species is fished sustainably, but with the current SPR levels, it can be assumed that the species is not overfished. This supports findings by De Graaf et al. (2015) who found an SPR of 0.8 for *S. viride* around St. Eustatius.

The stocks of *H. adscensionis* and *M. martinicus* both had a very high mean SPR of 99% with a low variability over the years. According to the used method, both these stocks are being harvested in a sustainable way. This is supported by the big difference between the size of being selected by the fishing gear and the size of maturation, which indicates that very few immature fish are being caught. Worldwide, both *H. adscensionis* and *M. martinicus* are classified by the IUCN as “Least Concern” (Dooley et al., 2015; Moore, Polanco Fernandez, Russell, & McEachran, 2015). This classification, in combination with the high SPR found in this study, implies that no special approach is needed for these species.

4.6 Suggestions

The fish species assessed in this study are mostly caught by traps, which are known to be barely species selective fishing gear (Stevenson & Stuart-Sharkey, 1980). One way traps can be altered to be more selective is enlarging the mesh size. A larger mesh size could cause catch numbers to drop, which can be effective in a single species fishery, but is harder to implement in a multispecies fishery like the one on St. Eustatius (Gomes, Erzini, & Mcclanahan, 2014; Johnson, 2010). One possibility to reduce the catch numbers of a few specific species would be to implement escape gaps, short or tall gaps in the corner of the traps. Johnson (2010) and Gomes et al. (2014) showed that escape gaps can reduce catch numbers of small or narrow bodied fish without significantly reducing the value per trap. Mbaru & McClanahan (2013) showed a 40% reduction of bycatch in traps with escape gaps compared to the conventional traps. The escape gaps were shown to be very effective for reducing the number of Acanthuridae caught, which are considered to be low-priced fish. In this study, the Acanthuridae species were especially overexploited or at risk of overexploitation. Implementing these escape gaps might therefore raise the SPR values of these species and hence improve the sustainability of the fishery. The escape gaps might also be a solution for the overexploitation of *C. fulva*, since this species is characterized by its relatively small size (De Souza et al., 2015; Trott, 2006).

Since the implementation of the St. Eustatius National Marine Park in 1996, a few studies have been performed on the effectiveness of the park in protecting fish species. One study showed higher densities of *C. fulva* inside the no-take reserves than outside the reserves (White et al., 2006). This observation shows the relevance of no-take zones in order to protect *C. fulva*. Since this species is considered to be overfished, it is of great importance that no illegal fishing takes place in the no-take reserves in order to achieve a healthy *C. fulva* population inside and, through the spill-over effect, also outside the reserves.

As stated earlier in the discussion (4.1 Assumptions of the model), one of the assumptions made is that the life history parameters found in literature are the correct life history parameters for the stocks assessed in this study. For the future, one major recommendation would be to study the life history parameters of the local stocks. A change in life history parameters might severely change the SPR of the assessed stock (Hordyk et al., 2014), hence it is essential to use life history parameters that represent the stock under assessment the best way possible.

5. Conclusion

The main goal of this assessment was to analyse the Spawning Potential Ratio (SPR) of ten different reef associated fish species to see if the fish stocks around St. Eustatius are fished in a sustainable way. The SPR was calculated using data from 2012 to 2020 and for all species no clear upward or downward trends in SPR were seen during these eight years.

The results presented in this report state that *A. chirurgus, A. coeruleus* and *C. fulva* might be experiencing overfishing based on SPR values below the 20% replacement level. Two species at risk of overfishing are *A. bahianus* and *O. chrysurus*, since the lower 95% confidence intervals are below the 20% replacement level for at least three years during the study period (2012-2020). *Balistes vetula* is in general expected to be fished sustainably with a small change of overexploitation in 2016. *Epinephelus guttatus, S. viride*, *H. adscensionis* and *M. martinicus* seem to be fished sustainably based on this study.

For *A. bahianus* it would be recommended to catch less smaller individuals, since a big proportion of the catch was below the size of maturation. For the other two Acanthuridae species, *A. chirurgus* and *A. coeruleus*, it would be recommended to lower the overall catch numbers. A possible solution could be escape gaps in the corners of the traps. Research in other areas have shown to effectively reduce the catch of Acanthuridae species and smaller fish in general, without significantly reducing the value per trap. Hence, implementing escape gaps in the traps would be recommended in order to reduce the catch numbers of the overexploited Acanthuridae species and build up healthy stocks.

As a result of the relatively small size of *C. fulva*, escape gaps might also help to reduce the overfishing on this species. Additionally, no-take reserves in the St. Eustatius National Marine Park have shown to hold higher densities of *C. fulva* than areas outside the no-take reserves. Strictly enforcing the no-take zones may be beneficial to the population status inside and outside the reserves.

Regarding the length frequency data, *M. martinicus*, *B. vetula, O. chrysurus* and *S. viride* have a sample size smaller than 400 individuals. For these species, it would be suggested to gather more length frequency data in order to conduct a more robust LB-SPR method assessment for these species. However, for all species assessed in this report, it would be recommended to keep monitoring the SPR in order to detect changes as early as possible. If a downward trend in SPR would be discovered for any species, further protection measures would be necessary.

The fish stocks assessed in this report are from a data-poor situation. Therefore, life history parameters were taken from literature, which means that these parameters are not specific for the stocks assessed in this report. As discussed before, the LB-SPR method uses ratios rather than individual parameters because the ratios are known to vary less between different stocks. However, it would be recommended to gather information on the individual life history parameters of these specific stocks, since a different value for one of the life history parameters could give a different SPR and thus a different conservation strategy. Research priority should be given to the life history parameters of the species with the lowest SPR. Until there is more information available on these specific stocks, in a data-poor fishery like the one on St. Eustatius, the LB-SPR method can be an effective tool to assess the sustainability of the fishery.

Acknowledgements

First of all, I would like to thank the Caribbean Netherlands Science Institute (CNSI) for receiving me as an intern and accommodating me at the institute. Special thanks goes out to my supervisor and promotor Kimani Kitson-Walters, thank you for your time and support during my stay on St. Eustatius and after.

I also would like to thank the whole IMBRSea consortium for giving me the opportunity to participate in such an international and interesting programme. It has been a motivating, informative and enjoyable time thanks to the coordination office, all the teachers and classmates. I also want to express gratitude to the University of the Algarve for the mobility grant they awarded me with, this has been a big help financially.

Last but not least, I want to thank my friends and family that helped and supported me before and during the programme.

References

Alagaraja, K. (2011). Simple Methods for Estimation of Parameters for Assessing Exploited Fish Stocks. *Indian Journal of Fisheries*, 177–208.

Anand, P. E. V., & Pillai, N. G. K. (2002). Reproductive biology of some common coral reef fishes of the Indian EEZ. *The Marine Biological Association of India*, *44*(2), 122–135.

Ault, J. S., Bohnsack, J. A., & Meester, G. A. (1998). A retrospective (1979-1996) multispecies assessment of coral reef fish stocks in the Florida keys. *Fishery Bulletin*, *96*(3), 395–414.

Ault, J. S., Smith, S. G., Luo, J., Monaco, M. E., & Appeldoorn, R. S. (2008). Length-based assessment of sustainability benchmarks for coral reef fishes in Puerto Rico. *Environmental Conservation*, *35*(3), 221–231. https://doi.org/10.1017/S0376892908005043

Ault, J. S., Smith, S. G., Meester, G. A., Luo, J., Bohnsack, J. A., & Miller, S. L. (2002). Baseline Multispecies Coral Reef Fish Stock Assessment for the Dry Tortugas. *Fisheries Science*, (August), 117.

Bervoets, T. (2010). *St. Eustatius National Marine Park: Report on the Economic Valuation of St. Eustatius' Coral Reef Resources*. St Eustatius.

Burton, M. L., Potts, J. C., & Carr, D. R. (2015). Age, growth and natural mortality of coney (Cephalopholis fulva) from the southeastern United States. *PeerJ*, (3). https://doi.org/10.7717/peerj.825

Cardwell, J. R., & Liley, N. R. (1991). Hormonal control of sex and color change in the stoplight parrotfish, Sparisoma viride. *General and Comparative Endocrinology*, *81*(1), 7–20. https://doi.org/10.1016/0016-6480(91)90120-U

Choat, J. H., Robertson, D. R., Ackerman, J. L., & Posada, J. M. (2003). An age-based demographic analysis of the Caribbean stoplight parrotfish Sparisoma viride. *Marine Ecology Progress Series*, *246*, 265–277. https://doi.org/10.3354/meps246265

Cushion, N. (2010). Growth, Reproductive Life-History Traits and Energy Allocation in Epinephelus guttatus (red hind),E. striatus (Nassau Grouper), and Mycteroperca venenosa (yellowfin grouper) (Family Serranidae, Subfamily Epinephelinae). *Open Access Dissertations*.

de Albuquerque, C. Q., Martins, A. S., de Oliveira, L. N., de Araújo, J. N., & Ribeiro, A. M. (2011). Age and growth of the queen triggerfish Balistes vetula (Tetraodontiformes, Balistidae) of the central coast of Brazil. *Brazilian Journal of Oceanography*, *59*(3), 231–239. https://doi.org/10.1590/s1679-87592011000300003

De Graaf, M., Piontek, S., Miller, D. C. M., Brunel, T., & Nagelkerke, L. A. J. (2015). *Status and trends of St. Eustatius coral reef ecosystem and fisheries: 2015 report card*.

De Souza, A. S., Dias Júnior, E. A., Galetti, P. M., Machado, E. G., Pichorim, M., & Molina, W. F. (2015). Wide-range genetic connectivity of Coney, Cephalopholis fulva (Epinephelidae), through oceanic islands and continental Brazilian coast. *Anais Da Academia Brasileira de Ciencias*, *87*(1), 121–136. https://doi.org/10.1590/0001-3765201520130411

Debrot, A. O., Houtepen, E., Meesters, E. H., Van Beek, I., Timmer, T., Boman, E., … Ballantine, D. L. (2014). *Habitat diversity and bio-diversity of the benthic seascapes of St. Eustatius*.

Dooley, J., Collette, B. B., Aiken, K. A., Marechal, J., Pina Amargos, F., Kishore, R., & Singh-Renton, S. (2015). Mulloidichthys martinicus. Retrieved July 25, 2020, from https://www.iucnredlist.org/species/190429/1951474

Dutch Caribbean Nature Alliance. (n.d.). St. Eustatius National Marine Park. Retrieved July 25, 2020, from https://www.dcnanature.org/st-eustatius-national-marine-park/

Ernawati, T., & Budiarti, T. W. (2020). IOP Conference Series: Earth and Environmental Science Life history and length base spawning potential ratio (LBSPR) of malabar snapper Lutjanus malabaricus (Bloch & Schneider, 1801) in western of South Sulawesi, Indonesia. *IOP Conference Series: Earth and Environmental Science*, *404*(1), 12–23. https://doi.org/10.1088/1755-1315/404/1/012023

Figuerola, M., Matos-Caraballo, D., & Torres, W. (1998). Maturation and Reproductive Seasonality of Four Reef Fish Species in Puerto Rico, 938-968.

Food and Agriculture Organization of the United Nations. (2018). *The State of World Fisheries and Aquaculture 2018 - Meeting the sustainable development goals*. Rome.

Glynn, P. W., & Manzello, D. P. (2015). Bioerosion and coral reef growth: A dynamic balance. In *Coral Reefs in the Anthropocene* (pp. 67–97). Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-94-017-7249-5_4

Gomes, I., Erzini, K., & Mcclanahan, T. R. (2014). Trap modification opens new gates to achieve sustainable coral reef fisheries. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *24*, 680–695. https://doi.org/10.1002/aqc.2389

Hallock, P. (2015). Changing influences between life and limestones in earth history. In *Coral Reefs in the Anthropocene* (pp. 17–42). Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-94-017-7249-5_2

Hawkins, J. P., Roberts, C. M., Gell, F. R., & Dytham, C. (2007). Effects of trap fishing on reef fish communities. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *17*(2), 111–132. https://doi.org/10.1002/aqc.784

Hommik, K., Fitzgerald, C. J., Kelly, F., & Shephard, S. (2020). Dome-shaped selectivity in LB-SPR: Length-Based assessment of data-limited inland fish stocks sampled with gillnets. *Fisheries Research*, *229*, 105574. https://doi.org/10.1016/j.fishres.2020.105574

Hordyk, A. R. (2019). LBSPR: Length-Based Spawning Potential Ratio.

Hordyk, A. R., Loneragan, N. R., & Prince, J. (2015). An evaluation of an iterative harvest strategy for data-poor fisheries using the length-based spawning potential ratio assessment methodology. *Fisheries Research*, *171*, 20–32. https://doi.org/10.1016/j.fishres.2014.12.018

Hordyk, A. R., Ono, K., Prince, J. D., & Walters, C. J. (2016). A simple length-structured model based on life history ratios and incorporating size-dependent selectivity: Application to spawning potential ratios for data-poor stocks. *Canadian Journal of Fisheries and Aquatic Sciences*, *73*(12), 1787–1799. https://doi.org/10.1139/cjfas-2015-0422

Hordyk, A. R., Ono, K., Sainsbury, K., Loneragan, N. R., & Prince, J. (2015). Some explorations of the life history ratios to describe length composition, spawning-per-recruit, and the spawning potential ratio. *ICES Journal of Marine Science*, *72*(1), 204–216. https://doi.org/10.1093/icesjms/fst235

Hordyk, A. R., Ono, K., Valencia, S., Loneragan, N. R., & Prince, J. (2014). A novel length-based empirical estimation method of spawning potential ratio (SPR), and tests of its performance, for small-scale, data-poor fisheries. *ICES Journal of Marine Science*, *72*(1), 217–231. https://doi.org/10.1093/icesjms/fsu004

ICES. (2012). *ICES Implementation of Advice for Data-limited Stocks in 2012 in its 2012 Advice*.

Jackson, J. B. C., Donovan, M. K., Cramer, K. L., & Lam, V. V. (2014). *Status and Trends of Caribbean Coral Reefs*. Gland, Switzerland.

Johnson, A. E. (2010). Reducing bycatch in coral reef trap fisheries: escape gaps as a step towards sustainability. *Marine Ecology Progress Series*, *415*, 201–209. https://doi.org/10.3352/meps08762

Julie K. Nielsen, & Andrew C. Seitz. (2017). Interannual site fidelity of Pacific halibut: potential utility of protected areas for management of a migratory demersal fish. *ICES Journal of Marine Science*, *73*(3), 849–864. https://doi.org/10.1093/ICESJMS

Langlois, T. J., Newman, S. J., Cappo, M., Harvey, E. S., Rome, B. M., Skepper, C. L., & Wakefield, C. B. (2015). Length selectivity of commercial fish traps assessed from in situ comparisons with stereo-video: Is there evidence of sampling bias? *Fisheries Research*, *161*, 145–155. https://doi.org/10.1016/j.fishres.2014.06.008

Liu, J., Zapfe, G., Shao, K.-T., Leis, J. L., Matsuura, K., Hardy, G., … Tyler, J. (2015). Balistes vetula (errata version published in 2016). *The IUCN Red List of Threatened Species 2015*.

Mardones, M., & Hordyk, A. R. (2019). *LBSPR: An R package for simulation and estimation using life-history ratios and length composition data. An aplication in Clam Fisheries Southern Chile.*

Marques, S. (2011). *Reprodução, Idade e Crescimento de Três Espécies da Família Epinephelidae no Litoral de Pernambuco*. Universidade Ferdera de Pernambuco, Pernambuco.

Mbaru, E. K., & McClanahan, T. R. (2013). Escape gaps in African basket traps reduce bycatch while increasing body sizes and incomes in a heavily fished reef lagoon. *Fisheries Research*, *148*, 90–99. https://doi.org/10.1016/j.fishres.2013.08.011

Moore, J., Polanco Fernandez, A., Russell, B., & McEachran, J. D. (2015). Holocentrus adscensionis. Retrieved July 25, 2020, from https://www.iucnredlist.org/species/16442472/16509817

Munro, J. L. (1983a). *Caribbean Coral Reef Fishery Resources*. (J. L. Munro, Ed.). Manila: International Center for Living Aquatic Resources Management.

Munro, J. L. (1983b). Epilogue: Progress in coral reef fisheries research: 1973-1982. *Carribean Coral Reef Fishery Ressources*, 276.

Mutz, S. J. (2006). *Comparative Growth Dynamics of Acanthurid Fishes*. James Cook University.

Nadon, M. O. (2019). Stock Assessment of Guam Coral Reef Fish, 2019. https://doi.org/10.25923/pyd6-7k49

Nagelkerken, I., & Faunce, C. H. (2007). Colonisation of artificial mangroves by reef fishes in a marine seascape. *Estuarine, Coastal and Shelf Science*, *75*(3), 417–422. https://doi.org/10.1016/j.ecss.2007.05.030

Nations, F. and A. O. of the U. (n.d.). 7. Biological overfishing of tropical stocks. Retrieved July 10, 2020, from http://www.fao.org/3/x6845e/X6845E07.htm

Prince, J. (2003). The barefoot ecologist goes fishing. *Fish and Fisheries*, *4*(4), 359–371. https://doi.org/10.1046/j.1467-2979.2003.00134.x

Prince, J. (2017). *Length Based Assessment of the Spawning Potential of Reef Fish from iQoliqoli Cokovata in Macuata: A Case study from Fiji*. Suva, Fiji.

Prince, J., Creech, S., Madduppa, H., & Hordyk, A. R. (2020). Length based assessment of spawning potential ratio in data-poor fisheries for blue swimming crab (Portunus spp.) in Sri Lanka and Indonesia: Implications for sustainable management. *Regional Studies in Marine Science*, *36*, 101309. https://doi.org/10.1016/j.rsma.2020.101309

Prince, J., Hordyk, A. R., Valencia, S. R., Loneragan, N. R., & Sainsbury, K. (2015). Revisiting the concept of Beverton-–Holt life-history invariants with the aim of informing data-poor fisheries assessment. *ICES Journal of Marine Science*, *72*(1), 194–203. https://doi.org/10.1093/icesjms/fsu011

Prince, J., Lalavanua, W., Tamanitoakula, J., Loganimoce, E., Vodivodi, T., Marama, K., … Mangubhai, S. (2019). *Spawning potential surveys reveal an urgent need for effective management*.

R Core Team. (2018). R: A Language and Environment for Statistical Computing. Vienna, Austria.

Rivera-Hernández, J. M., Peña Alvarado, N., Correa Vélez, K., Nemeth, R., Appeldoorn, R. S., & Shervette, V. (2019). Queen Triggerfish Reproductive Biology in U.S. Caribbean Waters. *Transactions of the American Fisheries Society*, *148*(1), 134–147. https://doi.org/10.1002/tafs.10124

Rudd, M. B. (2017). *Accounting for Variability and Biases in Data-limited Fisheries Stock Assessment*. University of Washington.

Sadovy, Y., Rosario, A., & Román, A. (1994). Reproduction in an aggregating grouper, the red hind, Epinephelus guttatus. In *Women in ichthyology: an anthology in honour of ET, Ro and Genie* (pp. 269–286). Springer Netherlands. https://doi.org/10.1007/978-94-011-0199-8_21

Shinozaki-Mendes, R. A., Vieira Hazin, F. H., De Oliveira, P. G., & De Carvalho, F. C. (2007). Reproductive biology of the squirrelfish, Holocentrus adscensionis (Osbeck, 1765), caught off the coast of Pernambuco, Brazil. *Scientia Marina*, *71*(4), 715–722. https://doi.org/10.3989/scimar.2007.71n4715

Slipke, J. W., Martin, A. D., Pitlo, J., & Maceina, M. J. (2002). Use of the Spawning Potential Ratio for the Upper Mississippi River Channel Catfish Fishery. *North American Journal of Fisheries Management*, *22*(4), 1295–1300. https://doi.org/10.1577/1548-8675(2002)022<1295:UOTSPR>2.0.CO;2

Smith, S. J., Hunt, J. J., & Rivard, D. (1993). *Risk Evaluation and Biological Reference Points for Fisheries Management*.

Spalding, M. D., Ravilious, C., & Green, E. P. (2001). *World Atlas of Coral Reefs* (9th ed.). London: The University of California Press.

STENAPA. (n.d.). St. Eustatius National Parks. Retrieved April 8, 2020, from https://www.statiapark.org/our-park/

Stevenson, D. K., & Stuart-Sharkey, P. (1980). Performance of Wire Fish Traps on the Western Coast of Puerto Rico. *Proceedings of the 32nd Annual Gulf and Caribbean Fisheries Institute*, 173–193.

Thórarinsson, K., & Jóhannesson, G. (1997). Correcting for variation in catchability: maturity-related catchability variation in Icelandic cod. *ICES Journal of Marine Science*, *54*(5), 787–796. https://doi.org/10.1006/jmsc.1996.0199

Trejo-Martínez, J., Brulé, T., Mena-Loría, A., Colás-Marrufo, T., & Sánchez-Crespo, M. (2011). Reproductive aspects of the yellowtail snapper Ocyurus chrysurus from the southern Gulf of Mexico. *Journal of Fish Biology*, *79*(4), 915–936. https://doi.org/10.1111/j.1095-8649.2011.03062.x

Trott, T. M. (2006). *Preliminary Analysis of Age, Growth, and Reproduction of Coney (Cephalopholis fulva) at Bermuda*.

Walters, C. J., & Martell, S. J. D. (2004). *Fisheries Ecology and Management*. Princeton University Press.

White, J., Esteban, N., & Polino, M. (2006). *Fisheries Baseline Assessment of Fisheries Baseline Assessment of Fisheries Baseline Assessment of Fisheries Baseline Assessment of Statia Marine*

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Wilson, S. C., Trukhanova, I., Dmitrieva, L., Dolgova, E., Crawford, I., Baimukanov, M., … Goodman, S. J. (2017). Assessment of impacts and potential mitigation for icebreaking vessels transiting pupping areas of an ice-breeding seal. *Biological Conservation*, *214*, 213–222. https://doi.org/10.1016/J.BIOCON.2017.05.028

Wolfe, S. M. (2003). *Age, Growth and the Annual Cycles of lipogenesis and Reproduction of Acanthurus bahianus in Southeastern Florida NSUWorks Citation*.

Annex

Annex A – List of gear

Scientific name	Diving Free	Diving Scuba	Handline	Pot	Total
Acanthurus coeruleus	0	0	11	3296	**3307**
Holocentrus adscensionis	0	53	11	1363	**1427**
Epinephelus guttatus	0	205	69	986	**1260**
Acanthurus chirurgus	0	12	0	1032	**1044**
Acanthurus bahianus	0	0	0	623	**623**
Cephalopholis fulva	0	76	25	473	**574**
Sparisoma viride	4	59	0	326	**389**
Balistes vetula	2	35	0	319	**356**
Mulloidichthys martinicus	0	0	1	233	**234**
Ocyurus chrysurus	0	2	0	208	**210**
	6	**442**	**117**	**8859**	**9424**

Annex B – Total length and fork length

Common name	Scientific name	Total length (TL) or Fork length (FL)
Blue tang	*Acanthurus coeruleus*	FL
Coney	*Cephalophilis fulva*	TL
Doctorfish	*Acanthurus chirurgus*	FL
Ocean surgeon	*Acanthurus bahianus*	FL
Queen Triggerfish	*Balistes vetula*	TL
Red Hind	*Epinephelus guttatus*	TL
Squirrelfish	*Holocentrus adscensionis*	FL
Stoplight Parrotfish	*Sparisoma viride*	FL
Yellow Goat Fish	*Mulloidichthys martinicus*	FL
Yellowtail Snapper	*Ocyurus chrysurus*	FL

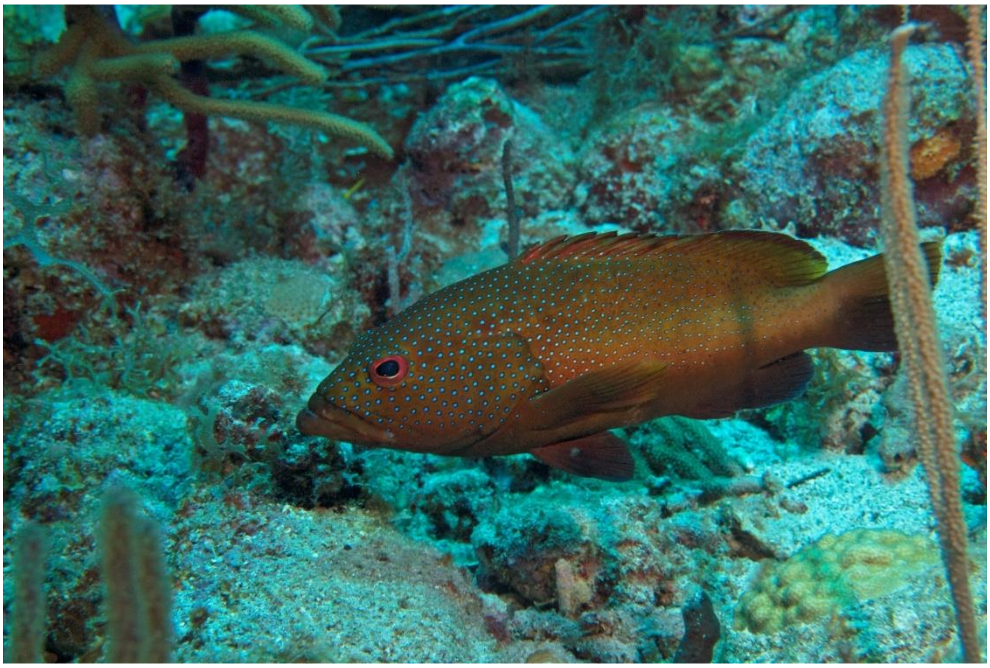
Annex C – Pictures of assessed species

Species 1: Ocean surgeonfish - Acanthurus bahianus*. Photo by Mark Bockstael, Dutch Caribbean Species Register, www.dutchcaribbeanspecies.org. License: CC BY.*

Species 2: Doctorfish - Acanthurus chirurgus*. Photo by Marta Rubio, Dutch Caribbean Species Register, www.dutchcaribbeanspecies.org. License: CC BY.*

Species 3: Blue tang - Acanthurus coeruleus*. Photo by Marion Haarsma, Dutch Caribbean Species Register, www.dutchcaribbeanspecies.org. License: CC BY-NC-ND.*

Species 4: Queen Triggerfish - Balistes vetula*. Photo by Floris Bennema, Dutch Caribbean Species Register, www.dutchcaribbeanspecies.org. License: CC BY-NC-ND.*



Species 5: Coney - Cephalopholis fulva*. Photo by Marion Haarsma, Dutch Caribbean Species Register, www.dutchcaribbeanspecies.org. License: CC BY-NC-ND.*

Species 6: Red hind - Epinephelus guttatus*. Photo by Marion Haarsma, Dutch Caribbean Species Register, www.dutchcaribbeanspecies.org. License: CC BY-NC-ND.*

Species 7: Squirrelfish - Holocentrus adscensionis*. Photo by Marion Haarsma, Dutch Caribbean Species Register, www.dutchcaribbeanspecies.org. License: CC BY-NC-ND.*

Species 8: Yellow Goatfish - Mulloidichthys martinicus*. Photo by Marion Haarsma, Dutch Caribbean Species Register, www.dutchcaribbeanspecies.org. License: CC BY-NC-ND.*

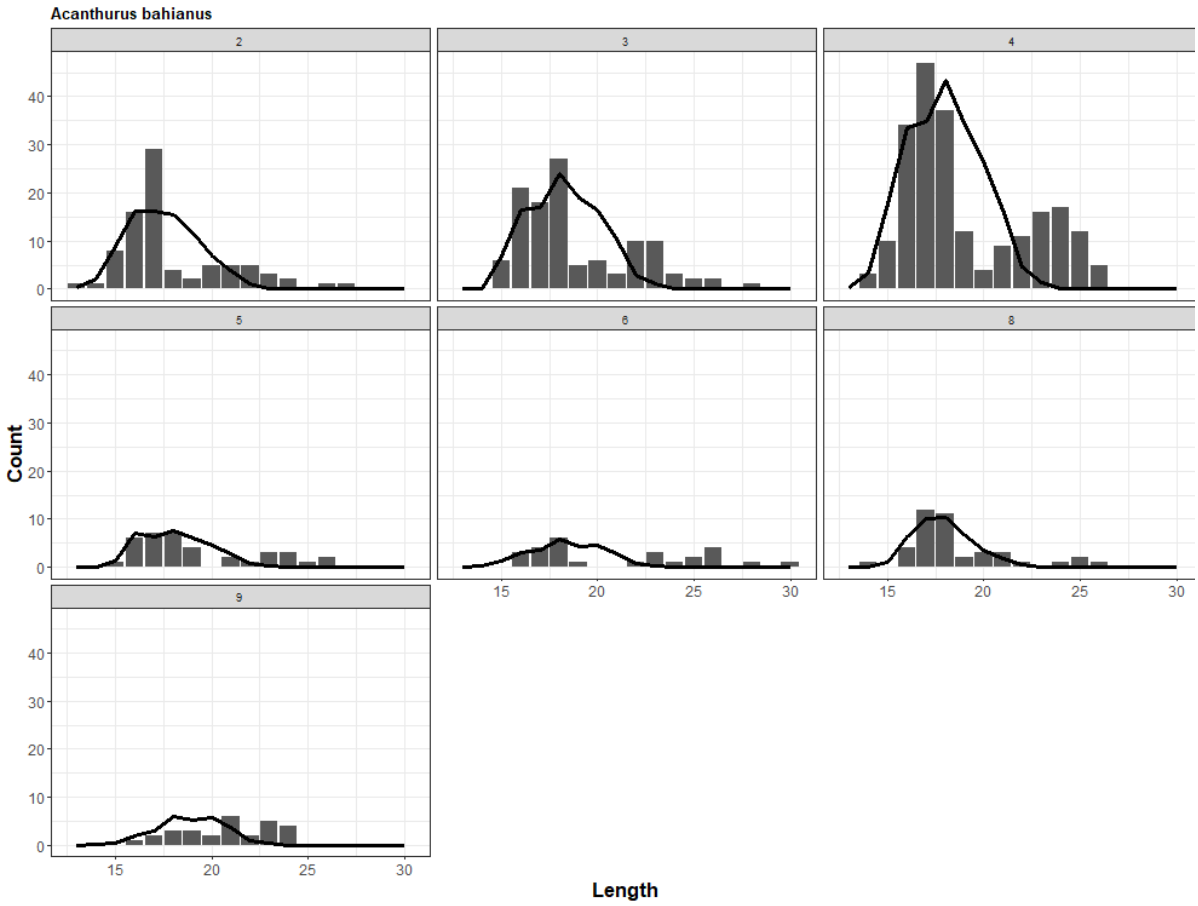
Species 9: Yellowtail Snapper - Ocyurus chrysurus*. Photo by Floris Bennema, Dutch Caribbean Species Register, www.dutchcaribbeanspecies.org. License: CC BY-NC-ND.*

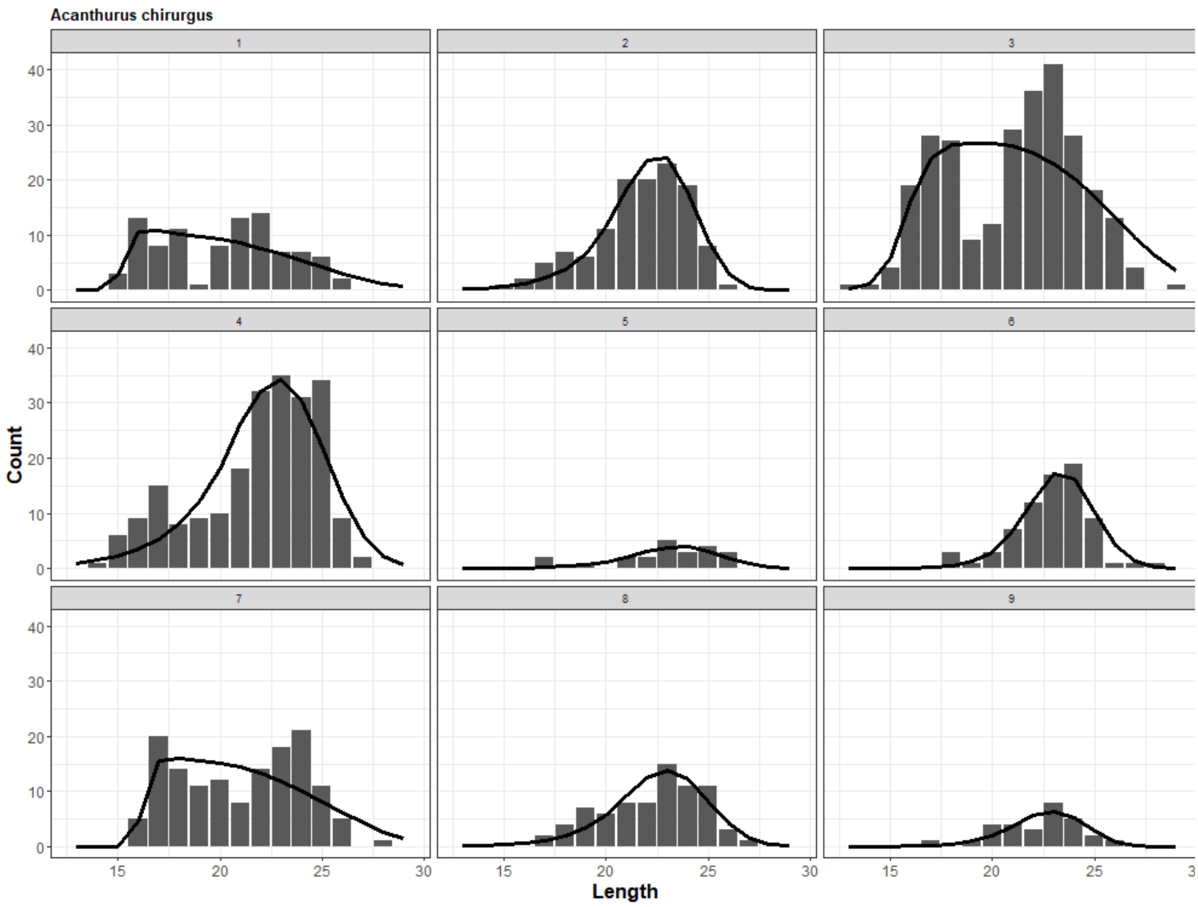
Species 10: Stoplight Parrotfish - Sparisoma viride*. Photo by Marion Haarsma, Dutch Caribbean Species Register, www.dutchcaribbeanspecies.org. License: CC BY-NC-ND.*

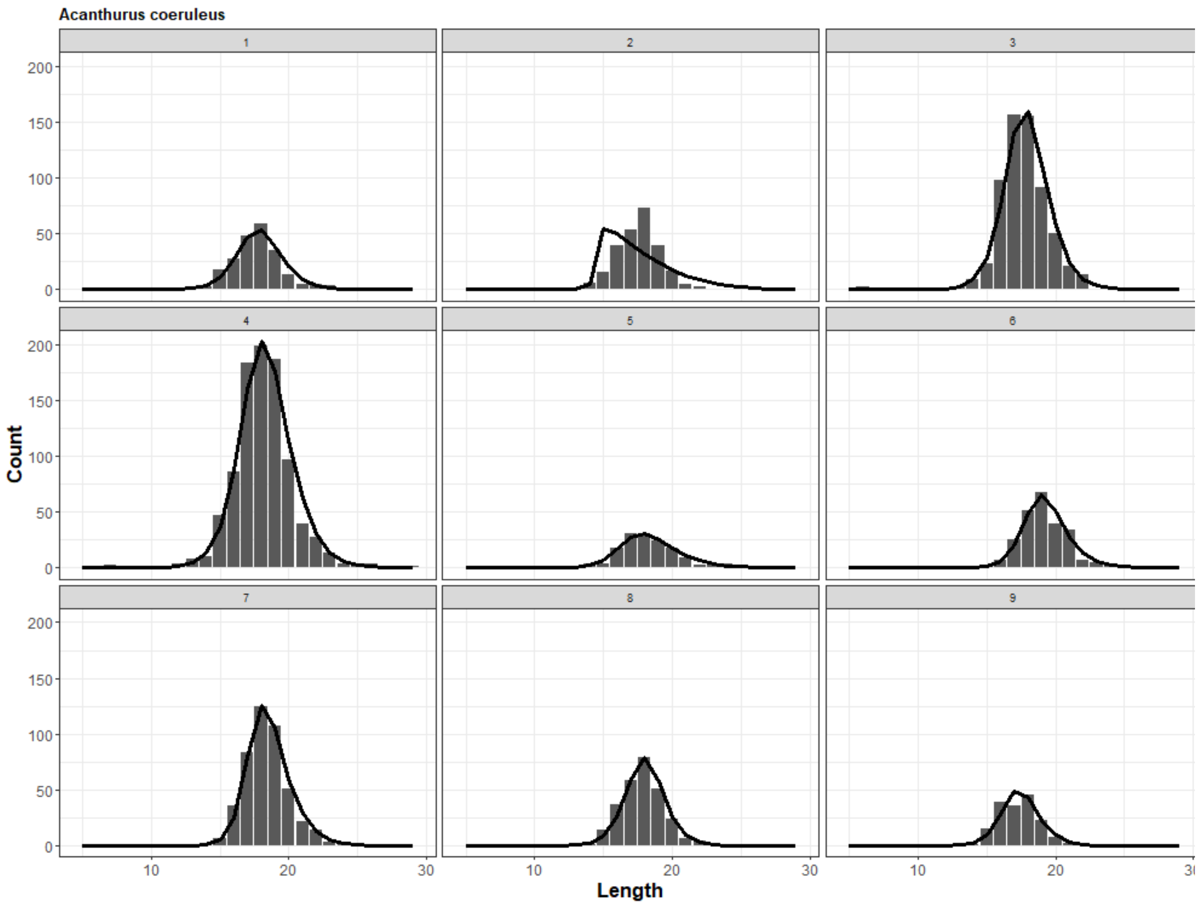
Annex D – Length frequency distribution with fitted LB-SPR model

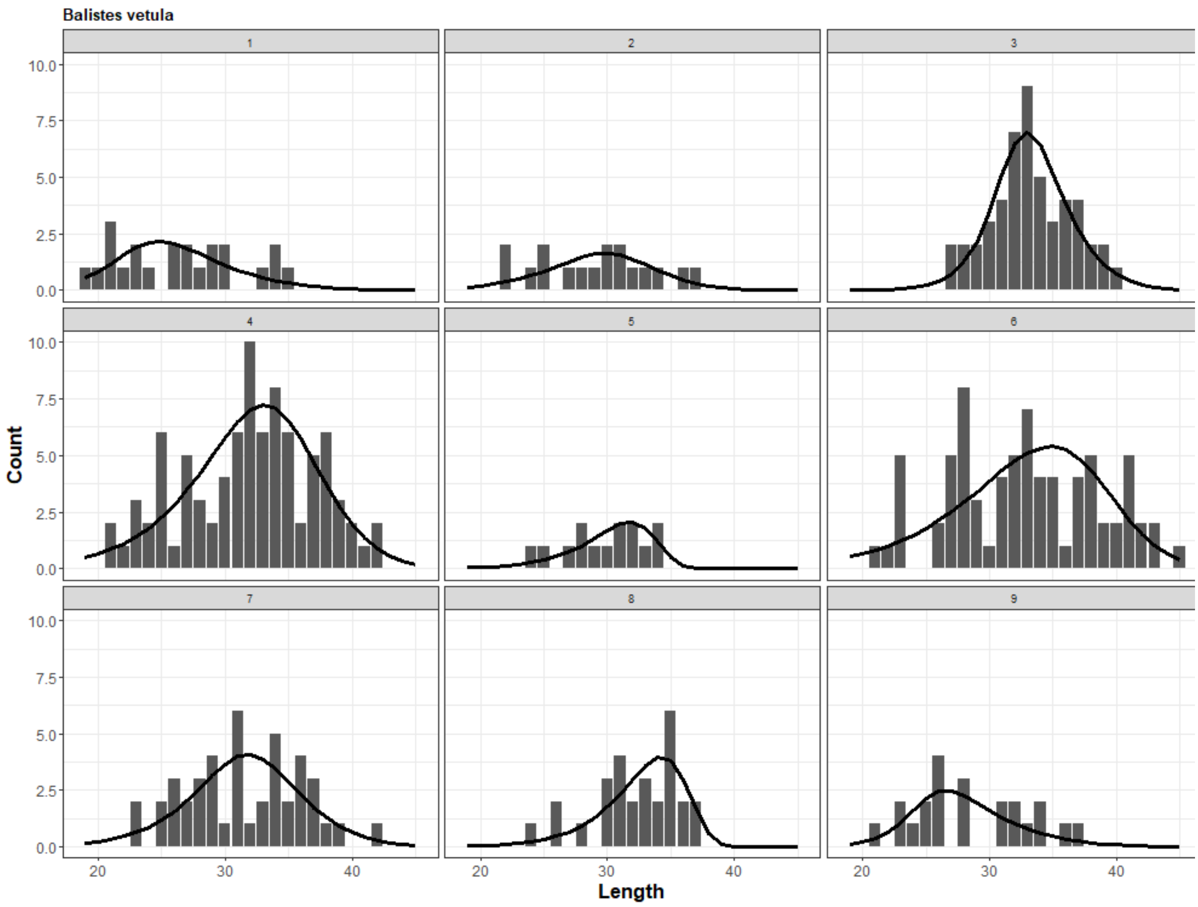
Length frequency distributions of the ten different species studied in this assessment. The graphs are split up in different length frequency distributions for different years, on top of each graph the grey bar with a number that stand for a certain year. Number 1 stands for 2012, number 9 stands for 2020, with in the top-left corner the first year of the assessment and in the bottom the latest year.

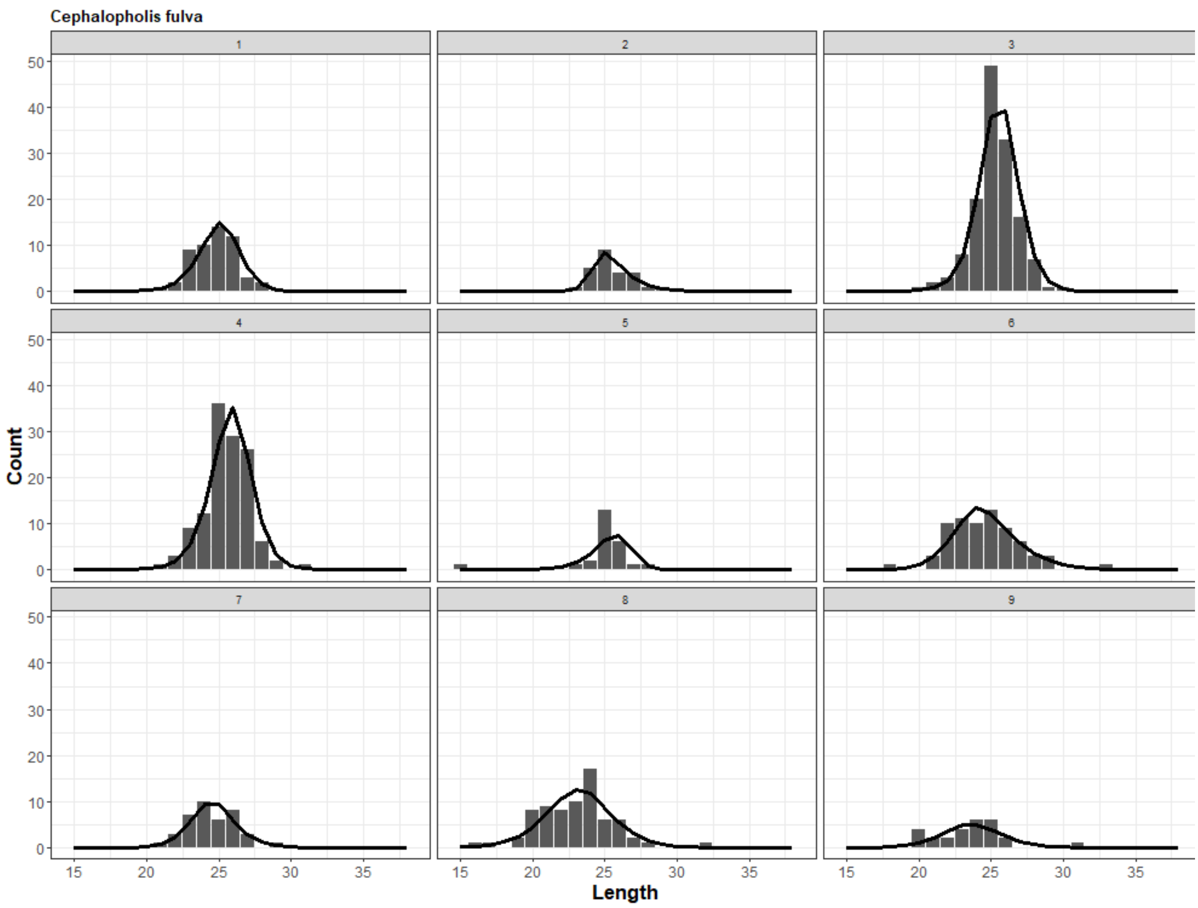
The length is given in centimetres and on the y-axis the frequency. The dark grey bars represent the amount of times a fish of a certain length class was caught and the black line represents the fitted LB-SPR model.

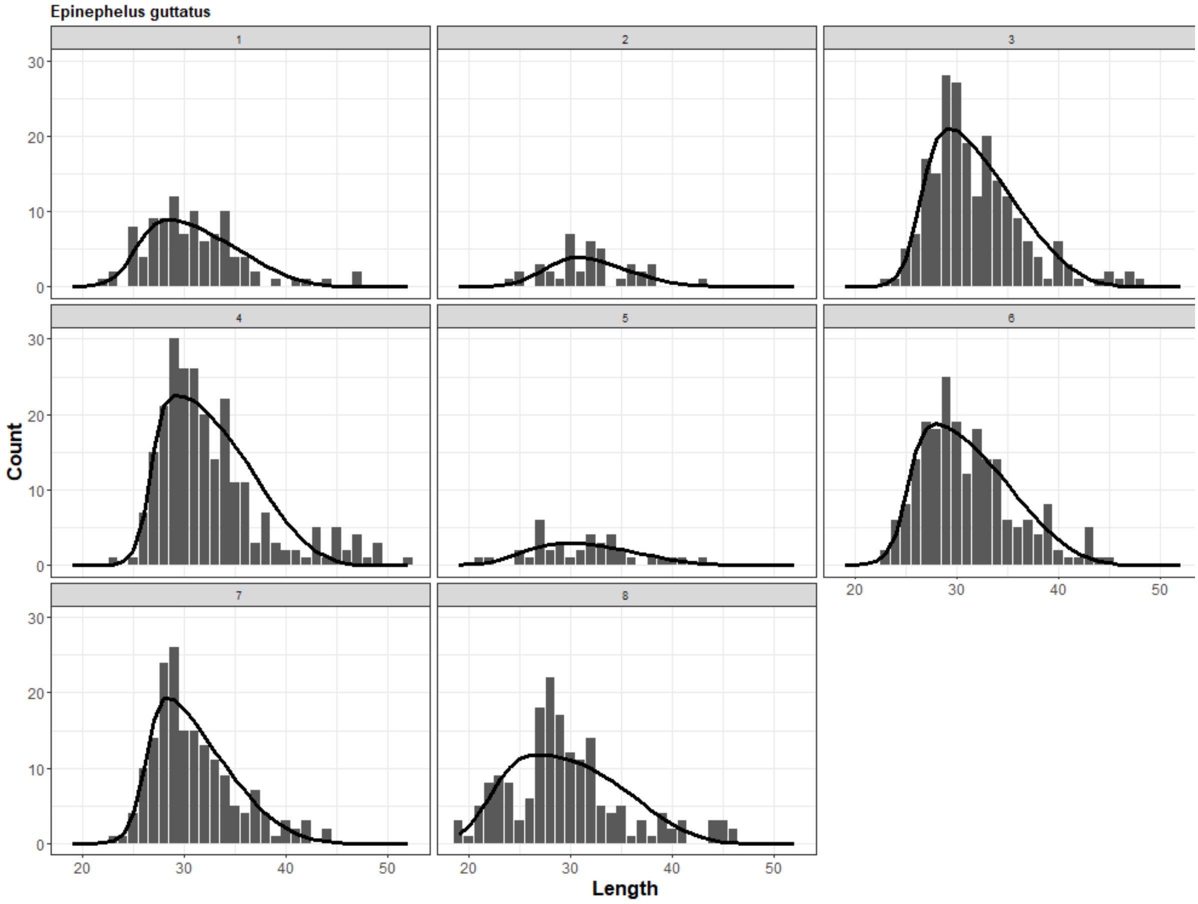


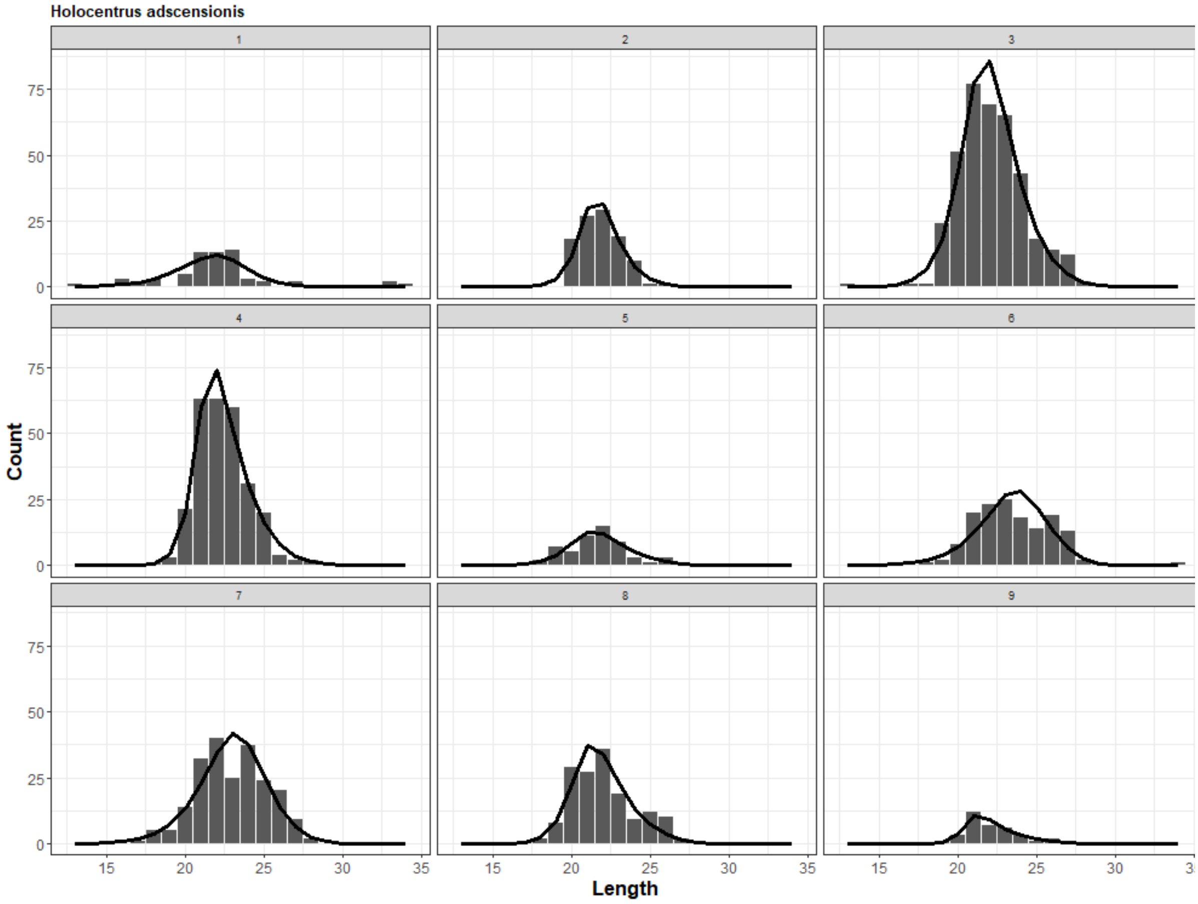

Acanthurus chirurgus
Count
Length


Acanthurus coeruleus
Count
Length


Balistes vetula
1
2
3
4
5
6
7
8
9
Count
Length


Cephalopholis fulva
1
2
3
4
5
6
7
8
9
Count
Length


Epinephelus guttatus
1
2
3
4
5
6
7
8
Count
Length
0
10
20
30
20
30
40
50


Holocentrus adscensionis
1
2
3
4
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6
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8
9
Count
Length
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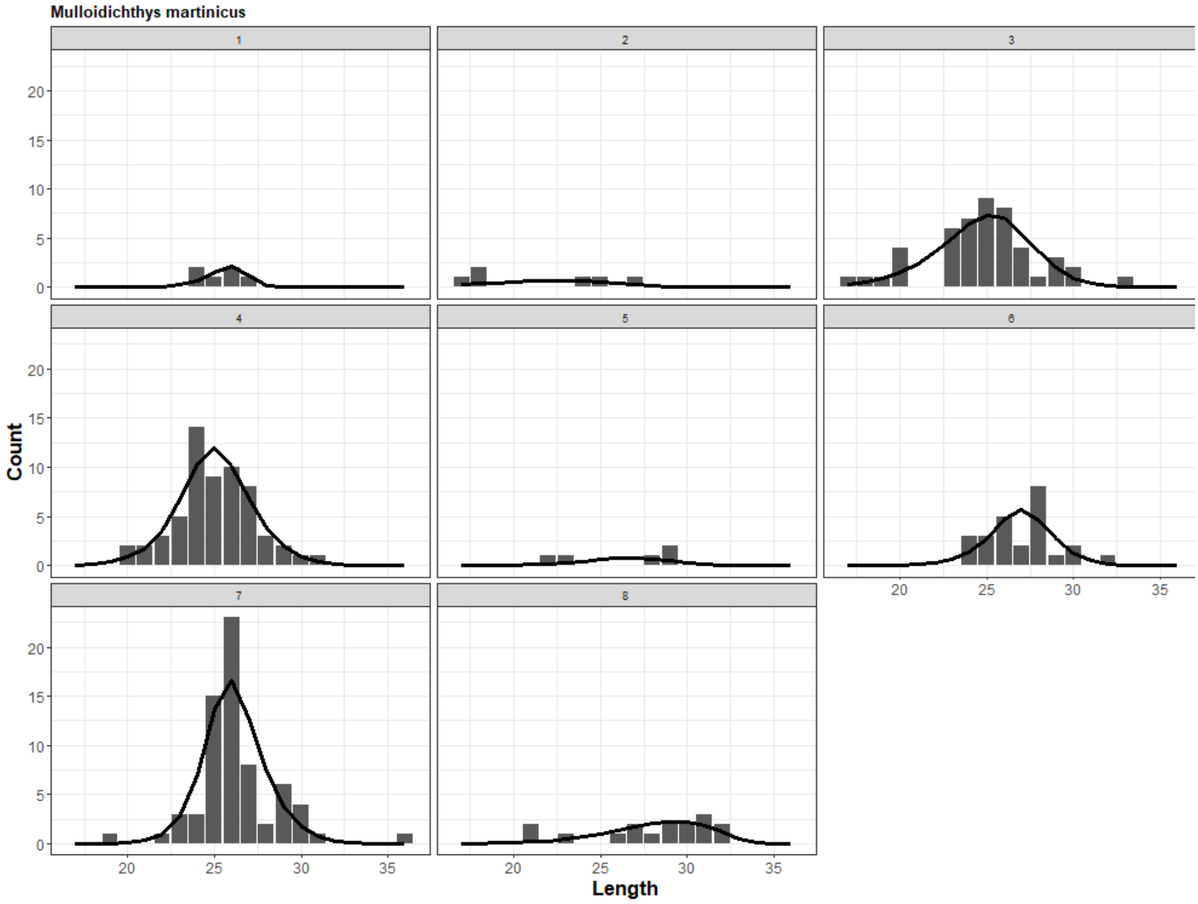
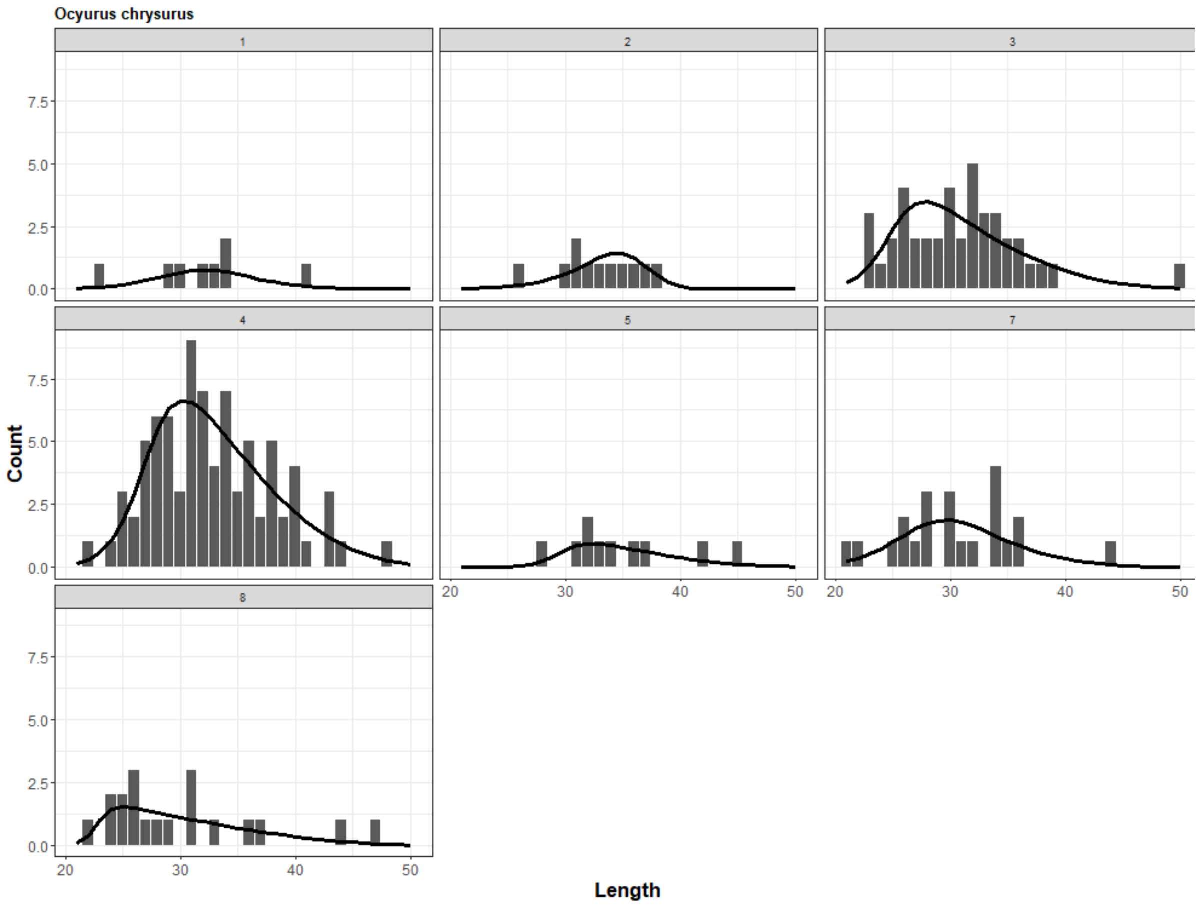
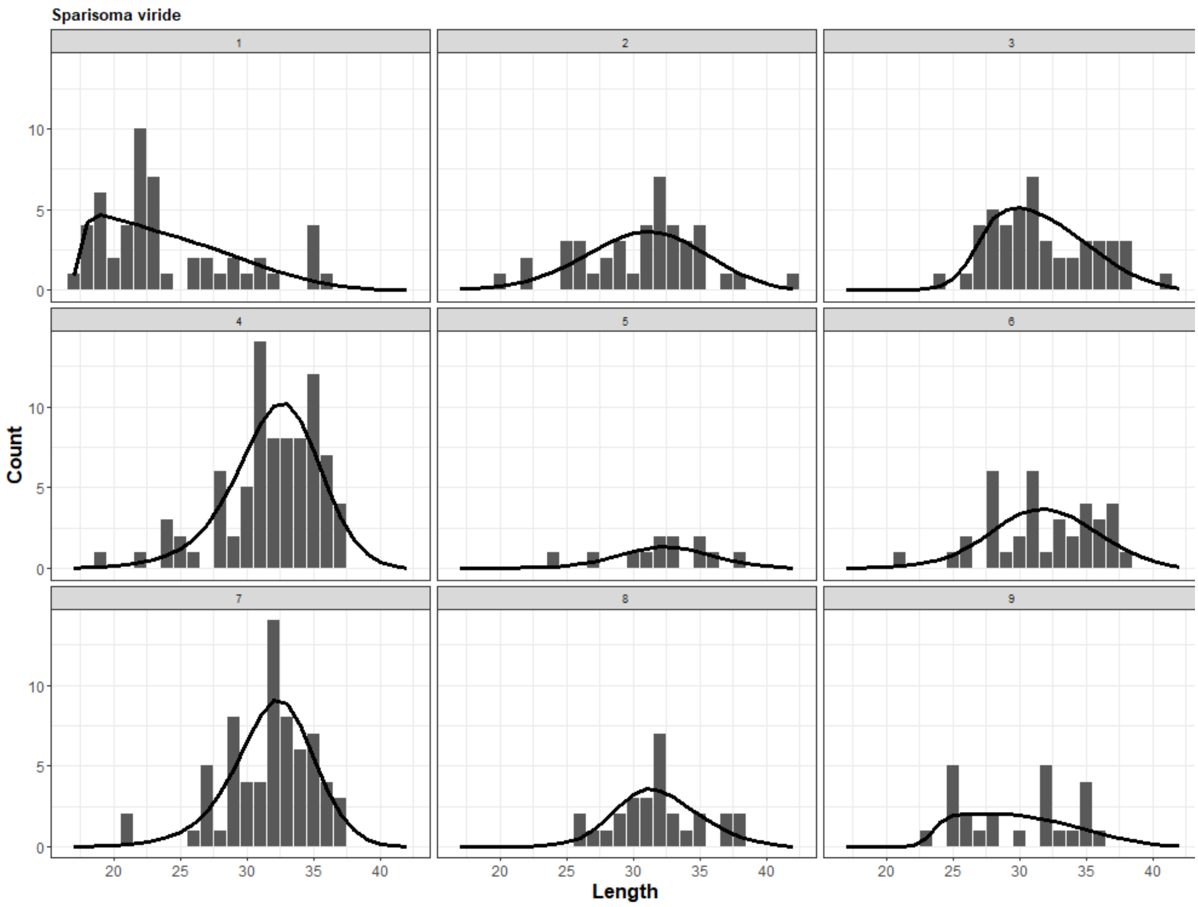
25
50
75
15
20
25
30
35


Mulloidichthys martinicus
1
2
3
4
5
6
7
8
Count
Length


Ocyurus chrysurus
1
2
3
4
5
7
8
Count
Length


Sparisoma viride
1
2
3
4
5
6
7
8
9
Count
Length
0
5
10
20
25
30
35
40