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# Stock assessment of the Southern Indian Ocean St. Paul and Amsterdam rock lobster stocks using statistical catch at age

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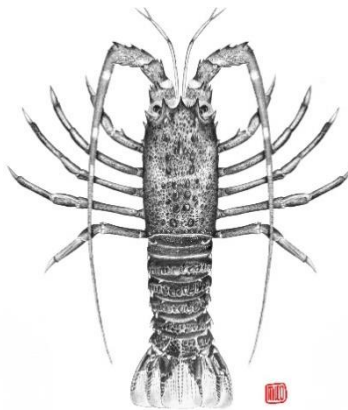
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September 2021

# STOCK ASSESSMENT OF THE SOUTHERN INDIAN OCEAN ST. PAUL AND AMSTERDAM ROCK LOBSTER STOCKS USING STATISTICAL CATCH AT AGE

Fishing campaign 2020-2021



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**Front page image:** *Jasus paulensis* (Heller, 1862) by N. Gasco, all rights reserved.

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**Details of contributions:**

Abstract: JS,

Introduction: JS

Materials and methods: JS

Results: JS,

Discussion: : JS

Clara Péron and Félix Massiot-Granier reviewed this document.

# 1. Abstract

This report presents new stock assessments for the rock lobster (*Jasus paulensis*) fishery of the Saint Paul and Amsterdam islands with data up to the last fishing campaign of 2020/21. These new assessments are based on statistical catch at age models using all available data except tagging program data.

Stock status trajectories for both stocks start from a period of unsustainable fishing in the 1980s and recovered in the 1990s. The assessment results indicate that exploitable biomass in 2020 is likely to be well above *BMSY*, biomass status ( $B/BMSY$ ) are 1.09 (0.86 - 1.50) and 2.12 (1.66 – 2.92) for Saint Paul and Amsterdam stocks respectively, and that fishing mortality is well below *FMSY*. These estimates are consistent with the results of preliminary assessment from biomass dynamic models.

The short-term projection scenarios that were tested show that current catch levels are compatible with the sustainability of the rock lobster stocks.

**KEYWORDS:** *Jasus paulensis*, Rock lobster, Saint Paul and Amsterdam islands, Statistical catch at age, Assessment, Population dynamic.

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## 2. Introduction

St. Paul and Amsterdam (SPA) islands are part of the French Southern and Antarctic Territories (TAAF) and are located in the subtropical zone of the South Indian Ocean. Initially focused on the exploitation of fur seals (*Arctocephalus tropicalis*) and demersal fishes, these islands have been exploited annually for rock lobsters (*Jasus paulensis*) since 1948.

Since 1995, the fishery has been managed by setting annual total allowable catches (TAC) for the rock lobster as well as technical prescriptions to control the fishing effort (e.g. fishing period, authorized fishing gear, mandatory fishing logbook, trap mesh size, legal-size of first catch, control of discards). Fishery observers are present on all fishing trips to collect biological and statistical data and complete logbooks. They monitor and transmit every week the catch data and the biological data collected onboard. Landings are controlled by an independent company and are matched with the observer data.

The key indicator for setting TAC is the Catch per Unit Effort (CPUE) trend, based on data of lobster catches per pot (by weight) and the numbers of pots recorded. Until now, the nominal CPUE was used directly without standardization based on the rationale that the fishing period, area and method have been kept throughout the time series. Until 2020, the fishery was managed to maintain the CPUE at the level of the long-term average and total catches have historically fluctuated between 350 and 400 tons per year. In 2020, a harvest control rule was set with a CPUE target corresponding to a reference period (2001 – 2010).

The stock assessment was performed over the period 1986-2020 using a4a model (Jardim et al., 2015), over age classes ranging from 3 to 9+. The a4a model is a statistical catch at age model (SCA), allowing flexibility to fit a wide range of models to the data.

## 3. Methodology

### Description of the fleet

Since 1980 and the introduction of fisheries monitoring, the fishing fleet is composed of a single mother ship, the “Austral”, which targets and lands mainly rock lobster fished from 4 coastal (operating in-depth inferior to 50 m) canots (“doris”) setting wooden pots in the kelp zone and 2 pilothouse fishing boats (“caseyeurs”) in the deepest area (operating in depth from 70 to 400 m) with lines of 20 steel pots. Rock lobsters are transshipped and weighted to the mother ship where catches are processed on the onboard factory. Fishing takes place during the austral

summer between the end of November of the year  $t$  and May of the year  $t + 1$  during which the vessel makes two fishing trips of approximately the same duration (two and a half months).

Before this period, the fishery suffered from the reckless fishing effort (legal and illegal) of the 1970s with catches reaching over 1 100 tons per year (Pruvost et al. 2015).

### Fishery data

All the fishery data gathered by observers aboard is stored in the “Pecheker” database host at MNHN Paris (Martin et al. 2021). Catch and effort data from commercial fisheries in SPA French EEZ are available for the period 1980-2020.

The daily data on pot fishing operations include information such as fishing date, area, number of traps deployed and total catches per species in numbers and weight and biological data.

### Biological data

High densities of rock lobsters, *J. paulensis*, have only been observed off St. Paul and Amsterdam. Lower numbers have been reported on seamounts along the South West Indian Ridge (Romanov 2003). The population in SPA is thought to form a single genetic stock, exchanging by larval dispersal between the two islands. A similar pattern was observed in *J. tristani*, synonymized species (Groeneveld et al. 2012), in the Tristan da Cunha archipelago. No genetic differentiation could be found between rock lobsters caught on the four islands separated by distances of up to 400 km, and depths that form a barrier to inter-island benthic migration of adults (von der Heyden et al., 2007). However, based on the different patterns in growth and demographic structures each island is used as an individualized area for the assessment of *J. paulensis*.

The sampling program collects biological data on a daily basis after transshipment from the small operating fishing vessels to the mother ship. It includes carapace length (CL), sex and weight of all sampled rock lobsters from 1986-2020. Ovigerous females are not present during the fishing season but are found throughout the austral winter and immature individuals below the legal size of 5.6 cm CL are released alive directly from small operating fishing vessels.

### Input data

#### Growth and maturity

The only available information on the growth of St Paul rock lobster is found in Grua (1960). Females reach sexual maturity at 6.5-7.5 cm CL (Grua, 1960), which would be equivalent to about 5-7 years after post-larval settlement. Other information from *J. tristani* (Tristan rock



lobsters) can be found in Pollock and Roscoe (1977) and Pollock (1981) and have been used by Johnston et al. (2013) for the assessment of Tristan rock lobster. Females reach 50% maturity at 5.6 cm CL at Inaccessible Is. and 5.9 cm CL at Nightingale Is. (Pollock and Roscoe, 1987, Pollock 1991). This information is based on tagging studies conducted in the 1970s.

In order to calculate length at age, parameters values for the von Bertalanffy growth function are presented in Table 1.

**TABLE 1 : ESTIMATED GROWTH PARAMETERS FROM THE SP AND AM FISHERY AND LITTERATURE.**

<b>Stock</b>	<b>Sex</b>	<b>k</b>	<b>L<sub>∞</sub></b>
Amsterdam	Males	0.11*	15.9**
	Females	0.06*	12.7**
Saint Paul	Males	0.11*	15.9**
	Females	0.06*	12.7**

\* estimates from Pollock and Roscoe (1977) and Pollock (1991)

\*\* 90% of the maximum CL observed in SPA (including outer banks)

The growth curve parameters above are based on mature lobsters (5.6 cm and larger). The growth of immature male and female spiny lobsters is similar, and it is only at maturity that the growth rate slows \*for females. The growth of immature individuals is assumed to be identical for males and females and the t0 parameter for males is assumed to be 0 and for females is adjusted to -6 as we only consider mature female in the catch.

### Weight at length relationship

Length-weight relationship was estimated using  $W = aCL^b$ , based on carapace length (CL) and whole weight (g) data collected in the vicinity of the SPA islands for both sexes since 1986. The parameter estimates are presented in Table 2.

The weight at length by sex and stock was weighted by the catch of the fishing trip.

**TABLE 2 : WEIGHT AT LENGTH PARAMETERS DERIVED FROM THE SP AND AM FISHERY.**

<b>Stock</b>	<b>Sex</b>	<b>a</b>	<b>b</b>
Amsterdam	Males (n= 358 579)	0.0011.	2.84
	Females (n= 131 061)	0.0019	2.53
Saint Paul	Males (n= 339 089)	0.00084	2.97
	Females (n= 180 169)	0.0012	2.79

### Catch at age

The available catch-at-size (CAS, Annex 1 and Annex 2) data covered the period 1986-2020 and the catch at age (CAA, Annex 3, Annex 4) data were generated by age slicing the catch based on the Von Bertalanffy growth function. These data were available for SP and AM on both sexes. All size classes from 3.3 cm to 14.3 cm CL were pooled in 4 mm intervals. Rock lobsters smaller than the legal size of 5.6 cm have been removed from the CAS as they are sorted and released with sorting errors of less than 0.1% per fishing trip with very high survival.

The CAS by sex (estimated on a subset of total catch) was scaled using the total catch of the fishing trip. The resulting CAA matrices for males and females were scaled using the total catch of the fishing trip and then merged into a single CAA matrix. Age plus groups were set to 8+.

### Natural mortality

The natural mortality  $M$  was set at  $0.15 \text{ (year}^{-1}\text{)}$  and constant for all age classes. Average  $M$  for main rock lobster stocks ranged from 0.1 to 0.3 (RAM legacy database 2020).

### Abundance index

CPUE time series were available from 1980 to 2020 for both stocks. Relative abundance indices were used in the form of standardized CPUE time series (Selles, 2020) which were assumed to be proportional to biomass. Standardized CPUE indices were calculated from a GLM model integrated effects of the fishing year, fishing period, fishing area, proxy of octopus abundance (CPUE) and fishing year-area interactions which correspond strictly to the operation of two fleets.

### Statistical catch at age

The a4a stock assessment implements a statistical catch-at-age model in R, making use of the FLR platform (Kell et al., 2007), and using automatic differentiation implemented in ADMB as the optimization engine (Fournier et al. 2012). To fit this model to data, there are certain components (submodels) that need to be given structure: fishing mortality (fmodel), survey catchability (qmodel), recruitment (srmodel), variance (vmodel) and first year's age structure (n1model). In the a4a framework, these submodels can incorporate linear functions of age and year, as well as fixed degrees of freedom splines which can vary with age, year, or both age and year.

The statistical catch at age model is based on the Baranov catch equation:

$$e^{E[\log C_{a,y}]} = \frac{F_{a,y}}{F_{a,y} + M_{a,y}} [1 - e^{-(F_{a,y} + M_{a,y})}] R_y e^{-\Sigma(F_{a,y} + M_{a,y})}$$

And the survey catchability:

$$e^{E[\log I_y]} = Q_y R_y e^{-\sum(F_{a,y} + M_{a,y})}$$

Where

$$C_{a,y} \sim \text{LogNormal}(E[\log C_{a,y}]; \sigma_{a,y}^2)$$

$$I_{a,y} \sim \text{LogNormal}(E[\log I_{a,y}]; \tau_{a,y}^2)$$

Subscripts a and y denote age and year respectively, M is natural mortality, F fishing mortality, R recruitment, Q survey catchability, C catch.

In order to reduce the number of parameters, M is assumed known, and the remaining parameters are written in terms of a linear combination of covariates described in submodels.

### Candidate models

For the assessment purposes, the following a4a submodels were tested:

F submodel : For the fishing mortality F, a separable submodel has been used, in which age and year effects are modelled by using thin plate regression splines (smoothers) provided by the package mgcv (Wood, 2003). The combined effect of both age and year is also tested on the fishing mortality with tensor products.

- F\_mod1 <- ~s(age, k = A) + s(year, k = Y)
- F\_mod2 <- ~s(age, k = A) + s(year, k = Y) + te(age, year, k = c(A, Y))

With Y [7; 15] and A [2; 5]

Q submodel: For the catchability of the biomass index Q, a constant model ( $\sim 1$ ) was assumed.

- Q\_mod1 <- list(~1)

SR submodel : For the recruitment R, a factor effect for years and a ricker model have been tested.

- Sr\_mod1 <- ~ factor(year)
- Sr\_mod2 <- ~ ricker(CV=0.2)

N1 submodel : For the initial age structure N1 a smoother was also applied.

- N1\_mod <- ~s(age, k=3)

Vmodel: For the observation variance  $\sigma^2$  of the CAA, the default spline through ages was selected and assumed no year effect, while the observation variances  $\tau^2$  of the tuning indices were all assumed constant throughout the years.

- `V_mod1 <- list(~s(age, k = 3), ~ 1)`
- `V_mod2 <- list(~s(age, k = 3), ~ s(year k = 5))`

All the combinations of the sub-models were tested using maximum likelihood estimation (MLE), compared using BIC criterion and evaluated according to the quality of residuals. The best fits were selected based on BIC criterion.

### Model fitting and Diagnostics

The best models were then fitted using Markov Chains Monte Carlo (MCMC) sampling. For the MCMCs, the first 500 000 iterations are dismissed (burn-in), and every 100th sample is taken from the 1000000 iterations (thin). Diagnostics of model convergence included visualization of the MCMC chains throughout trace-plots as well as Heidelberger and Welch (Heidelberger & Welch, 1992) and (Geweke, 1992) diagnostics as implemented in the coda package.

To evaluate CPUE fits, predicted CPUE indices were compared to the observed CPUE. Residual plots were also examined, and the randomness of model residuals was evaluated by means of the Root-Mean-Squared-Error (RMSE).

### Biological reference points, projection and phase plots

The best-fit model runs of the a4a model were used to calculate reference points based on yield per recruit analysis. A Ricker Stock Recruitment relationship was assumed and harvest management measures have been derived including Maximum Sustainable Yield (*MSY*),  $F_{0.1}$  (proxy of *FMSY*, fishing mortality that corresponds to a point on the yield per recruit curve where the slope is 10% of that at the origin) the fishing mortality corresponding to *MSY* (*FMSY*). The ratio of the spawning stock biomass (*SSB*) to *MSY* (*SSB/SSBMSY*) and the ratio of the fishing mortality to *MSY* (*F/FMSY*) were used for determining stock status trajectories using “Kobe plots”.

To explore potential Total Allowable Catch (TAC) levels, the model was used to predict stock status for different TACs over a 10-year period assuming a constant recruitment level equal to its averages over the last 5 years.

## 4. Results

### Model fit and convergence

The best fit specification of the models were the following:

Saint Paul rock lobster stock :

- F submodel:  $\sim\sim s(\text{age}, k = 4) + s(\text{year}, k = 7) + \text{te}(\text{age}, \text{year})$
- Sr submodel:  $\sim\text{ricker}(\text{CV}=0.2)$
- V submodel :  $\sim \text{list}(\sim s(\text{age}, k = 3), \sim 1)$

Amsterdam rock lobster stock :

- F submodel:  $\sim s(\text{age}, k = 4) + s(\text{year}, k = 9) + \text{te}(\text{age}, \text{year})$
- Sr submodel  $\sim \text{ricker}(\text{CV}=0.2)$
- V submodel :  $\sim \text{list}(\sim s(\text{age}, k = 3), \sim s(\text{year } k = 4))$

The model allowed for an effect of time and age and a combined effect of both these variables on the fishing mortality estimates (submodel fmod). The stock-recruitment was modelled as a Ricker function (submodel sr mod). Finally, a submodel for the model variance was specified so that more flexibility, particularly for the last years, could be allowed to fit.

The best models selected by the procedure displayed consistent residuals for both the catch and the CPUE indices, with no obvious trend detected (Figure 1). The models were able to predict both the CPUE indices and CAA although some extreme years were less accurately predicted resulting in systematic positive or negative residuals.

The CPUE indices predicted from the model fit were compared to the observed CPUE and indicated a lack of fit for peak years and the end of the time series where variance increases. This pattern is most prevalent for the Amsterdam rock lobster stock, but the overall fits of the abundance indices were good (Figure 2, Figure 3).

The visual inspection of trace plots for the model parameters showed adequate mixing (i.e., moving around the parameter space), which is indicative of convergence of the MCMC chains (Annex 5, Annex 6).

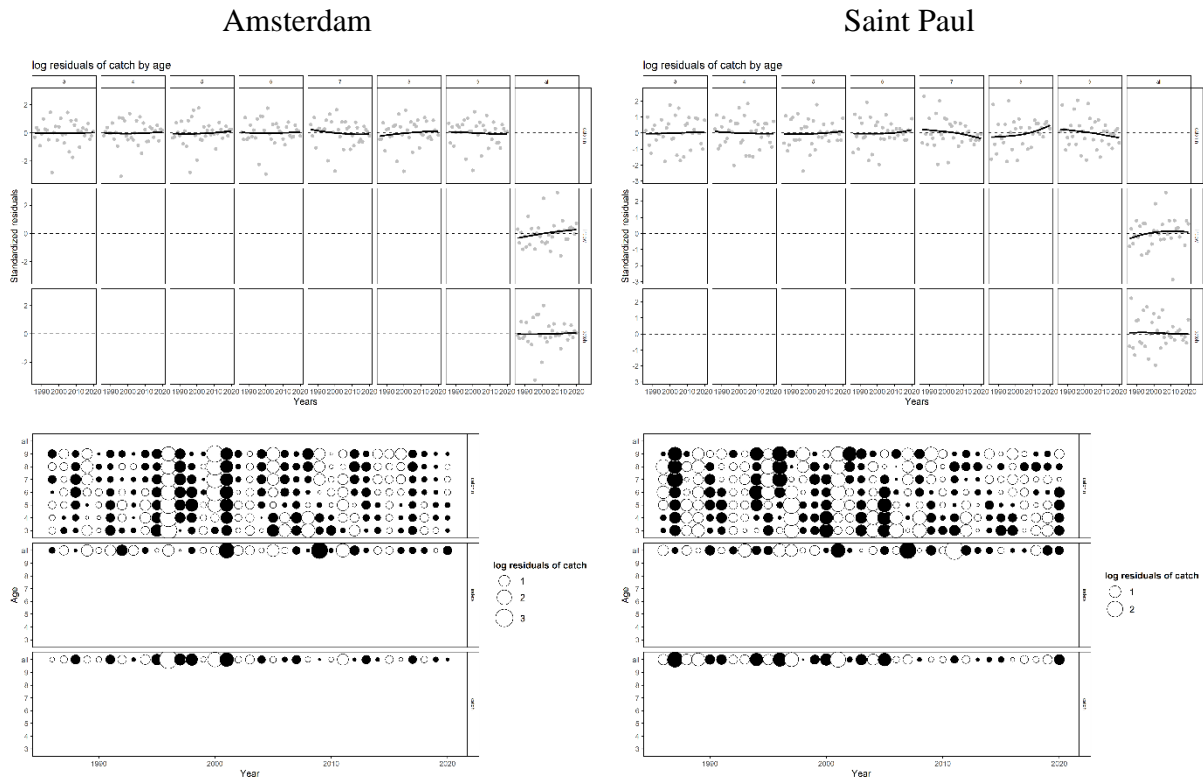


FIGURE 1 : LOG RESIDUALS OF CATCH AND CATCH PER UNIT EFFORT (CPUE) OF THE SPA ROCK LOBSTER.

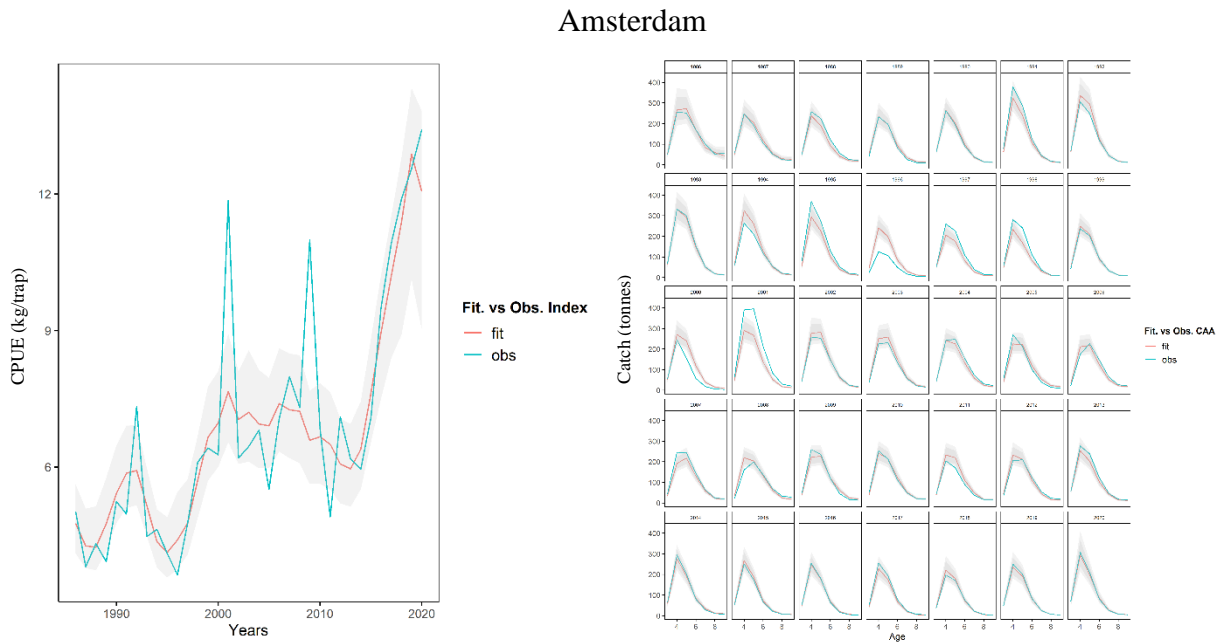
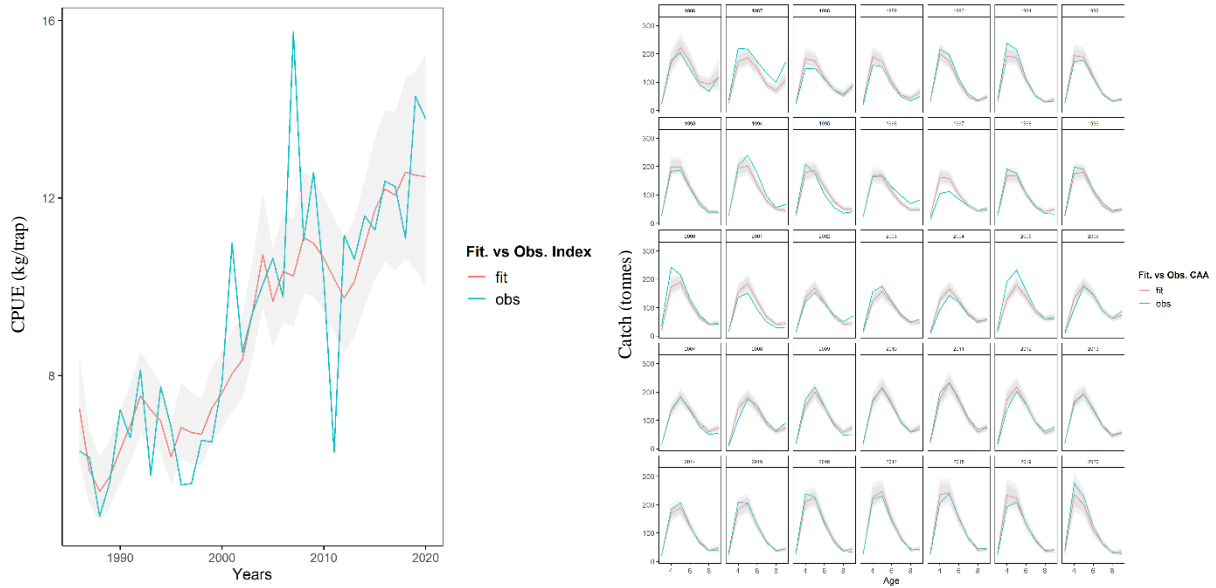


FIGURE 2 : OBSERVED (BLUE) AND PREDICTED (RED) CATCH PER UNIT EFFORT (CPUE) INDEX AND CATCH AT AGE OF THE AMSTERDAM ROCK LOBSTER.

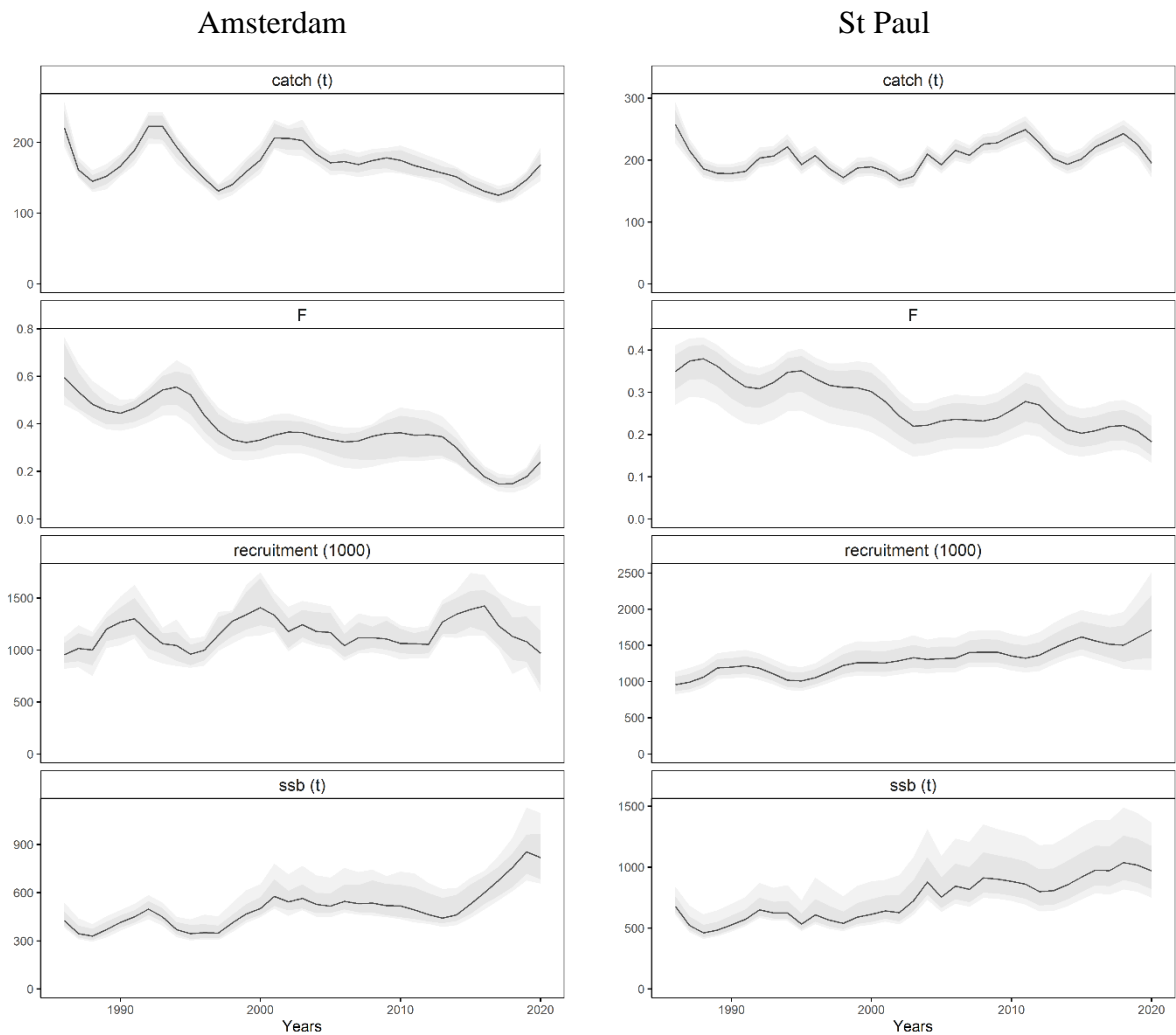
## Saint Paul



**FIGURE 3 : OBSERVED (BLUE) AND PREDICTED (RED) CATCH PER UNIT EFFORT (CPUE) INDEX AND CATCH AT AGE OF THE SAINT PAUL ROCK LOBSTER.**

### Exploitation status

For both stocks, the estimated SSB shows an increase in recent years, with the current values being the highest in the time series (Figure 4). This increase in SSB is related to the steady decline in catches since the beginning of the time series for the Amsterdam stock and a relatively constant catch level for the St. Paul stock.



**FIGURE 4 : TIME-SERIES OF FITTED CATCH (TONS), FISHING MORTALITY (F), RECRUITMENT (1000) AND SPAWNING STOCK BIOMASS (SSB TONS) OF THE SPA ROCK LOBSTER. SHADED AREAS INDICATE THE 95% CREDIBLE INTERVAL**

### Biological reference points, phase plots and projection

The standard biological reference points were close for the two rock lobster stocks.  $MSY$  estimates was centered around 188 tons (167 - 214; 95% C.I.) and 235 tons (165 - 399, 95% C.I.) resulting in  $F_{MSY}$  median estimates of 0.49 (0.46 - 0.53; 95% C.I.) and 0.25 (0.23 - 0.27; 95% C.I.) for Amsterdam and St. Paul rock lobster stock respectively.  $B_{MSY}$  estimates varied from 448 tons (404 – 503; 95% C.I.) for Amsterdam to 1157 tons (811 - 1926; 95% C.I.) for St. Paul (Table 3, Table 4).

The exploitable biomass of both rock lobster stocks has increased since the 2000s. The harvest rate fluctuated for much above  $F_{MSY}$  over the beginning of the time series followed by an overall decrease trend below of  $F_{MSY}$  (Figure 5). Models indicated that the Saint Paul rock lobster stock



was not overfished<sup>1</sup> ( $B > B_{MSY}$ ) and not subject to overfishing<sup>2</sup> ( $F < F_{MSY}$ ). The current biomass state  $B_{2020}$  over  $B_{MSY}$  was 9% above  $B_{MSY}$  (0.86 – 1.50; 95% C.I.) and the current fishing mortality  $F_{2020}$  over  $F_{MSY}$  is 27% below  $F_{MSY}$  (0.54 - 0.98; 95% C.I.). The situation is better for the Amsterdam rock lobster stock with a current biomass state 112% above  $B_{MSY}$  (1.65 – 2.92; 95% C.I.) and the current fishing mortality was 57% below  $F_{MSY}$  (0.31 - 0.62, 95% C.I.).

Kobe phase plots showed that rock lobster stocks do not appear to be overfished ( $B > B_{MSY}$ ) and that there is no overfishing (green phase  $F < F_{MSY}$ ) except in the late 1980s (Figure 6).

Projections based on a range of alternative constant TAC for the period 2021-2030 showed that the current exploitation levels are consistent with the MSY management objective (Figure 7).

**TABLE 3: SUMMARY OF POSTERIOR QUANTILES OF REFERENCE POINTS INDICATING THE MEDIAN AND THE 95% CREDIBLE INTERVAL FOR THE REFERENCE CASE MODEL FOR SAINT PAUL ROCK LOBSTER. B/B<sub>MSY</sub> AND F/F<sub>MSY</sub> ARE PRESENTED FOR THE FINAL ASSESSMENT YEAR.**

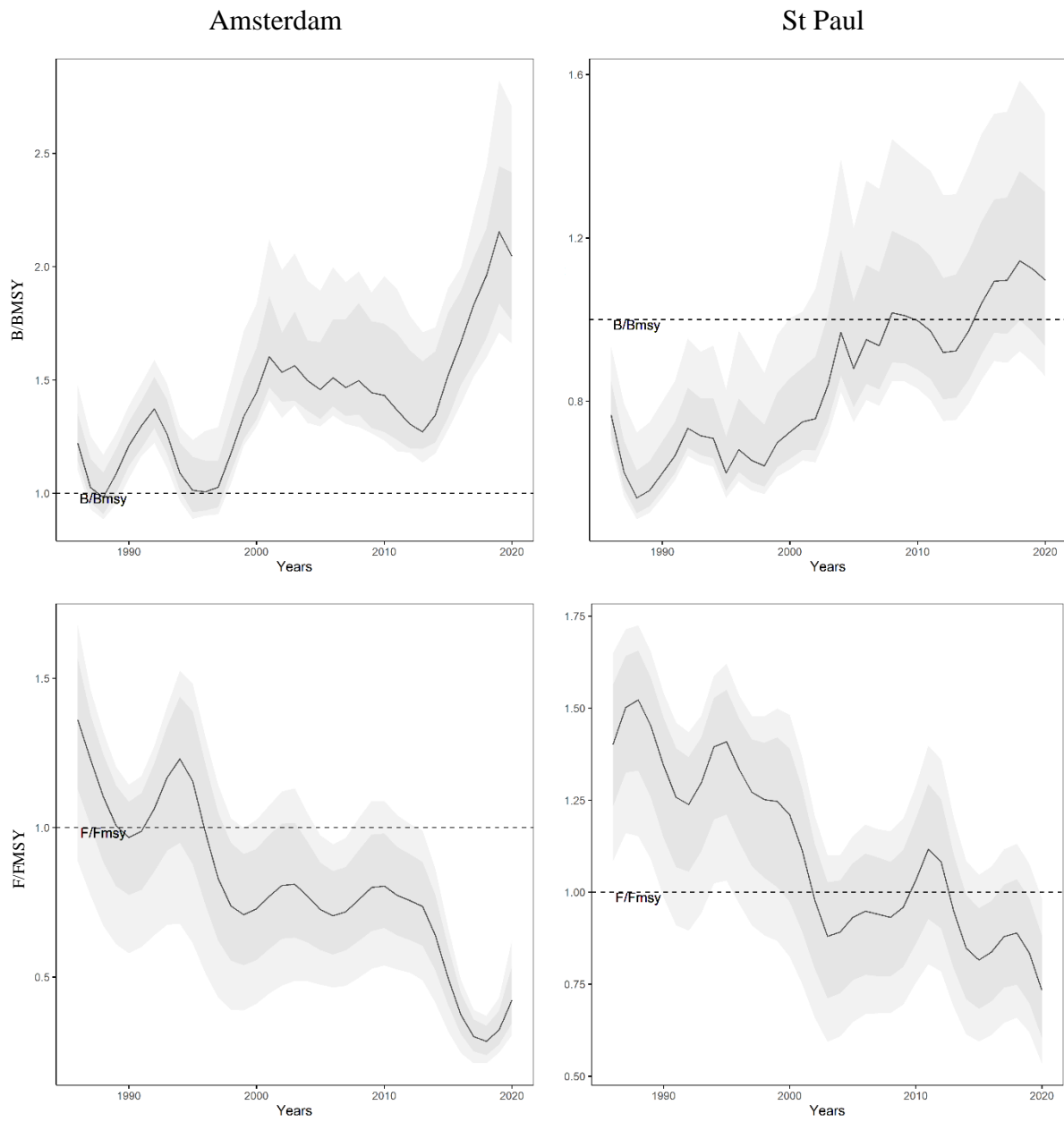
	Values
$B_0$	2 573 t (1802 – 4282)
$B_{MSY}$	1 157 t (811 – 1926)
$F_{MSY}$	0.26 (0.24 – 0.28)
$MSY$	235 t (165 – 399)
$\frac{B}{B_{MSY}}$	1.09 (0.86 – 1.50)
$\frac{B}{B_0}$	0.49 (0.39 – 0.67)
$\frac{F}{F_{MSY}}$	0.73 (0.54 – 0.98)

<sup>1</sup> Overfished refers to the biomass of a stock (B), the state upon which overfishing has occurred. The stock is no longer able to produce at a maximum sustainable yield.

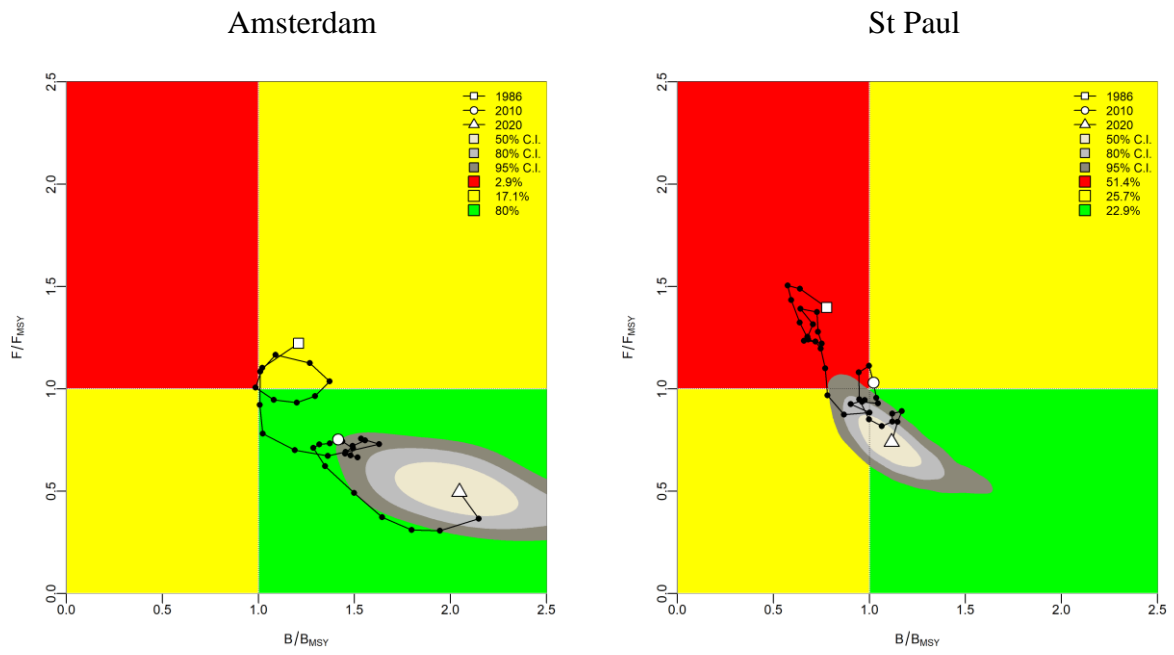
<sup>2</sup> Overfishing refers to the fishing mortality (F), the fishing mortality rate is higher than the rate that produces its maximum sustainable yield.

**TABLE 4: SUMMARY OF POSTERIOR QUANTILES OF REFERENCE POINTS INDICATING THE MEDIAN AND THE 95% CREDIBLE INTERVAL FOR THE REFERENCE CASE MODEL FOR AMSTERDAM ROCK LOBSTER. B/B<sub>MSY</sub> AND F/F<sub>MSY</sub> ARE PRESENTED FOR THE FINAL ASSESSMENT YEAR.**

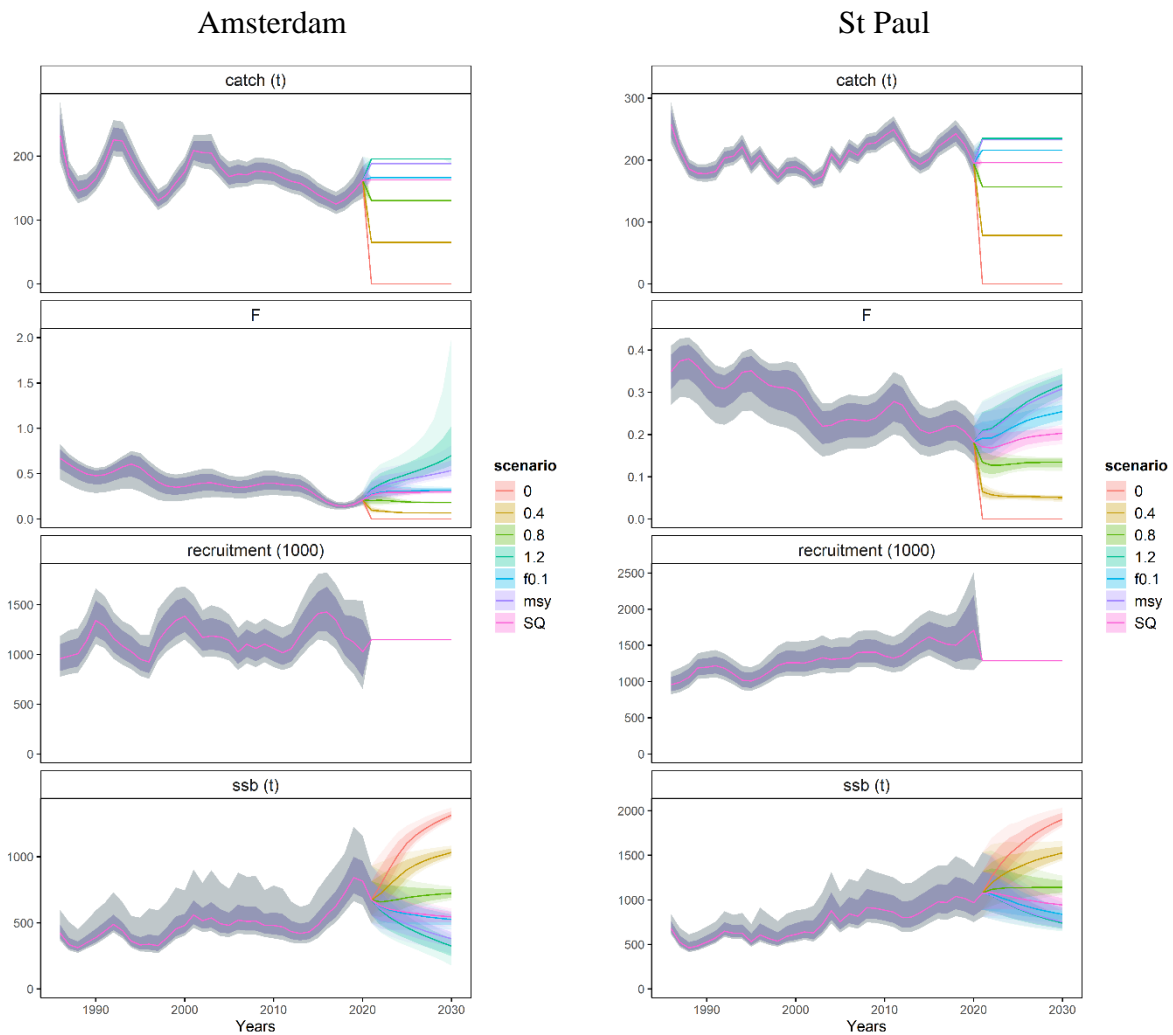
	<b>Values</b>
$B_0$	984 t (884 – 1 098)
$B_{MSY}$	597 t (516 – 708)
$F_{MSY}$	0.39 (0.37 – 0.40)
$MSY$	187 t (161 – 224)
$\frac{B}{B_{MSY}}$	2.12 1.65 – 2.92)
$\frac{B}{B_0}$	0.97 (0.76 – 1.33)
$\frac{F}{F_{MSY}}$	0.43 (0.31 – 0.62)



**FIGURE 5: TRENDS IN HARVEST RATE RELATIVE TO FMSY AND BIOMASS RELATIVE TO BMSY FOR THE SPA ROCK LOBSTER. LIGHT AND DARK SHADED GREY AREAS INDICATE 95% AND 50% CREDIBLE INTERVAL RESPECTIVELY.**



**FIGURE 6: KOBE PHASE PLOT SHOWING ESTIMATED TRAJECTORIES (1986-2019) OF  $B/B_{MSY}$  AND  $F/F_{MSY}$  FOR SPA ROCK LOBSTER STOCKS. DIFFERENT GREY SHADED AREAS DENOTE THE 50, 80 AND 95% CREDIBLE INTERVAL FOR THE TERMINAL ASSESSMENT YEAR. THE PROBABILITY OF TERMINAL YEAR POINTS FALLING WITHIN EACH QUADRANT IS INDICATED IN THE FIGURE LEGEND.**



**FIGURE 7: SHORT TERM PROJECTIONS (2021–2030) FOR SPA ROCK LOBSTER STOCKS OVER A SEQUENCE OF FUTURE TAC BASED ON CATCH MULTIPLIER (0, 0.4, 0.8, 1.8 CATCH IN 2020), STATUS QUO (SQ), F0.1 AND FMSY SCENARIOS. SHADED AREAS INDICATE 95% CREDIBLE INTERVAL.**

## 5. Discussion

SCA assessments of SPA rock lobsters suggest that the biomass of both stocks experienced a period of overexploitation prior to the start of the CAA series, followed by a relatively stable period from 1986 to 2000. Since 2000, have increased steadily with an acceleration over the last decade. The analysis shows that the status of both lobster stocks in 2020 is likely to be well above *BMSY* and that fishing mortality is below *FMSY*.

The short-term projection scenarios that were tested show that current catch levels are consistent with the sustainability of the rock lobster stocks.

The model presented here is an age-based model assuming a continuous growth of rock lobster which grows through a succession of moults. Very little information is available on age length keys of crustaceans, as they are hard to age, and the primary source of data is the size composition

of catches. Transitioning into an fully integrated age-based model is a priority especially to model size-based processes such as selectivity that is particularly important for SPA rock lobster stocks which are managed using minimum legal size. An integrated model would allow efficient use of data from the tagging program and corroborate trends in CPUE indices.

## 6. Acknowledgements

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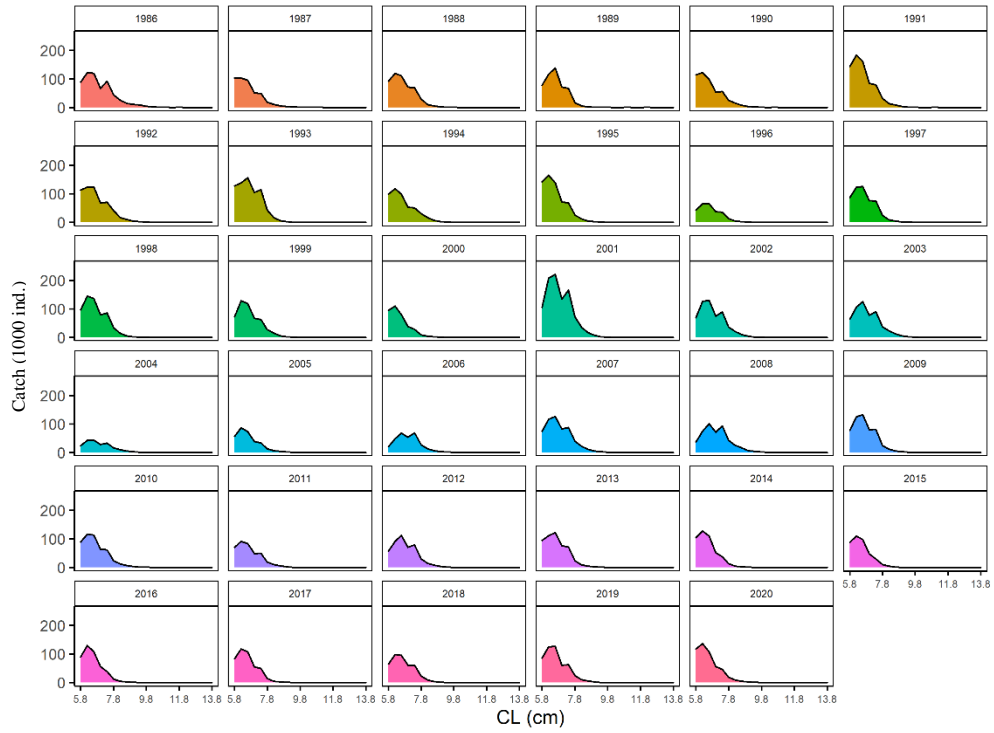


# 8. Annexes

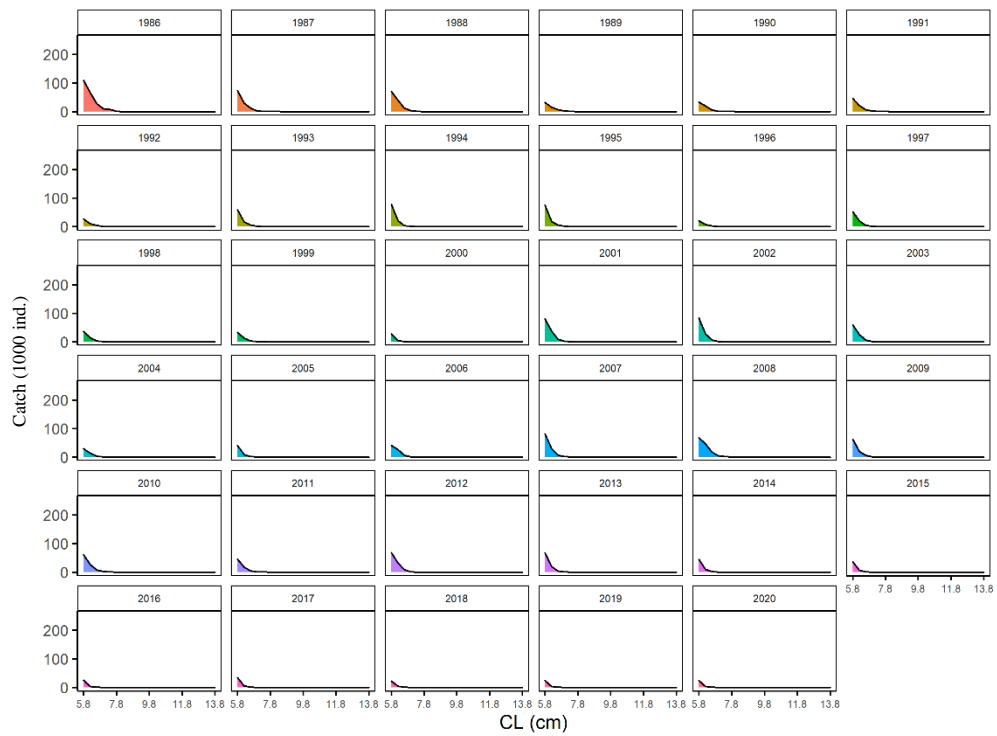
## Annex 1

Length distribution of total catch for Amsterdam rock lobster stock.

### Amsterdam - Male



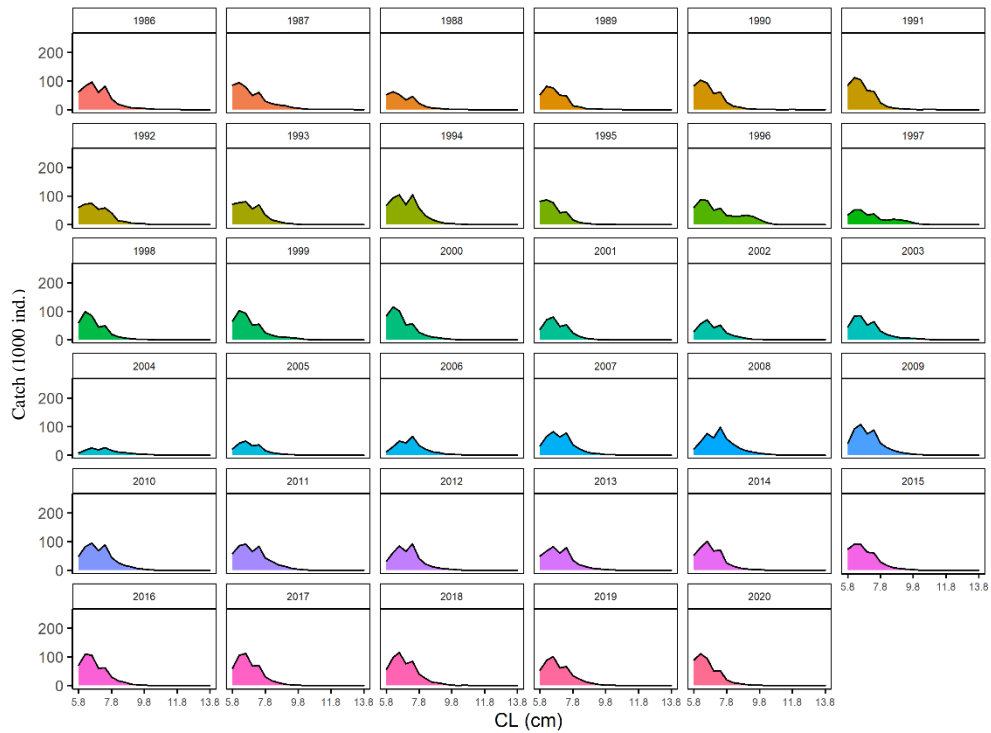
### Amsterdam - Female



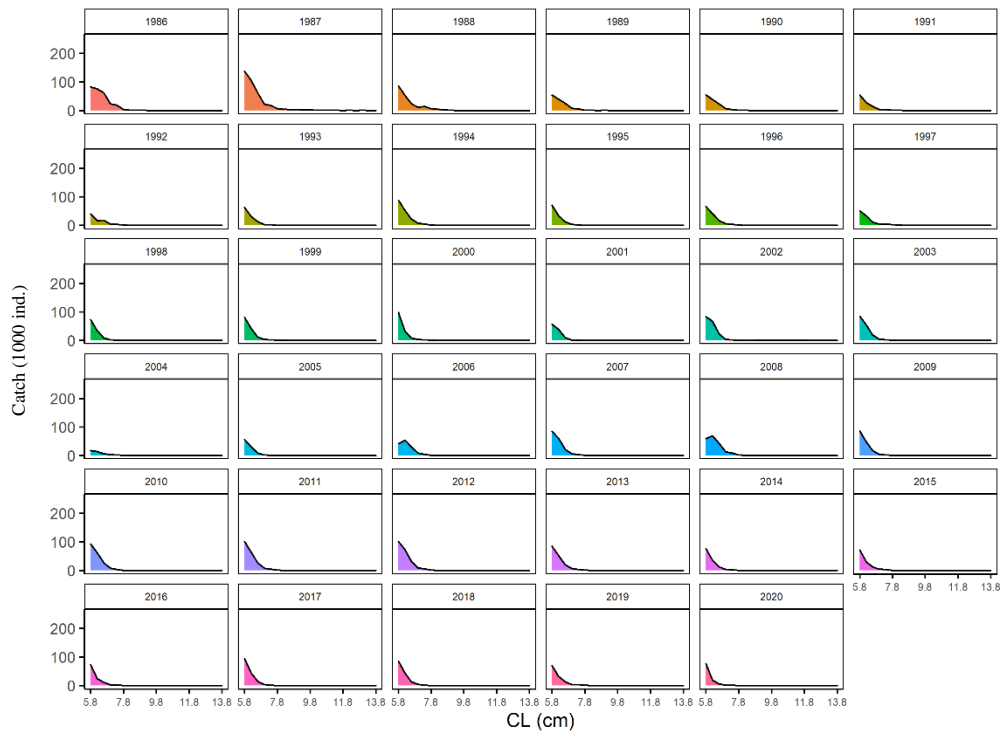
## Annex 2

Length distribution of total catch for Saint Paul rock lobster stock.

### Saint Paul – Male

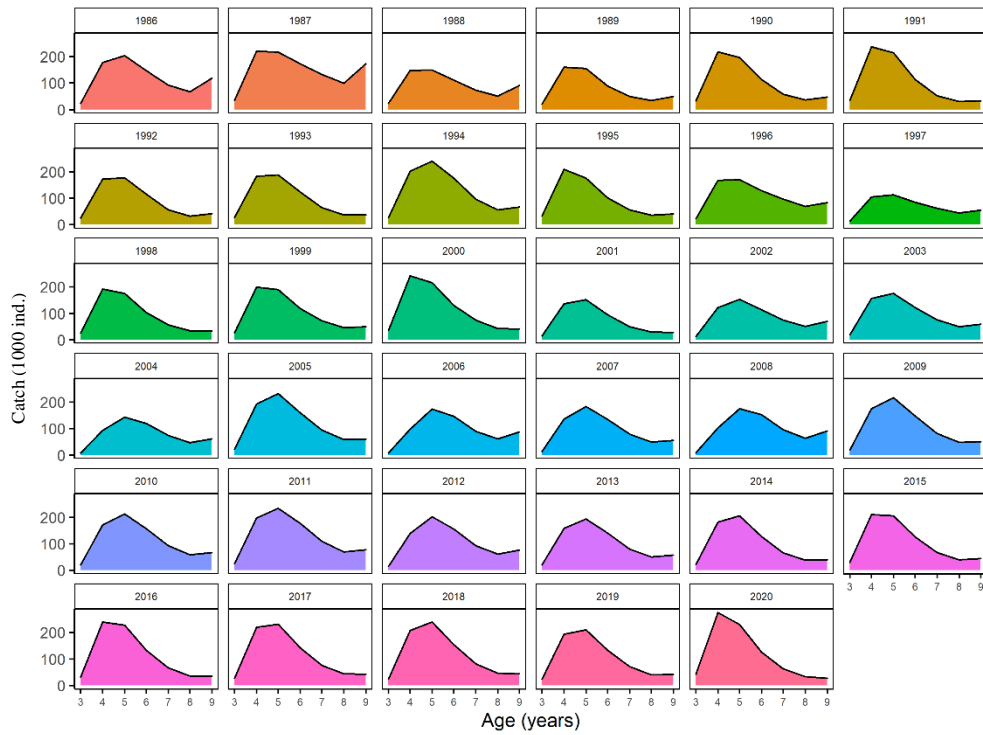


### Saint Paul – Female



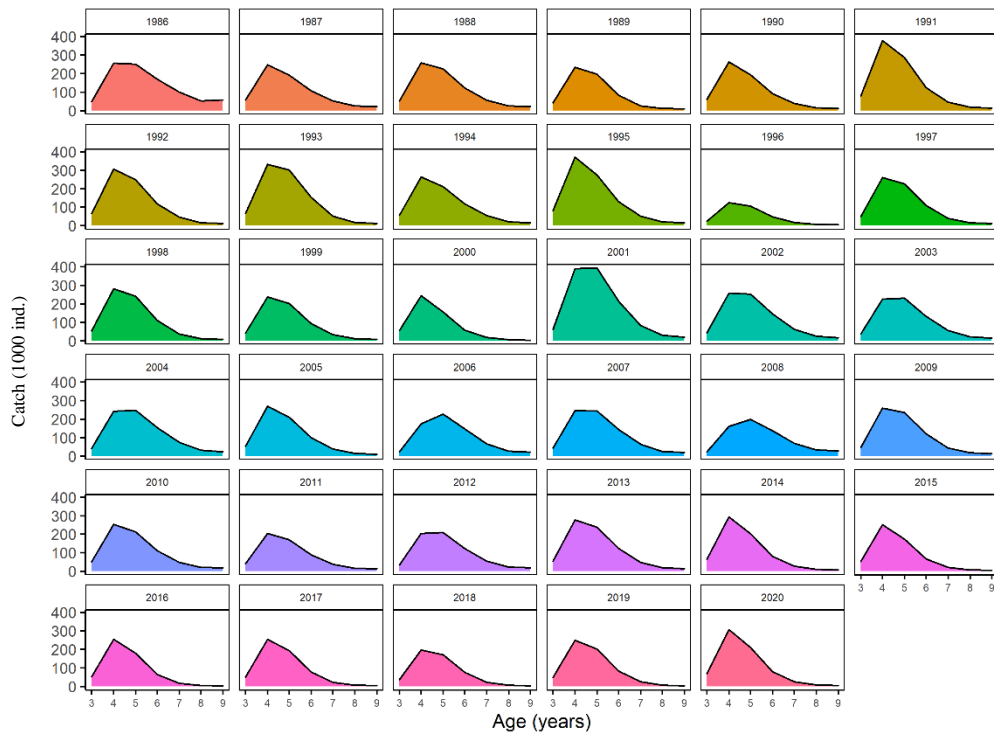
### Annex 3

Age distribution of total catch for Saint Paul rock lobster stock.



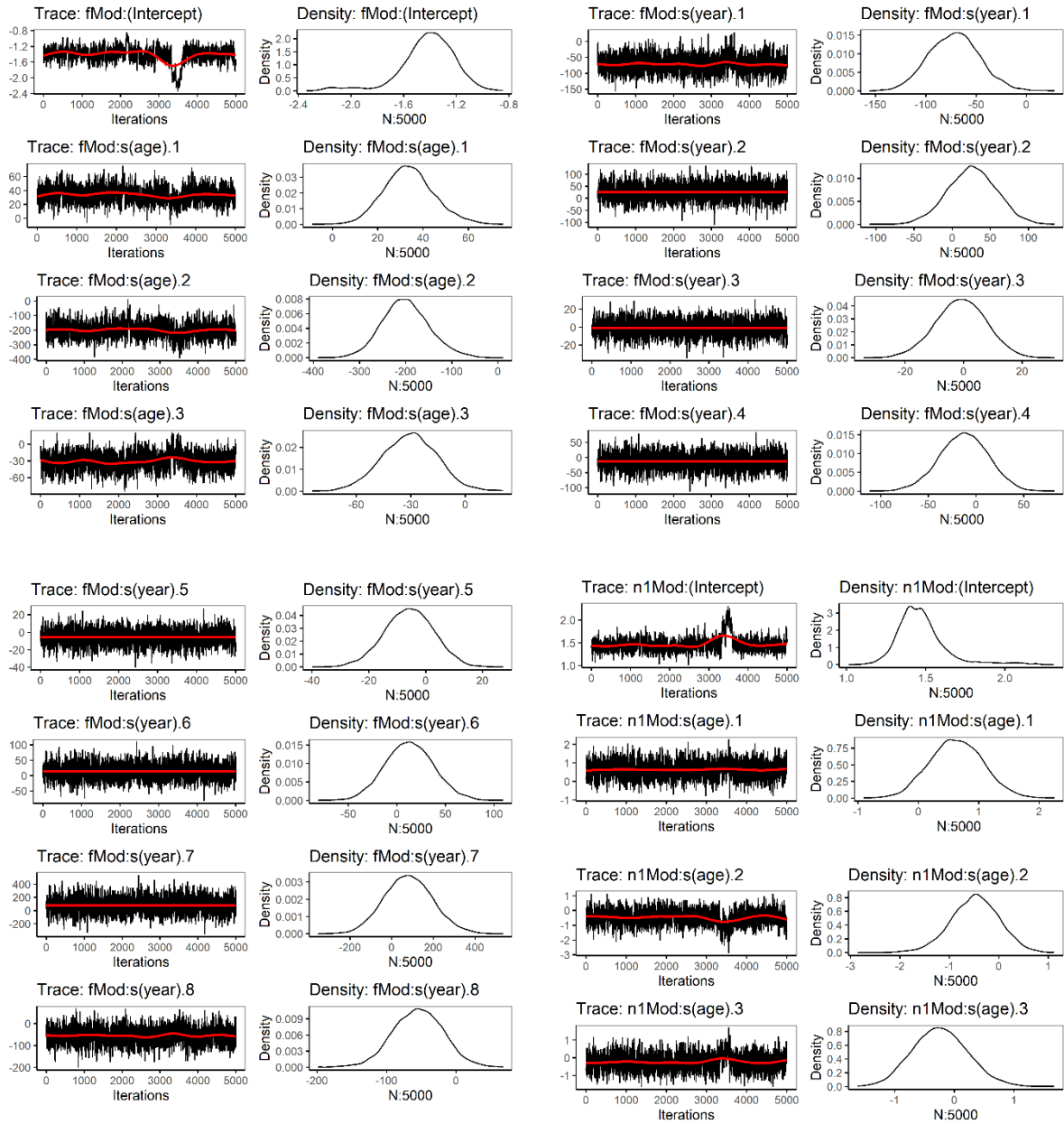
### Annex 4

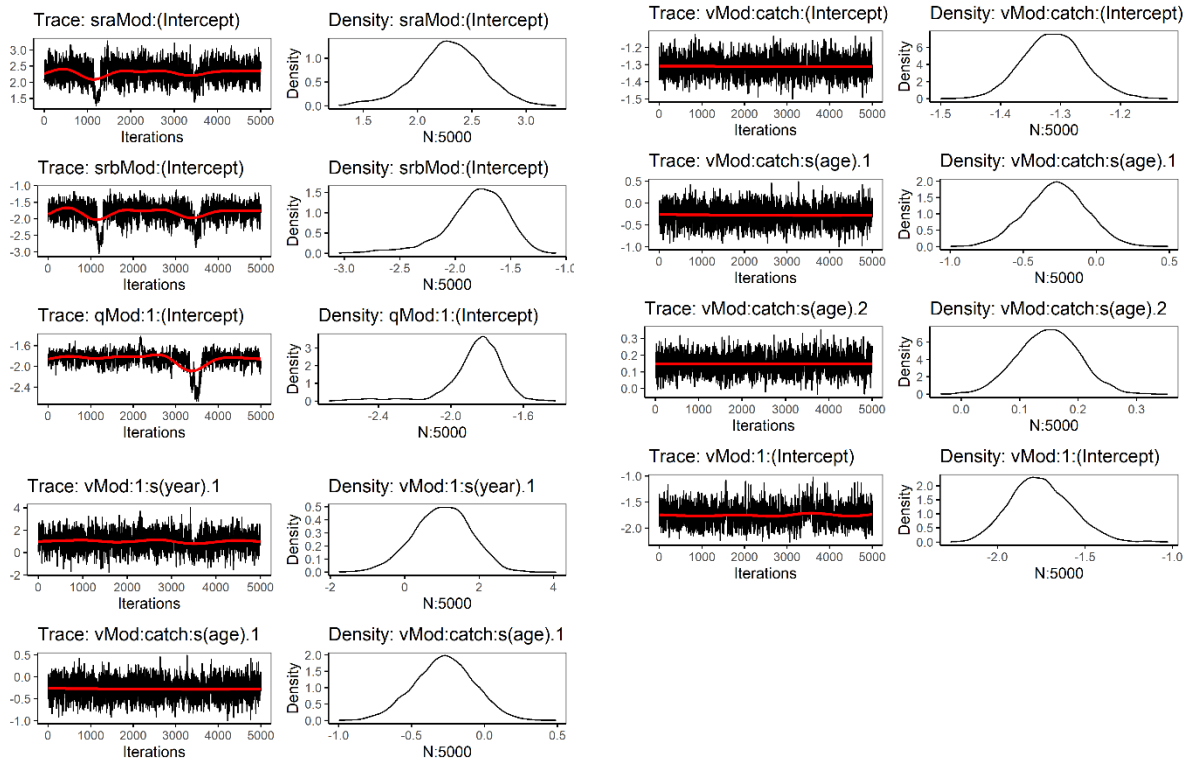
Age distribution of total catch for Amsterdam rock lobster stock.



## Annex 5

MCMC posterior trace plots for a selection of parameters of Amsterdam rock lobster stock model.





## Annex 6

MCMC posterior trace plots for Saint Paul rock lobster stock model.

