Searching spatial-temporal changes in intrinsic productivity of Antarctic Krill

Alternative analysis to know productivity in Krill 48.1 SubArea based on invariants parametres and fishery lenghts structures

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rm(list = ls())  
knitr::opts\_chunk$set(echo = FALSE,  
 message = FALSE,  
 warning = FALSE,  
 fig.align = 'center',  
 dev = 'jpeg',  
 dpi = 300,  
 fig.width = 6)  
#XQuartz is a mess, put this in your onload to default to cairo instead  
options(bitmapType = "cairo")   
# (https://github.com/tidyverse/ggplot2/issues/2655)  
# Lo mapas se hacen mas rapido

# ABSTRACT

Testing changes spatial and temporal in intrinsic productivity in Antarctic Krill (*Euphausia superba*) with Length-Based Spawning Potential Ratio (LBSPR).

One way to understand krill dynamics is through empirical data such as sizes structure from the fishery. In this sense we can, through the life history parameters and the sizes through the years, what should be the virgin reproductive potential (intrinsic productivity) and under the effects of fishing.

Recognizing the intrinsic productivity changes of krill based on their reproductive potential and how this changes in time and space, serves to recognize the particularities of this species and the implications that these results may have for management in the CCAMLR context.

*Keywords: Lenght Structure, Intrinsic productivity, SPR, Krill, 48.1 SubArea*

# 1. INTRODUCTION

The northern Antarctic Peninsula ecosystem is a critical region of the Southern Ocean for populations of Antarctic krill (*Euphausia superba*; hereafter krill) serving as a major spawning and recruitment area and as an overwintering hotspot, especially within Bransfield Strait. Over the last 40 years, climate driven changes have resulted in warming waters, declines in seasonal sea ice extent and duration ([Sharon E. Stammerjohn et al., 2008](#ref-Stammerjohn2008a); [S. E. Stammerjohn et al., 2008](#ref-Stammerjohn2008)), changing trends phytoplankton productivity ([Saba et al., 2014](#ref-Saba2014); [Siegel et al., 2013](#ref-Siegel2013)).

Additionally, changes have impacted the population dynamics of krill, resulting in distribution changes with consequent contraction of the population in the southwest Atlantic Ocean toward the peninsula ([A. Atkinson et al., 2009](#ref-Atkinson2009)). These changes in the population structure have been verified in krill for the last years also ([Reiss et al., 2020](#ref-Reiss2020); [Siegel et al., 2013](#ref-Siegel2013)). This changes (temporal and spatial) has implications for the reproductive potential of the species and this, in turn, for intrinsic productivity.

One way to understand and measure changes in intrinsic productivity is through assessing the ratio of krill reproductive potential. There are many length-based assessment methods to understand this changes between years ([Canales et al., 2021](#ref-Canales2021); [Froese et al., 2018](#ref-Froese2018); [A. R. Hordyk et al., 2016](#ref-Hordyk2016); [Rudd & Thorson, 2017](#ref-Rudd2017a)). On the other hand, one of the advantages of these methods is to use one of the most reliable and abundant sources in the sampling of fishing activities, such as size structures ([Canales et al., 2021](#ref-Canales2021)).

This changes in spatial and temporal structure of krill population has tried to be considered in management that performed CCAMLR (Commission for the Conservation of Antarctic Marine Living Resources), but does not consider reference points that can help in making decisions with scientific rigor. We propose to identify the differences in the reproductive potential of krill on the spatial and temporal scale, propose a species-specific reference point and thereby provide recommendations for the sustainable management of this fishery trough Spawning Pontential Ratio (SPR) from krill population catch in SubArea 48.1 in Antarctic Peninsula in Southern Ocean.

# 2. METHODOLOGY

## 2.1. Study area

The study area includes one of the sectors where today the largest amount of krill fishing is concentrated. In this case, the analyzes include the entire subarea 48.1. In order to have a better spatial definition of the behavior of krill dynamics, we will analyze the differences between the management strata defined in WG-EMM-2021/05 Rev. (WG-EMM-2021/05 ([2021](#ref-Dornam2021))), namely Brainsfield Straith, Elephant Island, Extra, Joinville Island and South West (Figure 1).

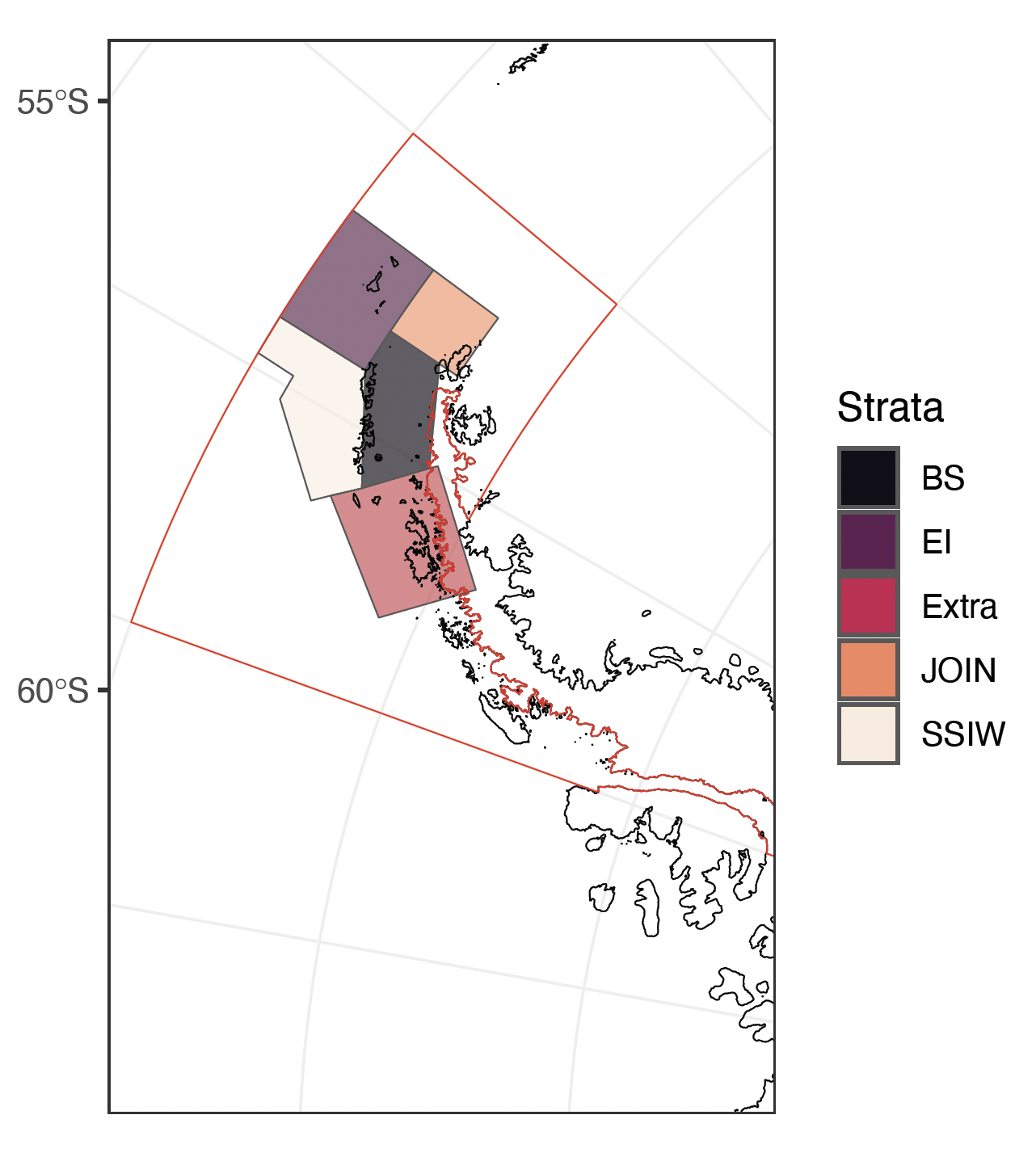


Figure 1. Subarea 48.1 and management strata considered in the spatio-temporal analysis of the intrinsic productivity of Krill (BS=Brainsfield Straith, EI= Elephant Island, Extra= Extra, JOIN= Joinville Island, SSWI= South West)

## 2.2. Data

For this analysis, data from the monitoring of the krill fishery were used, which have been systematically collected on board fishing vessels by the SISO (Scheme of International Scientific Observation) program carried out by CCAMLR. Krill sizes compositions were obtained from the entire area 48.1, which was joined in each management stratum defined at 2.1 section.

## 2.3 Assessment of intrinsic productivity

El potencial reproductivo del krill fue evaluado a traves de un metodo que mide el potencial reproductivo de las especies explotadas comercialmente conocido como LBSPR (Length Based Spawining Potential Ratio). The LBSPR method has been developed for data-limited fisheries, where few data are available other than a representative sample of the size structure of the vulnerable portion of the population (i.e., the catch) and an understanding of the life history of the species. The LBSPR method assumes the reproductive characteristics of the species based on the life history parameters, being able to establish strategies for long-lived species with low reproductive output as well as highly reproductive species with a high growth constant such as krill.([Prince & Hordyk, 2018](#ref-Prince2018)).

LBSPR uses length-composition data and as- sumptions about biological parameters to make a rapid assess- ment of stock status relative to unfished levels assuming equilibrium conditions .While LB-SPR can use multiple years of length data, status determination is based on one year of data at a time (i.e., estimates of status over multiple years are based on that year’s length composition alone). Mean-length mortality estimators, first developed by Beverton & Holt ([1957](#ref-Beverton1957)), assume that fishing mortality directly influences mean length of the catch and therefore in the reproductive potential of the species. Al l this concept about life history and implications in spawning potential ratio was revisited by Jensen ([1996](#ref-Jensen1996)).

here are two versions of the LBSPR model included in this methodology.

### 2.3.1. Age-Structured Length-Based Model

The LBSPR model described by ([A. Hordyk et al., 2014](#ref-Hordyk2014c); [A. R. Hordyk et al., 2016](#ref-Hordyk2016)), and tested in a MSE framework ([A. Hordyk et al., 2014](#ref-Hordyk2014c)), use a conventional age-structured equilibrium population model. An important assumption of this model structure is that selectivity is age-based not length-based.

### 2.3.2. Length-Structured Growth-Type-Group Model

A. R. Hordyk et al. ([2016](#ref-Hordyk2016)) describe a length-structured version of the LBSPR model that uses growth-type-groups (GTG) to account for size-based selectivity. The GTG-LBSPR model also has the ability to include variable M at size (by default M is assumed to be constant). The GTG-LBSPR model typically estimates a lower fishing mortality rate for a given size structure compared to the earlier age-structured model. This is because the age-structured model has a ‘regeneration assumption’, where, because of the age-based selectivity assumption, large individuals are expected even at high fishing mortality (large, young fish).

The default setting for the LBSPR package is to use the GTG-LBSPR model for all simulation and estimation. Control options in the simulation and estimation functions can be used to switch to the age-structured LBSPR model.

Like any assessment method, the LBSPR model relies on a number of simplifying assumptions. In particular, the LBSPR models are equilibrium based, and assume that the length composition data is representative of the exploited population at steady state. This methodology was implemented through the package A. Hordyk ([2021](#ref-LBSPR2021)).

## 2.4. References Point in Krill fishery

As measures of stock status, these length-based methods derive the spawning potential ratio (SPR) reference point, defined as the proportion of unfished reproductive potential at a given level of fishing pressure ([Goodyear, 1993](#ref-Goodyear1993)).

## 2.4. Simulation

The LBSPR package can be used to generate the expected size composition, the SPR, and relative yield for a given set of biological and exploitation pattern parameters.

## 2.5. LB\_pars Object to Antarctic Krill

The first thing to do is to create a LB\_pars object that contains all of the required parameters for the simulation model. LB\_pars is an S4 class object.

#### 2.5.1. Create a new LB\_pars Object

To create a new LB\_pars object you use the new function:

You can see the elements or slots of the LB\_pars object using the slotNames function:

## [1] "Species" "MK" "M" "Linf" "L\_units"   
## [6] "CVLinf" "L50" "L95" "Walpha" "Walpha\_units"  
## [11] "Wbeta" "FecB" "Steepness" "Mpow" "R0"   
## [16] "SL50" "SL95" "MLL" "sdLegal" "fDisc"   
## [21] "FM" "SPR" "BinMin" "BinMax" "BinWidth"

MyPars is an object of class LB\_pars. You can access the help file for classes by using the ? symbol (similar to how you find the help file for functions):

#class?LB\_pars

#### 2.5.2. Populate the LB\_pars Object with Krill parameters

The LB\_pars object has 25 slots. However, not all parameters need to be specified for the simulation model.

Some parameters are essential, and a warning message should appear if you attempt to progress without values (please let me know if there are issues).

Default values will be used for some of the other parameters if no value is specified. For example, the first slot (Species) is a character object that can be used for the species name. If this slot is left empty, the simulation model will populate it with a default value.

A message should alert you any time a default value is being used. The minimum parameters that are needed for the simulation model are:

Biology

* von Bertalanffy asymptotic length Linf
* M/K ratio (natural mortality)divided by von Bertalanffy K coefficient) MK
* Length at 50% maturity (L50)
* Length at 95% maturity (L95)

Exploitation

* Length at 50% selectivity (SL50)
* Length at 95% selectivity (SL95)
* Biological Reference Point (BRP). F/M ratio (FM) or Spawning Potential Ratio (SPR). If you specify both, the F/M value will be ignored.

Size Classes

-Width of the length classes (BinWidth)

Remember, you can find the help documentation for the LB\_pars object by typing: class?LB\_pars in the console.

To create an example parameter object regarding Maschette et al. ([2020](#ref-Maschette2020));

Creating parms template

BinMax not set. Using default of 1.3 Linf BinMin not set. Using default value of 0 You will notice some messages in the console alerting you that default values have been used. You can change these by specifying values in MyPars and re-running the LBSPRsim function.

We’ll manually set those values here so we don’t keep seeing the messages throughout the vignette. We can also choose to set the units for the length parameters by L\_units

## 2.6. Running the Simulation Model

Now we are ready to run the LBSPR simulation model. To do this we use the LBSPRsim function: ngtg function es el # de grupos para el GTG model, por default es 13)

MySim <- LBSPRsim(MyPars,   
 Control=list(modtype="GTG",   
 maxFM=1))

#### 2.6.1. The LB\_obj Object

The output of the LBSPRsim function is an object of class LB\_obj. This is another S4 object, and contains all of the information from the LB\_pars object and the output of the LBSPRsim function.

Many of the functions in the LBSPR package return an object of class LB\_obj. You should not modify the LB\_obj object directly. Rather, make changes to the LB\_pars object (MyPars in this case), and re-run the simulation model (or other functions, covered later in the vignette).

#### 2.6.2. Simulation Output

Let’s take a look at some of the simulated output.

MySim@SPR

## [1] 0.75

The simulated SPR is the same as our input value MyPars@SPR

What is the ratio of fishing mortality to natural mortality in this scenario?

## [1] 0.29

It is important to note that the F/M ratio reported in the LBSPR model refers to the apical F over the adult natural mortality rate. That is, the value for fishing mortality refers to the highest level of F experienced by any single size class.

If the selectivity pattern excludes all but the largest individuals from being exploited, it is possible to have a very high F/M ratio in a sustainable fishery (high SPR). And visceverse!!

#### 2.6.3. Control Options

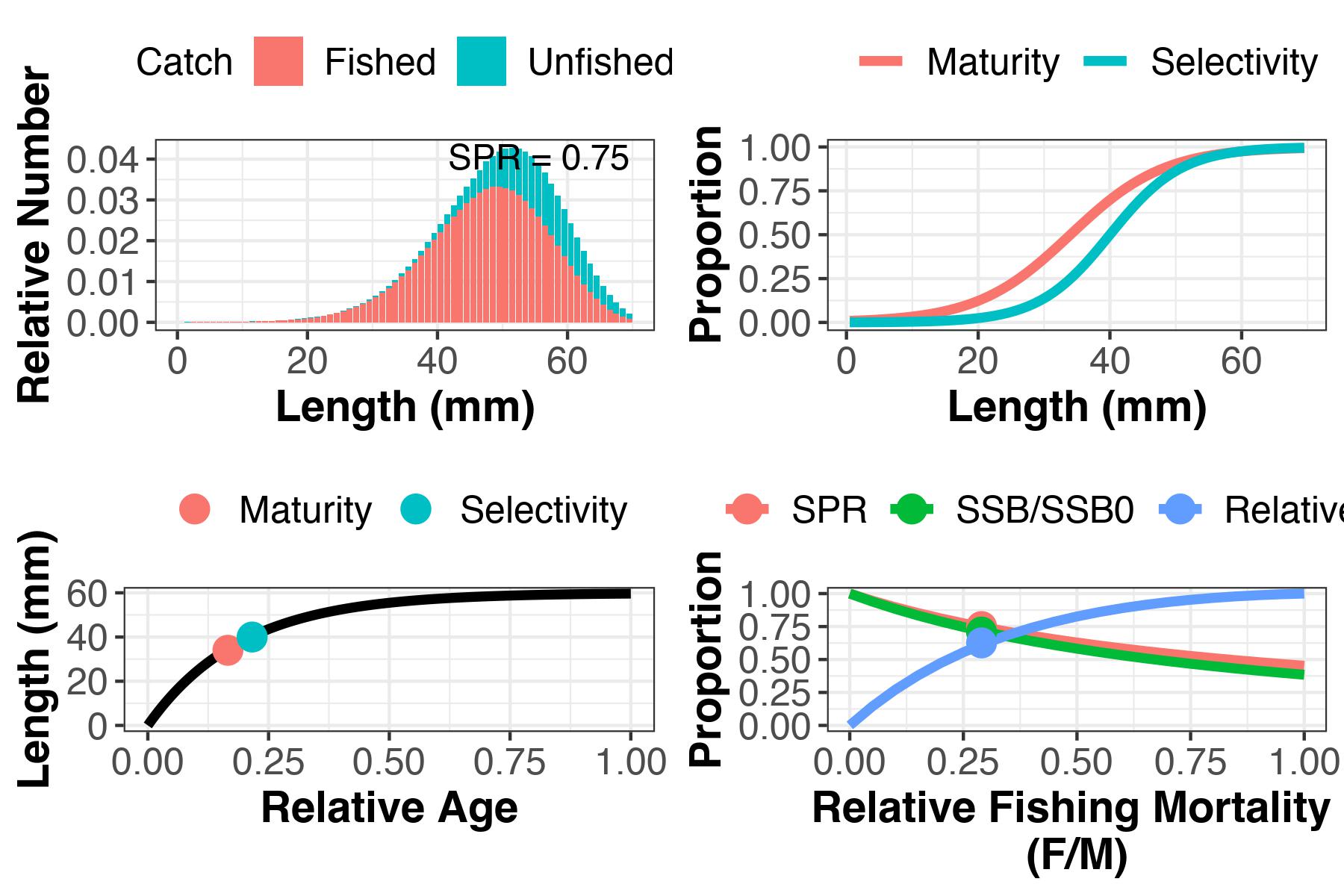
There are a number of additional parameters that can be modified to control other aspects of the simulation model.

For example, by default the LBSPR model using the Growth-Type-Group model (Hordyk et at. 2016). The Control argument can be used to switch to the Age-Structured model (Hordyk et al. 2015a, b):

See the help file for the LBSPRsim function for additional parameters for the Control argument.

#### 2.6.4. Plotting the Simulation

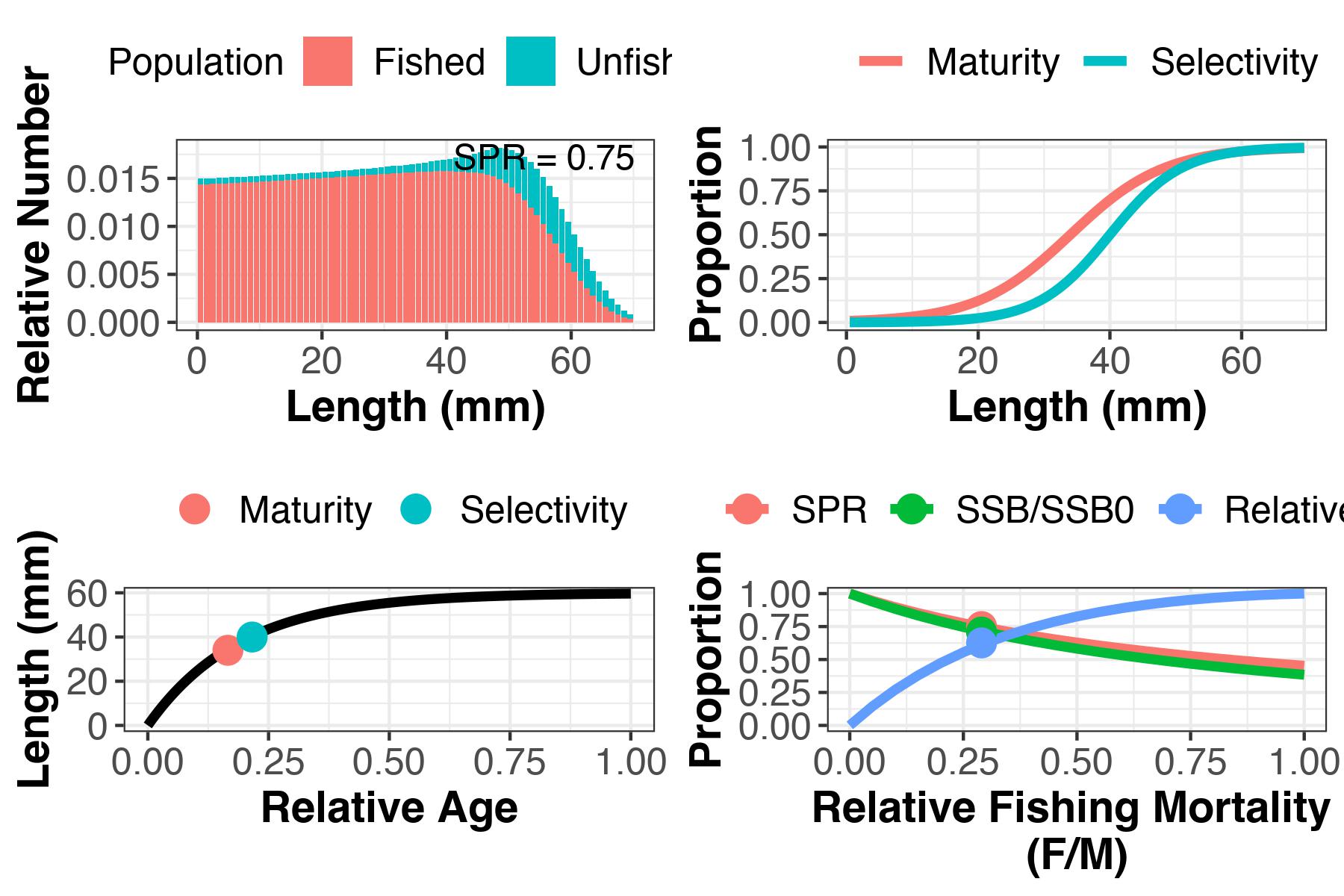
The plotSim function can be used to plot MySim:



Ploteo de Simulaci?n estructuras.

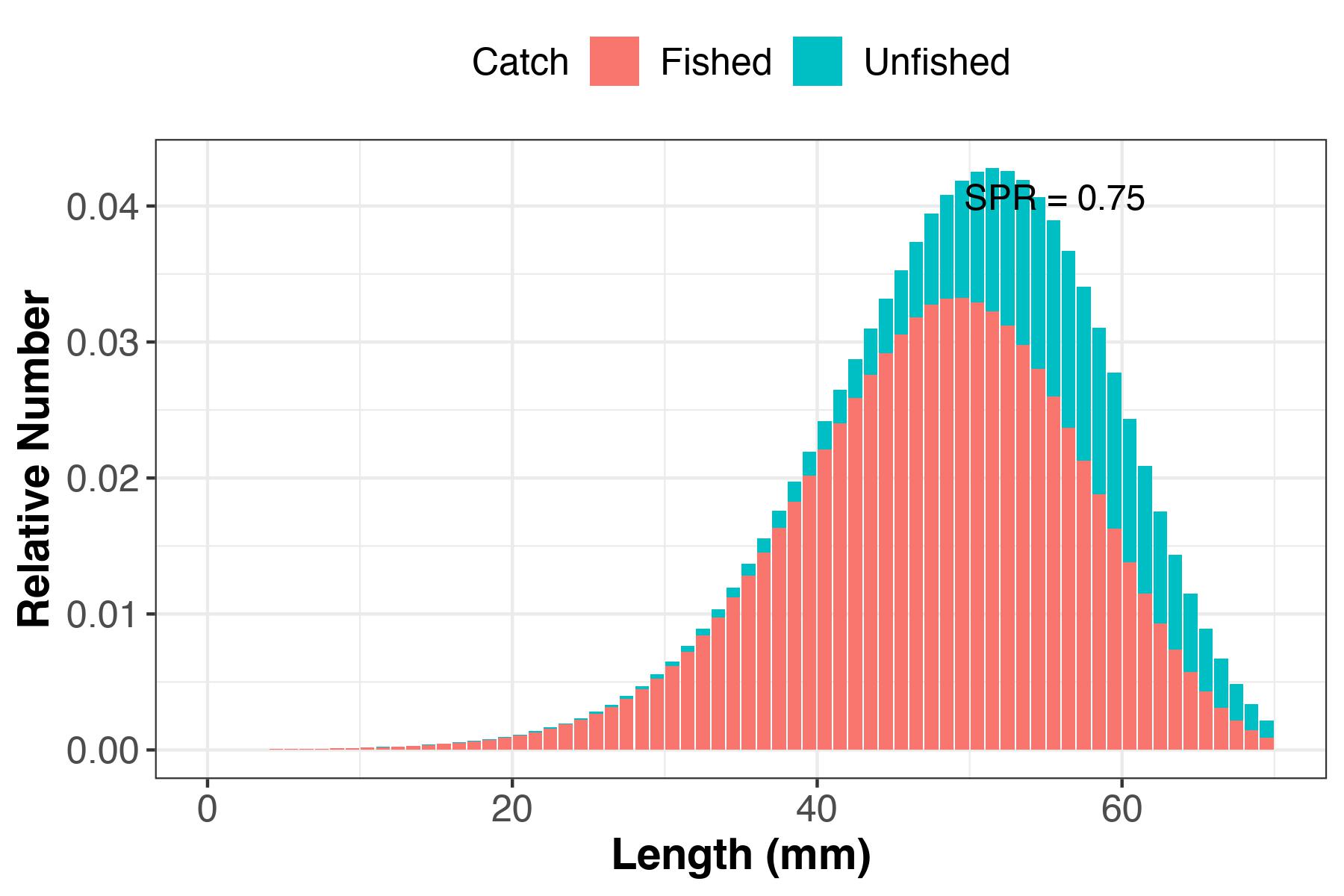
By default the function plots: a) the expected (equilibrium) size structure of the catch and the expected unfished size structure of the vulnerable population, b) the maturity and selectivity-at-length curves, c) the von Bertalanffy growth curve with relative age, and d) the SPR and relative yield curves as a function of relative fishing mortality (see note above on the F/M ratio).

The plotSim function can be controlled in a number of ways. For example, you can plot the expected unfished and fished size structure of the population by changing the lf.type argument:



Ploteo de Simulaci?n Population.

Individual plots can be created using the type argument:



Plot Leng Freq

See ?plotSim for more options for plotting the output of the LBSPR simulation model.

## 2.7 Fitting Empirical Krill Length Data

Two objects are required to fit the LBSPR model to length data: LB\_pars which contains the life-history parameters (described above) and LB\_lengths, which contains the length frequency data.

#### 2.7.1 Creating a LB\_lengths object

A LB\_lengths object can be created in two ways. The new function can be used to create an empty object which can be manually populated:

slotNames(MyLengths)

## [1] "LMids" "LData" "L\_units" "Years" "NYears" "Elog"

However, it is probably easier to create the LB\_lengths object by directly reading in a CSV file.

Now, we need set our directory again

#### 2.7.2 Reading Krill Data

Note that only the life history parameters need to be specified for the estimation model. The exploitation parameters will be estimated.

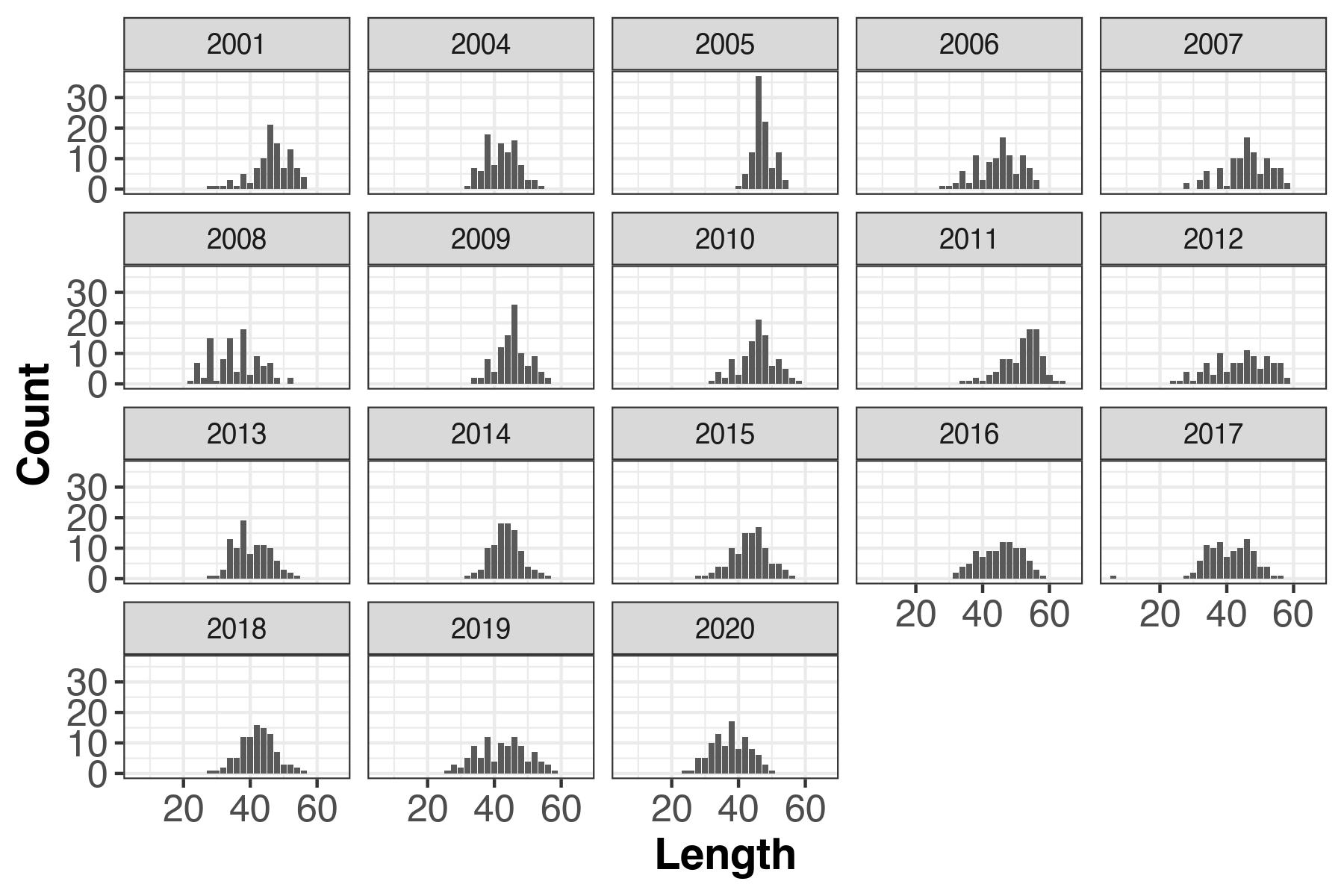
A length frequency data of krill set with multiple years (2001-2020):

Len1 <- new("LB\_lengths", LB\_pars=MyPars, file=paste0(datdir, "/Length\_481\_Krill\_2.csv"), dataType="freq",sep=";",header=T)

Another form to read data is: A length frequency data set with multiple years and a header row (identical to Len1 data, but with a header row):

#### 2.7.3 Plotting Length Data Krill

The plotSize function can be used to plot the imported length data. This is usually a good idea to do before proceeding with fitting the model, to confirm that everything has been read in correctly:



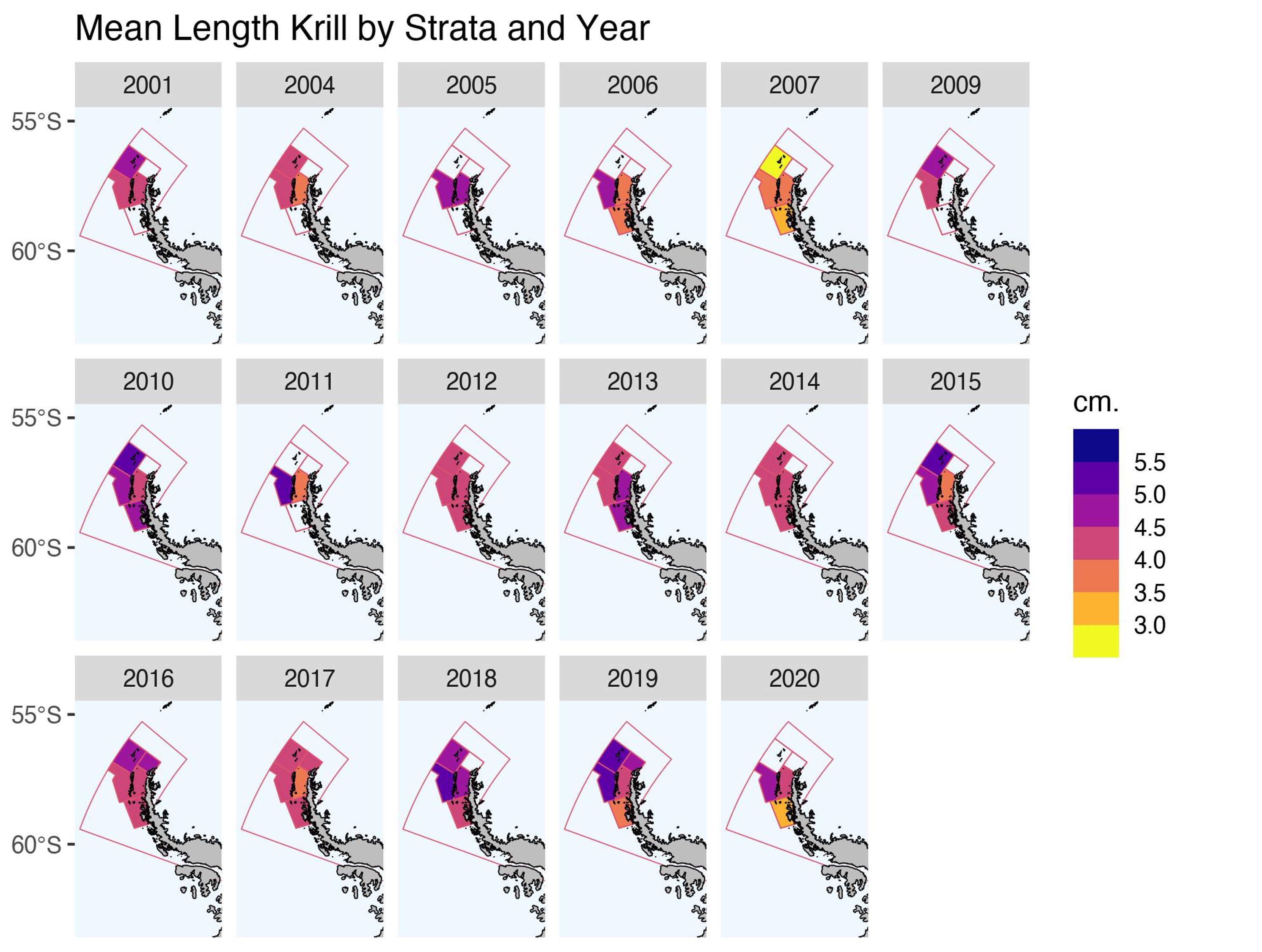
### 2.7.4. Fit the Model

The LBSPR model is fitted using the LBSPRfit function:

Note that the Control argument can be used to modify the additional parameters or LBSPR model type (see description in earlier section).

# 3. RESULTS

This consideration is because we have different size structure in each strata, like we can see in this figure.

 With this differences, we proceed to search intrinsic productivity (Spawning Potential Ratio) by strata and by years.

The LBSPR package uses a Kalman filter and the Rauch-Tung-Striebel smoother function (see FilterSmooth) to smooth out the multi-year estimates of SPR, F/M, and selectivity parameters.

The smoother parameter estimates can be accessed from the myFit object (which is an object of class LB\_obj [see earlier section for details]):

myFit1@Ests

## SL50 SL95 FM SPR  
## [1,] 45.59 55.77 5.35 0.30  
## [2,] 44.96 54.87 5.02 0.29  
## [3,] 44.87 54.76 4.80 0.30  
## [4,] 44.77 55.29 4.55 0.30  
## [5,] 44.28 55.03 4.27 0.30  
## [6,] 43.40 53.99 4.08 0.29  
## [7,] 43.78 54.25 4.00 0.30  
## [8,] 44.15 54.74 3.91 0.32  
## [9,] 44.33 55.09 3.78 0.33  
## [10,] 43.29 54.10 3.60 0.31  
## [11,] 42.32 52.54 3.61 0.29  
## [12,] 42.11 52.25 3.72 0.28  
## [13,] 41.98 52.36 3.77 0.27  
## [14,] 41.69 52.32 3.72 0.27  
## [15,] 40.93 51.55 3.68 0.26  
## [16,] 40.22 50.59 3.64 0.25  
## [17,] 39.48 49.77 3.56 0.25  
## [18,] 39.13 49.35 3.68 0.24

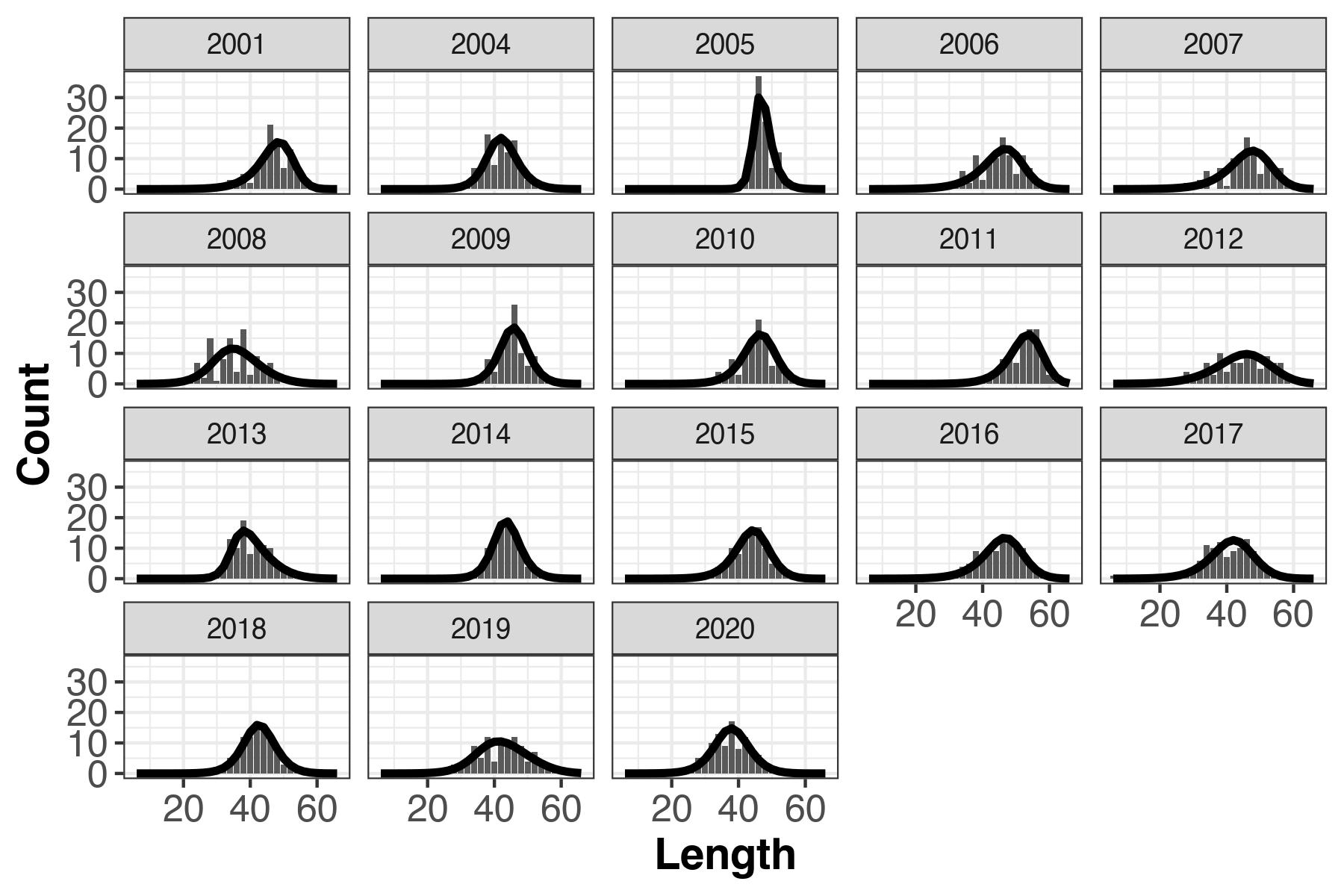
Note that by default the smoothed estimates are used in the plotting routines.

The individual point estimates for each year can be accessed from the LB\_obj object:

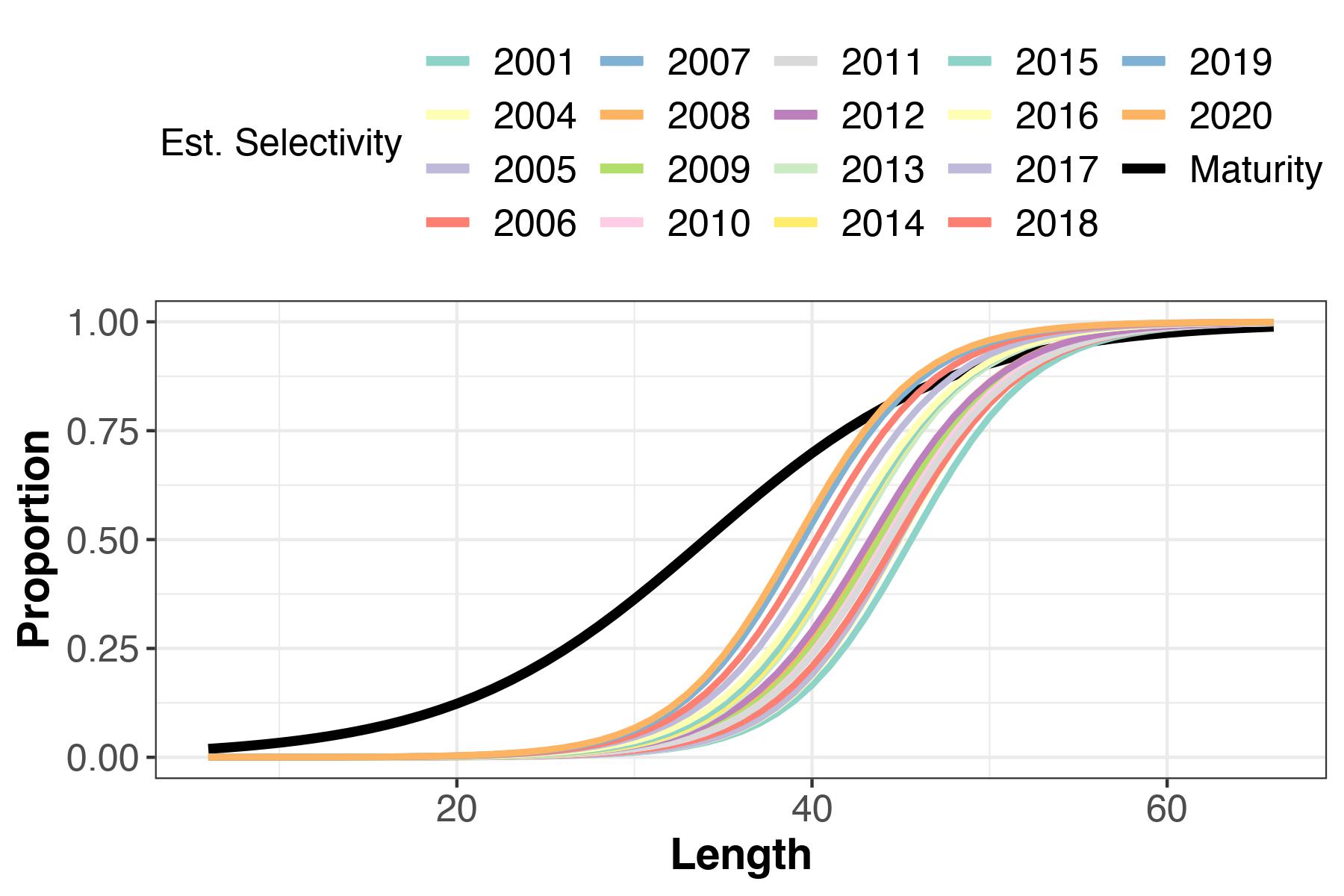
data.frame(rawSL50=myFit1@SL50, rawSL95=myFit1@SL95, rawFM=myFit1@FM, rawSPR=myFit1@SPR)

## rawSL50 rawSL95 rawFM rawSPR  
## 1 52.44 65.34 8.69 0.3390804  
## 2 39.43 46.97 3.92 0.2087088  
## 3 45.01 48.33 5.11 0.3251658  
## 4 48.63 63.15 4.89 0.3141996  
## 5 48.24 62.96 3.30 0.3718446  
## 6 30.72 40.89 3.04 0.1254271  
## 7 44.01 51.94 4.00 0.2960077  
## 8 45.92 56.19 4.39 0.3095126  
## 9 56.55 68.49 4.31 0.5789779  
## 10 42.64 59.75 1.64 0.3952354  
## 11 34.69 39.89 2.65 0.1931645  
## 12 41.36 48.17 4.35 0.2346415  
## 13 43.51 53.96 4.71 0.2468353  
## 14 46.46 59.59 3.59 0.3306032  
## 15 40.44 53.47 3.74 0.2114859  
## 16 40.45 49.14 4.10 0.2164218  
## 17 35.63 45.84 1.40 0.3311026  
## 18 35.62 45.10 4.97 0.1211154

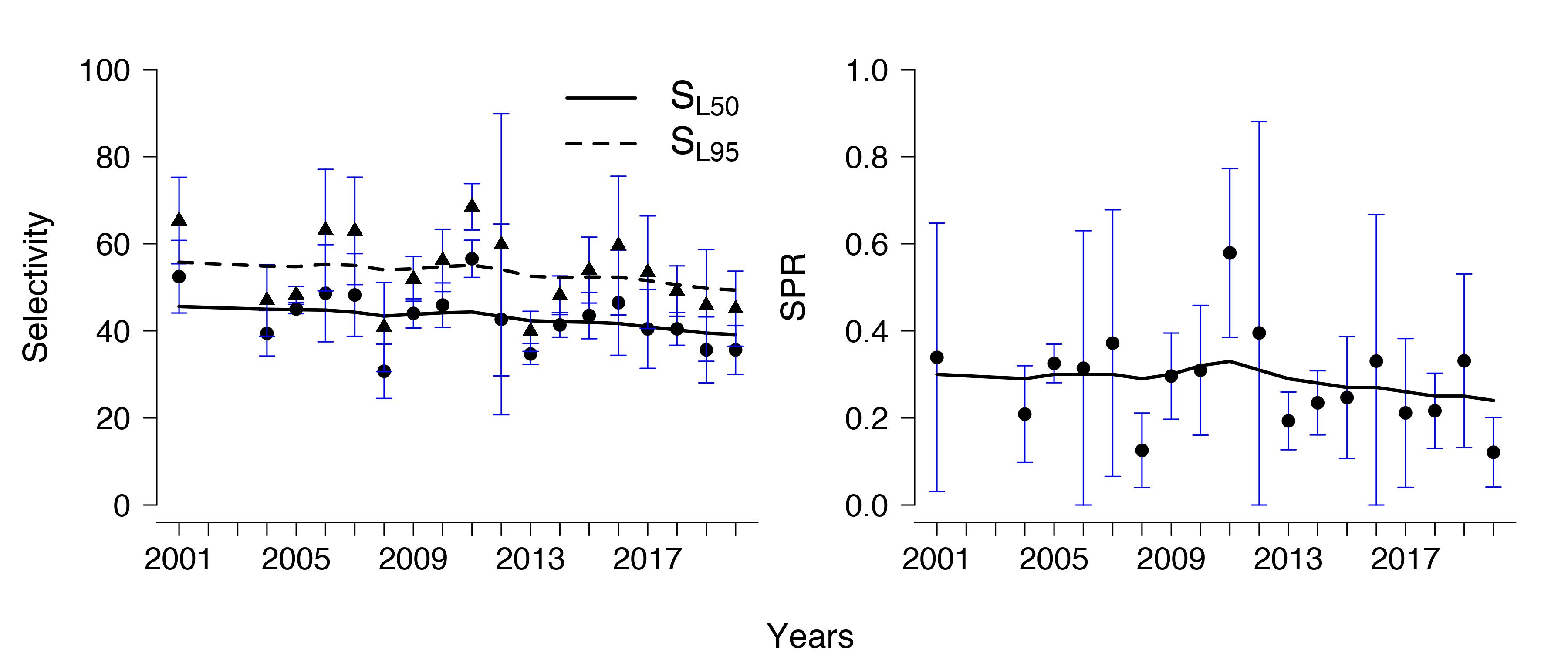
The plotSize function can also be used to show the model fit to the data:



Similarly, the plotMat function can be used to show the specified maturity-at-length curve, and the estimated selectivity-at-length curve:



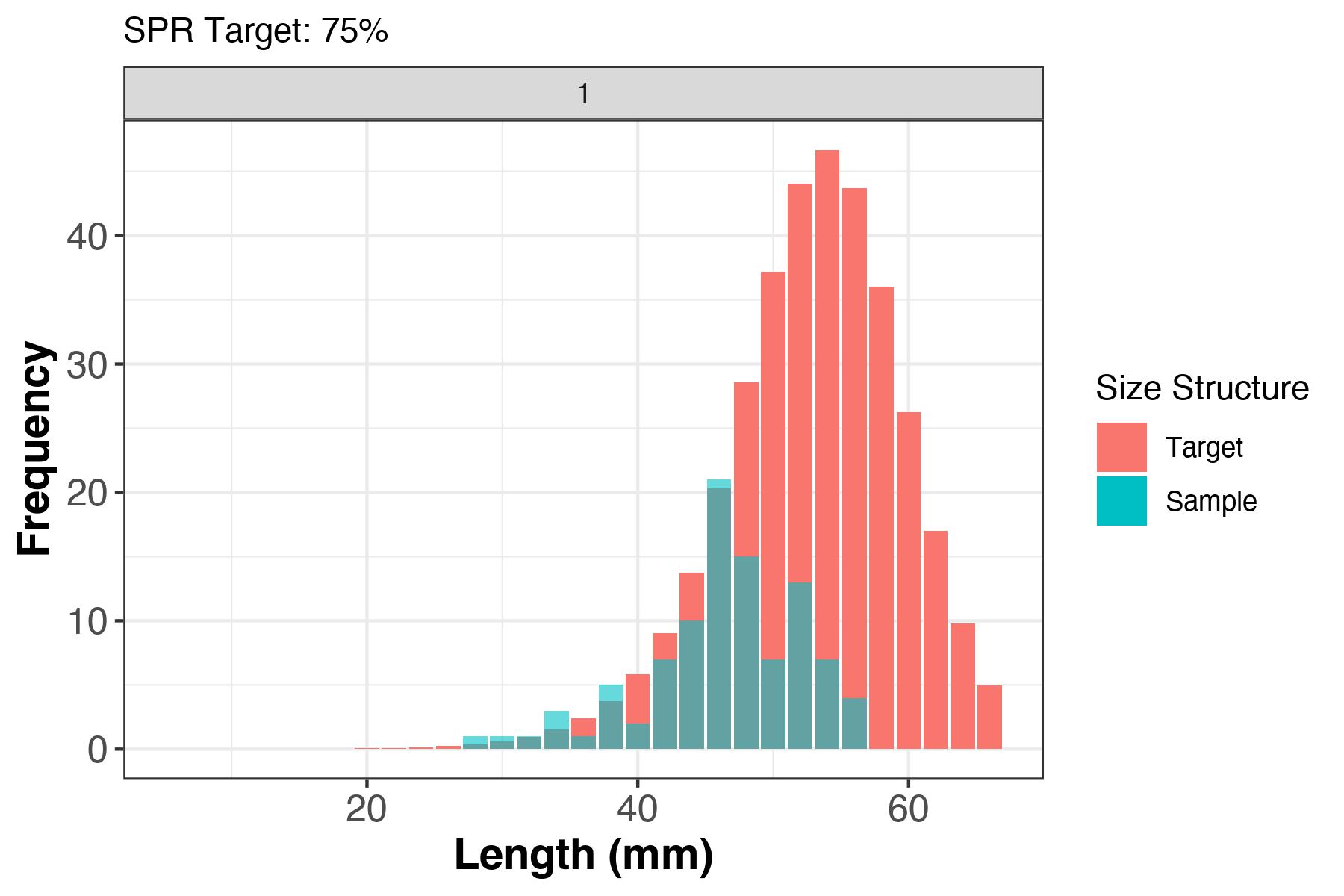
Finally, the plotEsts function can be used to visually display the estimated parameters. Note that this works for all data sets, but only makes sense when there are several years of data:



By default the plotting function adds the smoother line to the estimated points.

## 3.1. Comparing Observed Length Data to Target Size Structure

You can compare the observed size data against an expected size composition at a target SPR using the plotTarg function. To do this, you need a LB\_pars object with the life history parameters and the target SPR:



## 3.3. Reading length strata data

Brainsflied Strata

Lenbs <- new("LB\_lengths", LB\_pars=MyPars, file=paste0(datdir, "/Length\_481\_Krill\_2.csv"), dataType="freq",sep=";",header=T)

Elephan Island Strata

Lenei <- new("LB\_lengths", LB\_pars=MyPars, file=paste0(datdir, "/lenghtEI.csv"), dataType="freq",sep=";",header=T)

Extra Strata

Lenex <- new("LB\_lengths", LB\_pars=MyPars, file=paste0(datdir, "/lenghtExtra.csv"), dataType="freq",sep=";",header=T)

Join Strata

Lenjo <- new("LB\_lengths", LB\_pars=MyPars, file=paste0(datdir, "/lenghtJOIN.csv"), dataType="freq",sep=";",header=T)

SSIW Strata

Lenssiw <- new("LB\_lengths", LB\_pars=MyPars, file=paste0(datdir, "/lenghtSSIW.csv"), dataType="freq",sep=";",header=T)

## 3.4. Fit the Model by strata

The LBSPR model is fitted using the LBSPRfit function:

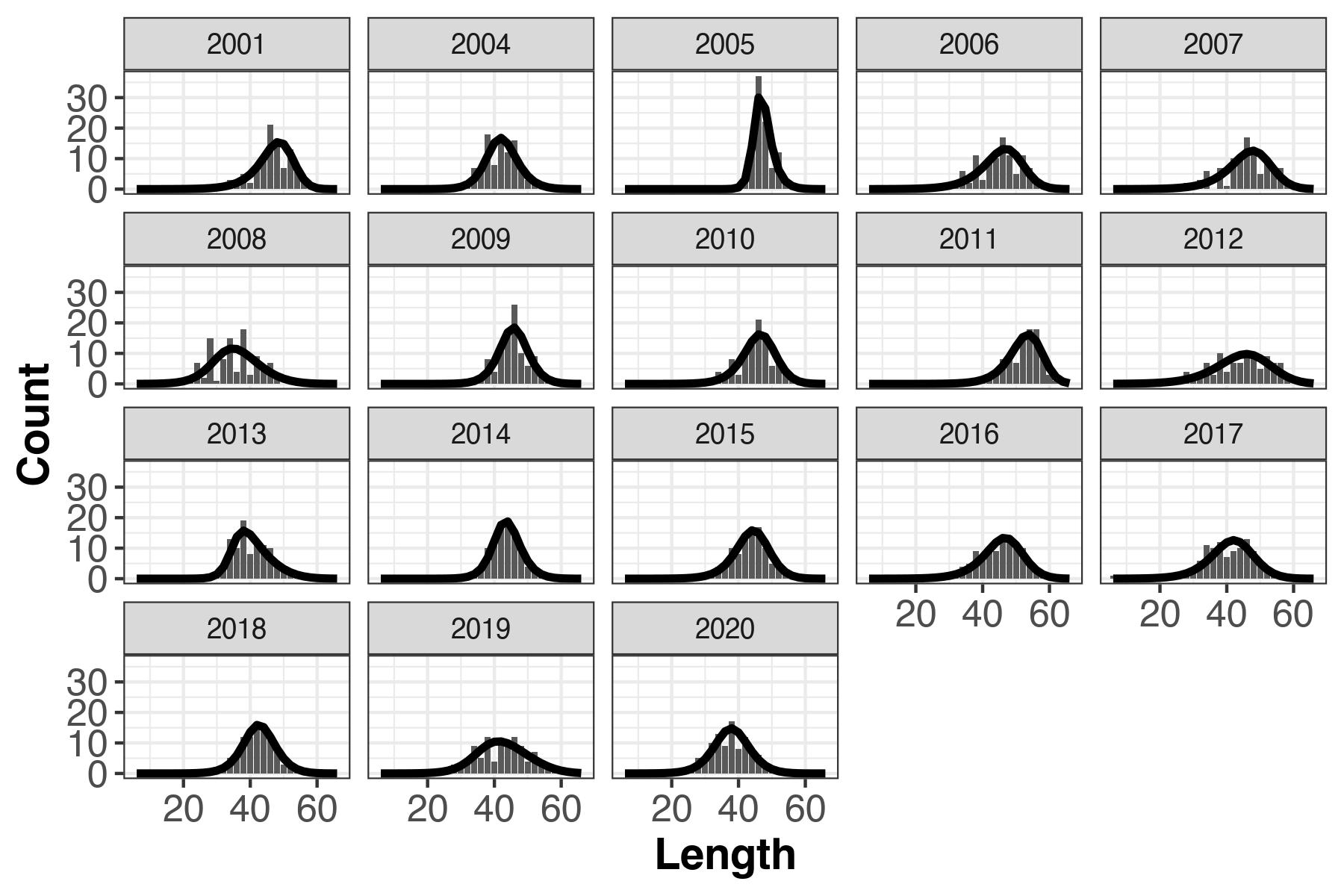
fitbs <- LBSPRfit(MyPars, Lenbs)  
fitei <- LBSPRfit(MyPars, Lenei)  
fitex <- LBSPRfit(MyPars, Lenex)  
fitjo <- LBSPRfit(MyPars, Lenjo)  
fitssiw <- LBSPRfit(MyPars, Lenssiw)

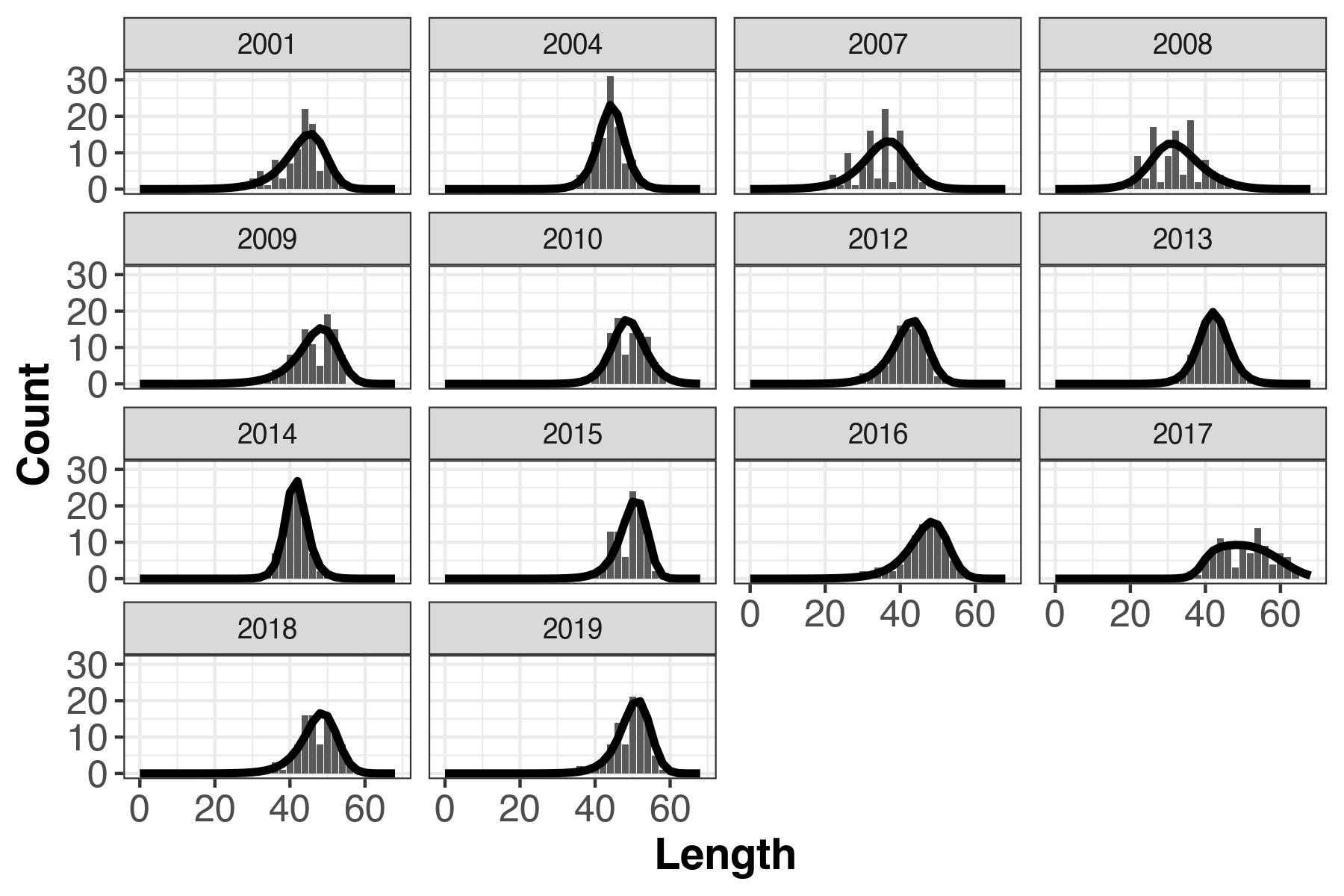
The smoother parameter estimates can be accessed from the myFit object (which is an object of class LB\_obj [see earlier section for details]): In this cae, we can look up estimates in Brainsfield Strata

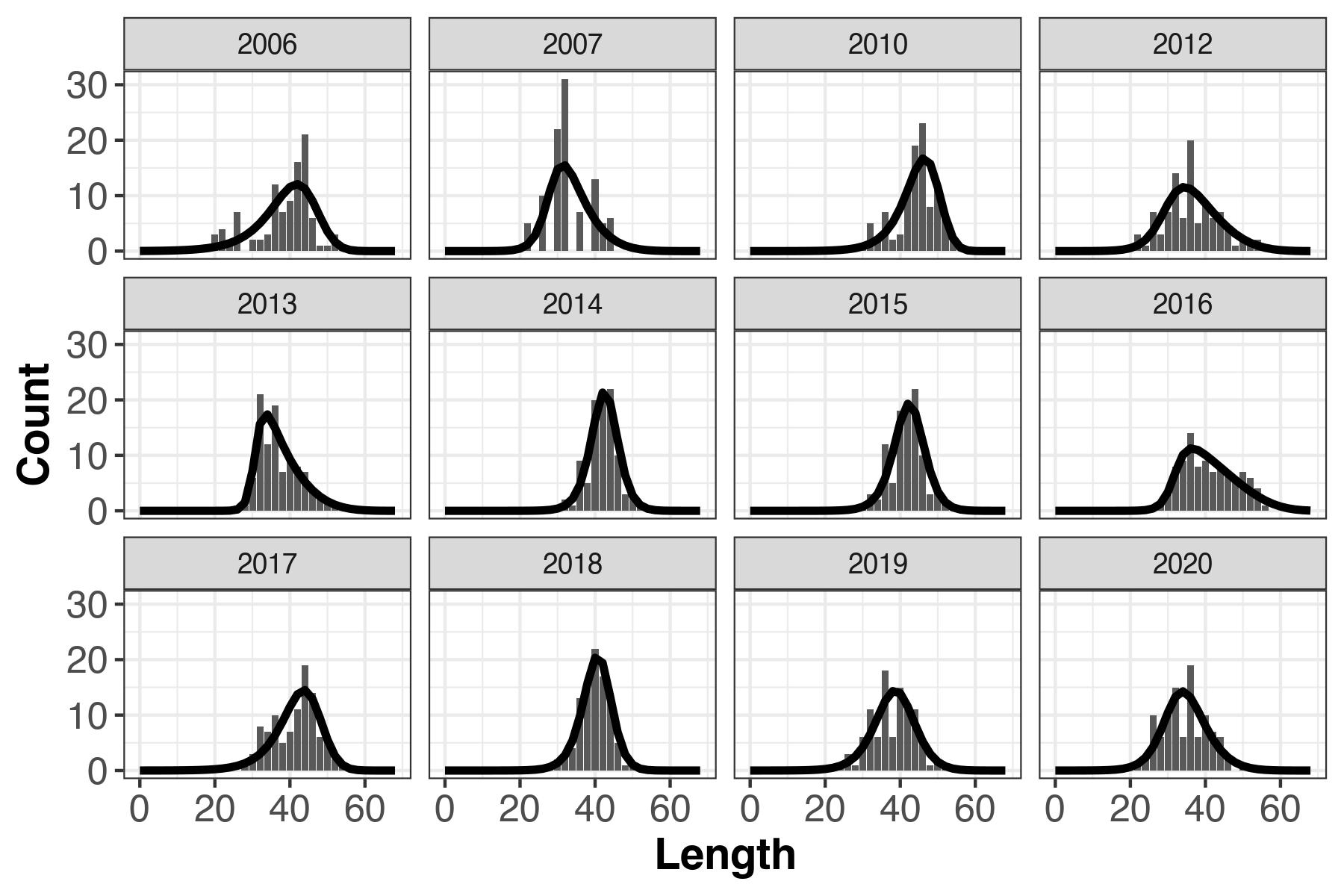
fitei@Ests

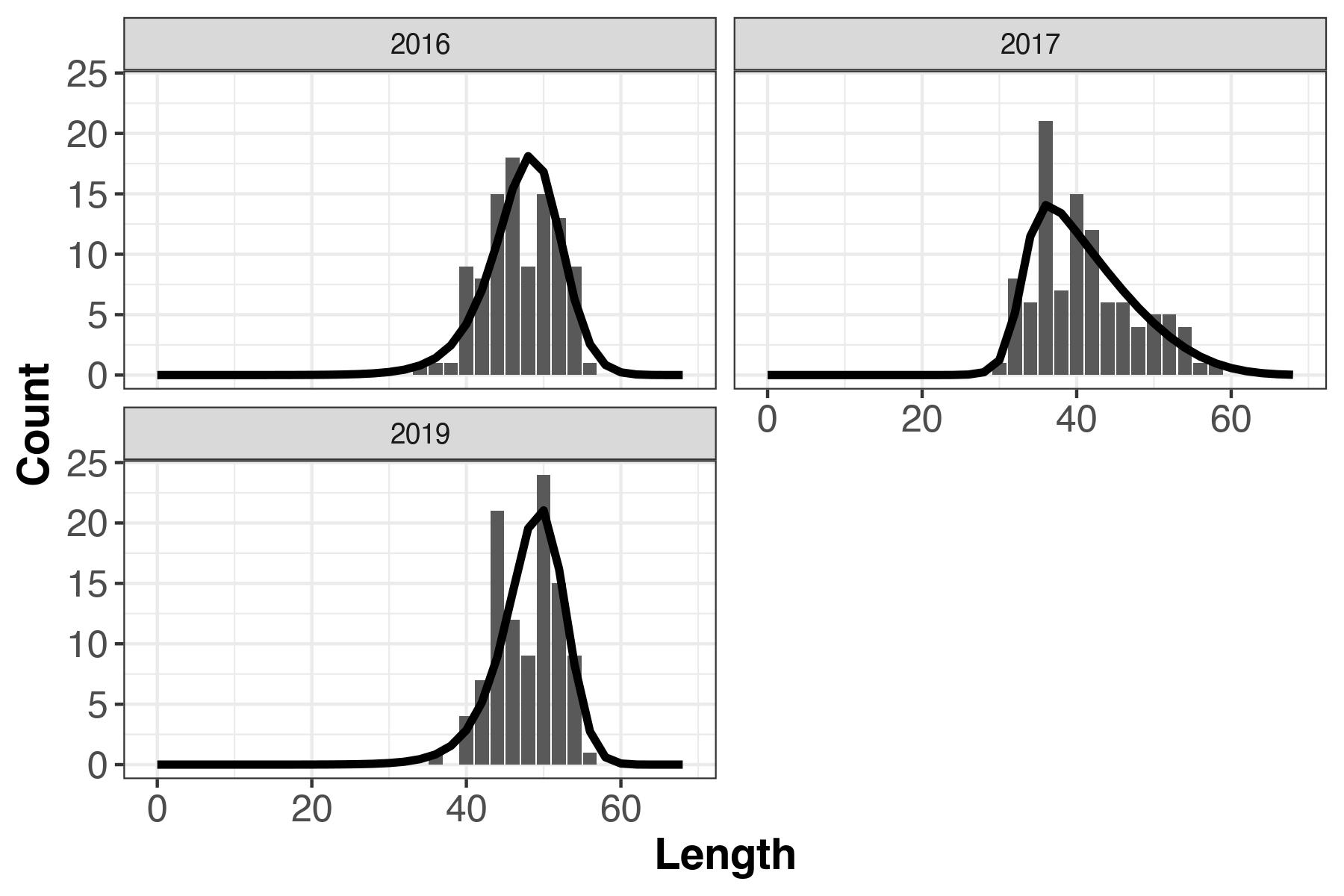
## SL50 SL95 FM SPR  
## [1,] 43.66 54.32 8.51 0.22  
## [2,] 43.10 53.47 8.17 0.21  
## [3,] 42.49 52.94 7.94 0.21  
## [4,] 42.48 52.71 7.80 0.22  
## [5,] 43.99 54.13 8.06 0.25  
## [6,] 44.51 54.19 8.01 0.27  
## [7,] 44.83 54.27 8.51 0.28  
## [8,] 45.12 54.14 8.76 0.29  
## [9,] 45.88 54.69 9.32 0.31  
## [10,] 47.24 56.25 9.98 0.36  
## [11,] 47.81 57.04 9.49 0.39  
## [12,] 47.77 56.79 8.75 0.44  
## [13,] 48.58 57.86 8.88 0.43  
## [14,] 49.11 58.44 9.02 0.43

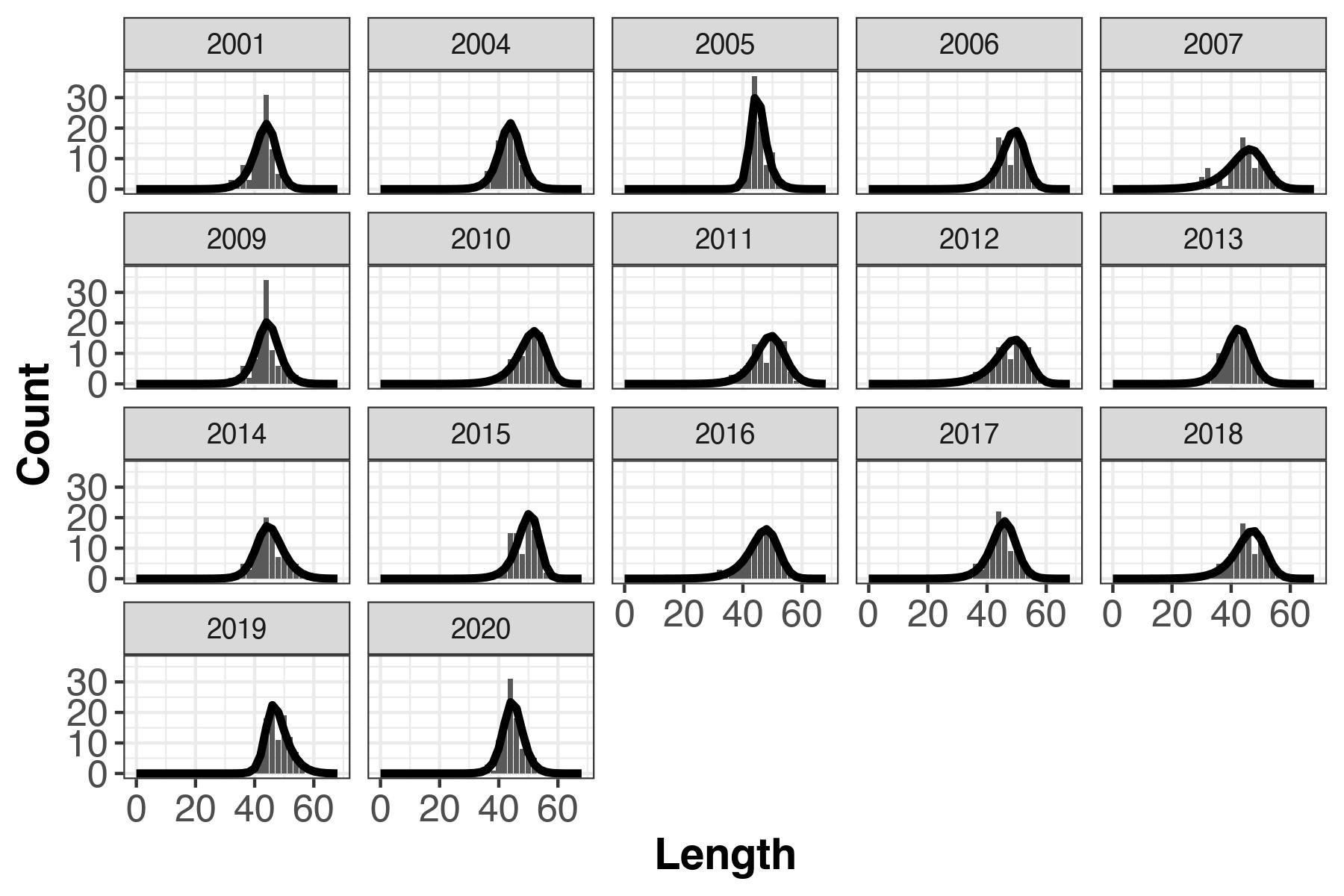
Plotting fits by strata

Fit Bransfield 

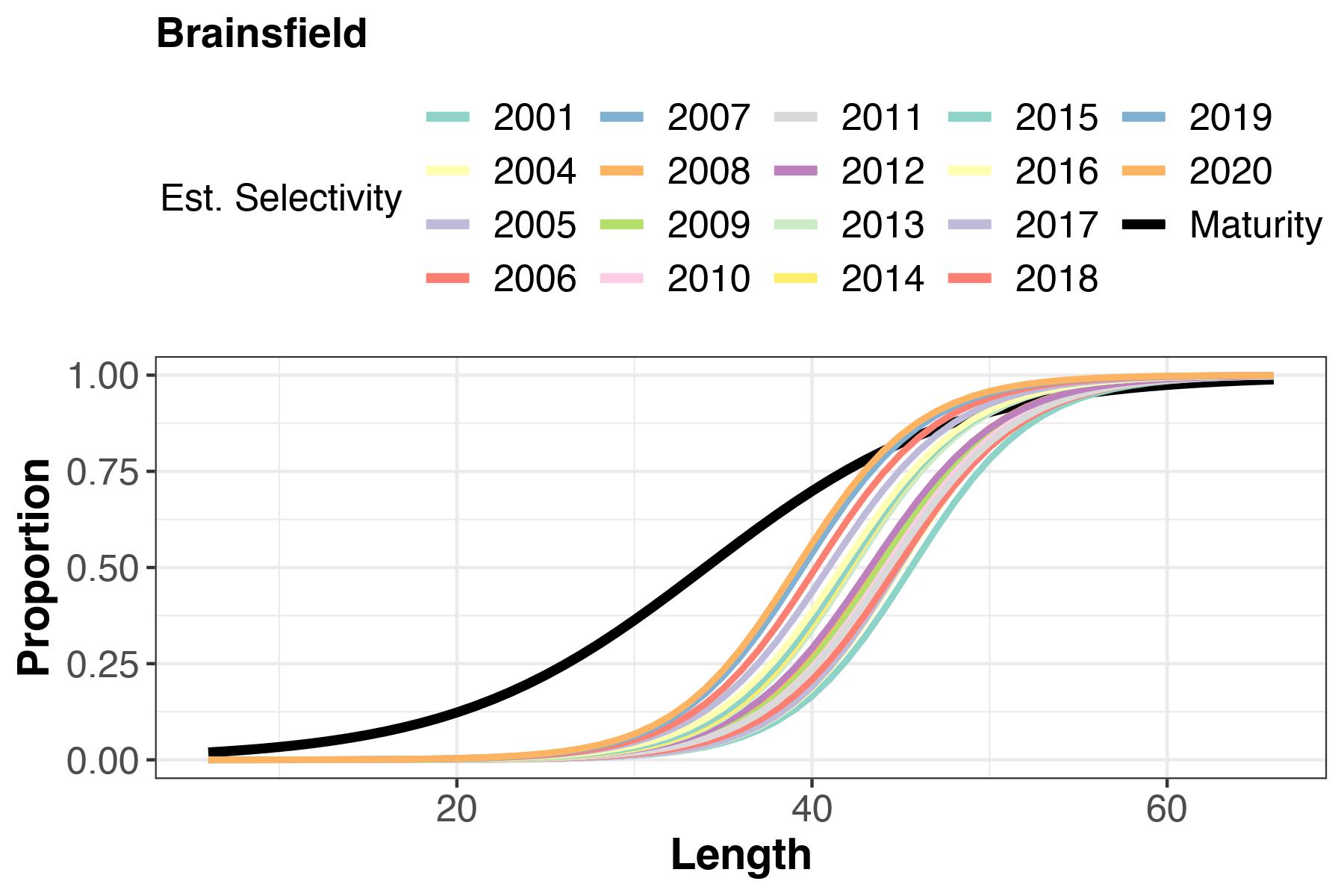
Fit Elephan Island 

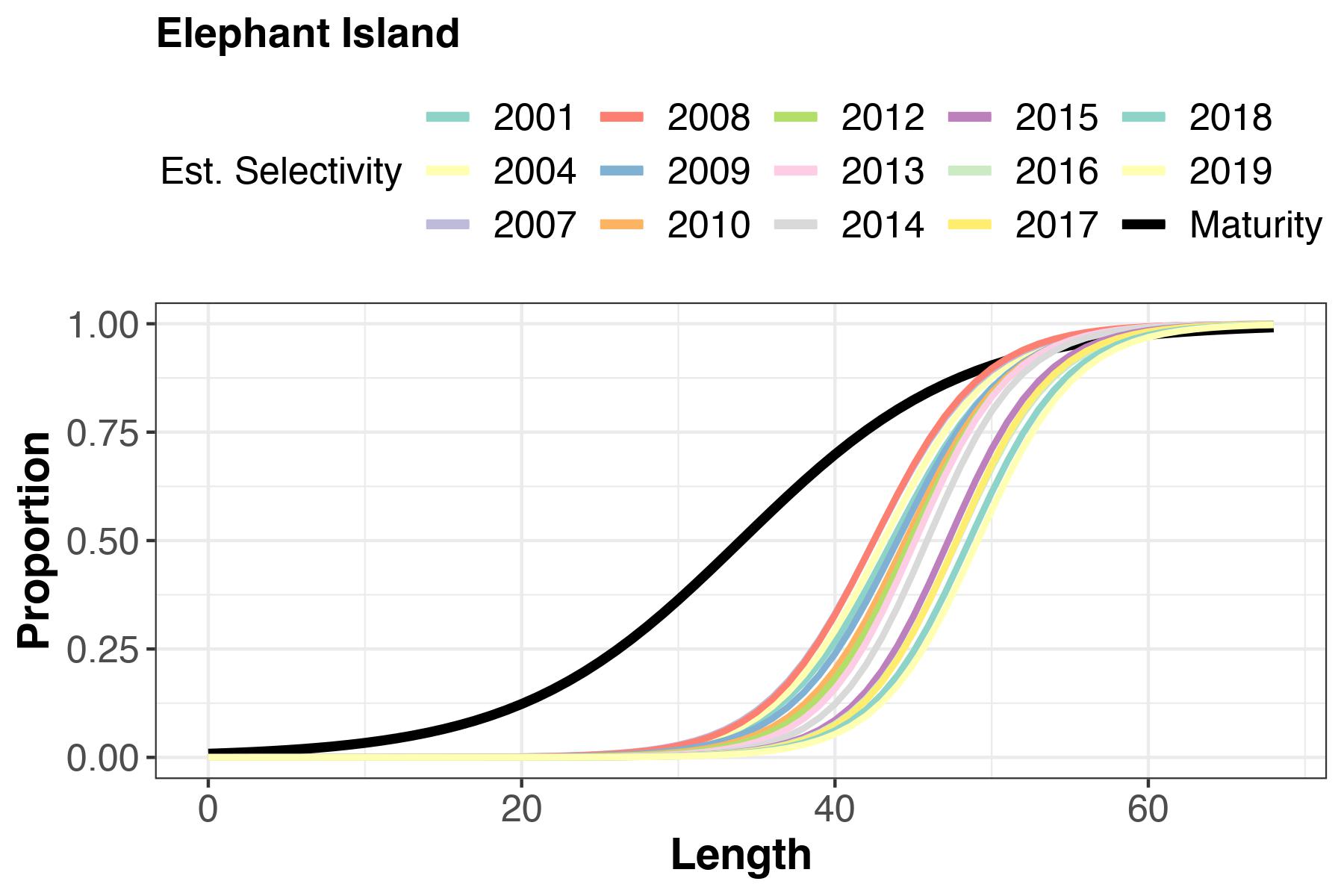
Fit Extra 

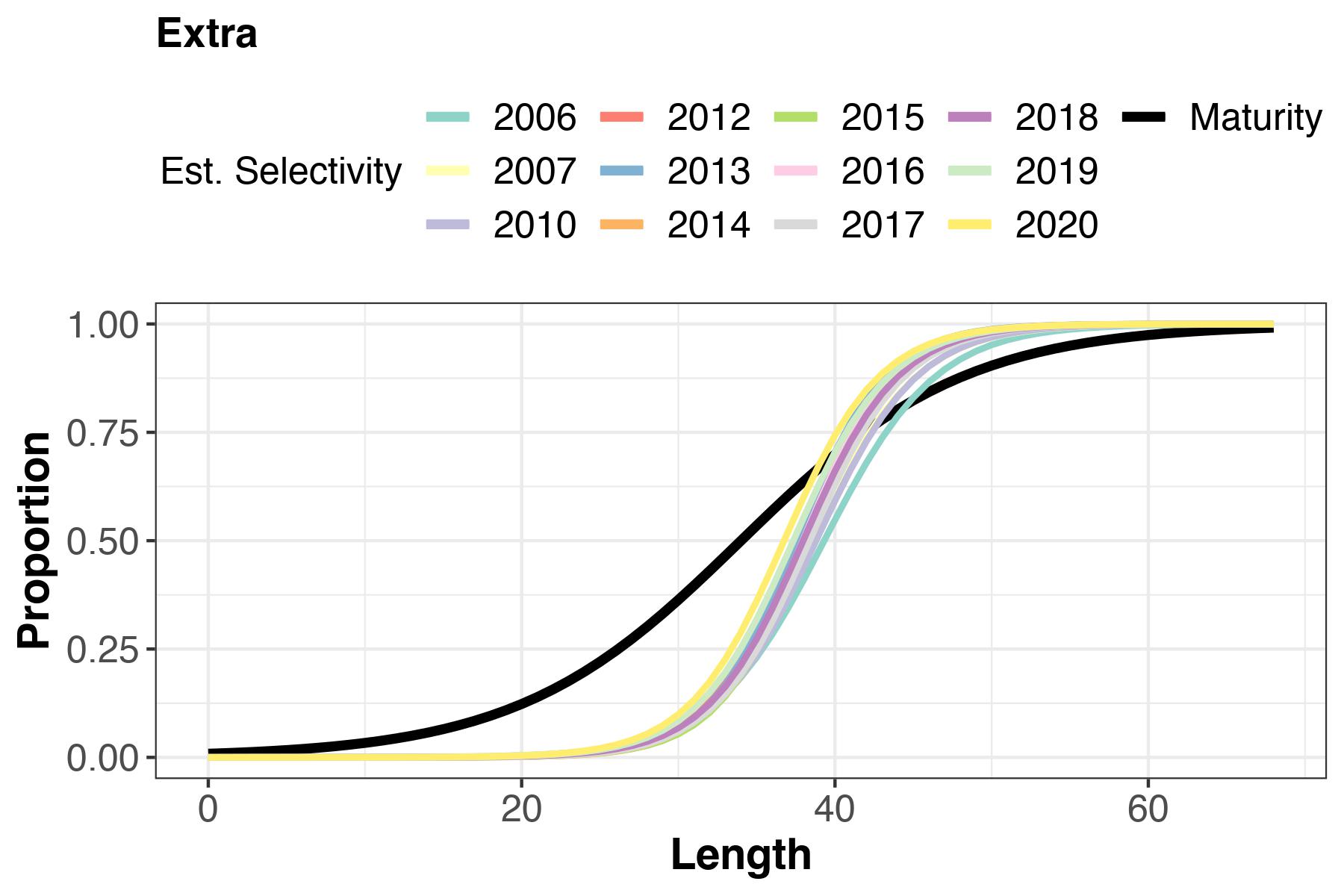
Fit Join 

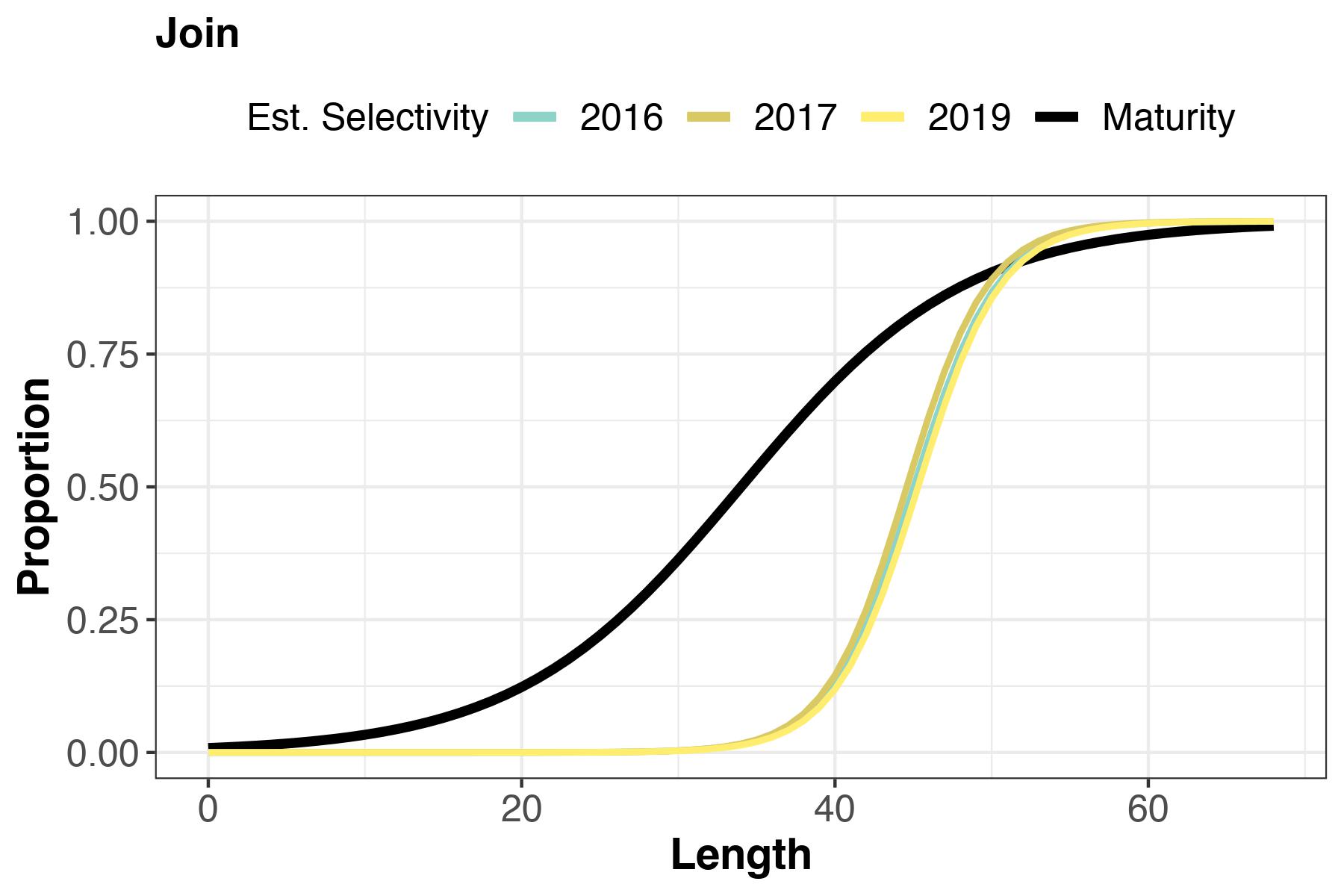
Fit SSIW 

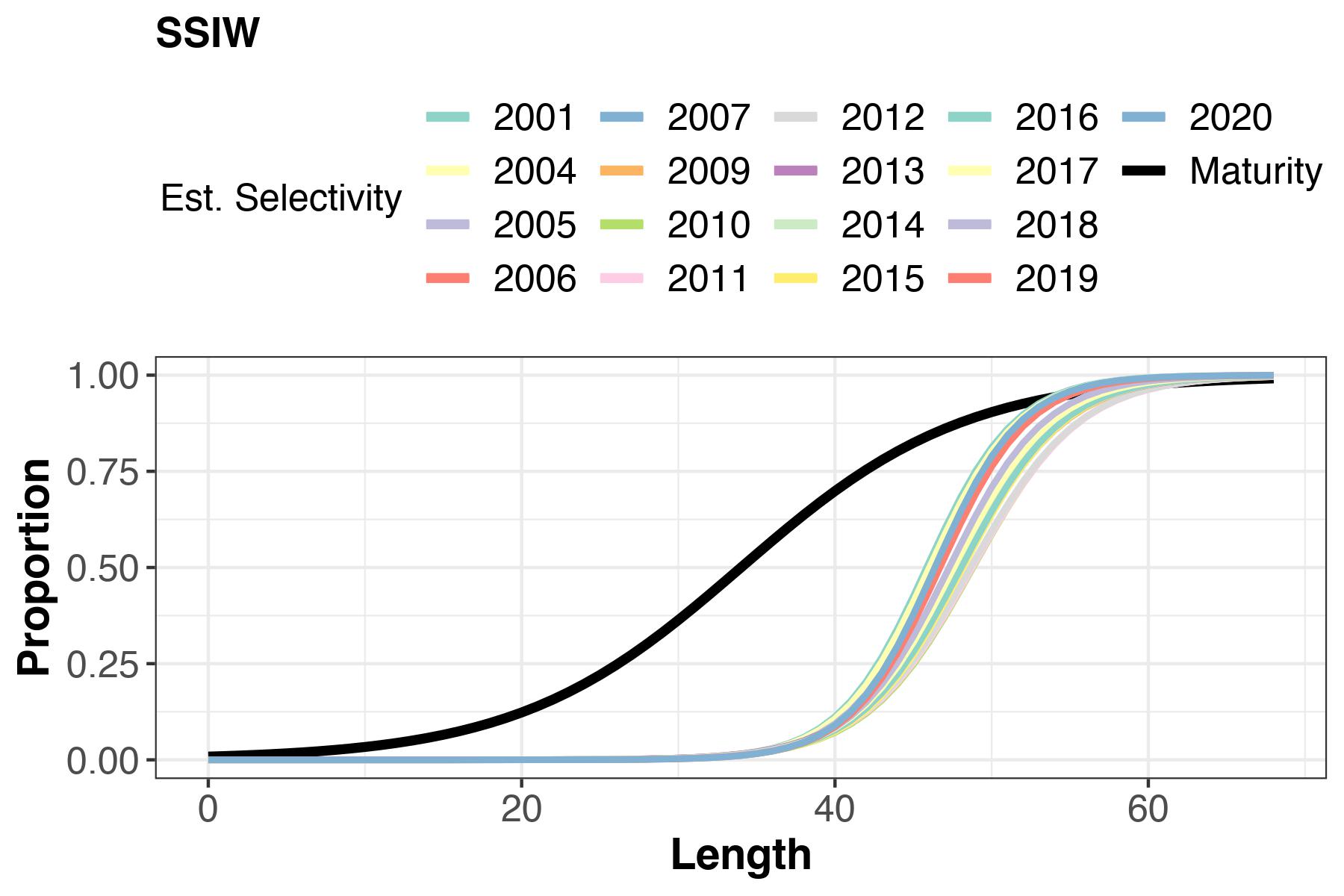
Now we use plotMat function to know specified maturity-at-length curve by strata, and the estimated selectivity-at-length curve.







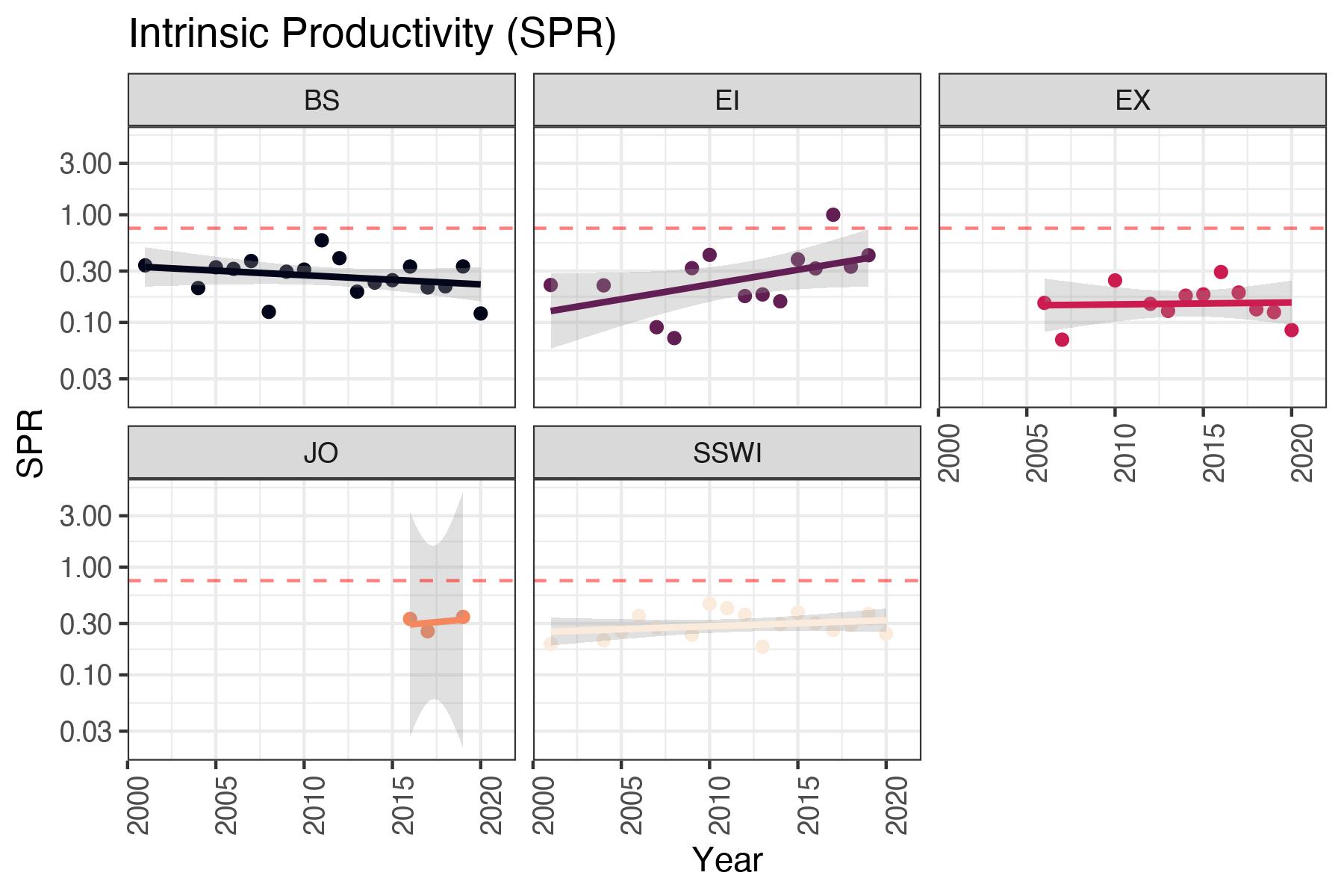




## 3.5. Comparing producivity between Strata

For this, we extract SPR from each slot in the fits models by strata.

Plot with all intrinsic productivity.



# 4. DISCUSSION

(En la discusión se resumen, interpretan y extrapolan los resultados, se analizan sus implicaciones y limitaciones, y se confrontan con las hipótesis planteadas, considerando cómo ha sido la perspectiva de otros autores.)

Identificar los cambios espaciales y temporales del krill en la PA ha sido uno de los mayores desafíos durante los ultimos años. El krill es una especie clave en el ambiente antartico y entender la dinamica población es un elemento basico para visivilizar los impactos en el funcionamenito de la trama trofica, conservacion del recurso y manejo de la pesquería. nunestro interes fue dimiensionar el potencial reproductivo de la especie a escalas finas de espacio y tiempo en la subarea 48.1, dado que en esta area es donde se ha concentrado la pesquería y el recurso durante los ultimos 20 años. Nuestro resultados indentifican variabilidad espaciotemporal del krill en diferentes estratos de manejo pesquero y a su vez fu posible proponer Pubtos Biologicos de rewferencia en función de las caracteristicas de la especie, lo cual constituye a su vez una recomendación para las actuales estrategia de explotacion que lleva a cabo la CCMLAR. En este sentido, identifican los periodos historicos pesqueros ren funcion del potencial reproductivo y a su vez se propone un manejo espacialente explicito en fincion de estos resultados

## 4.1. Cambios en estructura poblacional del Krill

Las cambios en la dinámica y estructura poblacional en el krill en la Península Antártica se manifiestan de varias maneras, como por ejemplo, en la distribución, biomasa, , reclutamiento, fenología entre otras. Los principales forzantes de estos cambios estan asociados al comportamiento cambiante de las distintas variables ambientales en el habitat del krill ([Saba et al., 2014](#ref-Saba2014); [**Flores2012a?**](#ref-Flores2012a); [**Pinones2016?**](#ref-Pinones2016); [**Veytia2021?**](#ref-Veytia2021); [**Flores2012?**](#ref-Flores2012); [**Walsh2020?**](#ref-Walsh2020)). Frente a este escenario cambiante, la productividad intrínseca poblacional, es decir, el potencial reproductivo de la especie también ha sufrido cambios en las ultimas decadas ([Angus Atkinson et al., 2022](#ref-Atkinson2022); [Perry, 2020](#ref-Perry2020); [**McBride2021?**](#ref-McBride2021)), tanto en la escala temporal así como la espacial. De igual manera la estructura poblacional del krill en la PA se ha visto impactada por este tipo de forzantes ambientales ([Reiss et al., 2020](#ref-Reiss2020); [Siegel et al., 2013](#ref-Siegel2013))

## 4.2. Datos pesqueros como indicadores poblacionales

El krill en la PA ha sido extraído comercialmente desde aproximadamente 1970 y constituye la pesquería mas grande del Océano Austral. Los datos de la actividad pesquera en torno al krill han sido sistematicamente colectados a bordo de las embarcaciones pesqueras a traves del programa SISO, con lo cual ha sido posible tambien identificar cambios de la dinamica poblacional que han ocurrido durantes las ultimas decada y entoda la zona de mayor explotacion. Cambios en la disponibilidad, distribucion, y concentracion, rendimiento del recurso se han visto reflejados en los datos ([Krüger, 2019](#ref-Kruger2019); [Santa Cruz et al., 2018](#ref-SantaCruz2018), [2022](#ref-SantaCruz2022); [**Atkinson2019a?**](#ref-Atkinson2019a)). Para identificar cambios la productividad intrinseca de la población del krill, utilizamos una de las piezas de información mas representativos de la dinamica poblaciional de los recursos marinos explotados que existen en este tipo de programas de monitoreo de pesquerías, en este caso, datos de frecuencia de talla de la captura. [Hordyk et al., 2014; Froese et al., 2018; Prince et al., 2015; Rudd y Thorson, 2018; Ault et al., 2019; Chong et al., 2019; Pilling et al., 2008; Hordyk et al., 2015; Mildenberger et al., 2017]. ; Froese et al., 2018). Este tipo de datos son abundantes y permite cubrir una gran escala temporal y espacial, en este caso, desde 1980 a 2020 y en toda la subarea 48.1 (Figura 1).

## 4.3. Diferencias temporales en la productividad intrinseca del krill

En terminos temporales, los estratos tienen diferencias en el potencial reproductivo y por consiguiente en la productividad intrinseca de la población. Durante los ultimos 20 años, el strato de elephant Island ha tenido un aumento del potencial reporductivo lllegando a niveles del 56% para el año 2020. Esto tiene relación con los cambios en los niveles de produccón primaria que han suceido en esta zona. (cita)

Para demostrar esto, analizamos mas de 20 años de indicadores poblacionales directos desde los datos de la pesquería para identificar cambios de la productividad intrínseca en escalas espaciotemporales del krill en la PA. Estos cambios fueron medidos cuantitativamente a través del potencial reproductivo mediante un nobel método de uso común en pesquerías del mundo que considera el uso de parametros de historia de vida, como madurez, crecimiento y tasa de crecimiento, estructuras de tallas y simulaciones basadas en paramettros invariantes

Cambios en la estructuración espacial de la población de krill han sido demostradas de variadas maneras. A. Atkinson et al. ([2009](#ref-Atkinson2009)); A. Atkinson et al. ([2008](#ref-Atkinson2008)) indica que la población muestra evidentes siítomas de contracción hacia el suroeste de la PA. Esta contracción de la distribución de la población tiene consecuencias otros fenomenos como en los rendimientos productivos que se manfiestan en indicadores pesqueros como lo demuestra Santa Cruz et al. ([2022](#ref-SantaCruz2022)); Santa Cruz et al. ([2018](#ref-SantaCruz2018)).

## 4.4. Diferencias espaciales en la productividad intrinseca del krill

En este método determinamos las diferencias entre estructururas de tallas simuladas del krill en función de sus parámetros de hisoria de vida (Maschette et al. ([2020](#ref-Maschette2020))) y las resultantes de la pesquería, lo cua lpermite conocer la diferencia entre el potencial reproductivo virginal y el que actualmente se captura.

## 4.5. Comparacion con otros estudios

Mace & Sissenwine (1993) Review and meta-analysis of SPR reference points for teleosts: 20% SPR as limit reference points, & 35-40% SPR for MSY that have been internationally recognized in the US, USA, Australia, NZ etc. ([Goodyear, 1993](#ref-Goodyear1993); [Mace, 2001](#ref-Mace2001)).

and increasing the mean length of krill, suggesting that recruitment events are declining ([A. Atkinson et al., 2009](#ref-Atkinson2009))

cambios en el potencial reproductivo por zona:

Angus Atkinson et al. ([2022](#ref-Atkinson2022)), Perry ([2020](#ref-Perry2020))

and have been used for assessments in the US South Atlantic, Pacific islands, and Caribbean (Ehrhardt and Ault 1992; Ault et al. 2005, 2008; Gedamke and Hoenig 2006; Nadon et al. 2015).

## 4.6. Consideraciones finales

* Preliminar outputs to know intrinsic productivity of Antarctic krill (*Euphausia superba*) in Antarctic Peninsula, SubArea 48.1.
* This method dont incorportate environmental variables
* Based in own krill dynamics
* Do sensitivity analysis based on Linf (5 scenarios)
* This code with methodology in this [link](https://github.com/MauroMardones/LBSPR_Krill)

# 5. REFERENCES

Atkinson, Angus, Hill, S. L., Reiss, C. S., Pakhomov, E. A., Beaugrand, G., Tarling, G. A., Yang, G., Steinberg, D. K., Schmidt, K., Edwards, M., Rombolá, E., & Perry, F. A. (2022). Stepping stones towards Antarctica: Switch to southern spawning grounds explains an abrupt range shift in krill. *Global Change Biology*, *28*(4), 1359–1375. <https://doi.org/10.1111/gcb.16009>

Atkinson, A., Siegel, V., Pakhomov, E. A., Jessopp, M. J., & Loeb, V. (2009). A re-appraisal of the total biomass and annual production of Antarctic krill. *Deep-Sea Research Part I: Oceanographic Research Papers*, *56*(5), 727–740. <https://doi.org/10.1016/j.dsr.2008.12.007>

Atkinson, A., Siegel, V., Pakhomov, E. A., Rothery, P., Loeb, V., Ross, R. M., Quetin, L. B., Schmidt, K., Fretwell, P., Murphy, E. J., Tarling, G. A., & Fleming, A. H. (2008). Oceanic circumpolar habitats of Antarctic krill. *Marine Ecology Progress Series*, *362*(June), 1–23. <https://doi.org/10.3354/meps07498>

Beverton, R., & Holt, S. (1957). *On the Dynamics of Exploited Fish Populations* (p. 540). SPRINGER-SCIENCE+BUSINES S MEDIA , B.V.

Canales, C. M., Punt, A. E., & Mardones, M. (2021). Can a length-based pseudo-cohort analysis (LBPA) using multiple catch length-frequencies provide insight into population status in data-poor situations? *Fisheries Research*, *234*(October 2020), 105810. <https://doi.org/10.1016/j.fishres.2020.105810>

Froese, R., Winker, H., Coro, G., Demirel, N., Tsikliras, A. C., Dimarchopoulou, D., Scarcella, G., Probst, W. N., Dureuil, M., & Pauly, D. (2018). A new approach for estimating stock status from length frequency data. *ICES Journal of Marine Science*, *76*(1), 350–351. <https://doi.org/10.1093/icesjms/fsy139>

Goodyear, C. P. (1993). Spawning stock biomass per recruit in fisheries management: foundation and current use. . *Risk Evaluation and Biological Reference Points for Fisheries Management*, *120*, 67–81.

Hordyk, A. (2021). *LBSPR: Length-based spawning potential ratio*. <https://CRAN.R-project.org/package=LBSPR>

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., Ono, K., Sainsbury, K., Loneragan, N., & Prince, J. (2014). *Spawning Potential Ratio*. *72*(2015), 204–216.

Jensen, A. L. (1996). Beverton and Holt life history invariants result from optimal trade-off of reproduction and survival. *Canadian Journal of Fisheries and Aquatic Sciences*, *53*(4), 820–822. <https://doi.org/10.1139/f95-233>

Krüger, L. (2019). Spatio-temporal trends of the Krill fisheries in the Western Antarctic Peninsula and Southern Scotia Arc. *Fisheries Management and Ecology*, *26*(4), 327–333. <https://doi.org/10.1111/fme.12363>

Mace, P. M. (2001). A new role for MSY in single-species and ecosystemrapproaches to fisheries stock assessment and management. *Fish and Fisheries*, *2*, 2–32. <https://doi.org/10.1046/j.1467-2979.2001.00033.x>

Maschette, D., Wotherspoon, S., Pavez, C., Ziegler, P., Thanassekos, S., Reid, K., Kawaguchi, S., Welsford, D., & Constable, A. (2020). *Generalised R Yield Model (Grym)*. <https://www.ccamlr.org/en/system/files/meeting{\_}documents/with{\_}cover/sc-39-bg-19.pdf>

Perry, F. (2020). *Antarctic krill recruitment in the south-west Atlantic sector of the Southern Ocean* (p. 310) [PhD thesis]. UNIVERSITY OF SOUTHAMPTON.

Prince, J., & Hordyk, A. (2018). *What to do when you have almost nothing : A simple quantitative prescription for managing extremely data- ­ poor fisheries*. *May*, 1–15. <https://doi.org/10.1111/faf.12335>

Reiss, C. S., Hinke, J. T., & Watters, G. M. (2020). Demographic and maturity patterns of Antarctic krill (Euphausia superba) in an overwintering hotspot. *Polar Biology*, *43*(9), 1233–1245. <https://doi.org/10.1007/s00300-020-02704-4>

Rudd, M. B., & Thorson, J. T. (2017). Accounting for variable recruitment and fishing mortality in length-based stock assessments for data-limited fisheries. *Canadian Journal of Fisheries and Aquatic Sciences*, *75*(7), 1019–1035. <https://doi.org/10.1139/cjfas-2017-0143>

Saba, G. K., Fraser, W. R., Saba, V. S., Iannuzzi, R. A., Coleman, K. E., Doney, S. C., Ducklow, H. W., Martinson, D. G., Miles, T. N., Patterson-Fraser, D. L., Stammerjohn, S. E., Steinberg, D. K., & Schofield, O. M. (2014). Winter and spring controls on the summer food web of the coastal West Antarctic Peninsula. *Nature Communications*, *5*. <https://doi.org/10.1038/ncomms5318>

Santa Cruz, F., Ernst, B., Arata, J. A., & Parada, C. (2018). Spatial and temporal dynamics of the Antarctic krill fishery in fishing hotspots in the Bransfield Strait and South Shetland Islands. *Fisheries Research*, *208*(August), 157–166. <https://doi.org/10.1016/j.fishres.2018.07.020>

Santa Cruz, F., Krüger, L., & Cárdenas, C. A. (2022). Spatial and temporal catch concentrations for Antarctic krill: Implications for fishing performance and precautionary management in the Southern Ocean. *Ocean & Coastal Management*, *223*(September 2021), 106146. <https://doi.org/10.1016/j.ocecoaman.2022.106146>

Siegel, V., Reiss, C. S., Dietrich, K. S., Haraldsson, M., & Rohardt, G. (2013). Distribution and abundance of Antarctic krill (Euphausia superba) along the Antarctic Peninsula. *Deep-Sea Research Part I: Oceanographic Research Papers*, *77*, 63–74. <https://doi.org/10.1016/j.dsr.2013.02.005>

Stammerjohn, Sharon E., Martinson, D. G., Smith, R. C., & Iannuzzi, R. A. (2008). Sea ice in the western Antarctic Peninsula region: Spatio-temporal variability from ecological and climate change perspectives. *Deep-Sea Research Part II: Topical Studies in Oceanography*, *55*(18-19), 2041–2058. <https://doi.org/10.1016/j.dsr2.2008.04.026>

Stammerjohn, S. E., Martinson, D. G., Smith, R. C., Yuan, X., & Rind, D. (2008). Trends in Antarctic annual sea ice retreat and advance and their relation to El Niño-Southern Oscillation and Southern Annular Mode variability. *Journal of Geophysical Research: Oceans*, *113*(3), 1–20. <https://doi.org/10.1029/2007jc004269>

WG-EMM-2021/05. (2021). *Results from the WG-ASAM intersessional e-group on Krill biomass estimates from acoustic surveys. WG-EMM-2021/05. WG-ASAM e-group on Krill biomass estimates from acoustic surveys.* (p. 16). Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR).