California Warty Sea Cucumber

Operating Model Report

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Introduction

Warty Sea Cucumbers (WSC) are long, soft-bodied, marine invertebrates in the class Holothuroidea. They are related to other organisms in the phylum Echinodermata such as sea urchins and sea stars. Their skeleton has been reduced to small calcarious pieces (ossicles) in the body wall, which have distinct species-specifc shapes.

The warty sea cucumber is distributed from Baja California to Monterey Bay, although it is uncommon north of Pt. Conception. WSC live in nearshore environments from the low intertidal to 150 feet, with the greatest densities observed between 60 and 98 ft. The distribution of these species on rocky or sandy substrates is patchy, but WSC display increases in densities in shallow waters during the spring and early summer which is believed to result from spawning aggregation.

Very little is known about the biology of WSC or the population status, and while CDFW is currently conducting a number of studies to increase the available information, WSC exhibit a number of life history features that make it difficult to apply traditional fisheries models. The primary source of uncertainty stems from an inability to determine the life span of WSC using traditional methods due to their lack of hard body structures that lay down annual rings (such as otoliths in fish) as well as the fact that tags do not stay attached to their soft body walls. This makes it very difficult to model size at age, natural mortality, and age at sexual maturity. There is also no information available on the recruitment dynamics of this stock. These are key parameters for assessing the biological vulnerability of the stock to fishing, and as a result this population is severely data limited.

Another unusual feature of this OM stems from the fact sea cucumbers have soft bodies, and will contract when touched. This makes obtaining accurate lengths, and weight is generally a more useful metric in determining the size of a sea cucumber. However, the DLMtool requires a size-based metric, and so the Department has followed the procedure used by Muscat (1983) of taking measurements on contracted individuals. Analysis has determined that using the contracted Length x Width is the most consistent size measurement, and so all size-based parameters are modeled in these units.

In constructing this operating model we have relied on the available published observations in the literature, proxy species, and expert judgement. Wide distributions were used to capture uncertainty. This MSE tested alternative hypotheses about the life span, growth rate, and age at maturity, and any Management Procedure considered for use in California must be robust to these assumptions.

The number of simulations for a final model run (nsim) was set at XXX and fishing was projected 50 years to the future (proyears). The management interval tested was 4 years. The maximum instantaneous fishing mortality rate for an age class (maxF) was set at 0.8, which is the default value in the DLMtool. The number of samples for stochastic MPs (reps) was set at 1, and the percentile of the sample of the management recommendation (pstar) used for any stochastic MPs was set at 0.5, meaning the median recommendation was selected.

Operating Model

The OM rdata file can be downloaded from here

Download and import into R using `myOM <- readRDS('OM.rdata')`

Species Information

Species: *Parastichopus parvimensis*

Common Name: *Not specified*

Management Agency: California Department of Fish and Wildlife

Region: Califorinia, USA

Sponsor: Resources Legacy Fund

Latitude: 34.42083

Longitude: -119.69819

OM Parameters

OM Name: Name of the operating model: WSC_CA

nsim: The number of simulations: 48

proyears: The number of projected years: 50

interval: The assessment interval - how often would you like to update the management system? 1

pstar: The percentile of the sample of the management recommendation for each method: 0.5

maxF: Maximum instantaneous fishing mortality rate that may be simulated for any given age class: 0.8

reps: Number of samples of the management recommendation for each method. Note that when this is set to 1, the mean value of the data inputs is used. 1

Source: A reference to a website or article from which parameters were taken to define the operating model

See full report for details

Stock Parameters

Mortality and age: maxage, R0, M, Msd

maxage: The maximum age of individuals that is simulated. There are maxage+1 (recruitment to age-0) age classes in the storage matrices. maxage is the plus group where all age-classes > maxage are grouped, unless option switched off with OM@cpars$plusgroup=0 . Single value. Positive integer.

Specified Value(s): 35

There is no information available on the life span of WSC, because there are no hard structures that can be used to determine their age. Tagging studies are difficult since external tags are frequently lost and internal tags can be shed through the body wall (CDFG 2008).

R0: Initial number of unfished recruits to age-0. This number is used to scale the size of the population to match catch or data, but does not affect any of the population dynamics unless the OM has been conditioned with data. As a result, for a data-limited fishery any number can be used for R0 . In data-rich stocks R0 may be estimated as part of a stock assessment, but for data limited stocks users can choose either an arbitrary number (say, 1000) or choose a number that produces simulated catches in recent historical years that are similar to real world catch data. Single value. Positive real number.

Specified Value(s): 7000

There is no information available on the magnitude of unfished recruitment. Since R0 acts as a scaling parameter, R0 was chosen to scale modeled historical catch to the range observed in the actual historical catch data (median of 200,000 lbs, max of 640,000 lbs)

M: The instantaneous rate of natural mortality. For each simulation a single value is drawn from a uniform distribution specified by the upper and lower bounds provided. Uniform distribution lower and upper bounds. Non-negative real numbers.

Specified Value(s): 0.15, 0.2

The rate of natural mortality in WSC is unknown. WSC was originally thought to have fairly high rates of natural mortality (CDFW 2008). Chávez et al. (2011) estimated the M of Warty Sea Cucumber using three different estimators developed by Pauly (1980), Hoenig (1983), and Jensen (1996) with M equal to 0.83, 0.85, and 0.9, respectively. However, these estimators were primarily developed based on observations of finfish life history traits and may be inappropriate for a species that likely exhibits markedly different growth patterns. For these reasons we consider this estimate unreliable, and it is incompatible with other life history information available for this species.

Bruckner (2006) speculated that California sea cucumber species have relatively high natural mortality rates, with a maximum age of 8 – 12 years (Bruckner 2006). However, CDFG (2008) suggested that the juveniles take 4-8 years to reach sexual maturity, and if this is true life spans are likely longer than 5-12 years. Studies of other holothurian species indicate longevity of at least several decades, and the slow recovery rates of over-exploited sea cucumber stocks suggest a low productivity. When marine protected areas (MPA) were established in Southern California it took WSC densities approximately 10 years to recover (David Kushner, personal communucation). This suggests the possibility of longer life spans and slower growth (two traits that are typically associated with low natural mortality). However, it is also possible that this slow recovery in WSC densities was due to infrequent recruitment success. A species displaying periodic recruitment along with the high rates of natural mortality associated with a short life span would display fluctuations in the populations within Southern California's MPAs, but yearly monitoring has shown fairly stable population levels in these protected areas.

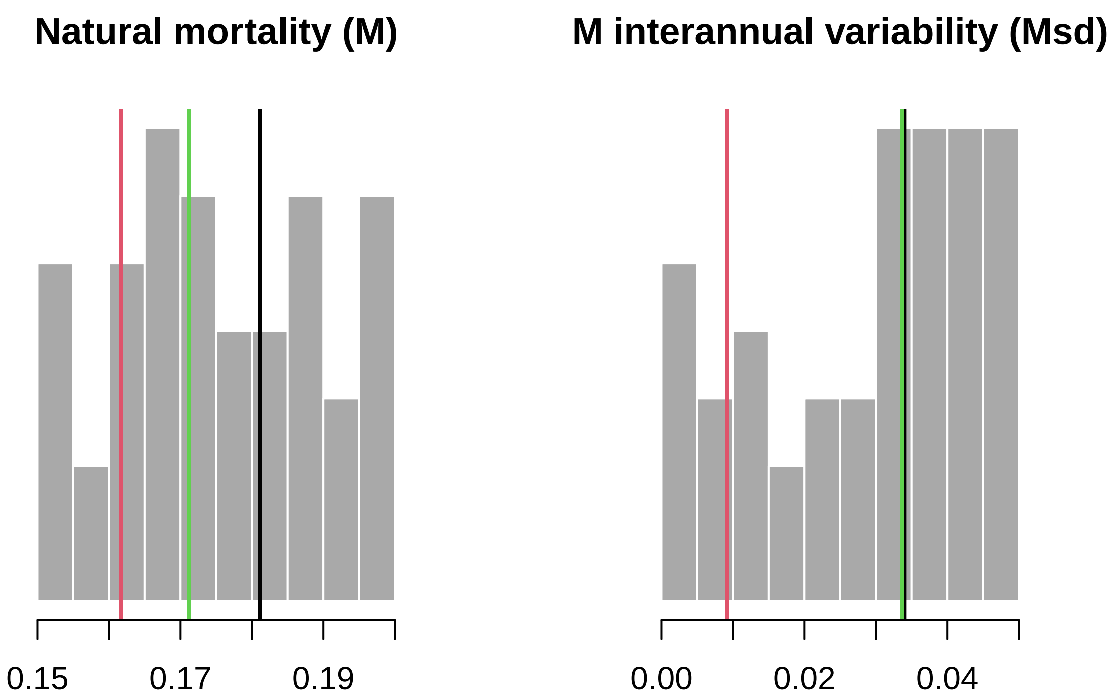
Given the high level of uncertainty surrounding life span and natural mortality we modeled three different plausible life history strategies for WSC. The "base case" scenario corresponds with what was considered most plausible based on the available literature and recent biological studies conducted by CDFW staff. Mortality was set to 0.12-0.17 in order to correspond with a maximum age of 15-25 years using the Quinn and Deriso (1999) mortality estimator. We also modeled a "short" life history strategy with an M of 0.21-0.42 corresponding with a maximum age of 7 to 14 years (Quinn and Deriso 1999). Given the emerging information on growth, recruit size, and size at maturity it is considered unlikely that WSC have a very short life span (>7 years). Given that there are many other species of sea cucumbers with multi-decade natural life spans, we also modeled a "long" life history strategy, with an M of 0.08- 0.12 corresponding with a maximum age of to 25-40 years (Quinn and Deriso 1999)

Msd: Inter-annual variation in M expressed as a coefficient of variation of a log-normal distribution. For each simulation a single value is drawn from a uniform distribution specified by the upper and lower bounds provided. If this parameter is positive, yearly M is drawn from a log-normal distribution with a mean specified by log(M) drawn for that simulation and a standard deviation in log space specified by the value of Msd drawn for that simulation. Uniform distribution lower and upper bounds. Non-negative real numbers

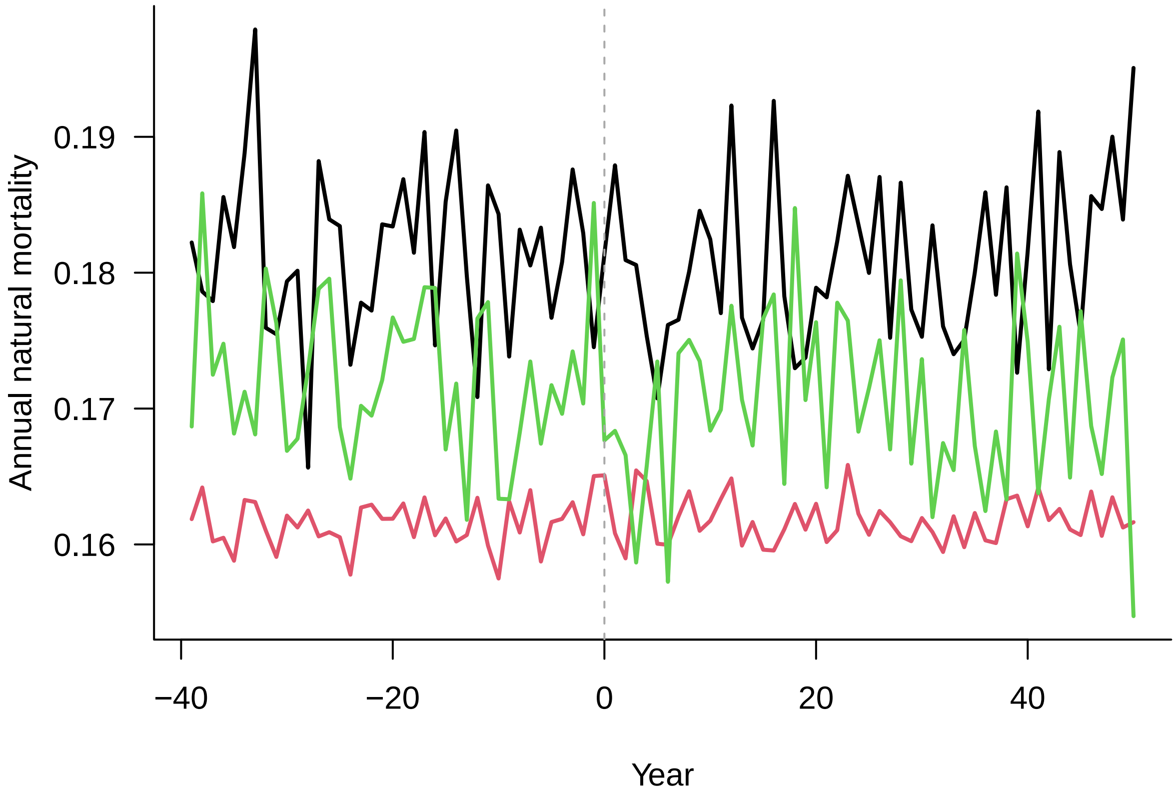
Specified Value(s): 0, 0.05

Natural Mortality Parameters

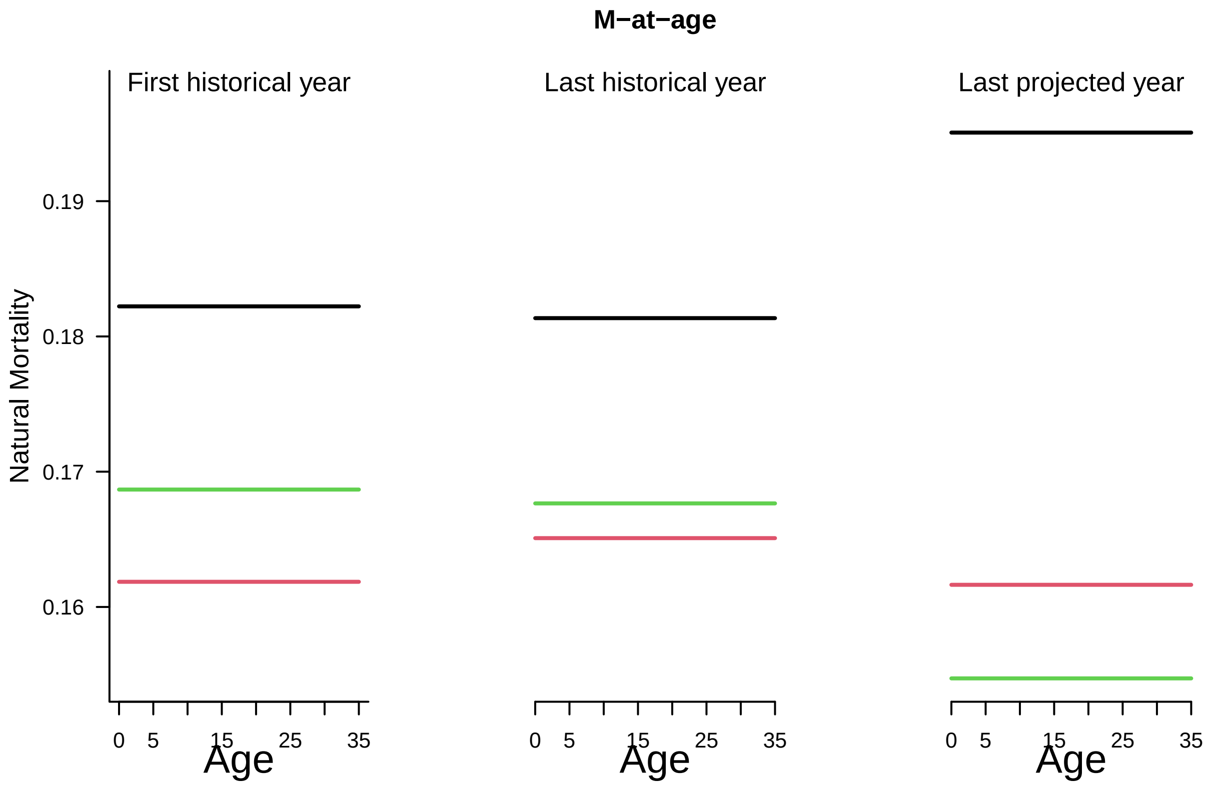
Sampled Parameters Histograms of simulations of `M`, and `Msd` parameters, with vertical colored lines indicating 3 randomly drawn values used in other plots:



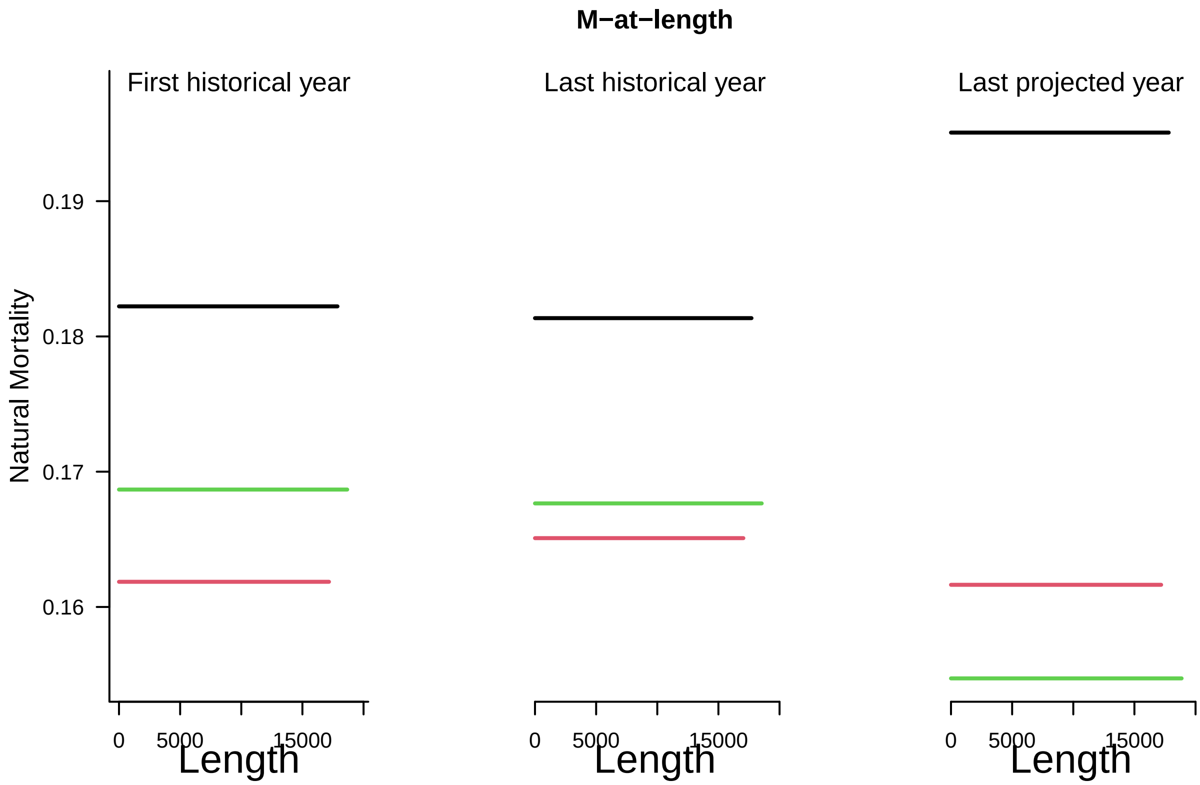
Time-Series The average natural mortality rate by year for adult fish for 3 simulations. The vertical dashed line indicates the end of the historical period:



M-at-Age Natural mortality-at-age for 3 simulations in the first historical year, the last historical year (i.e., current year), and the last projected year:



M-at-Length Natural mortality-at-length for 3 simulations in the first historical year, the last historical year (i.e., current year), and the last projected year:



Recruitment: h, SRrel, Perr, AC

h: Steepness of the stock recruit relationship. Steepness governs the proportion of unfished recruits produced when the stock is at 20% of the unfished population size. For each simulation a single value is drawn from a uniform distribution specified by the upper and lower bounds provided. This value is the same in all years of a given simulation. Uniform distribution lower and upper bounds. Values from 1/5 to 1.

Specified Value(s): 0.4, 0.6

We assumed a moderate steepness.

SRrel: Type of stock-recruit relationship. Use 1 to select a Beverton Holt relationship, 2 to select a Ricker relationship. Single value. Integer

Specified Value(s): 1

Beverton-Holt was used. There is no evidence for a hump-shaped stock-recruitment relationship.

Perr: Recruitment process error, which is defined as the standard deviation of the recruitment deviations in log space. For each simulation a single value is drawn from a uniform distribution specified by the upper and lower bounds provided. Uniform distribution lower and upper bounds. Non-negative real numbers.

Specified Value(s): 0.3, 0.6

Few data exist on recruitment trends. Sea cucumbers are thought to undergo sporadic recruitment (CDFG 2008), but this has not been studied directly. We assumed moderate variability in recruitment.

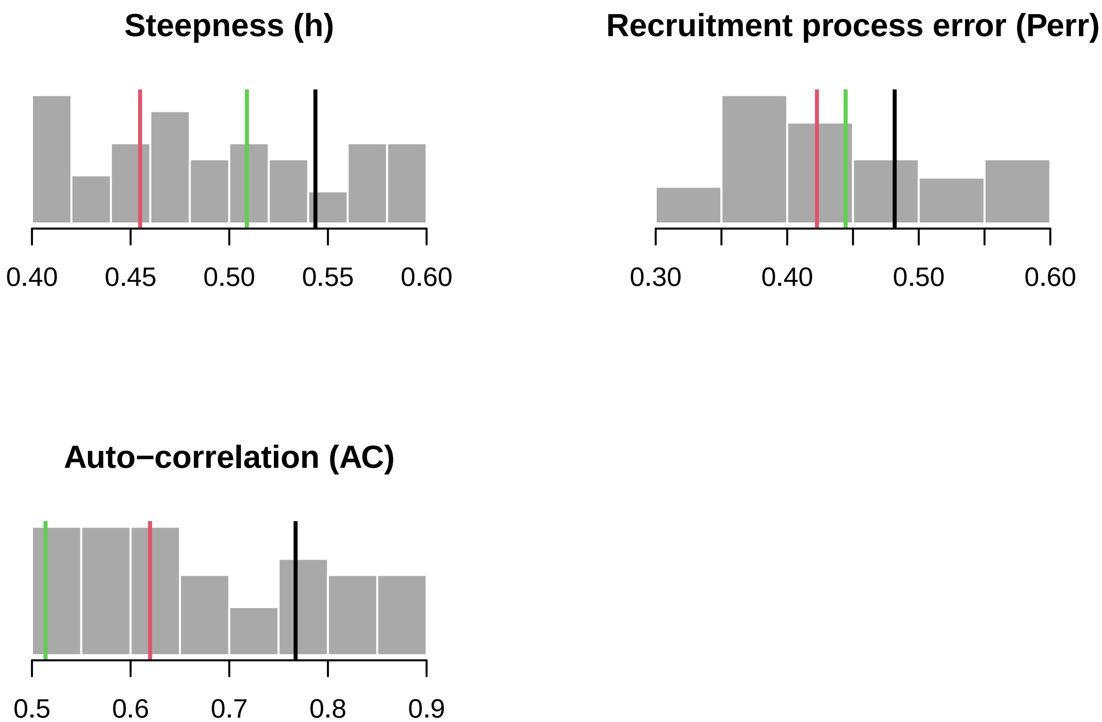
AC: Autocorrelation in the recruitment deviations in log space. For each simulation a single value is drawn from a uniform distribution specified by the upper and lower bounds provided, and used to add lag-1 auto-correlation to the log recruitment deviations. Uniform distribution lower and upper bounds. Non-negative real numbers.

Specified Value(s): 0.5, 0.9

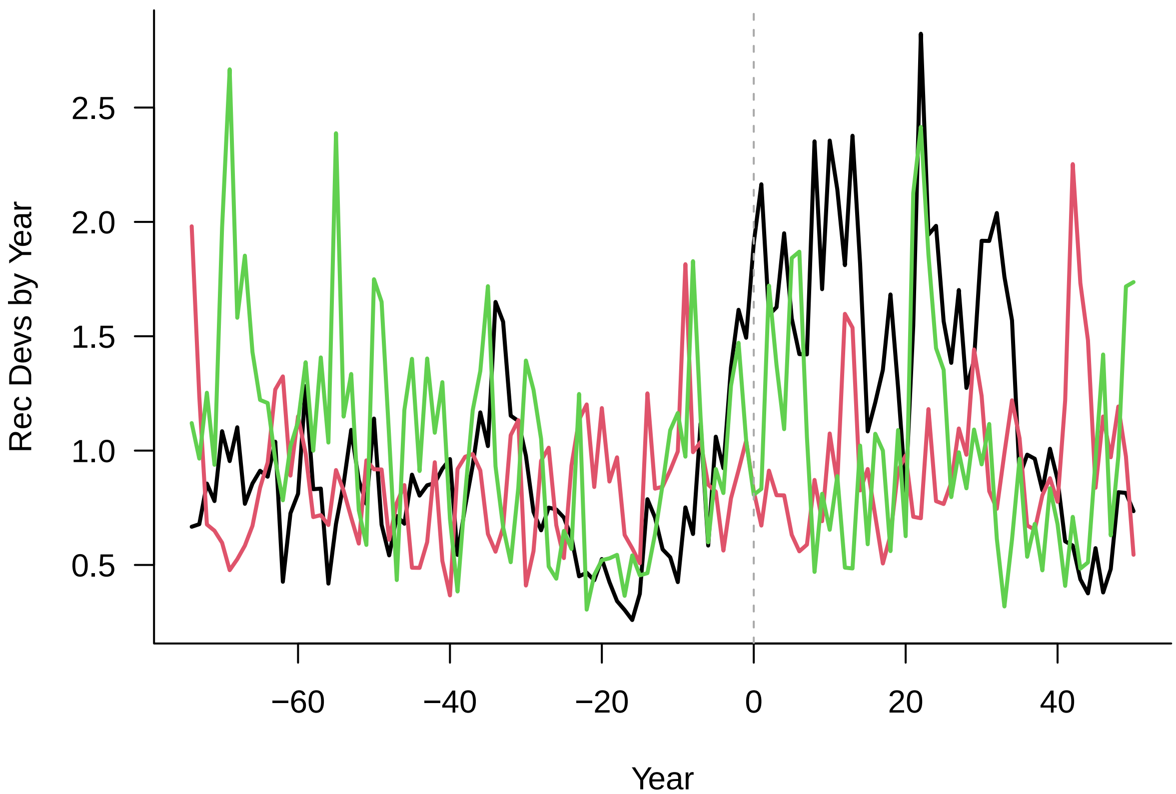
We assumed moderate to high autocorrelation.

Recruitment Parameters

Sampled Parameters Histograms of 48 simulations of steepness (`h`), recruitment process error (`Perr`) and auto-correlation (`AC`) for the Beverton-Holt stock-recruitment relationship, with vertical colored lines indicating 3 randomly drawn values used in other plots:



Time-Series Time-series plot showing 3 samples of recruitment deviations for historical and projection years:



Growth: Linf, K, t0, LenCV, Ksd, Linfsd

Linf: The von Bertalanffy growth parameter Linf, which specifies the average maximum size that would reached by adult fish if they lived indefinitely. For each simulation a single value is drawn from a uniform distribution specified by the upper and lower bounds provided. This value is the same in all years unless Linfsd is a positive number. Uniform distribution lower and upper bounds. Positive real numbers.

Specified Value(s): 17000, 19500

Growth has not been measured directly in WSC due to difficulties in estimating age via tagging studies or direct ageing. Currently, there is no method to directly age Warty Sea Cucumber, and their soft tissues make long term tag-recapture studies difficult. Muscat (1983) had success in tagging and tracking individuals for up to 44 months; however, this study was mainly focused on movement behavior and no growth estimates were provided.

Measuring sea cucumber growth is also complicated by the fact that WSC undergo visceral atrophy each year. This means that the weight of an individual changes depending on the time of year. During atrophy the gonad, circulatory system, and respiratory tree are resorbed and reduced in size, and the gut degenerates. Feeding and locomotion stop prior to visceral atrophy, which occurs in the fall. Following the resorption of the visceral tissue, the animal loses 25 percent of its body weight. The weight of the body wall cycles during the year, being the lowest early in the year and the highest in early fall, prior to the start of visceral atrophy. Within two to four weeks regeneration begins. The WSC can reach up to 20 inches in total length, but the ability of sea cucumbers to contract makes total length estimates unrelaible. The CDFW measures contracted length and width of WSC on the sea floor during diver surveys, and all length measurements reported here for the California WSC are in units of underwater contracted length. Length x Width frequency data from the CDFW shows a modal length of ~6000 mm and a maximum observed length around 19500 mm. Based on this information, it was determined that a suitable range for the Linf parameter was 17000

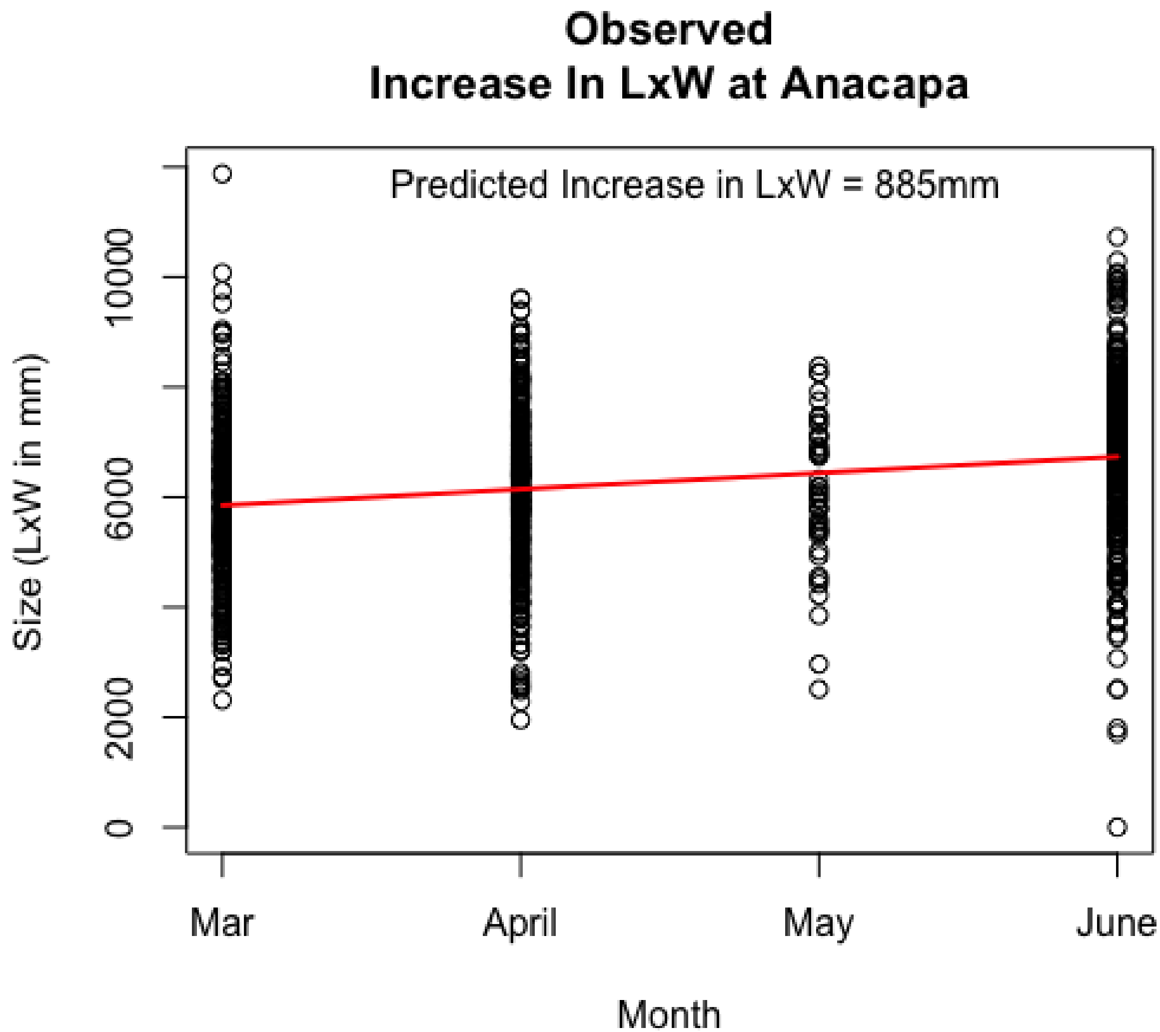
– 19500 mm.

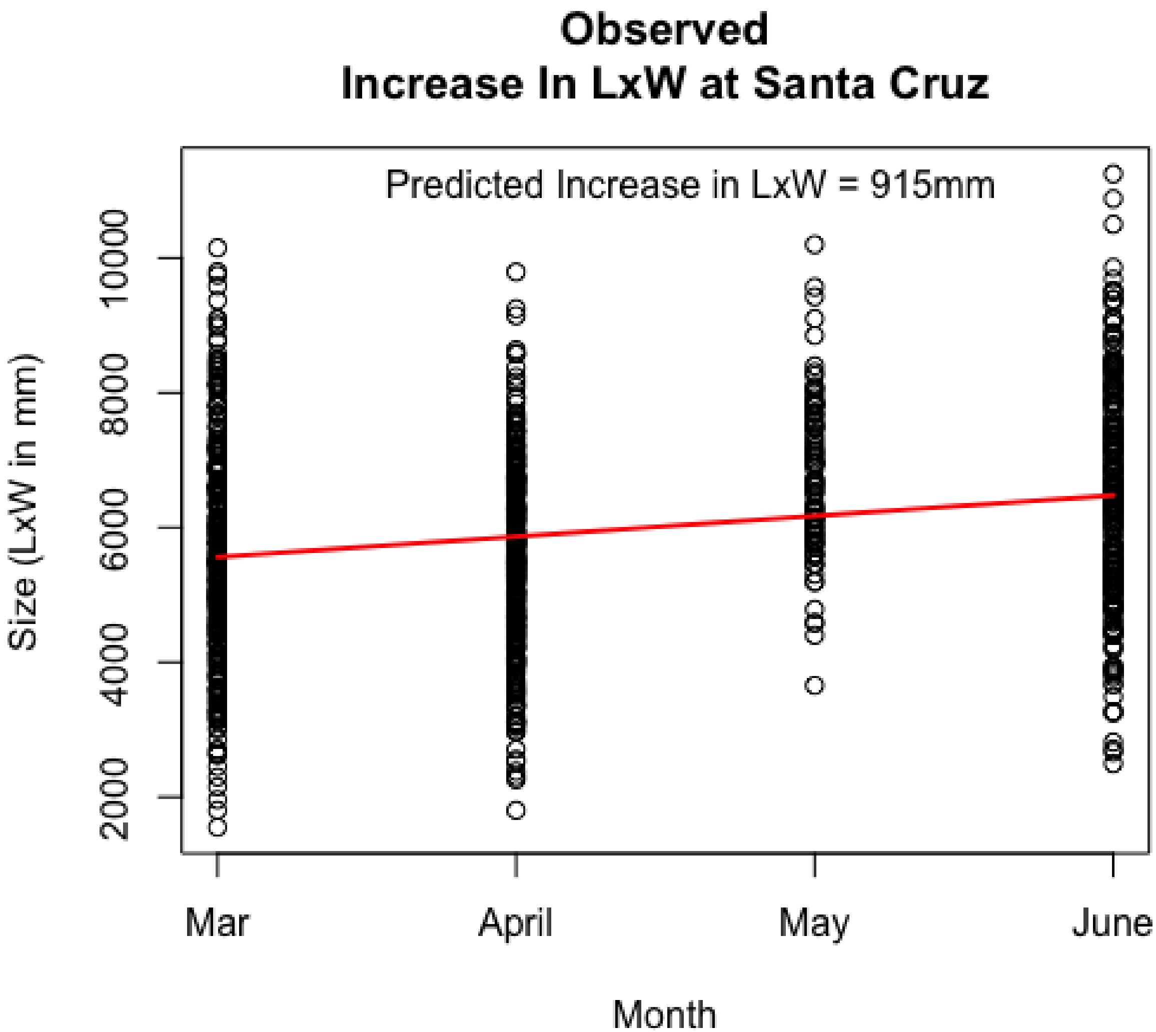
K: The von Bertalanffy growth parameter k, which specifies the average rate of growth. For each simulation a single value is drawn from a uniform distribution specified by the upper and lower bounds provided. This value is the same in all years unless Ksd is a positive number. Uniform distribution lower and upper bounds. Positive real numbers.

Specified Value(s): 0.08, 0.13

Chavez et al. (2011) estimated a K value of 0.6 using the ELEFAN method. There are few details of the ELEFAN analysis in Chavez et al. (2011) and estimates of K can be highly variable using this method. Most literature suggests that growth rates for sea cucumber are relatively slow (Bruckner 2006), whereas a value of K=0.6 would typically be considered relatively fast growth. For this reason this estimate was considered unreliable.

In the absence of any information on the growth rates of WSC, we examined the observed change in size frequency (LxW) from survey data during the peak spawning months (March to June). Studies have shown that sea cucumbers display seasonal growth patterns, in which they grow during the spawning season, and after the spawning season is done they stop feeding and exhibit little to no growth, and in some cases have even displayed negative growth during this time period. Muscat found high site fidelity during the spawning season as well, and we assumed that a) it was likely that individuals were being repeatedly measured each month, and b) the increase in the mean size observed at each site from March through June was due to growth rather than immigration of larger individuals. Based on these assumptions we fit linear models to the LXW frequency data to estimate the increase in size each year.


Observed
Increase In LxW at Anacapa
Predicted Increase in LxW = 885mm
Size (LxW in mm)
0
2000
6000
10000
Mar
April
May
June
Month



There was variation between sites and years, but this analysis indicated an average increase in LxW of ~900mm. Assuming that the Linf parameter falls between 12000 and 15000mm, this suggests that mature WSC may be achieving approximately 6-8% of their asymptotic length each year. However, growth rates may slow in older sea cucumbers. This was used as a starting to point for constructing a von Bertalanffy growth curve that was consistent with the assumed natural mortality rate/life span as well as the size at sexual maturity. Based on this, we assumed a growth rate of 0.06-0.11 in the base case operating model.

t0: The von Bertalanffy growth parameter t0, which specifies the theoretical age at a size 0. For each simulation a single value is drawn from a uniform distribution specified by the upper and lower bounds provided. Uniform distribution lower and upper bounds. Non-positive real numbers.

Specified Value(s): 0, 0

No information exists for estimates of t0, and it was fixed at zero.

LenCV: The coefficient of variation (defined as the standard deviation divided by mean) of the length-at-age. For each simulation a single value is drawn from a uniform distribution specified by the upper and lower bounds provided to specify the distribution of observed length-at-age, and the CV of this distribution is constant for all age classes (i.e, standard deviation increases proportionally with the mean). Uniform distribution lower and upper bounds. Positive real numbers.

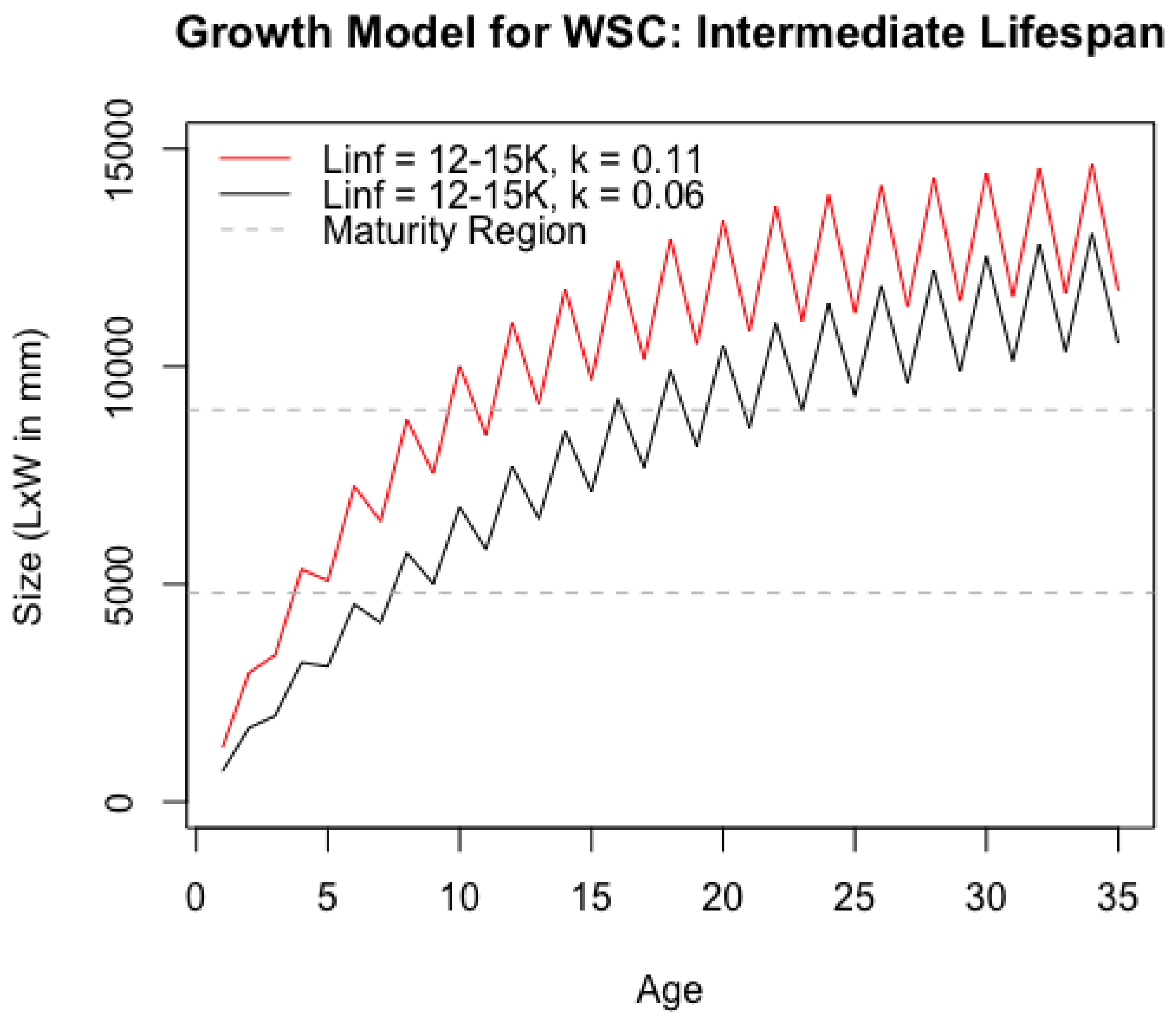


Figure 1: Predicted size (LxW in mm) of Warty Sea Cucumber at each age based on assumptions about maximum size and life span. The red curve shows the range of size at age under an assumed growth rate (k) of 0.11, and the blue curve shows the range of size at age under an assumed growth rate of 0.06

Specified Value(s): 0.05, 0.15

Because of the unusual parameterization of the size of an individual WSC (LxW in mm), as well as the lack of information about the age of the population, the CV around length at age is unknown. We assume that it ranges from 5-15%.

Ksd: Inter-annual variation in K. For each simulation a single value is drawn from a uniform distribution specified by the upper and lower bounds provided. If this parameter has a positive value, yearly K is drawn from a log-normal distribution with a mean specified by the value of K drawn for that simulation and a standard deviation (in log space) specified by the value of Ksd drawn for that simulation. Uniform distribution lower and upper bounds. Non-negative real numbers.

Specified Value(s): 0, 0.03

We modeled a small amount of year to year variation in the growth rate to account for changing environmental conditions from year to year.

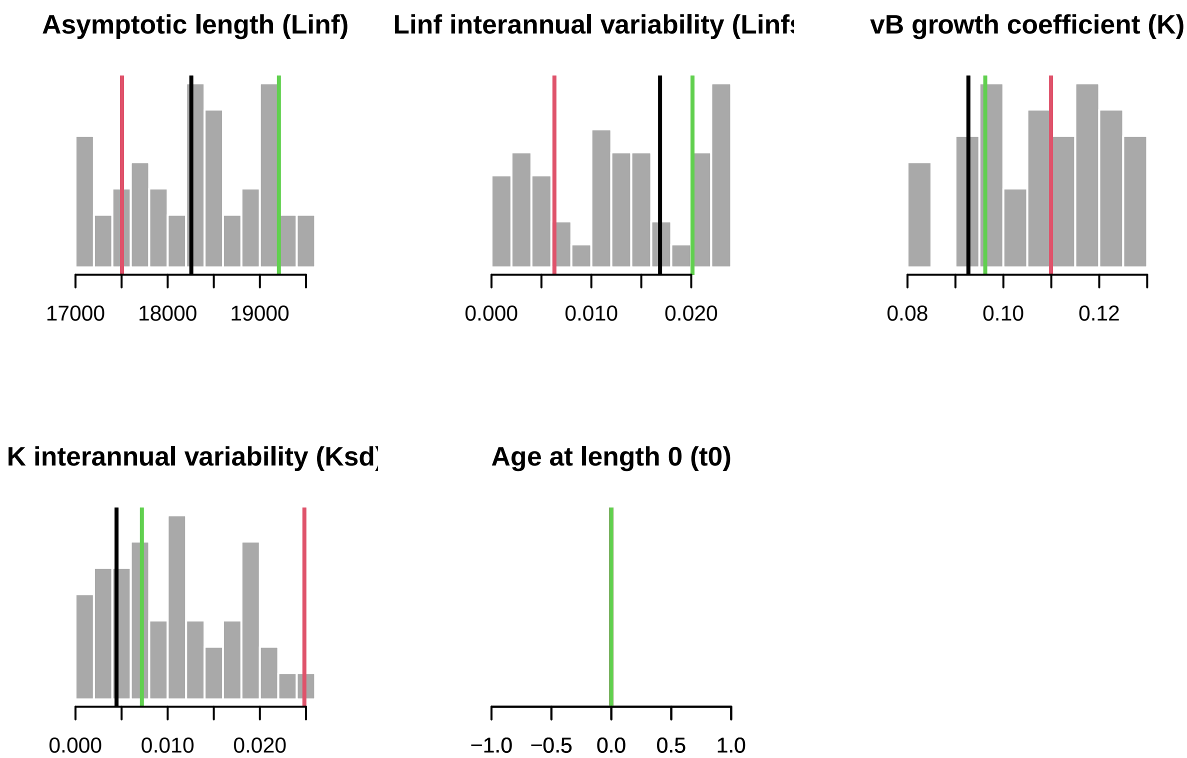
Linfsd: Inter-annual variation in Linf. For each simulation a single value is drawn from a uniform distribution specified by the upper and lower bounds provided. If this parameter has a positive value, yearly Linf is drawn from a log-normal distribution with a mean specified by the value of Linf drawn for that simulation and a standard deviation (in log space) specified by the value of Linfsd drawn for that simulation. Uniform distribution lower and upper bounds. Non-negative real numbers.

Specified Value(s): 0, 0.03

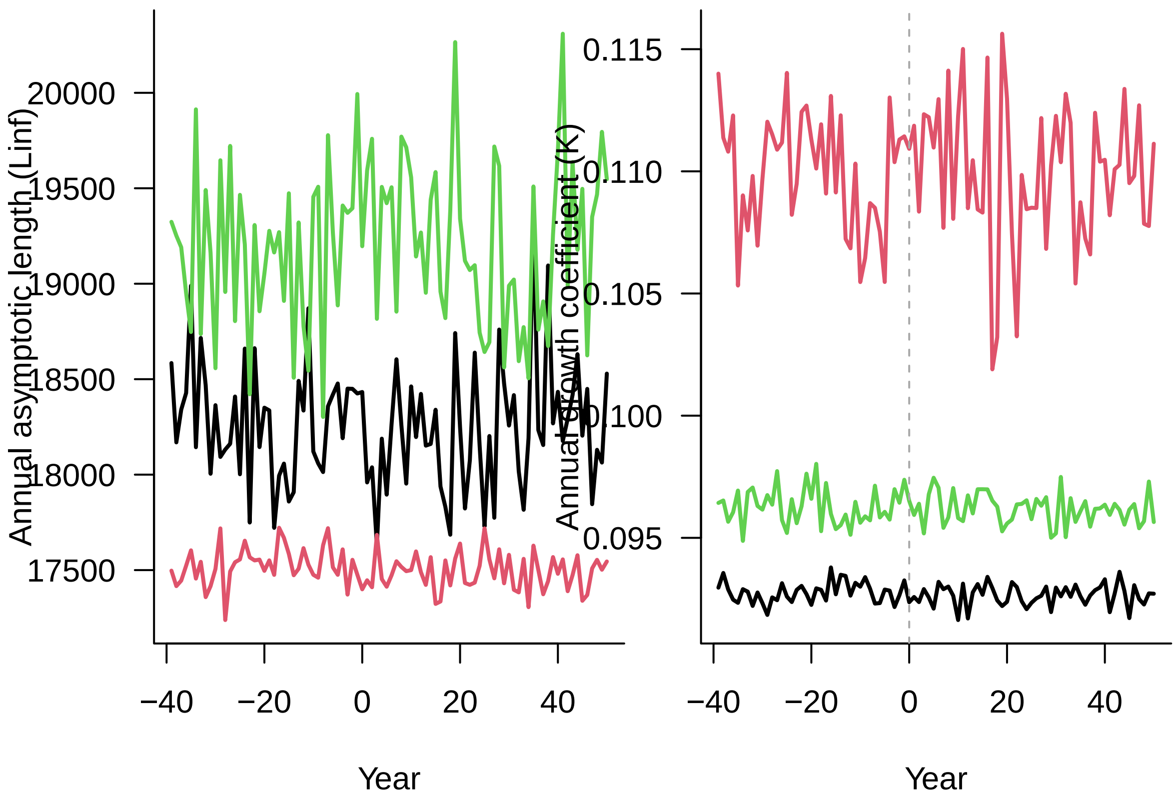
We modeled a small amount of year to year variation in the maximum average size to account for changing environmental conditions from year to year.

Growth Parameters

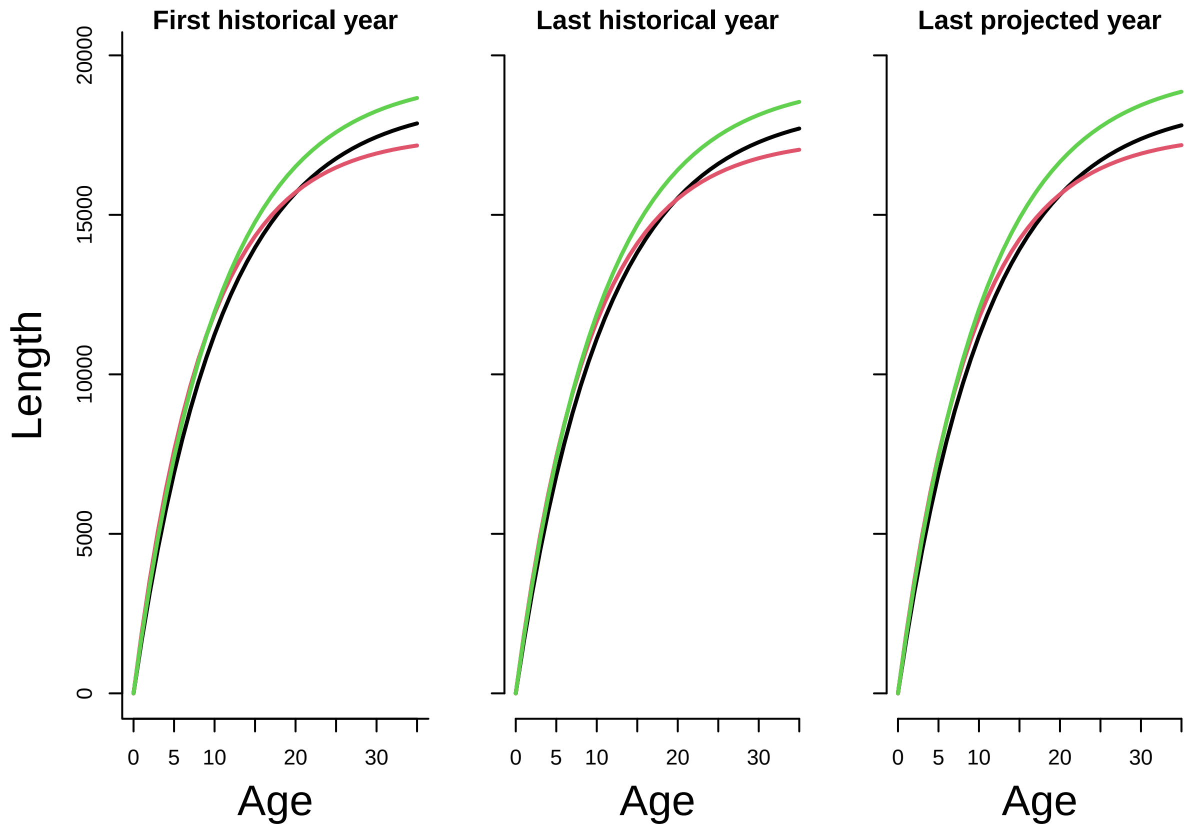
Sampled Parameters Histograms of simulations of von Bertalanffy growth parameters `Linf`, `K`, and `t0`, and inter-annual variability in Linf and K (`Linfsd` and `Ksd`), with vertical colored lines indicating 3 randomly drawn values used in other plots:



Time-Series The Linf and K parameters in each year for 3 simulations. The vertical dashed line indicates the end of the historical period:



Growth Curves Sampled length-at-age curves for 3 simulations in the first historical year, the last historical year, and the last projection year.



Maturity: L50, L50_95

L50: Length at 50% maturity. For each simulation a single value is drawn from a uniform distribution specified by the upper and lower bounds provided. The L50 and L50_95 parameters are converted to ages using the growth parameters provided and used to construct a logistic curve to determine the proportion of the population that is mature in each age class. Uniform distribution lower and upper bounds. Positive real numbers.

Specified Value(s): 4500, 5500

Juveniles are thought to become reproductively mature at four to eight years (CDFG 2008), but there are no direct estimates of the age at maturity. Very few juvenile WSC are ever observed. Some WSC with total lengths between 13-30mm have been found, and these are assumed to be young of the year. Since 2013 CDFW staff have collected individuals to determine whether they are mature or not based on gonad presence. Detecting mature individuals is difficult because WSC gonads increase in size prior to the spring spawning season, but after spawning decrease in size to be very small or completely absent.

This makes it difficult to know whether the individual sampled is immature or has already spawned, and this may mean that mature individuals are misclassified as immature, which would result in a positively biased estimate of the size at maturity. It is likely this is the reason for wide size range of immature animals seen in the figure below.

We estimated the size at maturity in two different ways. Based on the available data estimated weight at 50% maturity is 75g and probabilty of being 95% mature at 140g. These values were used to estimate the mean LxW at each of these weights (4800 mm and 8000 mm respectively). We also fit a logistic maturity ogive to the maturity data collected during the spawning months only (April-June) to estimate the LxW at 50% and 95% maturity. This yielded estimated L50 and L95 parameters of ~6000 and 12500 mm, respectively, which is much larger than the converted maturtity at weight estimates. Given the potential bias associated

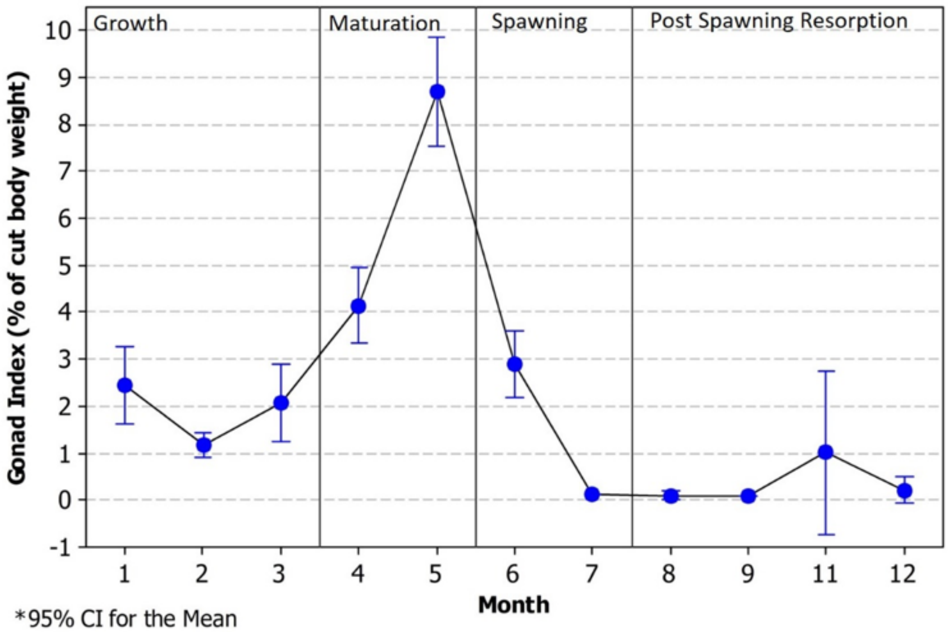


Figure 2: Gonad weight as a percentage of body size throughout the year for Warty Sea Cucumber. Gonad weight peaks during the spring spawning season.

with this estimate, it was decided to used the observed weight at maturity estimates (converted to LxW) in the base model, and model a higher size at maturity as an uncertainty scenario.

The number of males observed during recent CDFW surveys at small sizes (LxW < 6000) is slightly larger than the number of females. If juvenile WSC are cryptic until maturity, when they emerge to join spawning aggregations, this suggests that males may mature at a smaller size than females. In this OM we model a single maturity ogive for both sexes.

L50_95: Difference in lengths between 50% and 95% maturity. For each simulation a single value is drawn from a uniform distribution specified by the upper and lower bounds provided. The value drawn is then added to the length at 50% maturity to determine the length at 95% maturity. This parameterization is used instead of specifying the size at 95 percent maturity to avoid situations where the value drawn for the size at 95% maturity is smaller than that at 50% maturity. The L50 and L50_95 parameters are converted to ages using the growth parameters provided and used to construct a logistic curve to determine the proportion of the population that is mature in each age class. Uniform distribution lower and upper bounds. Positive real numbers.

Specified Value(s): 2500, 3500

Maturity Parameters

Sampled Parameters Histograms of simulations of `L50` (length at 50% maturity), and `L95` (length at 95% maturity), with vertical colored lines indicating 3 randomly drawn values used in other plots:

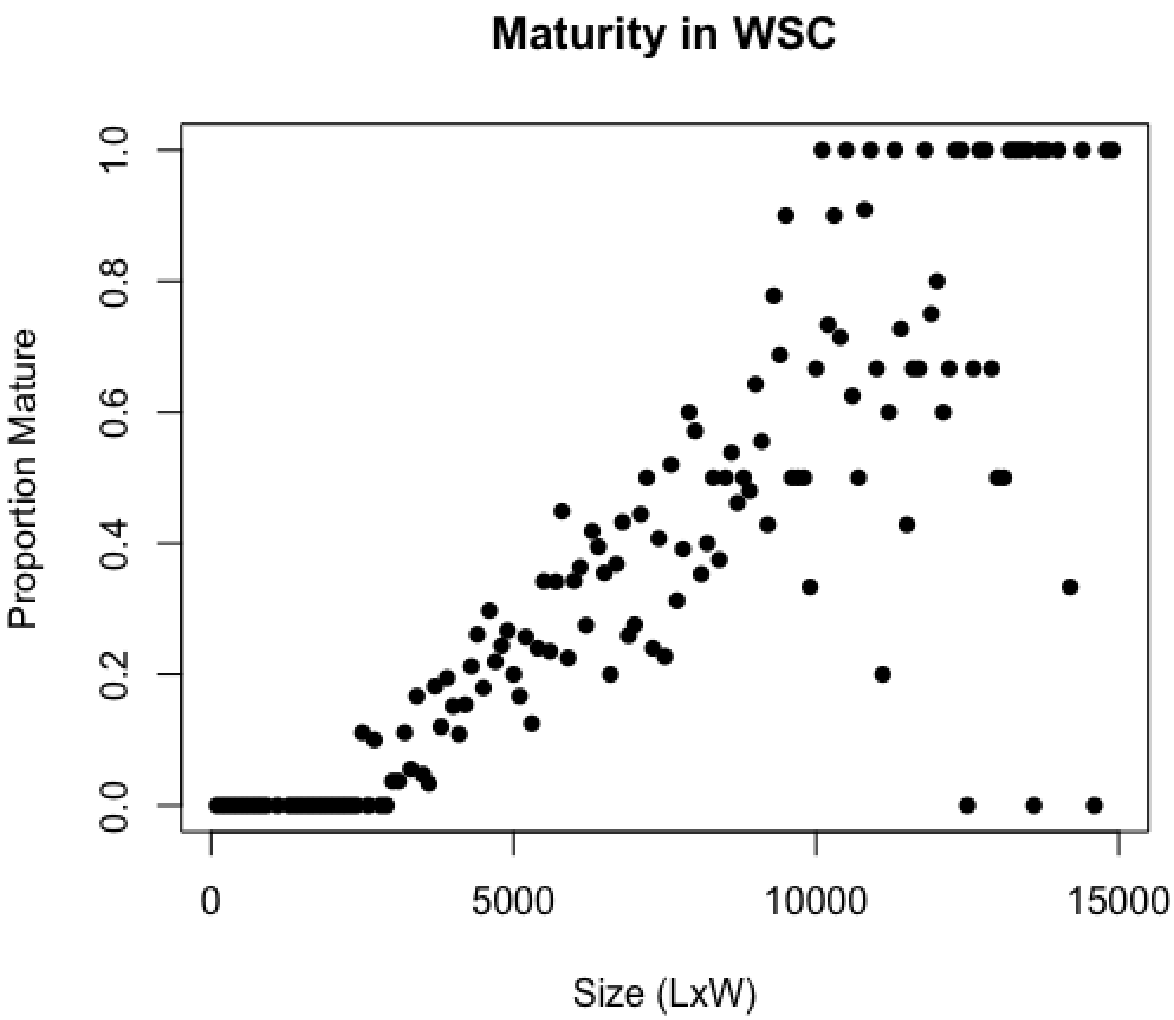


Figure 3: Gonad weight as a percentage of body size throughout the year for Warty Sea Cucumber. Gonad weight peaks during the spring spawning season.

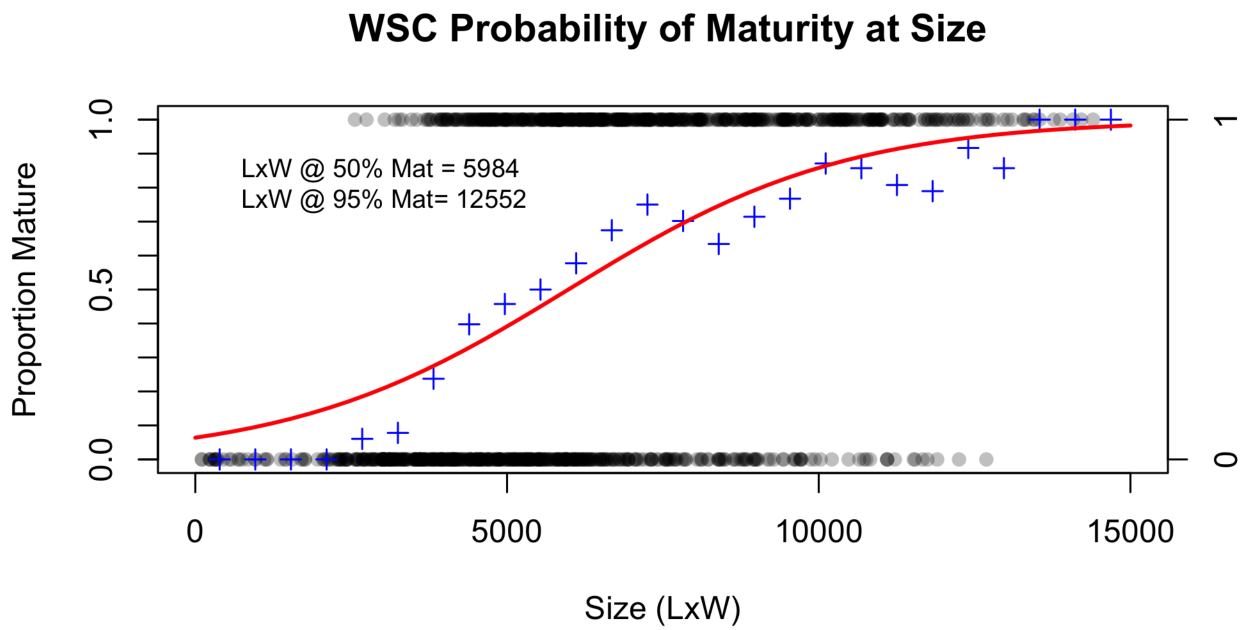


Figure 4: Maturity probability curve for WSC.

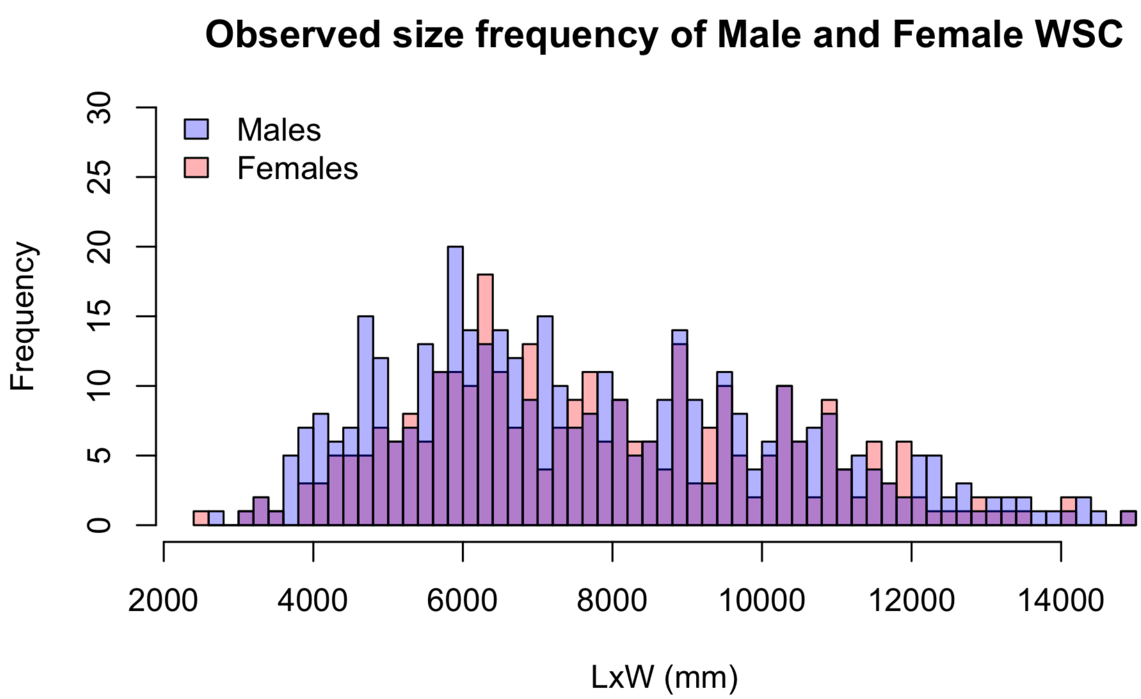
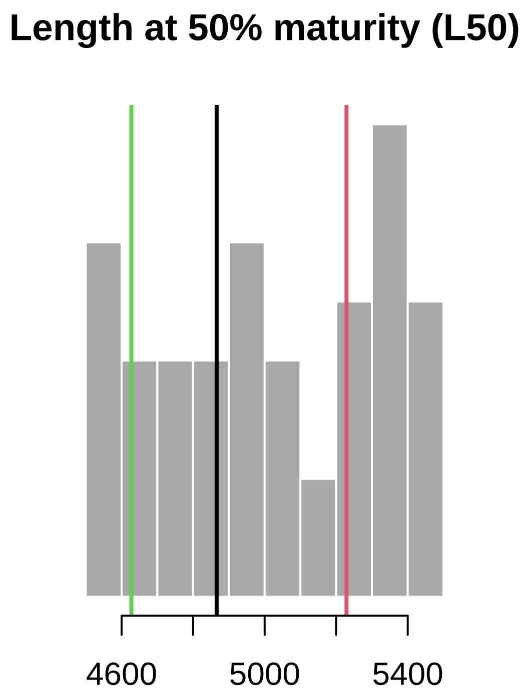
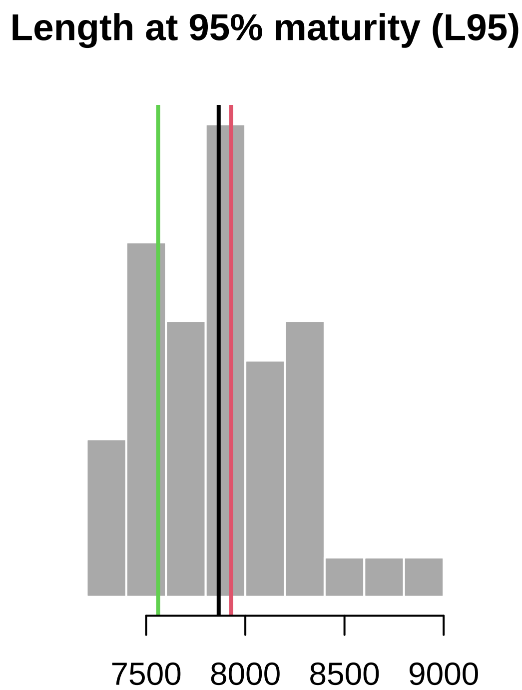
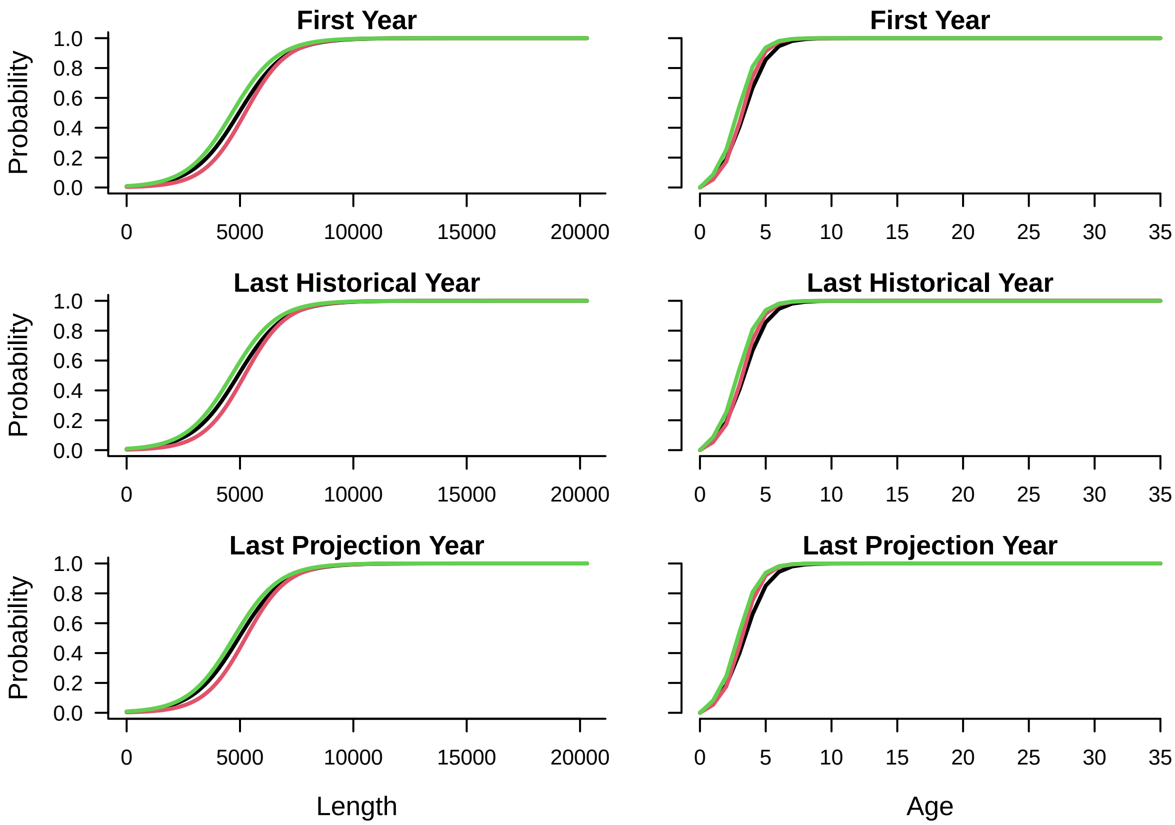


Figure 5: Size Frequncy of Male and Female WSC.





Maturity at Age and Length Maturity-at-age and -length for 3 simulations in the first historical year, the last historical year (i.e., current year), and the last projected year:



Stock depletion and Discard Mortality: D, Fdisc

D: Estimated current level of stock depletion, which is defined as the current spawning stock biomass divided by the unfished spawning stock biomass. For each simulation a single value is drawn from a uniform distribution specified by the upper and lower bounds provided. This parameter is used during model initialization to select a series of yearly historical recruitment values and fishing mortality rates that, based on the information provided, could have resulted in the specified depletion level in the simulated last historical year. Uniform distribution lower and upper bounds. Positive real numbers (typically < 1)

Specified Value(s): 0.1, 0.25

The Channel Islands National Park Service has been monitoring the density of warty sea cucumbers along fixed transects at sites in Channel Islands since 1982 (see Data Report for more information). Some of the monitoring sites are in no take MPAs (2 sites since 1978, 12 more since 2003) and some are fished (19 sites at the time of this report).
The transect data was used to calculate the mean density per year in order to develop a fishery-independent index of abundance that extends back to the early development of the dive fishery for WSC. Only data collected from sites at Santa Cruz Island and Anacapa Island were used, because these areas had high densities before the fishery developed and were considered to be suitable habitat for WSC (personal communication, David Kushner, CINP). In addition, only data collected in the spring and summer months (May through August) were used in the index because WSC are known to aggregate to spawn during the spring, but appear to disperse during the fall, when observed densities are very low. Since 2005, 8 of the 17 sites surveyed at Anacapa and Santa Cruz islands occur inside MPAs, and so the index data from inside MPAs was weighted by the proportion of WSC habitat that occurs within MPAs (15.7%) to avoid over representation of surveys from inside MPAs, which might inflate estimates of the mean density of the population.

The other data set used was the total reported catch for the fishery corrected based on the estimated proportion that was landed cut vs. whole. It is believed that prior to 2005 the majority of WSC were landed whole, but after that fishermen began processing at sea, which reduces the weight by 50%. In 2019 reporting requirements were changed, and fishermen reported landing 74% of the total catch (by weight) cut, while the rest were landed whole. This correction factor was applied to the total catch data from 2005 on to estimate the total removals. For comparison, models were also fit to the reported catch, and to a corrected version of the catch that assumed that all WSC were landed cut after 2005 (and thus catches were doubled after that date to estimate the maximum possible total removals).

The Schaefer models were fit to two alternate catch data sets, the reported catch and the corrected catch (see Data Report for more information). Models were also fit with two different indices of abundance, one with the mean density per year across all sites, and one with the mean density per year across fished sites only.

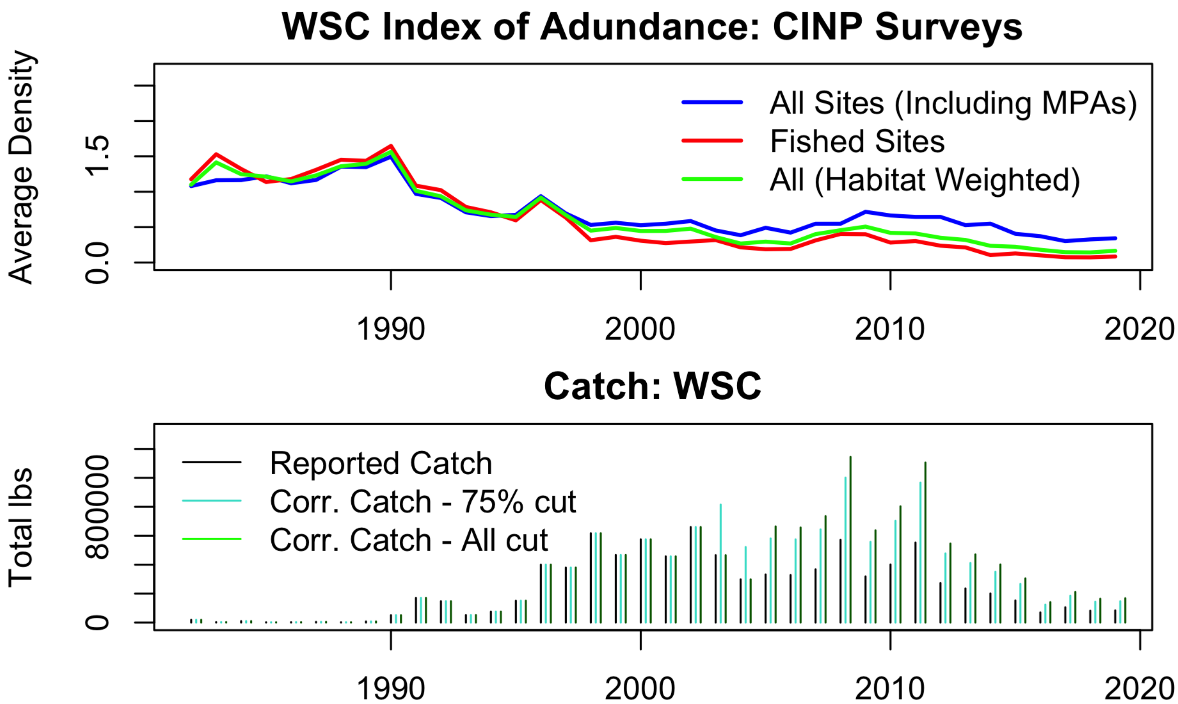


Figure 6: Time series data available for Schaefer model. Top: CINP KFM index of abundance from all survey sites (blue) and fished survey sites. Bottom: Reported and corrected catch from the WSC dive fishery

The current biomass estimates for the WSC stock depended on which index of abundance was used. In the model fits to index data from all surveyed sites (including MPAs) and the various different historical catch time series the estimates ranged from 44-47% of unfished biomass, while the estimates were only 10-12% of unfished biomass when the index from only the fished sites was used. This suggests that the population can be considered to be at a healthy level only when sea cucumbers within the MPAs are included, but are highly depleted to the point of being overfished when only the population outside the MPAs is considered. However, given that these results may over-represent the population inside MPAs, we also fit a model to the index weighted by habitat. In the model fit to this index as well as the corrected catch based on 2019 reported landing conditions, current depletion was estimated to be at 22% for the entire population, and 12% in the fished sites. Because this data was considered to be the most reliable we modeled current depletion values ranging between 10 and 25% of unfished in the base model.

Fdisc: The instantaneous discard mortality rate the stock experiences when fished using the gear type specified in the corresponding fleet object and discarded. For each simulation a single value is drawn from a uniform distribution specified by the upper and lower bounds provided. Uniform distribution lower and upper bounds. Non-negative real numbers.

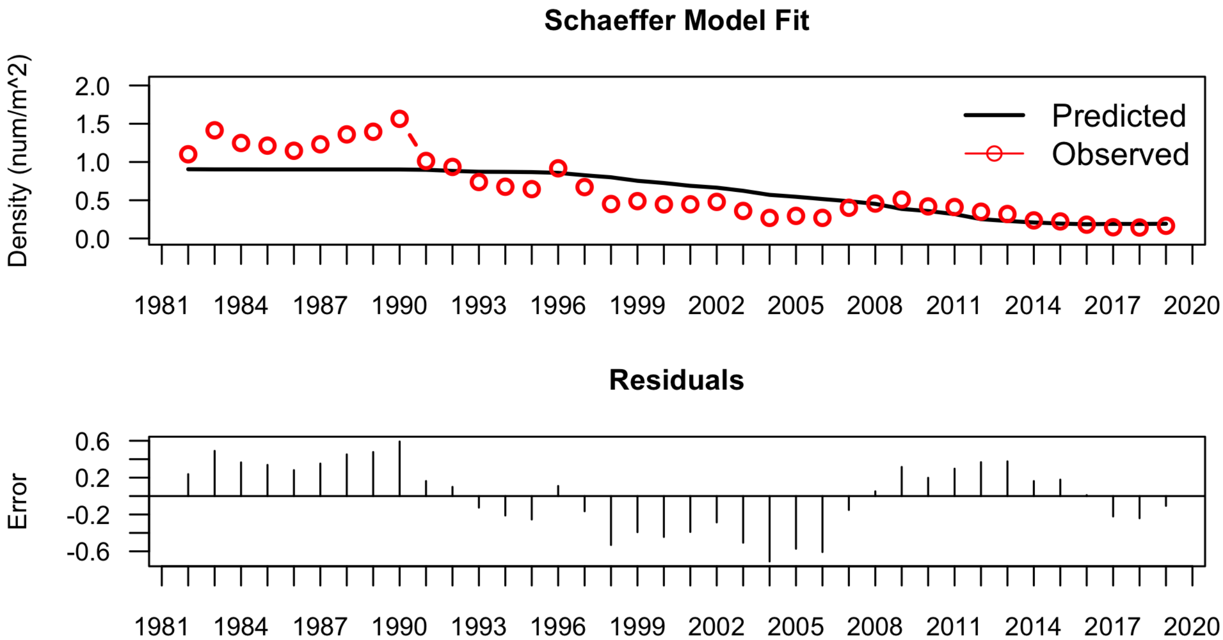


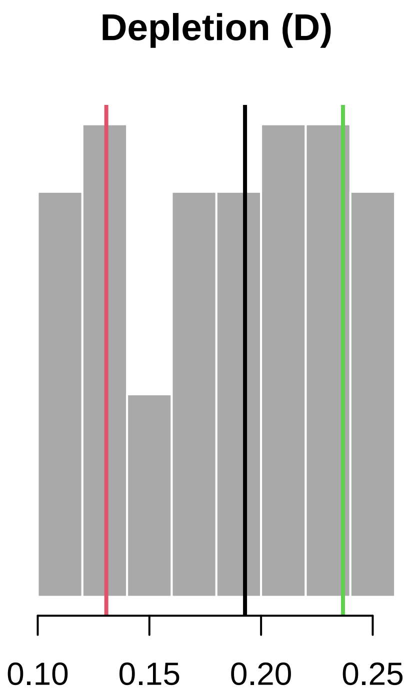
Figure 7: Schaefer model fit to corrected catch data and survey index of abundance from fished sites.

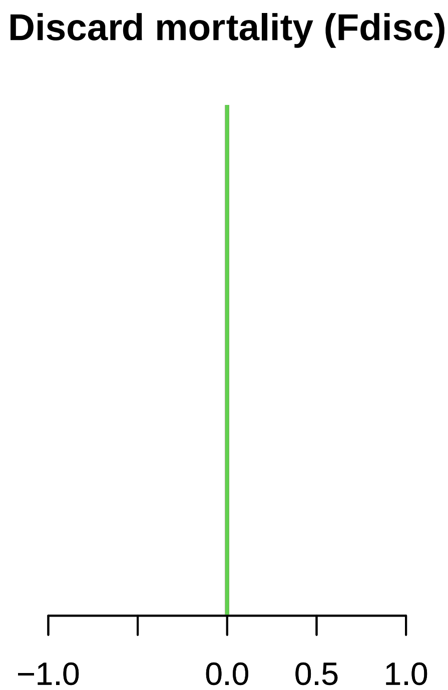
Specified Value(s): 0, 0

Because this is a dive fishery, in which WSC are harvested by hand, the fishery is very selective, and there are thought to be no discards. Therefore the assumed discard mortality rate is 0. There is currently no size limit.

Depletion and Discard Mortality

Sampled Parameters Histograms of simulations of depletion (spawning biomass in the last historical year over average unfished spawning biomass; `D`) and the fraction of discarded fish that are killed by fishing mortality (`Fdisc`), with vertical colored lines indicating 3 randomly drawn values.





Length-weight conversion parameters: a, b

a: The alpha parameter in allometric length-weight relationship. Single value. Weight parameters are used to determine catch-at-age and population-at-age from the number of individuals in each age class and the length of each individual, which is drawn from a normal distribution determined by the Linf , K , t0 , and LenCV parameters. As a result, they function as a way to scale between numbers at age and biomass, and are not stochastic parameters. Single value. Positive real number.

Specified Value(s): 0

Because the total weight of WSC can vary throughout the year based on the weight of their gonad (which grows prior to spawning season) as well as the weight of their stomach contents, the most consistent metric for WSC weight is the "cut weight"" (aka body wall weight) of individuals after all viscera and water has been removed from the body cavity during the months when spawning aggregations occur. WSC lose approximately 50% of their weight when cut, and many WSC are landed after undergoing this type of processing. For this reason, we fit a model to morphometric data collected during March through June (the spawning months) to estimate the relationship between LxW (in mm) and cut weight (in g).

b: The beta parameter in allometric length-weight relationship. Single value. Weight parameters are used to determine catch-at-age and population-at-age from the number of individuals in each age class and the length of each individual, which is drawn from a normal distribution determine by the Linf , K , t0 , and LenCV parameters. As a result, they function as a way to scale between numbers at age and biomass, and are not stochastic parameters. Single value. Positive real number.

Specified Value(s): 1.23

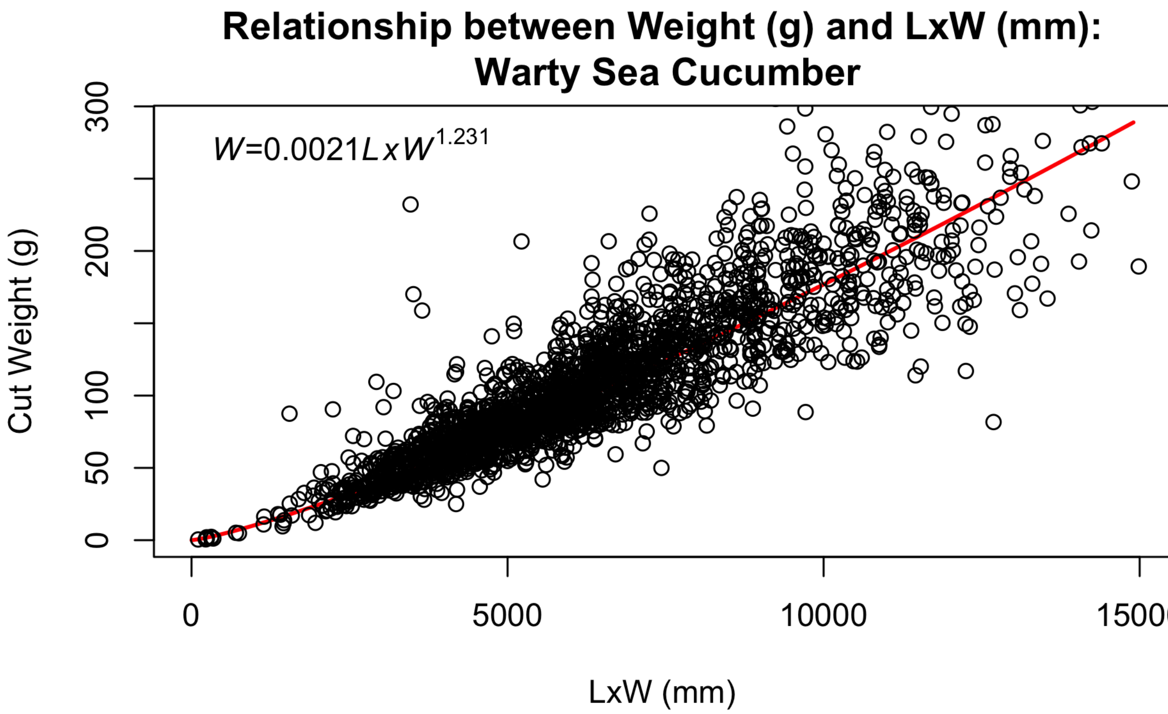


Figure 8: Predicted cut weight (in g) at size (LxW in mm) of Warty Sea Cucumber from data collected by CDFW between 2013 and 2018

Spatial distribution and movement: Size_area_1, Frac_area_1, Prob_staying

Size_area_1: The size of area 1 relative to area 2. The fraction of the unfished biomass in area 1. Please specify numbers between 0 and 1. For each simulation a single value is drawn from a uniform distribution specified by the upper and lower bounds provided. For example, if Size_area_1 is 0.2, then 20% of the total area is allocated to area 1. Fishing can occur in both areas, or can be turned off in one area to simulate the effects of a no take marine reserve. Uniform distribution lower and upper bounds. Positive real numbers.

Specified Value(s): 0.16, 0.16

WSC are found in shallow rocky reef and sandy kelp forest habitats in Southern California. Because of this WSC have received protection from fishing from the establishment of MPAs in this area between 2003 and 2012. Based on sea floor mapping data we estimate that 15.7% of WSC habitat is now inside MPAs. We modeled this protection provided to the stock by assuming Area 1 to be a no-fishing MPA that is 15.7% of the total available habitat.

Frac_area_1: The fraction of the unfished biomass in area 1. Please specify numbers between 0 and 1. For each simulation a single value is drawn from a uniform distribution specified by the upper and lower bounds provided. For example, if Frac_area_1 is 0.5, then 50% of the unfished biomass is allocated to area 1, regardless of the size of area 1 (i.e, size and fraction in each area determine the density of fish, which may impact fishing spatial targeting). In each time step recruits are allocated to each area based on the proportion specified in Frac_area_1. Uniform distribution lower and upper bounds. Positive real numbers.

Specified Value(s): 0.16, 0.16

We assumed that the population of WSC is distributed proportionally to the available habitat.

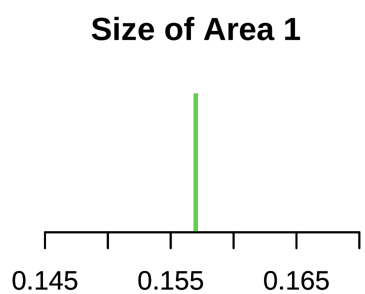
Prob_staying: The probability of individuals in area 1 remaining in area 1 over the course of one year. Please specify numbers between 0 and 1. For each simulation a single value is drawn from a uniform distribution specified by the upper and lower bounds provided. For example, in an area with a Prob_staying value of 0.95 each fish has a 95% probability of staying in that area in each time step, and a 5% probability of moving to the other area. Uniform distribution lower and upper bounds. Positive fraction.

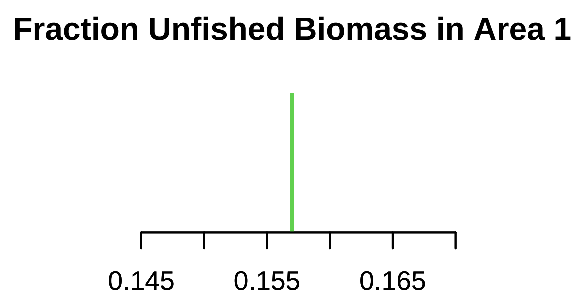
Specified Value(s): 0.95, 0.99

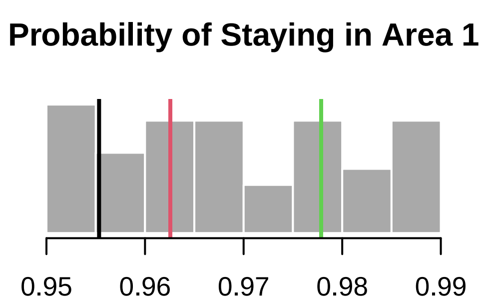
WSC move by crawling along the bottom using tube feet located on their ventral portion of their body and/or by contracting their body wall. At Santa Catalina Island, WSC were found to display movements of up to 0.2 miles (0.35 km) and remain at the same reef for up to 6 months at Santa Catalina Island (Muscat, 1983). This suggests that they have a small home range. The residency times of WSC were found be greater for individuals tagged during the spawning period (May) than individuals tagged during a non-spawning period (December), indicating that one of the primary times when Warty Sea Cucumbers move is to aggregate during the spawning season. The increase of densities within observed within MPAs in Southern California provides further evidence that WSC have small home ranges, and thus receive protection from no fishing zones.

Spatial & Movement

Sampled Parameters Histograms of 48 simulations of size of area 1 (`Size_area_1`), fraction of unfished biomass in area 1 (`Frac_area_1`), and the probability of staying in area 1 in a year (`Frac_area_1`), with vertical colored lines indicating 3 randomly drawn values used in other plots:







Fleet Parameters

Historical years of fishing, spatial targeting: nyears, Spat__targ

nyears: The number of years for the historical simulation. Single value. For example, if the simulated population is assumed to be unfished in 1975 and this is the year you want to start your historical simulations, and the most recent year for which there is data available is 2019, then nyears equals 45.

Specified Value(s): 40

The Warty Sea Cucumber dive fishery began in southern California in 1978, with divers targeting Warty Sea Cucumber around the Channel Islands. The WSC fishery began in 1978. Prior to that there was no known harvest of WSC. Initially, there was no code to specify WSC landings on fish tickets, and so WSC landings were grouped with other invertebrates. In 1980 the Department created a separate landing code to track sea cucumber landings. It is assumed that landings before 1980 were very low, and so we model the fishery starting in 1980, when the landings time series begins.

Spat_targ: Distribution of fishing in relation to vulnerable biomass (VB) across areas. The distribution of fishing effort is proportional to VBˆSpat_targ. Upper and lower bounds of a uniform distribution. For each simulation a single value is drawn from a uniform distribution specified by the upper and lower bounds provided. This parameter allows the user to model either avoidance or spatial targeting behavior by the fleet. If the parameter value is 1, fishing effort is allocated across areas in proportion to the population density of that area. Values below 1 simulate an avoidance behavior and values above 1 simulate a targeting behavior.

Specified Value(s): 1, 1

The WSC fleet does not display any particular spatial targeting or avoidance behavior.

Trend in historical fishing effort (exploitation rate), interannual variability in fishing effort: EffYears, EffLower, EffUpper, Esd

EffYears: Vector indicating the historical years where there is information available to infer the relative fishing effort expended.This vector is specified in terms of the position of the year in the vector rather than the calendar year. For example, say our simulation starts with an unfished stock in 1975,and the current year (the last year for which there is data available) is 2019. Then there are 45 historical years simulated, and EffYears should include numbers between 1 and 45. Note that there may not be information available for every historical year, especially for data poor fisheries. In these situations, the EffYears vector should include only the positions of the years for which there is information, and the vector may be shorter than the total number of simulated historical years (nyears).

During the first 10 years of the Warty Sea Cucumber dive fishery (1980 to 1989), participation was extremely limited, with no more than six fishermen and ten individual vessels making at least one landing in a given year. This changed rapidly in the early 1990s as the number of active vessels peaked at an all-time record high of 105 vessels in 1991 and 220 active fishermen. Since then, the average number of active vessels has been 39 with a range of 21 to 57. Because there are no limits on the amount of effort each fishermen can expend, participation is not a good metric for tracking effort. While divers are required to fill out logs documenting fishing effort, this information is considered to be unreliable. In addition, the catch data, which is sometimes used to parameterize changes in historical fishing effort trends, may be under-reported after 2000 due to a change in how sea cucumber were landed (whole vs. cut, with cut being preferred after the early 2000s). For this reason, historical fishing effort was assumed to follow the number of yearly landing receipts, which are a proxy for the number of fishing trips.

EffLower: Lower bound on relative fishing effort corresponding to EffYears. EffLower must be a vector that is the same length as EffYears describing how fishing effort has changed over time. Information on relative fishing effort can be entered in any units provided they are consistent across the entire vector because the data provided will be scaled to 1 (divided by the maximum number provided).

Lower and upper bounds were set at +/- 10% of the annual effort estimates.

EffUpper: Upper bound on relative fishing effort corresponding to EffYears. EffUpper must be a vector that is the same length as EffYears describing how fishing effort has changed over time. Information on relative fishing effort can be entered in any units provided they are consistent across the entire vector because the data provided will be scaled to 1 (divided by the maximum number provided).

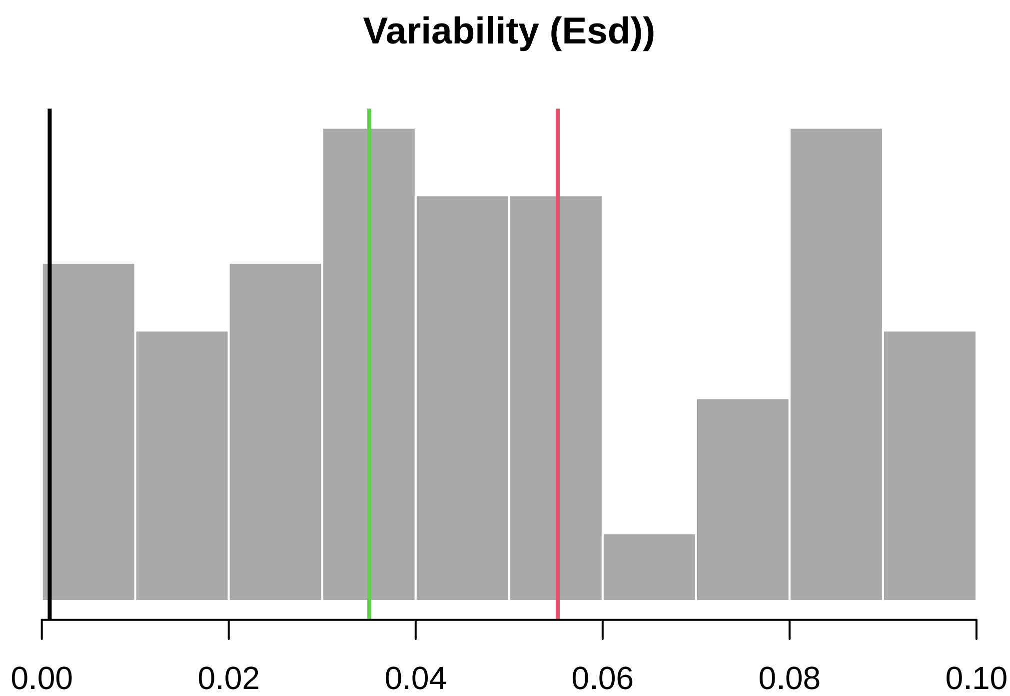
EffYears	EffLower	EffUpper
1980	0.00411	0.00503
1981	0.00117	0.00144
1982	0.01350	0.01650
1983	0.01640	0.02010
1984	0.02110	0.02580
1985	0.02170	0.02660
1986	0.02290	0.02800
1987	0.02350	0.02870
1988	0.01470	0.01800
1989	0.00822	0.01010
1990	0.03580	0.04380
1991	0.27000	0.33000
1992	0.14600	0.17900
1993	0.07110	0.08690
1994	0.09690	0.11800
1995	0.19800	0.24200
1996	0.31000	0.37900
1997	0.35600	0.43500
1998	0.54800	0.67000
1999	0.41200	0.50400
2000	0.47600	0.58200
2001	0.40900	0.50000
2002	0.62600	0.76500
2003	0.53300	0.65200
2004	0.41500	0.50800
2005	0.34100	0.41600
2006	0.34000	0.41500
2007	0.40300	0.49300
2008	0.66000	0.80600
2009	0.50300	0.61500
2010	0.61400	0.75100
2011	0.90000	1.10000
2012	0.42500	0.52000
2013	0.41600	0.50800
2014	0.35000	0.42700
2015	0.33100	0.40500
2016	0.19200	0.23400
2017	0.27000	0.33000
2018	0.22400	0.27400
2019	0.19000	0.23200

Esd: Additional inter-annual variability in fishing mortality rate. For each historical simulation a single value is drawn from a uniform distribution specified by the upper and lower bounds provided. If this parameter has a positive (non-zero) value, the yearly fishing mortality rate is drawn from a log-normal distribution with a standard deviation (in log space) specified by the value of Esd drawn for that simulation. This parameter applies only to historical projections.

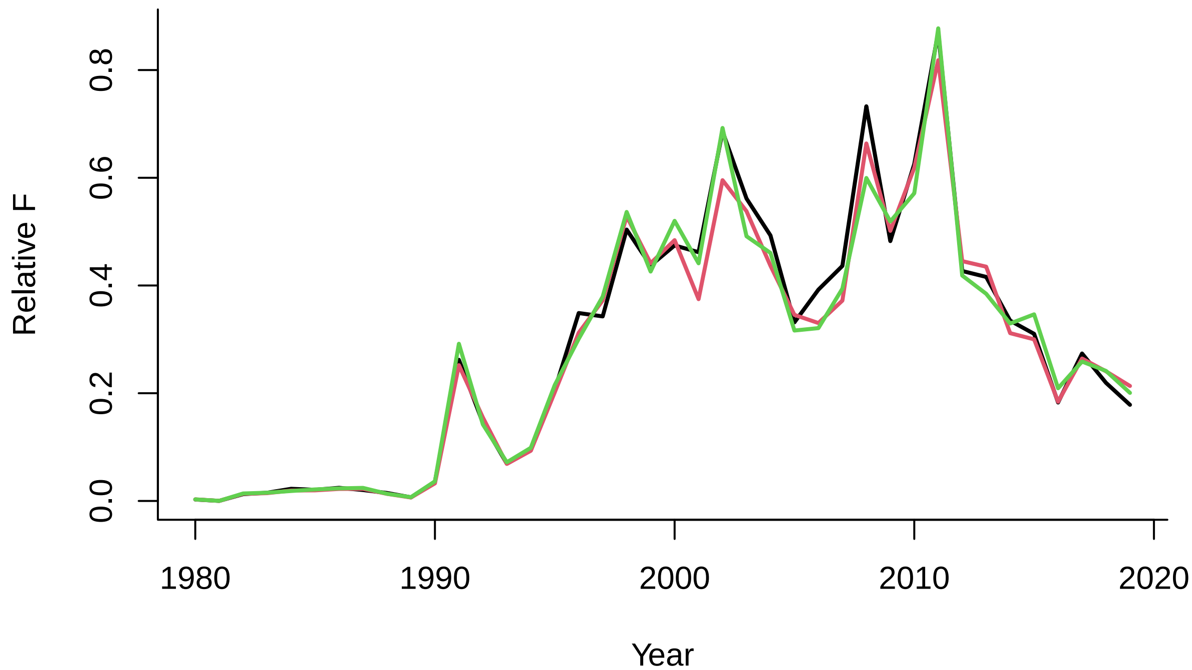
Specified Value(s): 0, 0.1

Historical Effort

Sampled Parameters Histograms of 48 simulations of inter-annual variability in historical fishing mortality (`Esd`), with vertical colored lines indicating 3 randomly drawn values used in the time-series plot:



Time-Series Time-series plot showing 3 trends in historical fishing mortality (`OM@EffUpper` and `OM@EffLower` or `OM@cpars$Find`):



Annual increase in catchability, interannual variability in catchability: qinc, qcv

qinc: Mean temporal trend in catchability (also though of as the efficiency of fishing gear) parameter, expressed as a percentage change in catchability (q) per year. For each simulation a single value is drawn from a uniform distribution specified by the upper and lower bounds provided. Positive numbers indicate an increase and negative numbers indicate a decrease. q then changes by this amount for in each year of the simulation This parameter applies only to forward projections.

Specified Value(s): -0.5, 0

It is assumed that catchability may decrease in the future due to the seasonal closure that was enacted in 2019, which limits fishermen access during the spawning aggregation period. Fishermen are likely to be less efficient in the future.

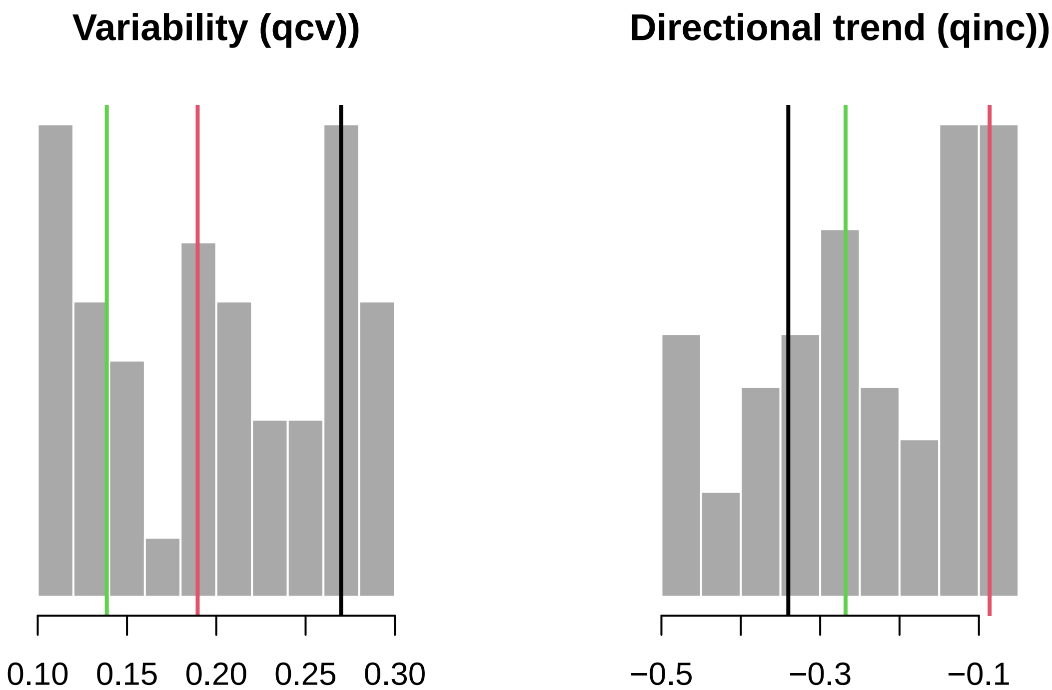
qcv: Inter-annual variability in catchability expressed as a coefficient of variation. For each simulation a single value is drawn from a uniform distribution specified by the upper and lower bounds provided. This parameter applies only to forward projections.

Specified Value(s): 0.1, 0.3

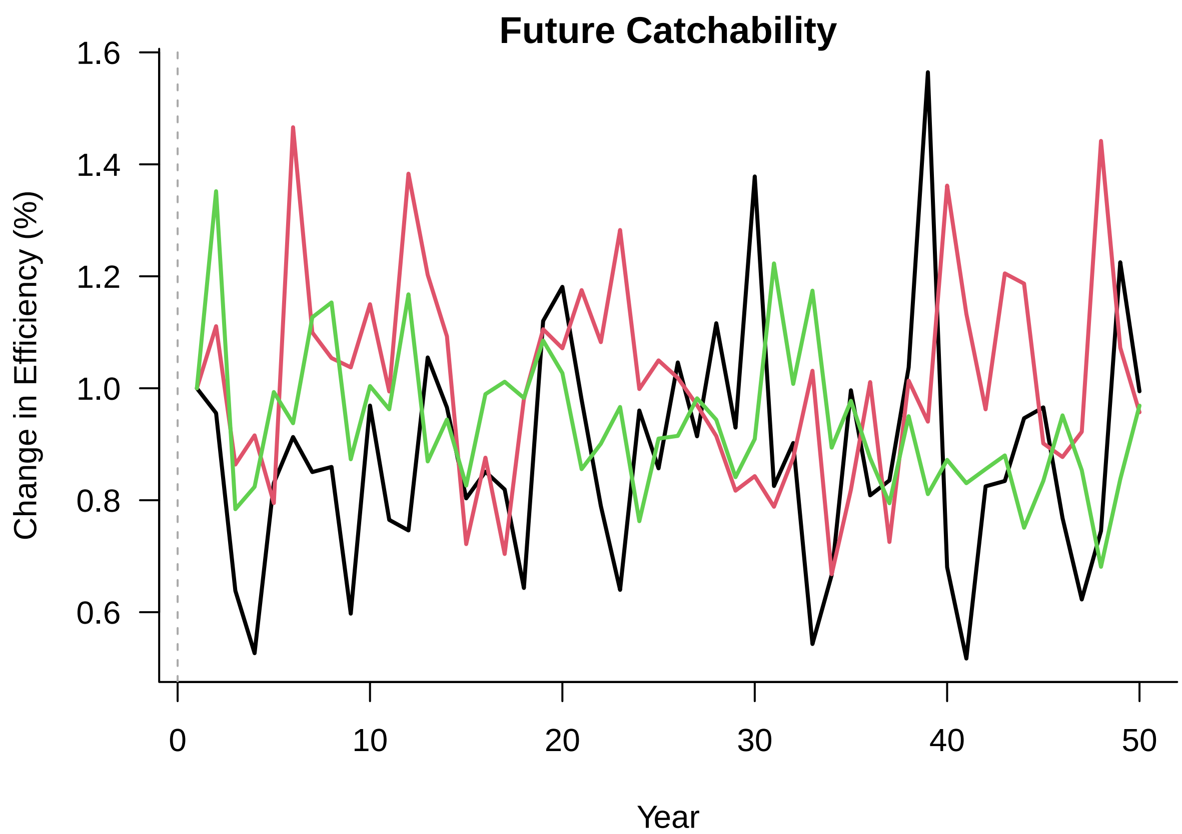
There is no information available on catchability.

Future Catchability

Sampled Parameters Histograms of 48 simulations of inter-annual variability in fishing efficiency (`qcv`) and average annual change in fishing efficiency (`qinc`), with vertical colored lines indicating 3 randomly drawn values used in the time-series plot:



Time-Series Time-series plot showing 3 trends in future fishing efficiency (catchability):



Fishery gear length selectivity: L5, LFS, Vmaxlen, isRel

L5: Shortest length at which 5% of the population is vulnerable to selection by the gear used in this fleet. Values can either be specified as lengths (in the same units used for the maturity and growth parameters in the stock object) or as a percentage of the size of maturity (see the parameter isRel for more information). For each simulation a single value is drawn from a uniform distribution specified by the upper and lower bounds provided. This value is the same in all years unless cpars is used to provide time-varying selection.

Specified Value(s): 2727, 2905

Information from the dive surveys that have been conducted approximately monthly by CDFW since 2013 was used to estimate the selectivity of this fishery. WSC are harvested by hand by divers. Small individuals (with a LxW below ~3500 mm) are rarely observed, and it is thought that juveniles may exhibit cryptic behavior until a) they are either sexually mature, at which point they join spawning aggregations in the spring, the time of year when they are most easy to find, or b) they are large enough to be relatively invulnerable to predation. We assumed that during surveys CDFW divers can find and measure the same sizes that fishermen find, and so we fit a logistic selectivity model to LxW frequency data collected from surveys to estimate the size at 5% and full selection. We modeled these values +/- the standard error of the estimate.

LFS: Shortest length at which 100% of the population is vulnerable to selection by the gear used by this fleet. Values can either be specified as lengths (in the same units used for the maturity and growth parameters in the stock object) or as a percentage of the size of maturity (see the parameter isRel for more information). For each simulation a single value is drawn from a uniform distribution specified by the upper and lower bounds provided. This value is the same in all years unless cpars is used to provide time-varying selection.

Specified Value(s): 4000, 5000

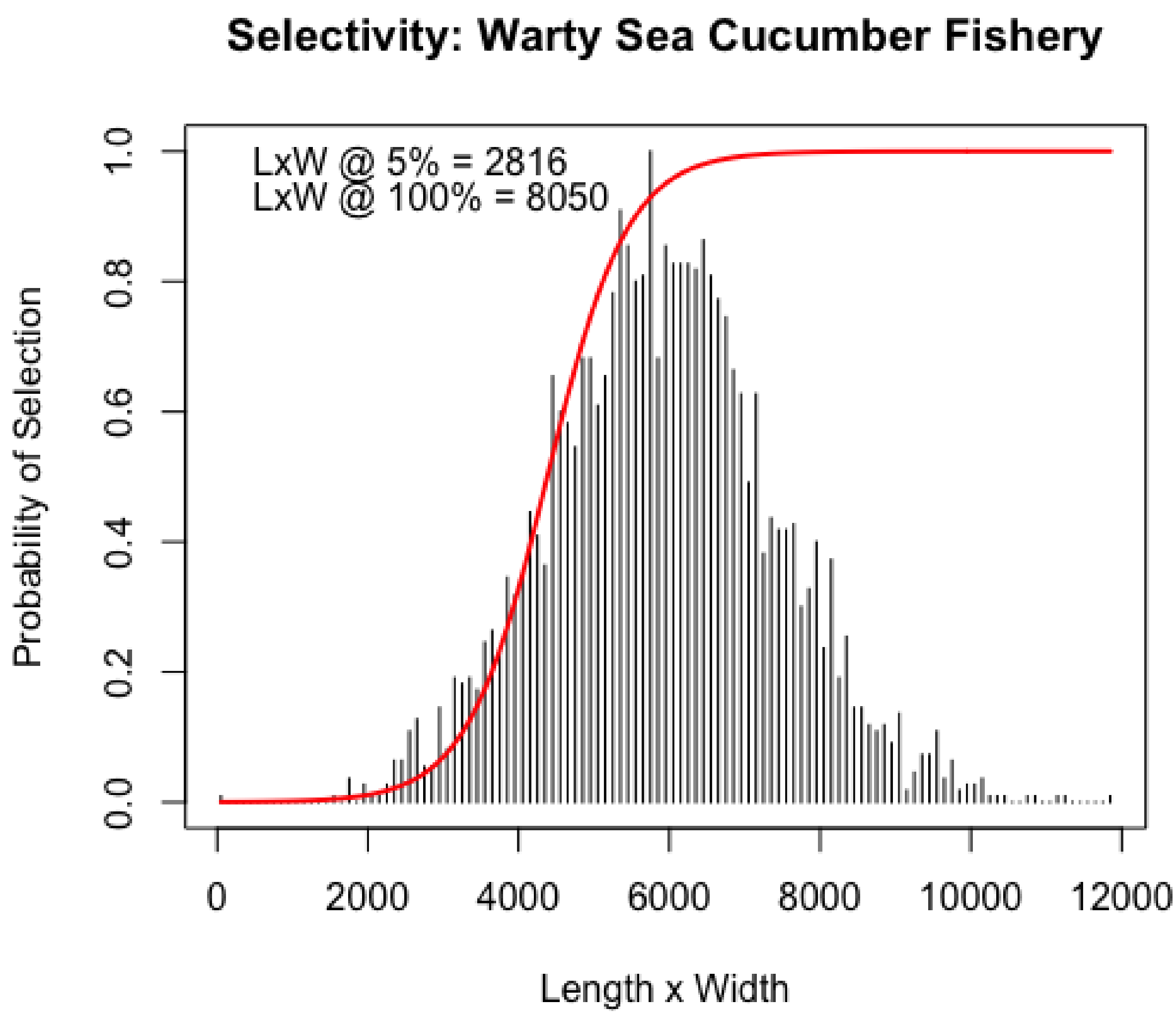


Figure 9: Predicted cut weight (in g) at size (LxW in mm) of Warty Sea Cucumber from data collected by CDFW between 2013 and 2018

Vmaxlen: Proportion of fish selected by the gear at the asymptotic length ('Stock@Linf'). Upper and Lower bounds between 0 and 1. A value of 1 indicates that 100% of fish are selected at the asymptotic length, and the selection curve is logistic. If Vmaxlen is less than 1 the selection curve is dome shaped. For example, if Vmaxlen is 0.4, then only 40% of fish are vulnerable to the fishing gear at the asymptotic length.

Specified Value(s): 1, 1

Large WSC are fully vulnerable.

isRel: Specify whether selection and retention parameters use absolute lengths or relative to the size of maturity. Single logical value (TRUE or FALSE).

Specified Value(s): FALSE

Fishery length retention: LR5, LFR, Rmaxlen, DR

LR5: Shortest length at which 5% of the population is vulnerable to retention by the fleet. Values can either be specified as lengths (in the same units used for the maturity and growth parameters in the stock object) or as a percentage of the size of maturity (see the parameter isRel for more information). For each simulation a single value is drawn from a uniform distribution specified by the upper and lower bounds provided. This value is the same in all years unless cpars is used to provide time-varying selection.

Specified Value(s): 2727, 2905

There is currently no size limit in this fishery, so the retention curve was set to be equal to the selectivity curve, and was assumed to be logistic.

LFR: Shortest length where 100% of the population is vulnerable to retention by the fleet. Values can either be specified as lengths (in the same units used for the maturity and growth parameters in the stock object) or as a percentage of the size of maturity (see the parameter isRel for more information). For each simulation a single value is drawn from a uniform distribution specified by the upper and lower bounds provided. This value is the same in all years unless cpars is used to provide time-varying selection.

Specified Value(s): 4000, 5000

Rmaxlen: Proportion of fish retained at the asymptotic length ('Stock@Linf'). Upper and Lower bounds between 0 and 1. A value of 1 indicates that 100% of fish are retained at the asymptotic length, and the selection curve is logistic. If Rmaxlen is less than 1 the retention curve is dome shaped. For example, if Rmaxlen is 0.4, then only 40% of fish at the asymptotic length are retained.

Specified Value(s): 1, 1

Large WSC are fully retained.

DR: Discard rate, defined as the proportion of fully selected fish that are discarded by the fleet. Upper and Lower bounds between 0 and 1, with a value of 1 indicates that 100% of selected fish are discarded. For each simulation a single value is drawn from a uniform distribution specified by the upper and lower bounds provided.

Specified Value(s): 0, 0

Because this is a dive fishery, in which WSC are harvested by hand, there are thought to be no discards.

Current Year: CurrentYr

CurrentYr: The last historical year simulated before projections begin. Single value. Note that this should match the last historical year specified in the Data object, which is usually the last historical year for which data is available.

Specified Value(s): 2019

The current year for this fishery is 2019, the most recent year when there is catch and effort data available.

Existing Spatial Closures: MPA

MPA: Logical argument (TRUE or FALSE). Creates an MPA in Area 1 for all years if true is selected. Defaults to FALSE.

Specified Value(s): FALSE

Due to the spawning aggregation behavior of Warty Sea Cucumber in shallow depths of less than 100 ft (30.5 m), on and around rocky reef habitat, the current network of MPAs in California likely play an important role in providing refuge to spawning populations. The 2x3 matrix specifies the timing of MPA closures during the fishery history and the proportion of fishing grounds removed for two areas. Historical years are specified in column 1. Proportion of grounds closed in areas 1 and 2 are specified in columns 2 and 3. Area 1 represents MPAs and area 2 represents open fishing grounds. The CDFW estimates that 15.7% of Warty Sea Cucumber habitat (both reef and soft sediments) occurs inside the boundaries of MPAs in southern California within this species primary depth range < 100 ft (30.5 m). 52.3% of this area received protection in 2003 when the Channel Islands MPAs were created, while the remaining areas were closed to fishing in 2012 when the South Coast MPA network was established.

Obs Parameters

Catch statistics: Cobs, Cbiascv, CAA_nsamp, CAA_ESS, CAL_nsamp, CAL_ESS

Cobs: Observation error around the total catch. Observation error in the total catch is expressed as a coefficient of variation (CV). Cobs requires upper and lower bounds of a uniform distribution, and for each simulation a CV is sampled from this distribution. Each CV is used to specify a log-normal error distribution with a mean of 1 and a standard deviation equal to the sampled CV. The yearly observation error values for the catch data are then drawn from this distribution. For each time step the simulation model records the true catch, but the observed catch is generated by applying this yearly error term (plus any bias, if specified) to the true catch.

Specified Value(s): 0.1, 0.3

No justification provided.

Cbiascv: Log-normally distributed coefficient of variation controlling the sampling bias in observed catch for each simulation. Bias occurs when catches are systematically skewed away from the true catch level (for example, due to underreporting of catch or undetected illegal catches). Cbiascv is a single value specifying the standard deviation of a log-normal distribution with a mean of 1 and a standard deviation equal to the sampled CV. For each simulation a bias value is drawn from this distribution, and that bias is applied across all years.

Specified Value(s): 0.2

In general, we assume that CDFW is able to track the catch of commercial fisheries accurately, with no persistent biases except in the case of poaching or unrecorded recreational fishing. However, the way that WSC landings have been reported has changed over time, with weight being recorded for both whole and cut fish at different points in time (See Data Object Report for more detail), and this has lead to a great deal of uncertainty about the true amount of historical catch. There is also concern based on recent information from CDFW enforcement that some processors may not be submitting fish tickets, and thus landings have gone unreported. We assumed that the bias in reported catch could range from 65% to 95% of the true catch amount.

CAA_nsamp: Number of catch-at-age observations collected per time step. For each time step a single value is drawn from a uniform distribution specified by the upper and lower bounds provided. Positive integers.

Specified Value(s): 0, 0

No CAA samples are collected.

CAA_ESS: Effective sample size of catch-at-age observations collected per time step. For each time step a single value is drawn from a uniform distribution specified by the upper and lower bounds provided. CAA_ESS should not exceed CAA_nsamp. Positive integers.

Specified Value(s): 0, 0

No CAA samples are collected.

CAL_nsamp: Number of catch-at-length observations collected per time step. For each time step a single value is drawn from a uniform distribution specified by the upper and lower bounds provided. Positive integers.

Specified Value(s): 600, 1000

Currently, no CAL samples are collected, because the size of landed sea cucumbers has not been recorded. However, this type of data would be possible to collect via an at sea or port sampling program.

CAL_ESS: Effective sample size. For each time step a single value is drawn from a uniform distribution specified by the upper and lower bounds provided. CAL_ESS should not exceed CAL_nsamp. Positive integers.

Specified Value(s): 600, 1000

No CAL samples are currently collected.

Index imprecision, bias and hyperstability: Iobs, Btobs, Btbiascv, beta

Iobs: Observation error in the relative abundance index expressed as a coefficient of variation (CV). Iobs requires upper and lower bounds of a uniform distribution, and for each simulation a CV is sampled from this distribution. Each CV is used to specify a log-normal error distribution with a mean of 1 and a standard deviation equal to the sampled CV. The yearly observation error values for the index of abundance data are then drawn from this distribution. For each time step the simulation model records the true change in abundance, but the observed index is generated by applying this yearly error term (plus any bias, if specified) to the true relative change in abundance. Positive real numbers.

Specified Value(s): 0.7, 1.3

Due to the fact that the dive logs are considered unreliable there is no CPUE index for this fishery.

Btobs: Observation error in the absolute abundance expressed as a coefficient of variation (CV). Btobs requires upper and lower bounds of a uniform distribution, and for each simulation a CV is sampled from this distribution. Each CV is used to specify a log-normal error distribution with a mean of 1 and a standard deviation equal to the sampled CV. The yearly observation error values for the absolute abundance data are then drawn from this distribution. For each time step the simulation model records the true abundance, but the observed abundance is generated by applying this yearly error term (plus any bias, if specified) to the true abundance. Positive real numbers.

Specified Value(s): 0.7, 1.3

The survey has followed the same protocol since the early 1980s, in which SCUBA divers count the number of Warty Sea Cucumbers encountered at randomly selected points along 100m transect lines at 33 fixed locations throughout the northern Channel Islands. We calculated the coefficient of variation for the survey index of abundance across all years (figure below). Note that standard deviations were higher in the early years when fewer sites were surveyed, but then increased again after 12 survey sites became no take MPAs. We assumed simulated survey values would have a CV ranging between the minimum and maximum CV values.

Btbiascv: Log-normally distributed coefficient (CV) controlling error in observations of the current stock biomass. Bias occurs when the observed index of abundance is is systematically higher or lower than the true relative abundance. Btbiascv is a single value specifying the standard deviation of a log-normal distribution

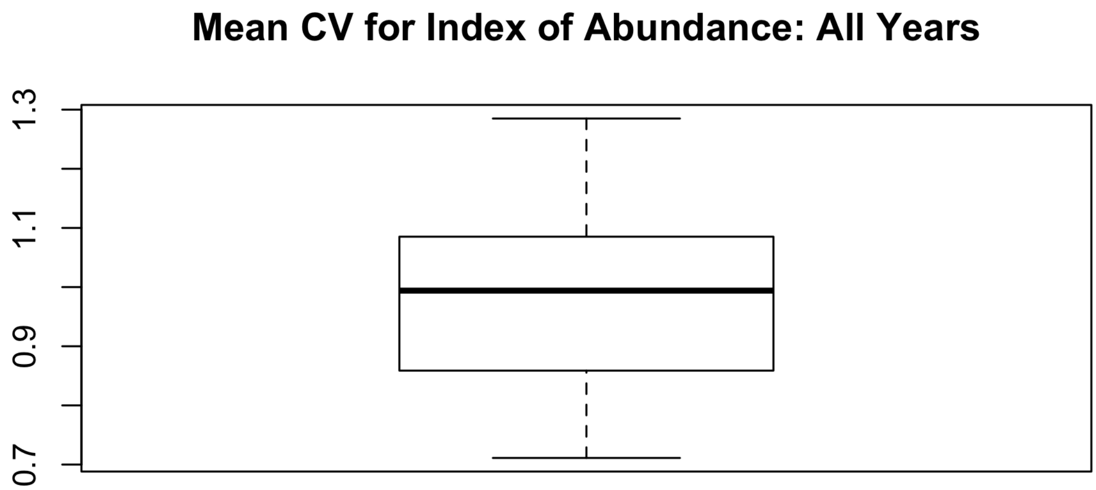


Figure 10: Distribution of Coefficients of Variation (ratio of the mean to the standard deviation) for mean survey index of abundance per year.

with a mean of 1 and a standard deviation equal to the sampled CV. For each simulation a bias value is drawn from this distribution, and that bias is applied across all years. Positive real numbers.

Specified Value(s): 0

There are no known biases associated with the CINP KFM survey data.

beta: A parameter controlling hyperstability/hyperdepletion in the measurement of abundance. For each simulation a single value is drawn from a uniform distribution specified by the upper and lower bounds provided. Values below 1 lead to hyperstability (the observed index decreases more slowly than the true abundance) and values above 1 lead to hyperdepletion (the observed index decreases more rapidly than true abundance). Positive real numbers.

Specified Value(s): 0.8, 1.2

The Btobs index is assumed to be linearly related to the true abundance of WSC. While WSC are known to form spawning aggregations in the spring, CINP surveys begin in May, and observations in May-August are used. It is thought that aggregations are dispersing during this time. We modeled a range of values between 0.8 and 1.2.

Bias in maturity, natural mortality rate and growth parameters: LenMbiascv, Mbiascv, Kbiascv,t0biascv, Linfbiascv

LenMbiascv: Log-normal coefficient of variation for sampling bias in observed length at 50 percent maturity. LenMbiascv is a single value specifying the standard deviation of a log-normal distribution with a mean of 1 and a standard deviation equal to the sampled CV. For each simulation a bias value is drawn from this distribution, and that bias is applied across all years. Positive real numbers.

Specified Value(s): 0.1

For all other observation error parameters we used the generic observation error parameters within the DLMtool. This is because there are currently no sampling protocols in place with which to assess any biases associated with sampling these parameters

Mbiascv: Log-normal coefficient of variation for sampling bias in observed natural mortality rate. Uniform distribution lower and upper bounds. Mbiascv is a single value specifying the standard deviation of a log-normal distribution with a mean of 1 and a standard deviation equal to the sampled CV. For each simulation a bias value is drawn from this distribution, and that bias is applied across all years. Positive real numbers.

Specified Value(s): 0.4

No justification provided.

Kbiascv: Log-normal coefficient of variation for sampling bias in observed growth parameter K. Kbiascv is a single value specifying the standard deviation of a log-normal distribution with a mean of 1 and a standard deviation equal to the sampled CV. For each simulation a bias value is drawn from this distribution, and that bias is applied across all years. Positive real numbers.

Specified Value(s): 0.3

No justification provided.

t0biascv: Log-normal coefficient of variation for sampling bias in observed t0. t0biascv is a single value specifying the standard deviation of a log-normal distribution with a mean of 1 and a standard deviation equal to the sampled CV. For each simulation a bias value is drawn from this distribution, and that bias is applied across all years. Positive real numbers.

Specified Value(s): 0.1

No justification provided.

Linfbiascv: Log-normal coefficient of variation for sampling bias in observed maximum length. Linfbiascv is a single value specifying the standard deviation of a log-normal distribution with a mean of 1 and a standard deviation equal to the sampled CV. For each simulation a bias value is drawn from this distribution, and that bias is applied across all years. Positive real numbers.

Specified Value(s): 0.1

No justification provided.

Bias in length at first capture, length at full selection: LFCbiascv, LFSbiascv

LFCbiascv: Log-normal coefficient of variation for sampling bias in observed length at first capture. LFCbiascv is a single value specifying the standard deviation of a log-normal distribution with a mean of 1 and a standard deviation equal to the sampled CV. For each simulation a bias value is drawn from this distribution, and that bias is applied across all years. Positive real numbers.

Specified Value(s): 0.05

No justification provided.

LFSbiascv: Log-normal coefficient of variation for sampling bias in length-at-full selection. LFSbiascv is a single value specifying the standard deviation of a log-normal distribution with a mean of 1 and a standard deviation equal to the sampled CV. For each simulation a bias value is drawn from this distribution, and that bias is applied across all years. Positive real numbers.

Specified Value(s): 0.05

No justification provided.

Bias in fishery reference points, unfished biomass, FMSY, FMSY/M ratio, biomass at MSY relative to unfished: FMSY_Mbiascv, BMSY_B0biascv

FMSY_Mbiascv: Log-normal coefficient of variation for sampling bias in estimates of the ratio of the fishing mortality rate that gives the maximum sustainable yield relative to the assumed instantaneous natural mortality rate. FMSY/M. FMSY_Mbiascv is a single value specifying the standard deviation of a log-normal distribution with a mean of 1 and a standard deviation equal to the sampled CV. For each simulation a bias value is drawn from this distribution, and that bias is applied across all years. Positive real numbers.

Specified Value(s): 0.2

No justification provided.

BMSY_B0biascv: Log-normal coefficient of variation for sampling bias in estimates of the BMSY relative to unfished biomass (BMSY/B0). BMSY_B0biascv is a single value specifying the standard deviation of a log-normal distribution with a mean of 1 and a standard deviation equal to the sampled CV. For each simulation a bias value is drawn from this distribution, and that bias is applied across all years. Positive real numbers.

Specified Value(s): 0.2

No justification provided.

Management targets in terms of the index (i.e., model free), the total annual catches and absolute biomass levels: Irefbiascv, Crefbiascv, Brefbiascv

Irefbiascv: Log-normal coefficient of variation for sampling bias in the observed relative index of abundance (Iref). Irefbiascv is a single value specifying the standard deviation of a log-normal distribution with a mean of 1 and a standard deviation equal to the sampled CV. For each simulation a bias value is drawn from this distribution, and that bias is applied across all years. Positive real numbers.

Specified Value(s): 0.2

No justification provided.

Crefbiascv: Log-normal coefficient of variation for sampling bias in the observed reference catch (Cref). Crefbiascv is a single value specifying the standard deviation of a log-normal distribution with a mean of 1 and a standard deviation equal to the sampled CV. For each simulation a bias value is drawn from this distribution, and that bias is applied across all years. Positive real numbers.

Specified Value(s): 0.2

No justification provided.

Brefbiascv: Log-normal coefficient of variation for sampling bias in the observed reference biomass (Bref). Brefbiascv is a single value specifying the standard deviation of a log-normal distribution with a mean of 1 and a standard deviation equal to the sampled CV. For each simulation a bias value is drawn from this distribution, and that bias is applied across all years. Positive real numbers.

Specified Value(s): 0.5

No justification provided.

Depletion bias and imprecision: Dbiascv, Dobs

Dbiascv: Log-normal coefficient of variation for sampling bias in the observed depletion level. Dbiascv is a single value specifying the standard deviation of a log-normal distribution with a mean of 1 and a standard deviation equal to the sampled CV. For each simulation a bias value is drawn from this distribution, and that bias is applied across all years. Positive real numbers.

Specified Value(s): 0.5

No justification provided.

Dobs: Log-normal coefficient of variation controlling error in observations of stock depletion among years. Observation error in the depletion expressed as a coefficient of variation (CV). Dobs requires the upper and lower bounds of a uniform distribution, and for each simulation a CV is sampled from this distribution. Each CV is used to specify a log-normal error distribution with a mean of 1 and a standard deviation equal to the sampled CV. The yearly observation error values for the depletion data are then drawn from this distribution. For each time step the simulation model records the true depletion, but the observed depletion is generated by applying this yearly error term (plus any bias, if specified) to the true depletion.

Specified Value(s): 0.05, 0.1

No justification provided.

Recruitment compensation and trend: hbiascv, Recbiascv, sigmaRbiascv

hbiascv: Log-normal coefficient of variation for sampling persistent bias in steepness. hbiascv is a single value specifying the standard deviation of a log-normal distribution with a mean of 1 and a standard deviation equal to the sampled CV. For each simulation a bias value is drawn from this distribution, and that bias is applied across all years. Positive real numbers.

Specified Value(s): 0.2

No justification provided.

Recbiascv: Log-normal coefficient of variation for sampling persistent bias in recent recruitment strength. Recbiascv requires the upper and lower bounds of a uniform distribution, and for each simulation a CV is sampled from this distribution. Each CV is used to specify a log-normal error distribution with a mean of 1 and a standard deviation equal to the sampled CV. The yearly bias values for the depletion data are then drawn from this distribution. Positive real numbers.

Specified Value(s): 0.1, 0.3

No justification provided.

sigmaRbiascv: Log-normal coefficient of variation for sampling persistent bias in recruitment variability. sigmaRbiascv is a single value specifying the standard deviation of a log-normal distribution with a mean of 1 and a standard deviation equal to the sampled CV. For each simulation a bias value is drawn from this distribution, and that bias is applied across all years. Positive real numbers.

Specified Value(s): 0.1

No justification provided.

Effort: Eobs, Ebiascv

Eobs: Observation error around the total effort. Observation error in the total effort is expressed as a coefficient of variation (CV). Eobs requires upper and lower bounds of a uniform distribution, and for each simulation a CV is sampled from this distribution. Each CV is used to specify a log-normal error distribution with a mean of 1 and a standard deviation equal to the sampled CV. The yearly observation error values for the effort data are then drawn from this distribution. For each time step the simulation model records the true effort, but the observed effort is generated by applying this yearly error term (plus any bias, if specified) to the true effort.

Specified Value(s): 0, 0

No justification provided.

Ebiascv: Log-normally distributed coefficient of variation controlling the sampling bias in observed effort for each simulation. Bias occurs when effort is systematically skewed away from the true effort level. Ebiascv is a single value specifying the standard deviation of a log-normal distribution with a mean of 1 and a standard deviation equal to the sampled CV. For each simulation a bias value is drawn from this distribution, and that bias is applied across all years.

Specified Value(s): 0

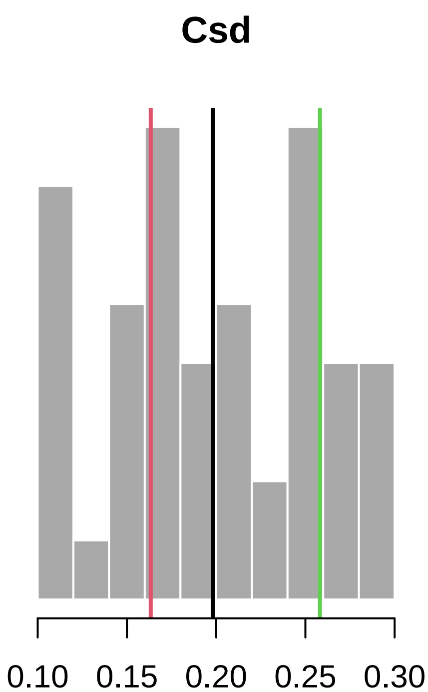
No justification provided.

Obs Plots

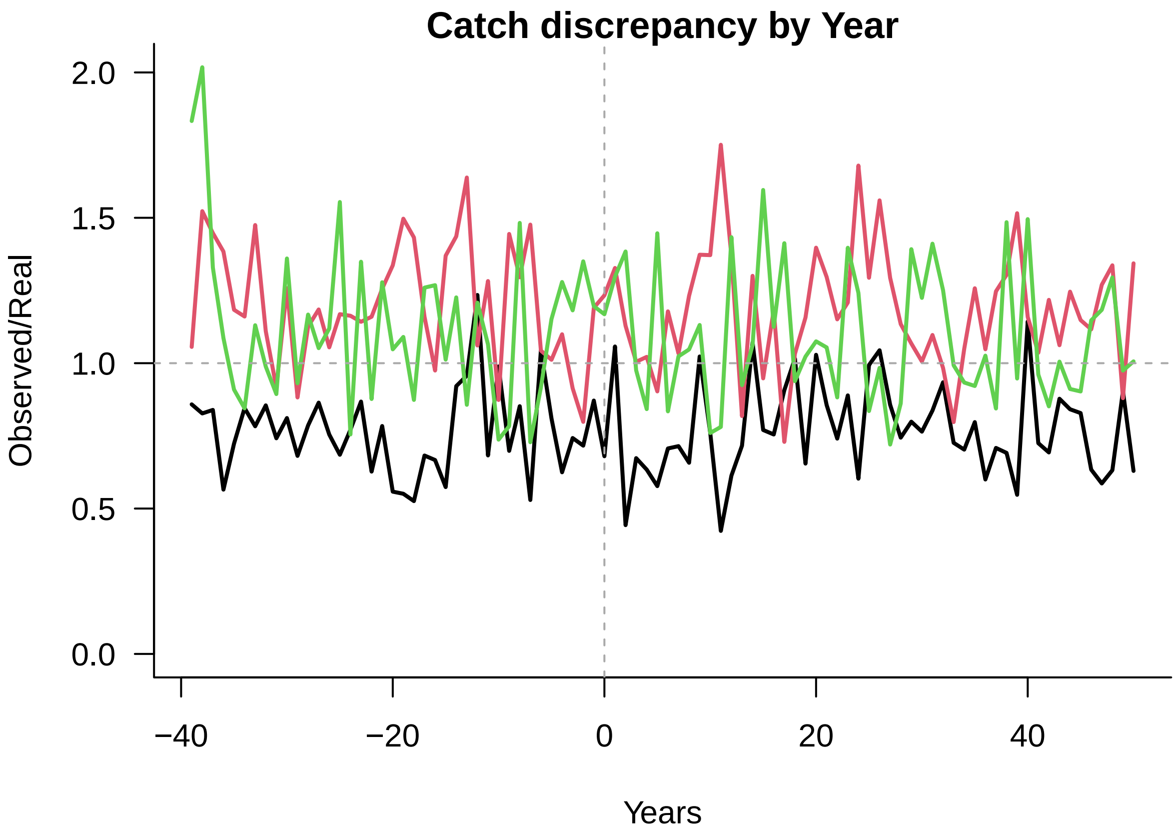
Observation Parameters

Catch Observations

Sampled Parameters Histograms of 48 simulations of inter-annual variability in catch observations (`Csd`) and persistent bias in observed catch (`Cbias`), with vertical colored lines indicating 3 randomly drawn values used in other plots:

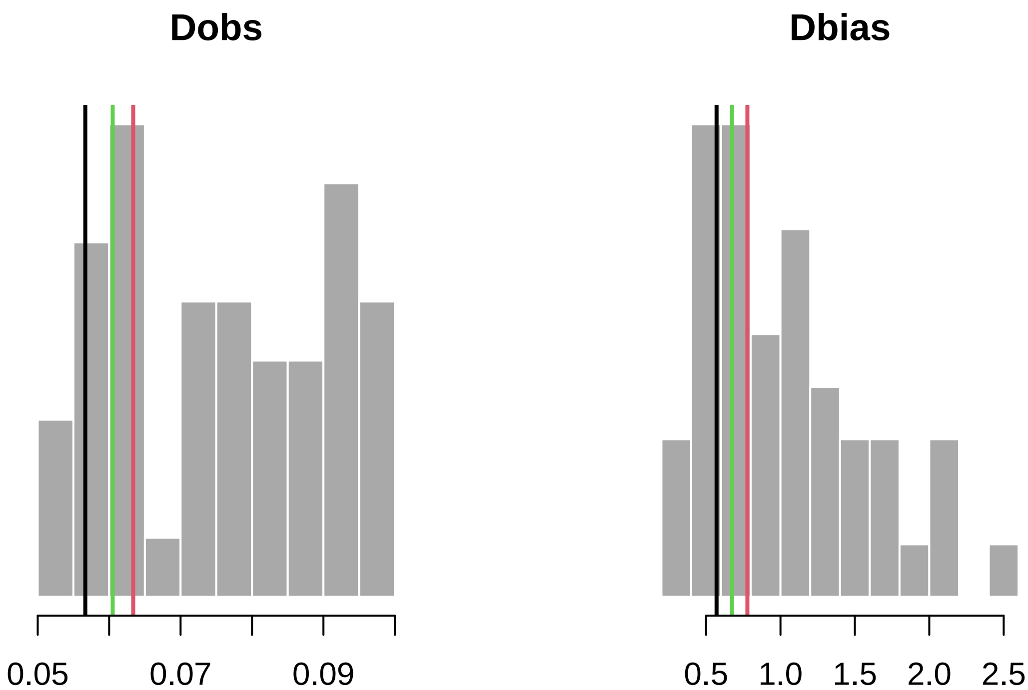


Time-Series Time-series plots of catch observation error for historical and projection years:

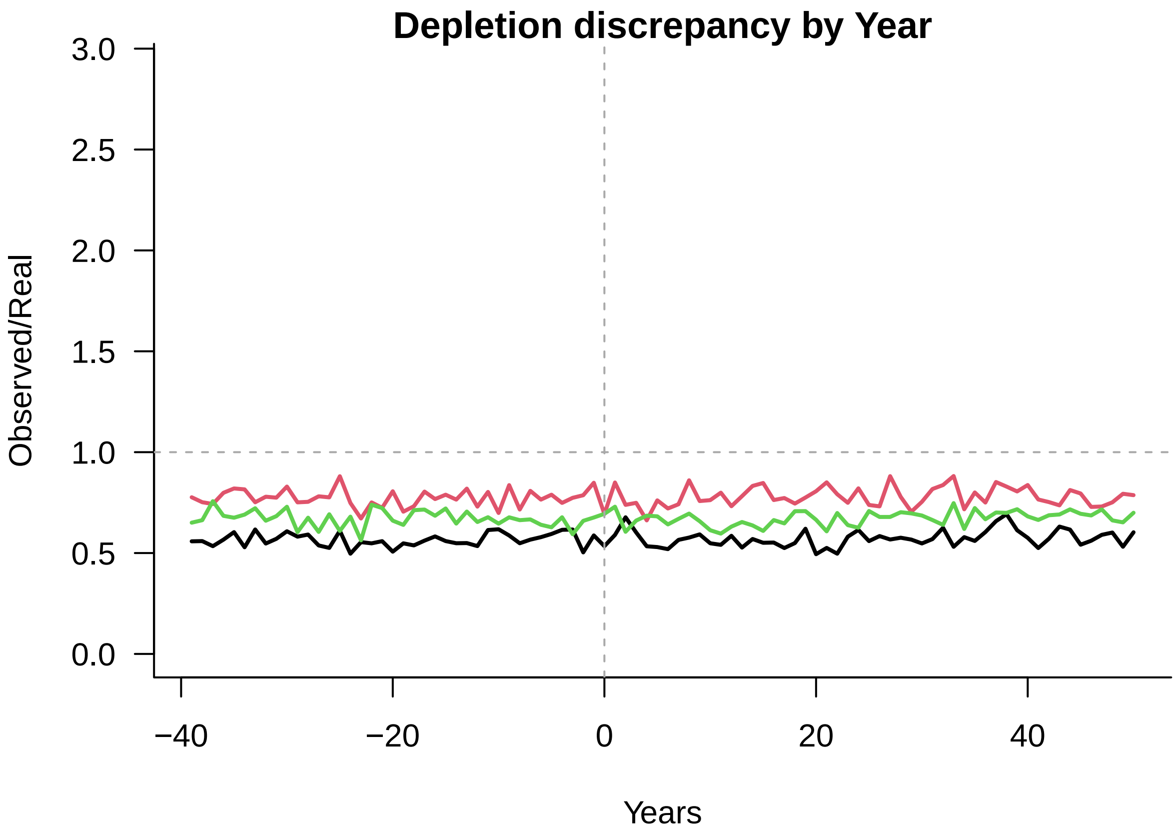


Depletion Observations

Sampled Parameters Histograms of 48 simulations of inter-annual variability in depletion observations (`Dobs`) and persistent bias in observed depletion (`Dbias`), with vertical colored lines indicating 3 randomly drawn values used in other plots:

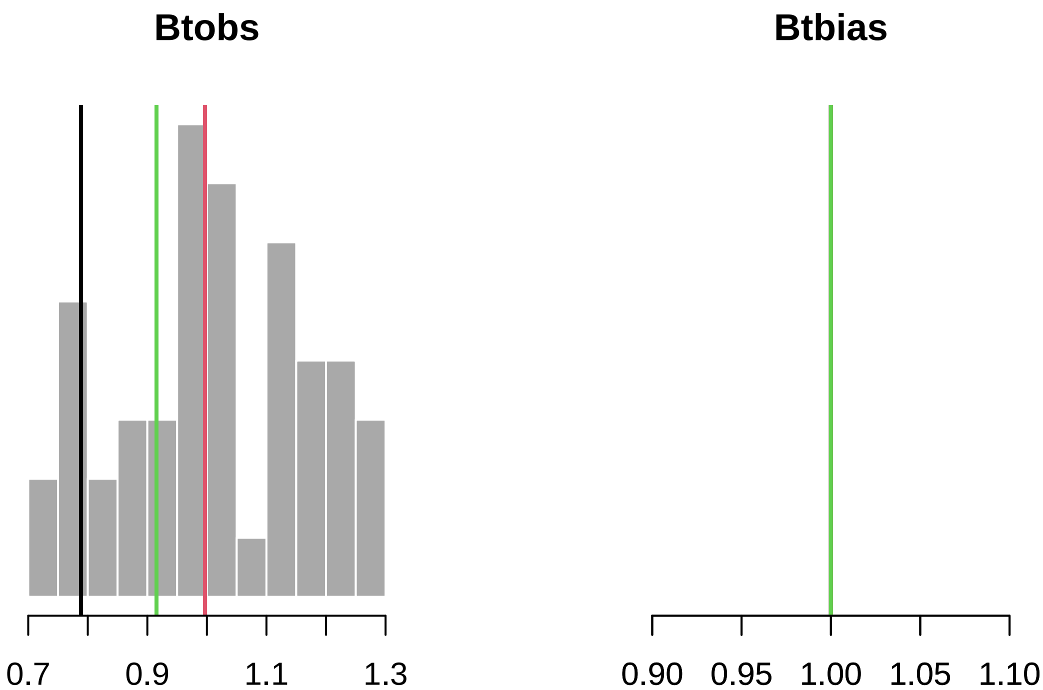


Time-Series Time-series plots of depletion observation error for historical and projection years:

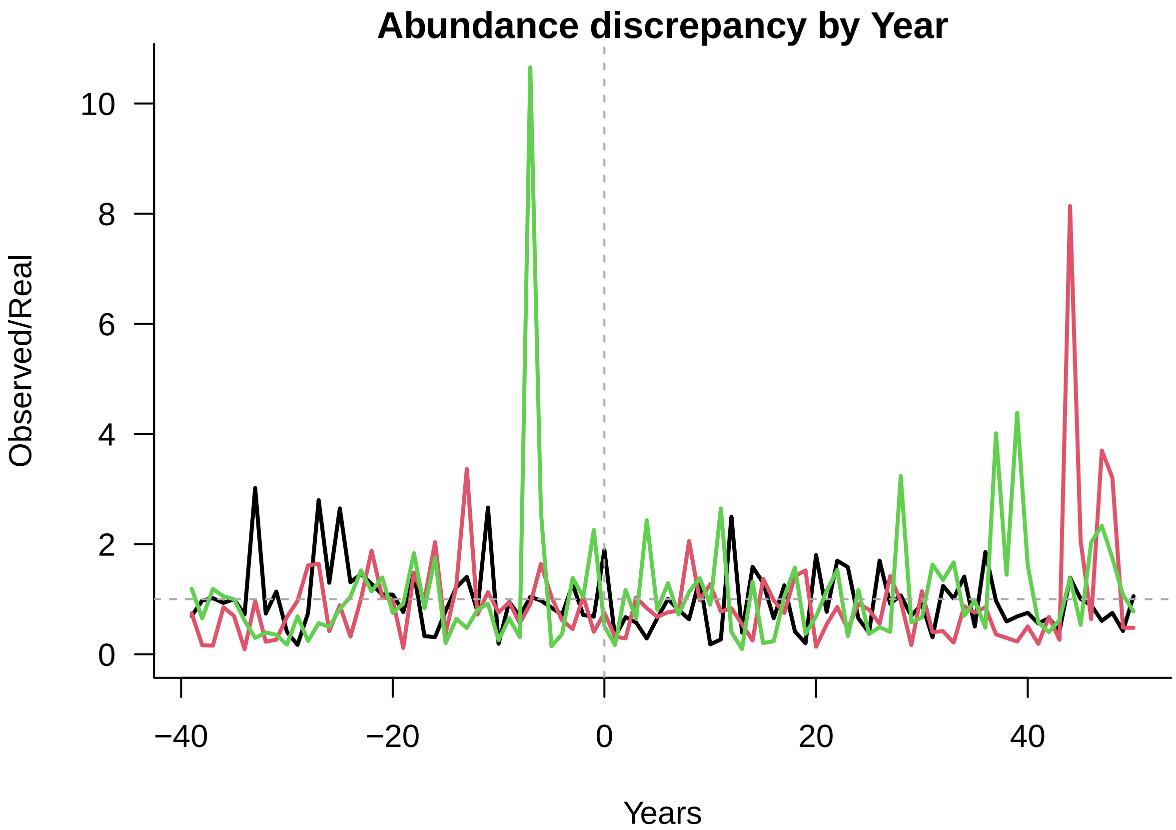


Abundance Observations

Sampled Parameters Histograms of 48 simulations of inter-annual variability in abundance observations (`Btobs`) and persistent bias in observed abundance (`Btbias`), with vertical colored lines indicating 3 randomly drawn values used in other plots:

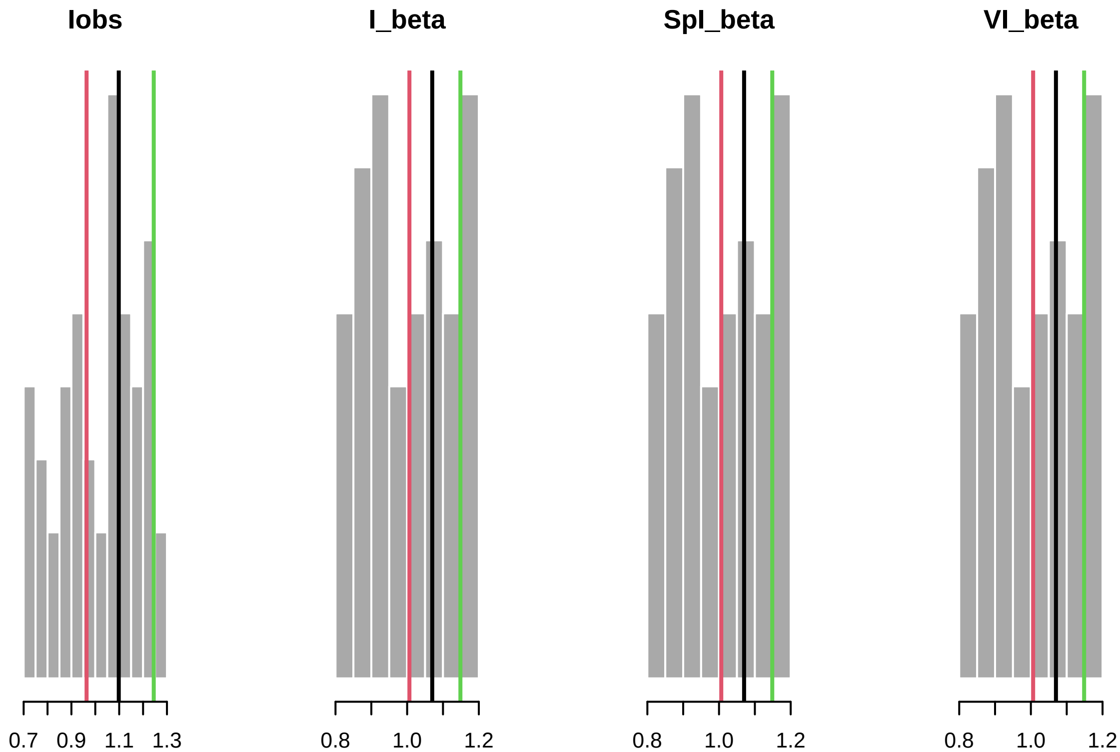


Time-Series Time-series plots of abundance observation error for historical and projection years:

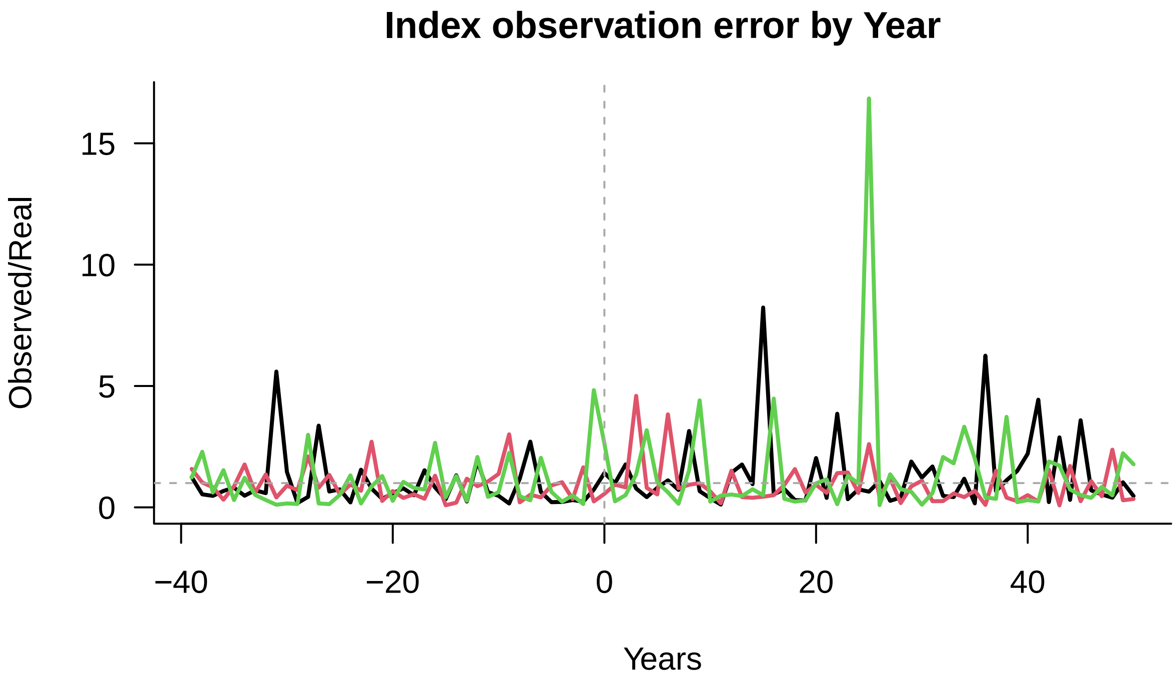


Index Observations

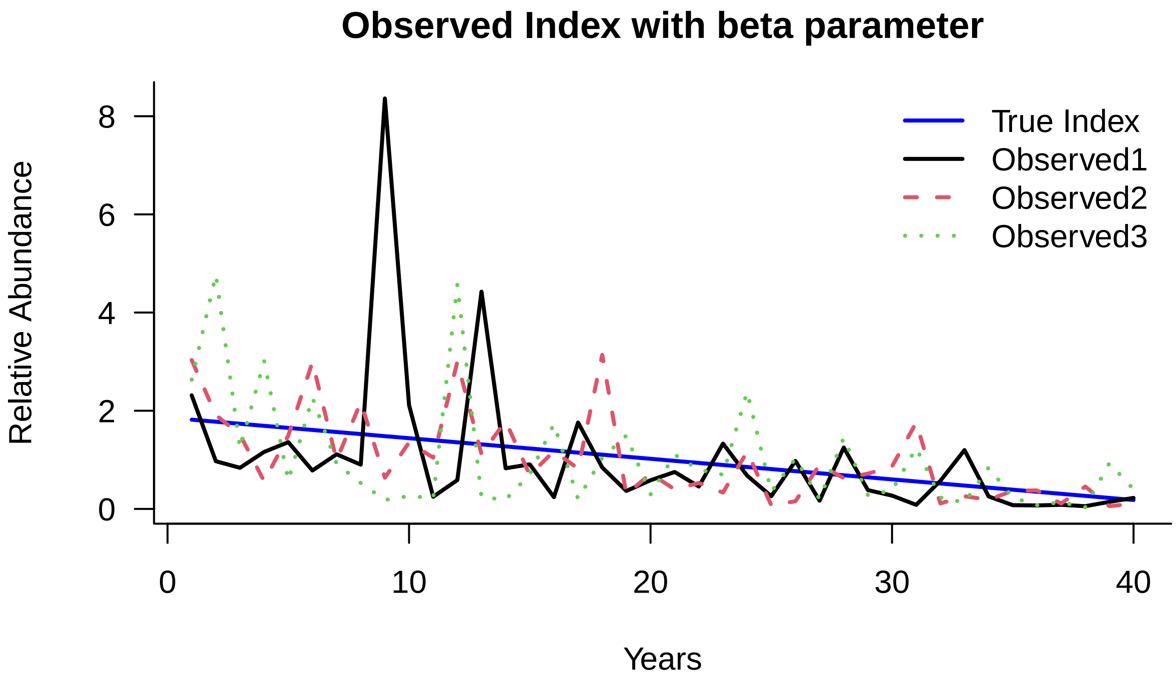
Sampled Parameters Histograms of 48 simulations of inter-annual variability in index observations (`Iobs`) and hyper-stability/depletion in observed index (`beta`), with vertical colored lines indicating 3 randomly drawn values used in other plots:



Time-Series Time-series plot of 3 samples of index observation error:

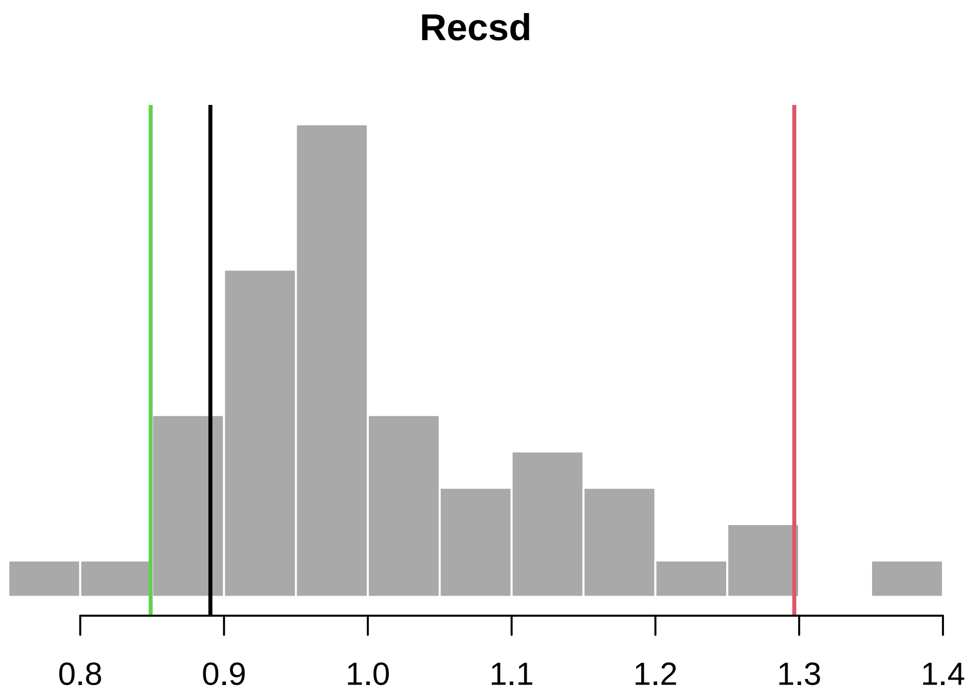


Plot showing an example true abundance index (blue) with 3 samples of index observation error and the hyper-stability/depletion parameter (`beta`):

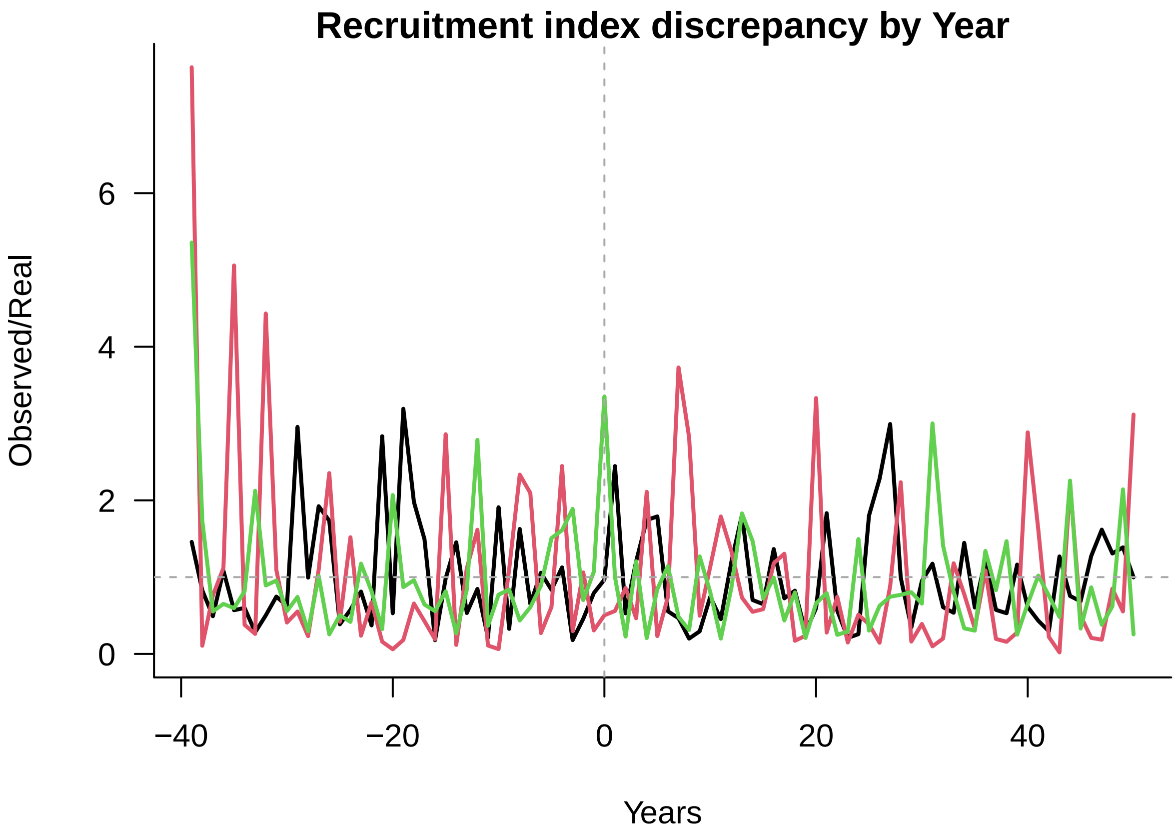


Recruitment Observations

Sampled Parameters Histograms of 48 simulations of inter-annual variability in index observations (`Recsd`) , with vertical colored lines indicating 3 randomly drawn values used in other plots:

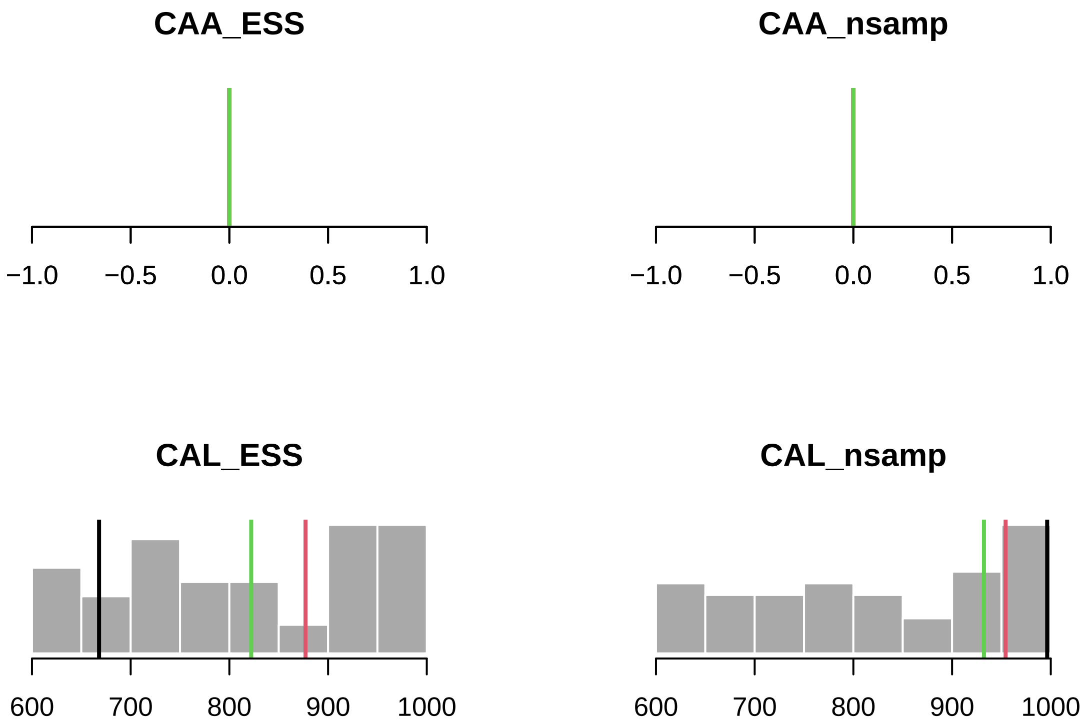


Time-Series Timeseries plots of observeration error for recruitment:



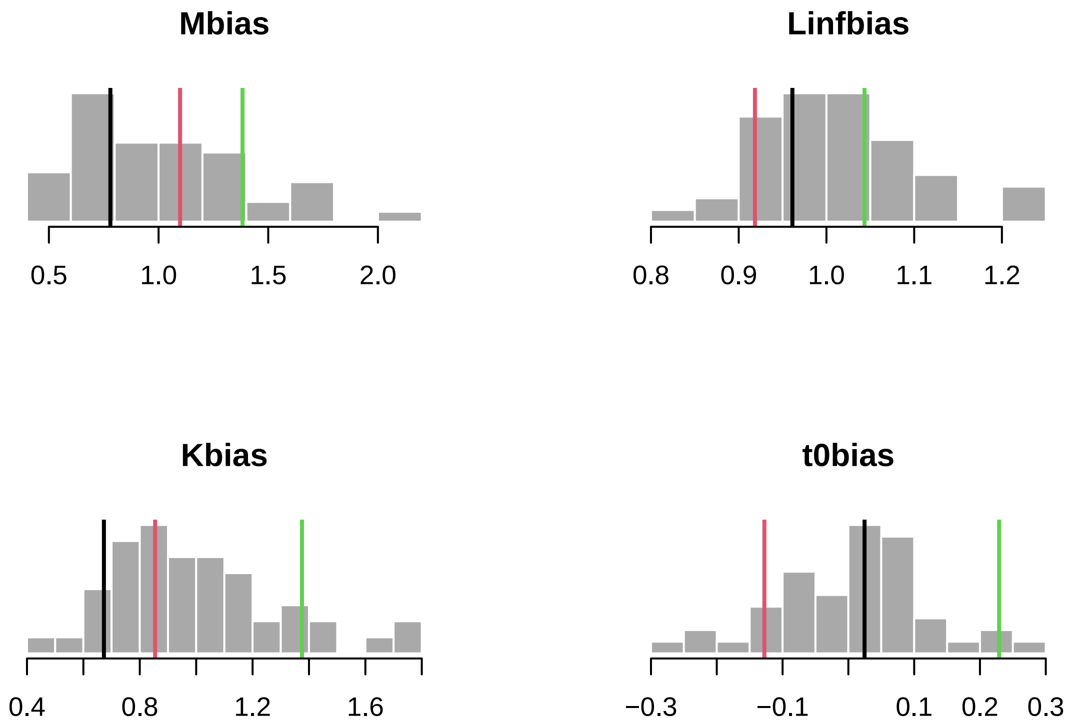
Composition Observations

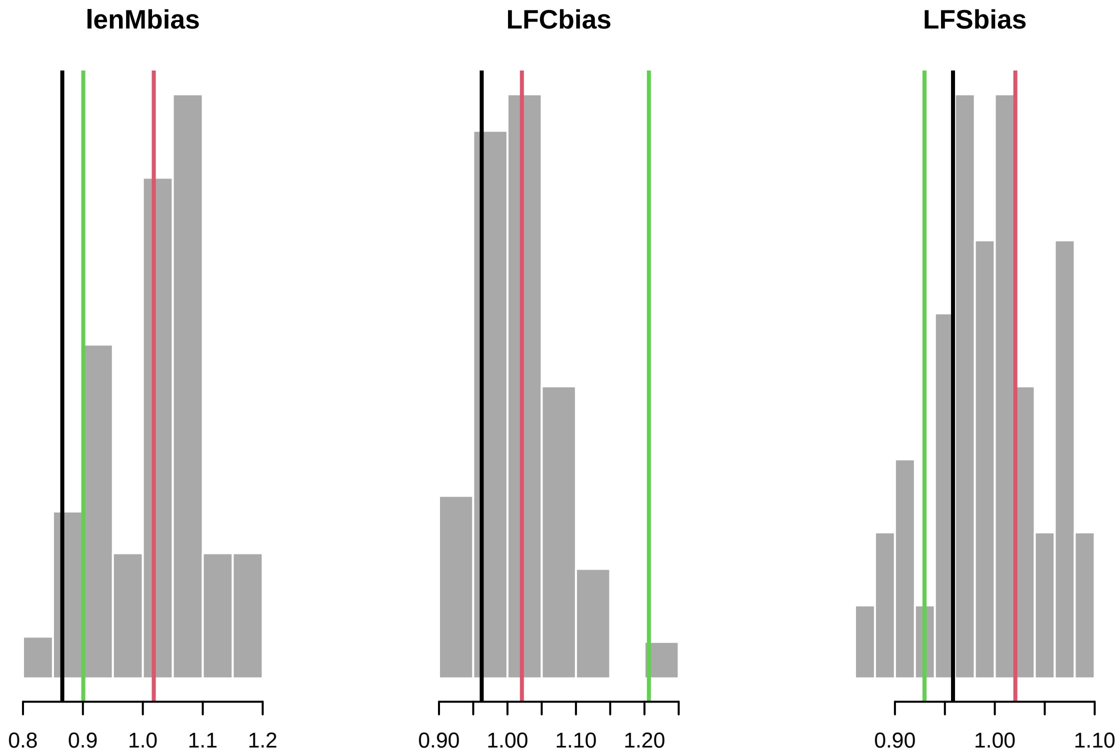
Sampled Parameters Histograms of 48 simulations of catch-at-age effective sample size (`CAA_ESS`) and sample size (`CAA_nsamp`) and catch-at-length effective (`CAL_ESS`) and actual sample size (`CAL_nsamp`) with vertical colored lines indicating 3 randomly drawn values:



Parameter Observations

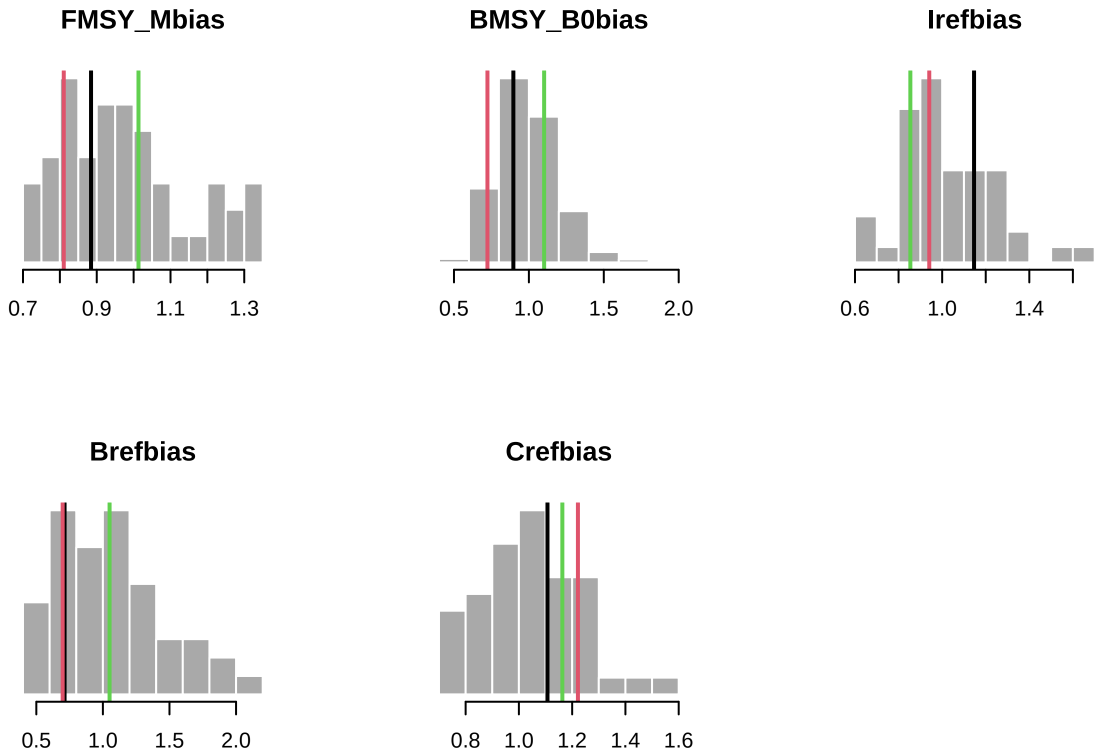
Sampled Parameters Histograms of 48 simulations of bias in observed natural mortality (`Mbias`), von Bertalanffy growth function parameters (`Linfbias`, `Kbias`, and `t0bias`), length-at-maturity (`lenMbias`), and bias in observed length at first capture (`LFCbias`) and first length at full capture (`LFSbias`) with vertical colored lines indicating 3 randomly drawn values:


Mbias
0.5
1.0
1.5
2.0
Linfbias
0.8
0.9
1.0
1.1
1.2
Kbias
0.4
0.8
1.2
1.6
t0bias
−0.3
−0.1
0.1
0.2
0.3



Reference Point Observations

Sampled Parameters Histograms of 48 simulations of bias in observed FMSY/M (`FMSY_Mbias`), BMSY/B0 (`BMSY_B0bias`), reference index (`Irefbias`), reference abundance (`Brefbias`) and reference catch (`Crefbias`), with vertical colored lines indicating 3 randomly drawn values:



Imp Parameters

Perfect implementation was assumed for all parameters.

Output Control Implementation Error: TACFrac, TACSD

TACFrac: Mean fraction of recommended TAC that is actually taken. For each historical simulation a single value is drawn from a uniform distribution specified by the upper and lower bounds provided. This value is the mean TAC fraction obtained across all years of that simulation, and a yearly TAC frac is drawn from a log-normal distribution with the simulation mean and a coefficient of variation specified by the value of TACSD drawn for that simulation. If the value drawn is greater than 1 the amount of catch taken is greater than that recommended by the TAC, and if it is less than 1 the amount of catch taken is less than that recommended by the TAC. Positive real numbers.

Specified Value(s): 1, 1

TACSD: Log-normal coefficient of variation in the fraction of recommended TAC that is actually taken. For each historical simulation a single value is drawn from a uniform distribution specified by the upper and lower bounds provided. This value is used, along with the TACFrac drawn for that simulation, to create a log-normal distribution that yearly values specifying the actual amount of catch taken are drawn from. Positive real numbers.

Specified Value(s): 0, 0

Effort Control Implementation Error: TAEFrac, TAESD

TAEFrac: Mean fraction of recommended TAE that is actually taken. For each historical simulation a single value is drawn from a uniform distribution specified by the upper and lower bounds provided. This value is the mean TAE fraction obtained across all years of that simulation, and a yearly TAE frac is drawn from a log-normal distribution with the simulation mean and a coefficient of variation specified by the value of TAESD drawn for that simulation. If the value drawn is greater than 1 the amount of effort employed is greater than that recommended by the TAE, and if it is less than 1 the amount of effort employed is less than that recommended by the TAE. Positive real numbers.

Specified Value(s): 1, 1

TAESD: Log-normal coefficient of variation in the fraction of recommended TAE that is actually taken. For each historical simulation a single value is drawn from a uniform distribution specified by the upper and lower bounds provided. This value is used, along with the TAEFrac drawn for that simulation, to create a log-normal distribution that yearly values speciying the actual amount of efort employed are drawn from. Positive real numbers.

Specified Value(s): 0, 0

Size Limit Control Implementation Error: SizeLimFrac, SizeLimSD

SizeLimFrac: Mean fraction of recommended size limit that is actually retained. For each historical simulation a single value is drawn from a uniform distribution specified by the upper and lower bounds provided. This value is the mean size limit fraction obtained across all years of that simulation, and a yearly size limit fraction is drawn from a log-normal distribution with the simulation mean and a coefficient of variation specified by the value of SizeLimSD drawn for that simulation. If the value drawn is greater than 1 the size of fish retained is greater than that recommended by the size limit, and if it is less than 1 the amount of size of fish retained is less than that recommended by the size limit. Positive real numbers.

Specified Value(s): 1, 1

SizeLimSD: Log-normal coefficient of variation in the fraction of recommended size limit that is actually retained. For each historical simulation a single value is drawn from a uniform distribution specified by the upper and lower bounds provided. This value is used, along with the SizeLimFrac drawn for that simulation, to create a log-normal distribution that yearly values speciying the actual fraction of the size limit retained are drawn from. Positive real numbers.

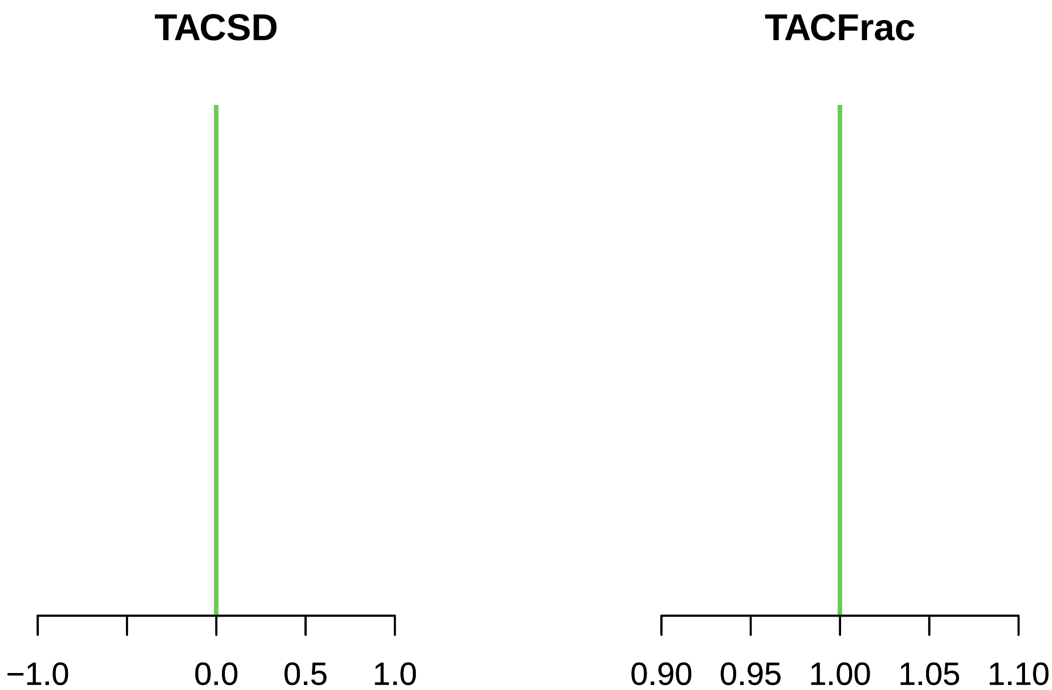
Specified Value(s): 0, 0

Imp Plots

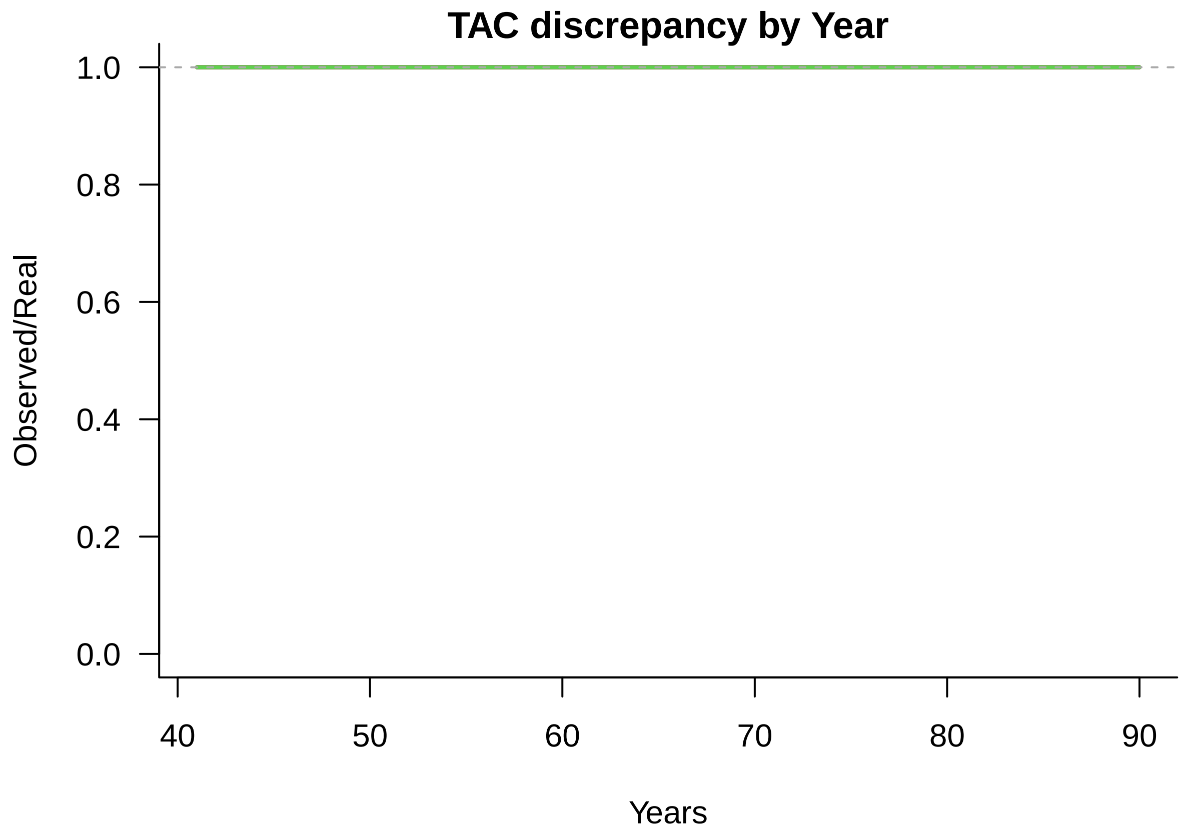
Implementation Parameters

TAC Implementation

Sampled Parameters Histograms of 0 simulations of inter-annual variability in TAC implementation error (`TACSD`) and persistent bias in TAC implementation (`TACFrac`), with vertical colored lines indicating 3 randomly drawn values used in other plots:

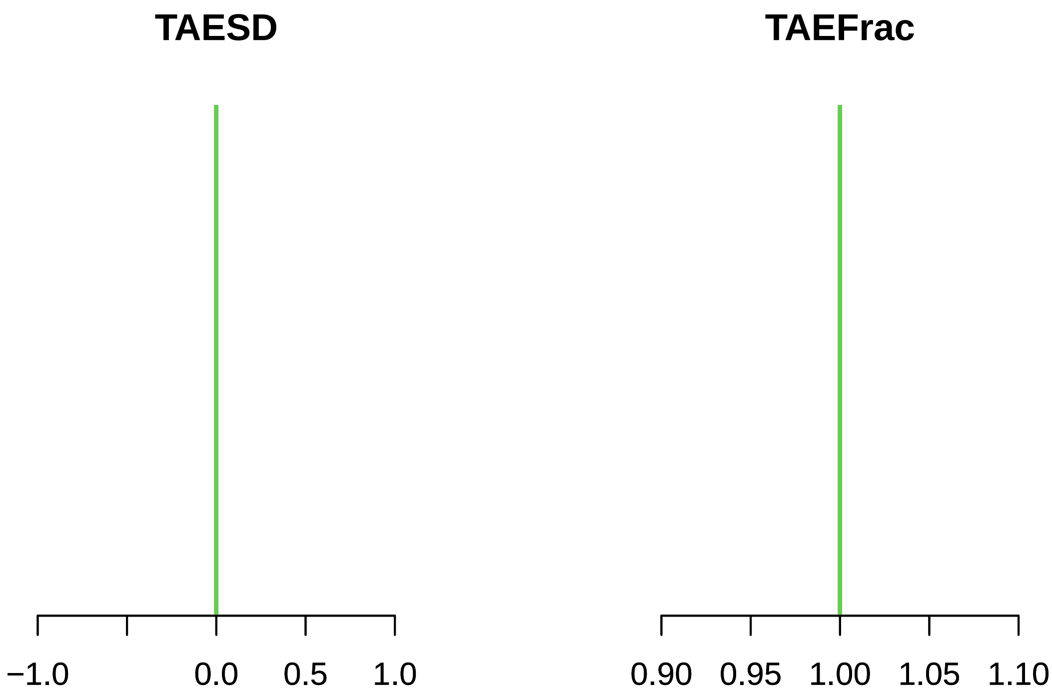


Time-Series Time-series plots of 0 samples of TAC implementation error by year:

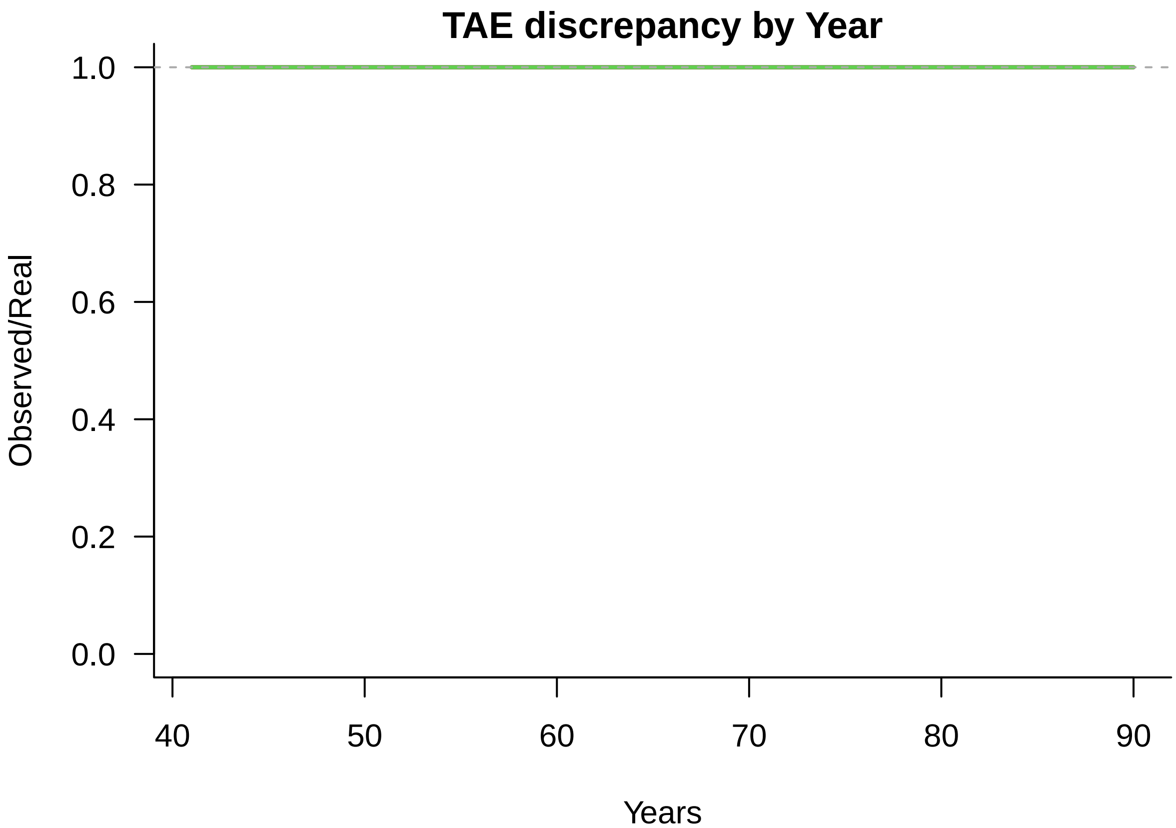


TAE Implementation

Sampled Parameters Histograms of 0 simulations of inter-annual variability in TAE implementation error (`TAESD`) and persistent bias in TAC implementation (`TAEFrac`), with vertical colored lines indicating 3 randomly drawn values used in other plots:

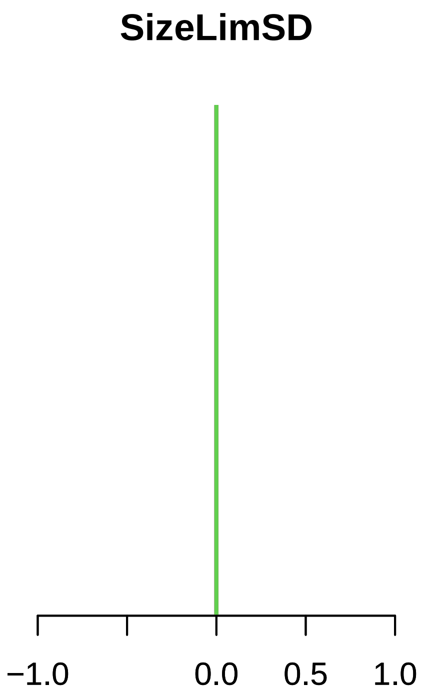


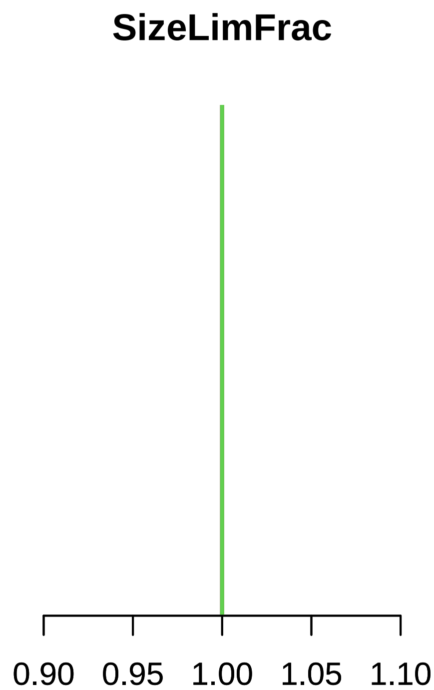
Time-Series Time-series plots of 0 samples of TAE implementation error by year:



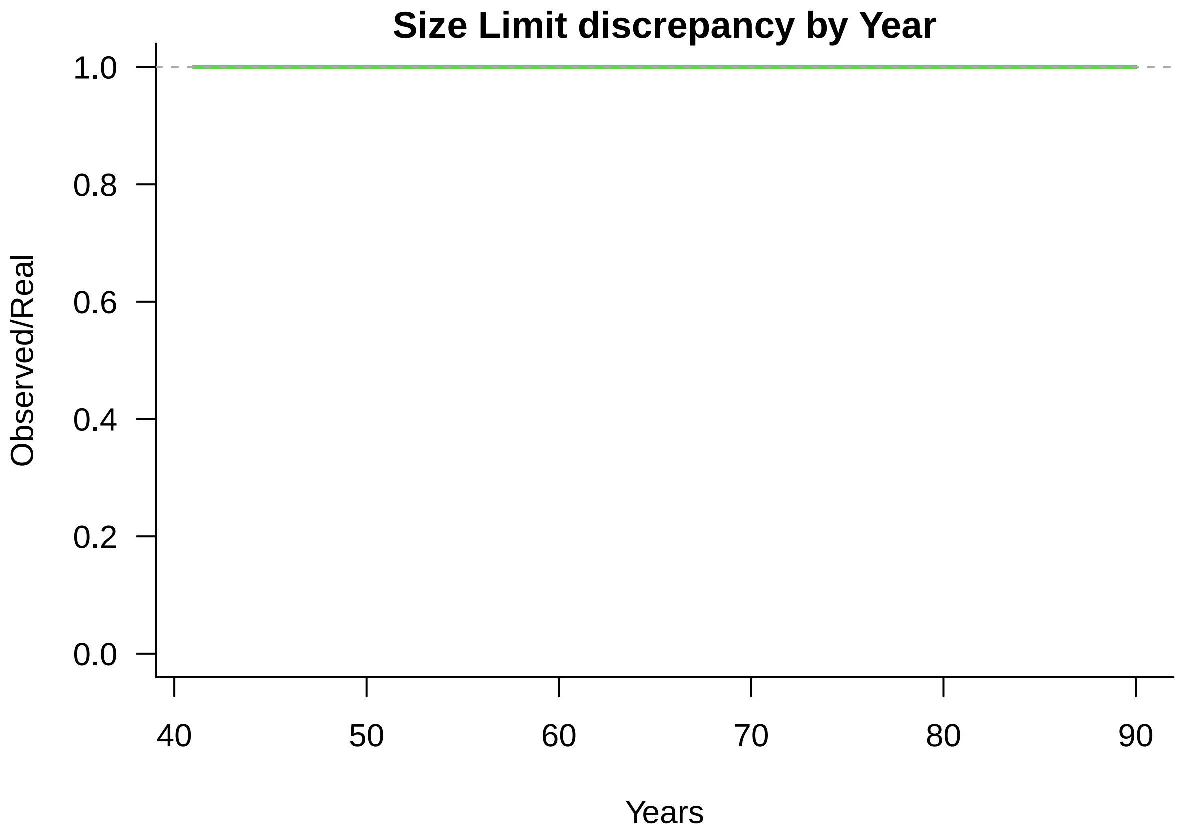
Size Limit Implementation

Sampled Parameters Histograms of 0 simulations of inter-annual variability in size limit implementation error (`SizeLimSD`) and persistent bias in size limit implementation (`SizeLimFrac`), with vertical colored lines indicating 3 randomly drawn values used in other plots:





Time-Series Time-series plots of 0 samples of Size Limit implementation error by year:

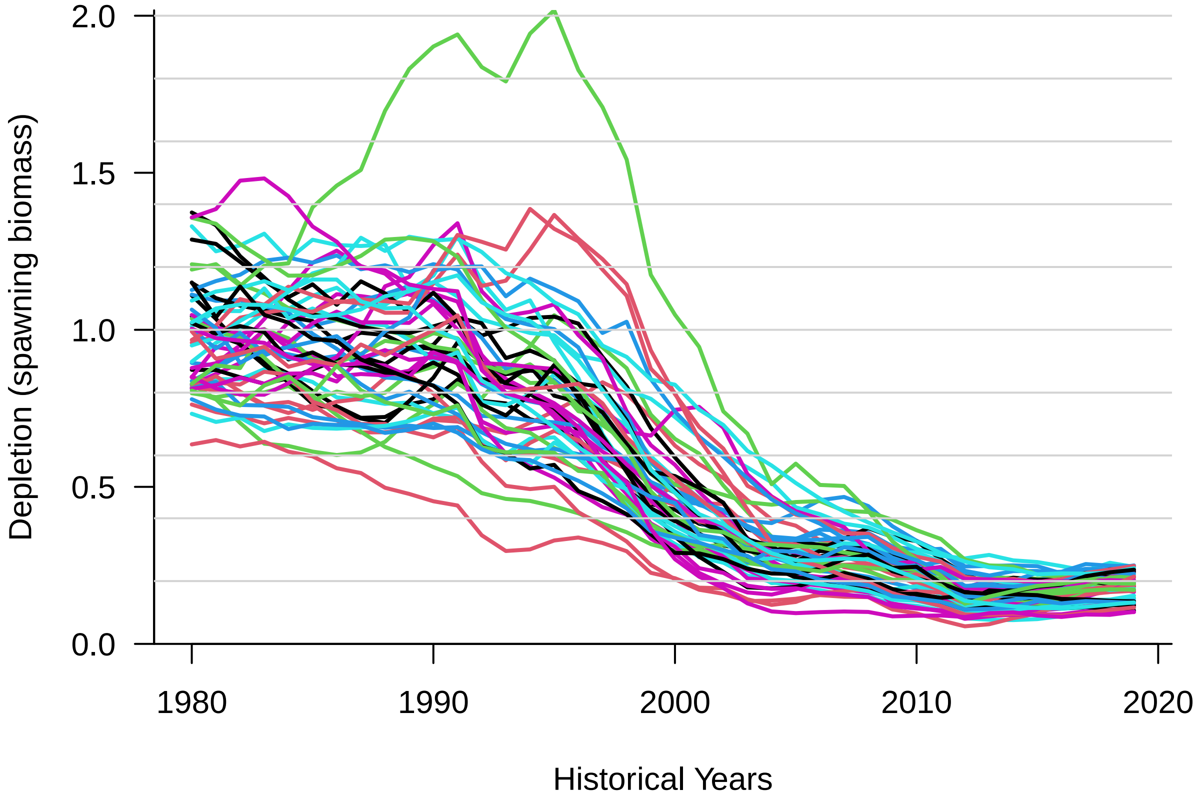


Historical Simulation Plots

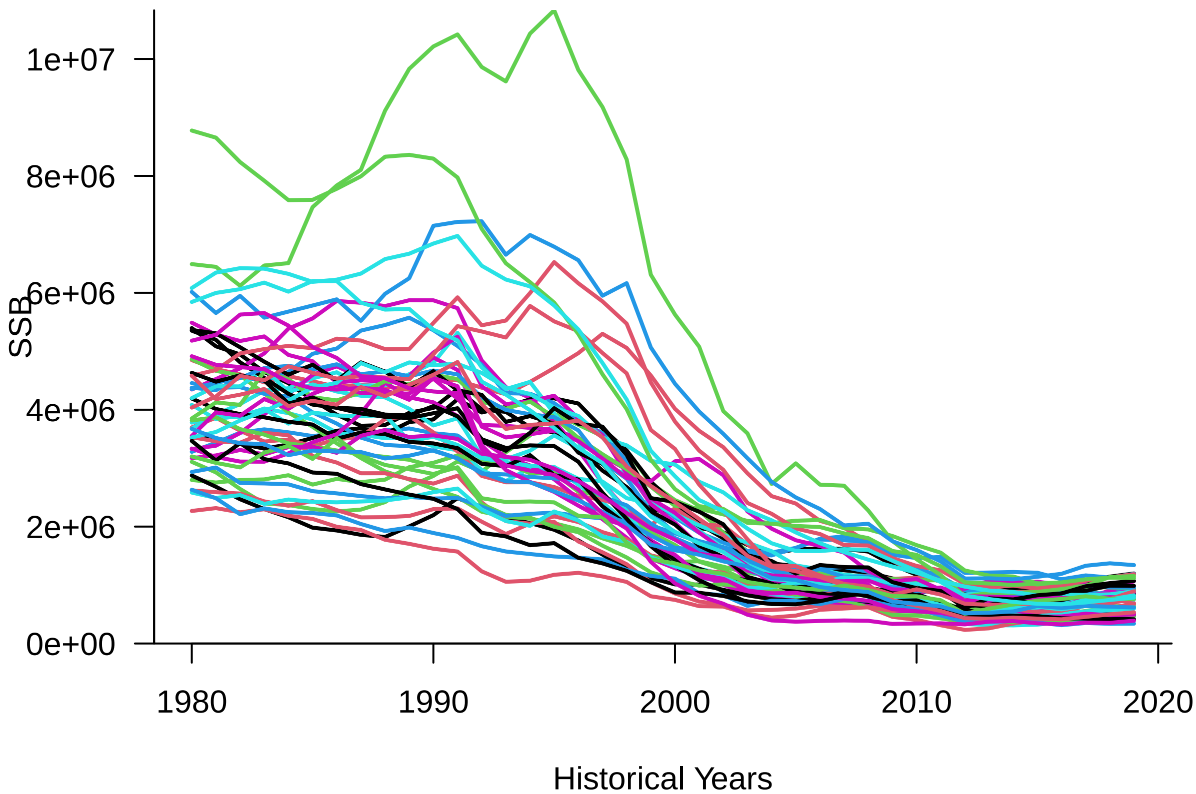
Historical Time-Series

Spawning Biomass

Depletion Time-series plots of SB/SB0:

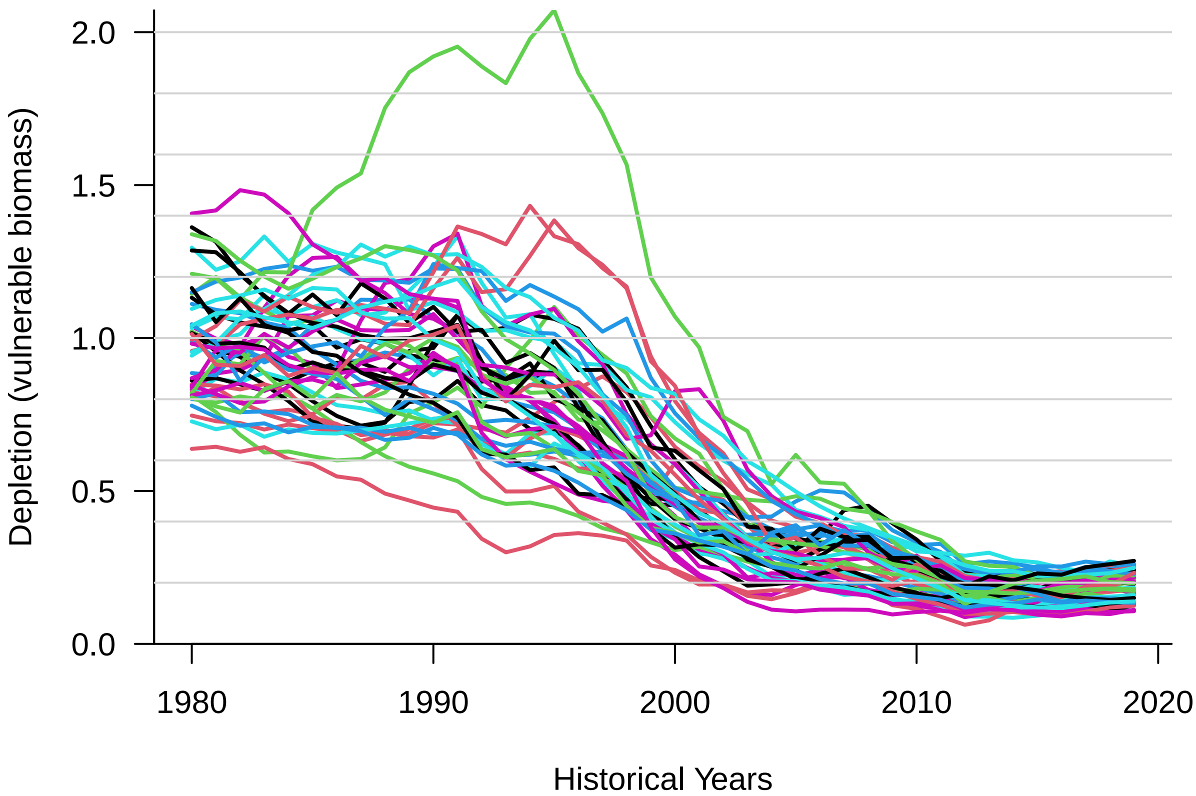


Absolute Time-series plots of absolute SB:

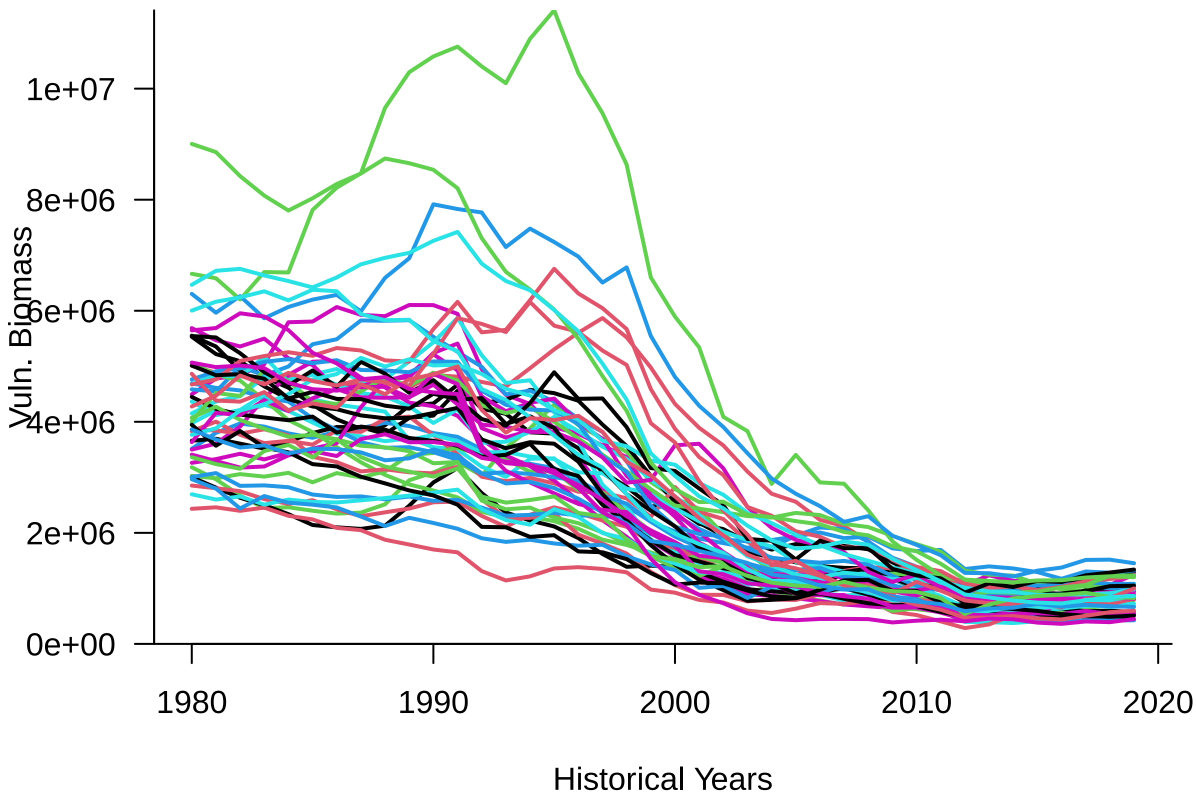


Vulnerable Biomass

Depletion Time-series plots of VB/VB0:

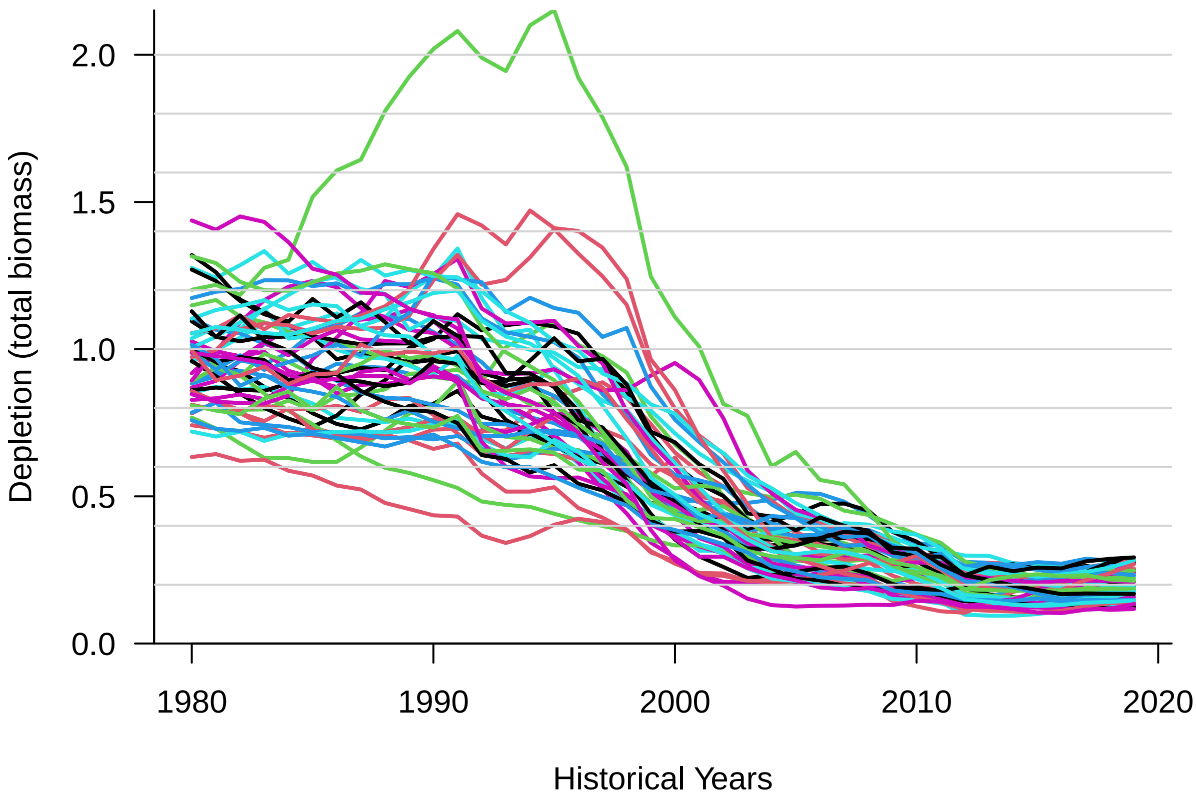


Absolute Time-series plots of absolute VB:

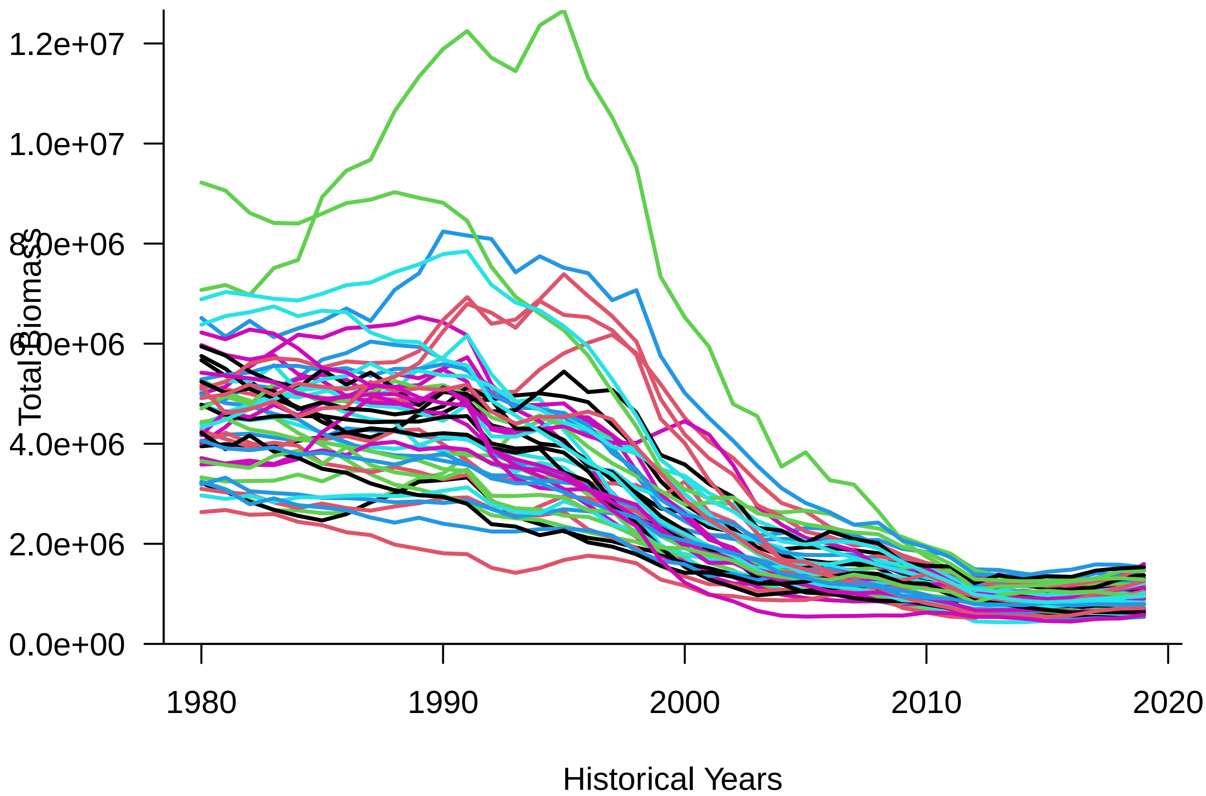


Total Biomass

Depletion Time-series plots of B/B0:

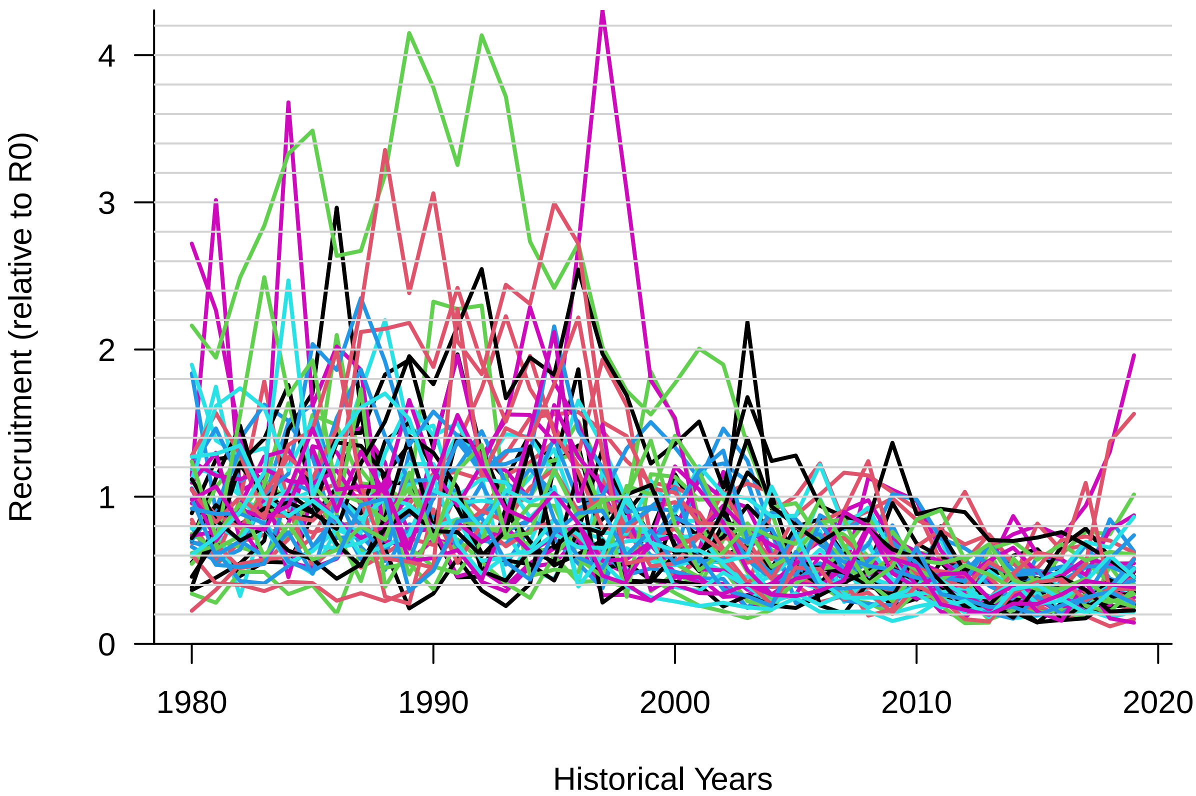


Absolute Time-series plots of absolute B:

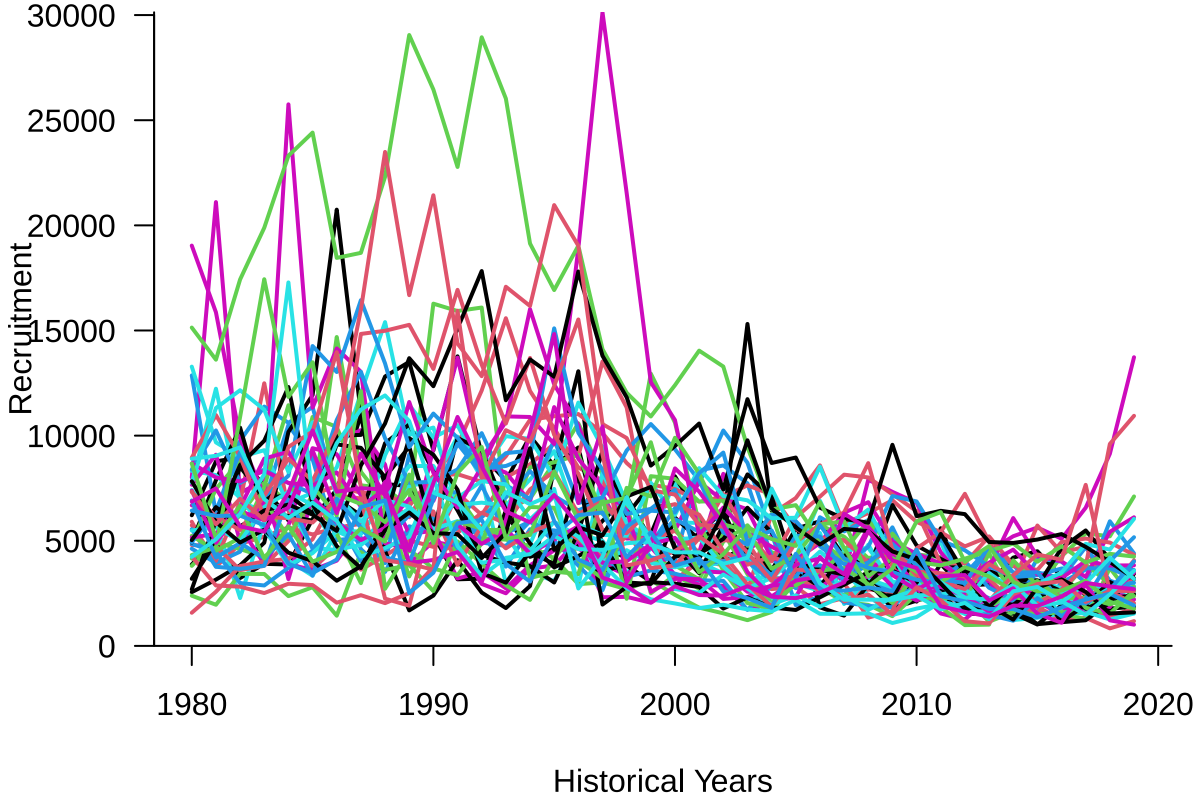


Recruitment

Relative Time-series plot of recruitment relative to R0:

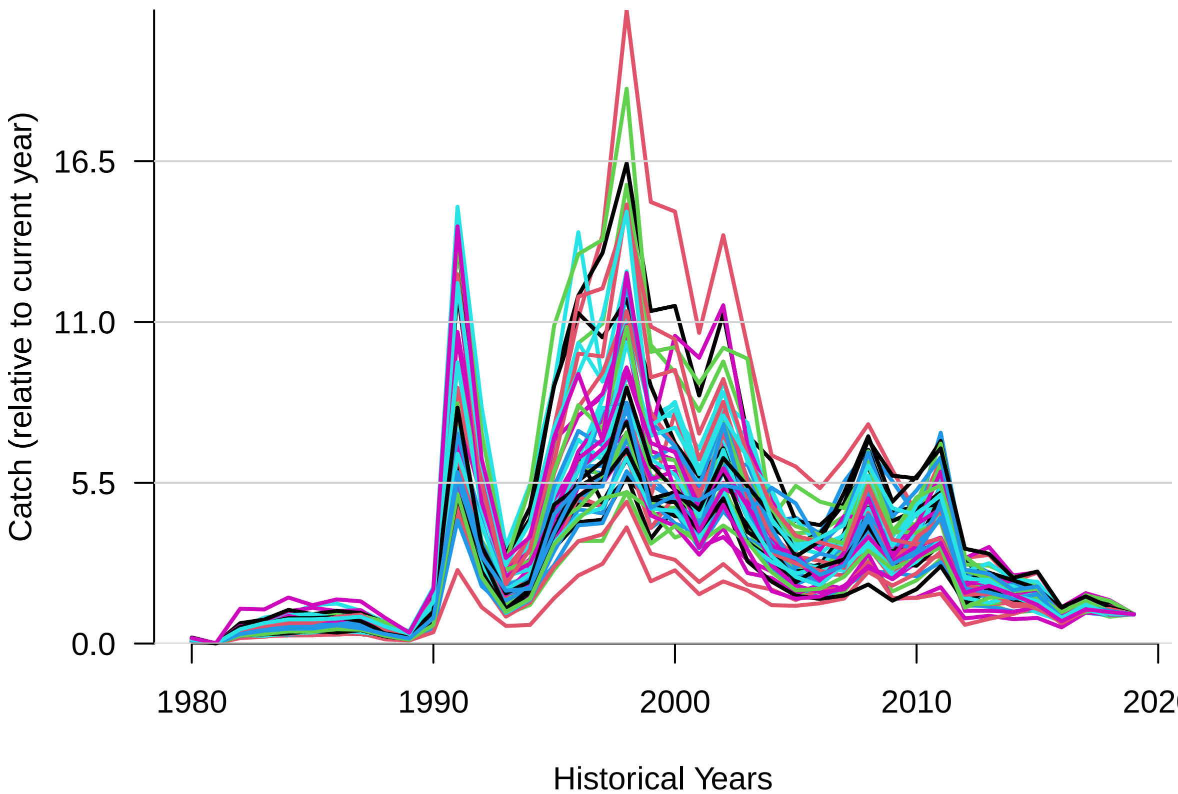


Absolute Time-series plot of absolute recruitment:

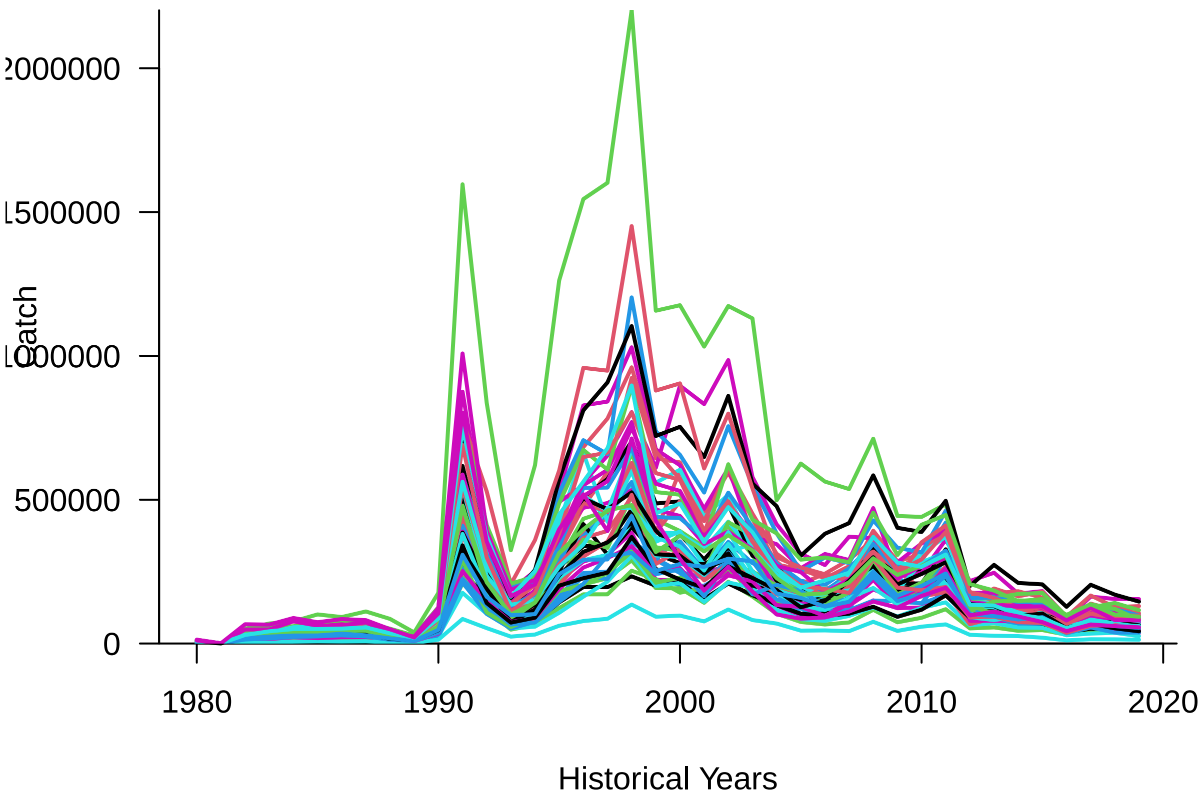


Catch

Relative Time-series of catch relative to the current year:

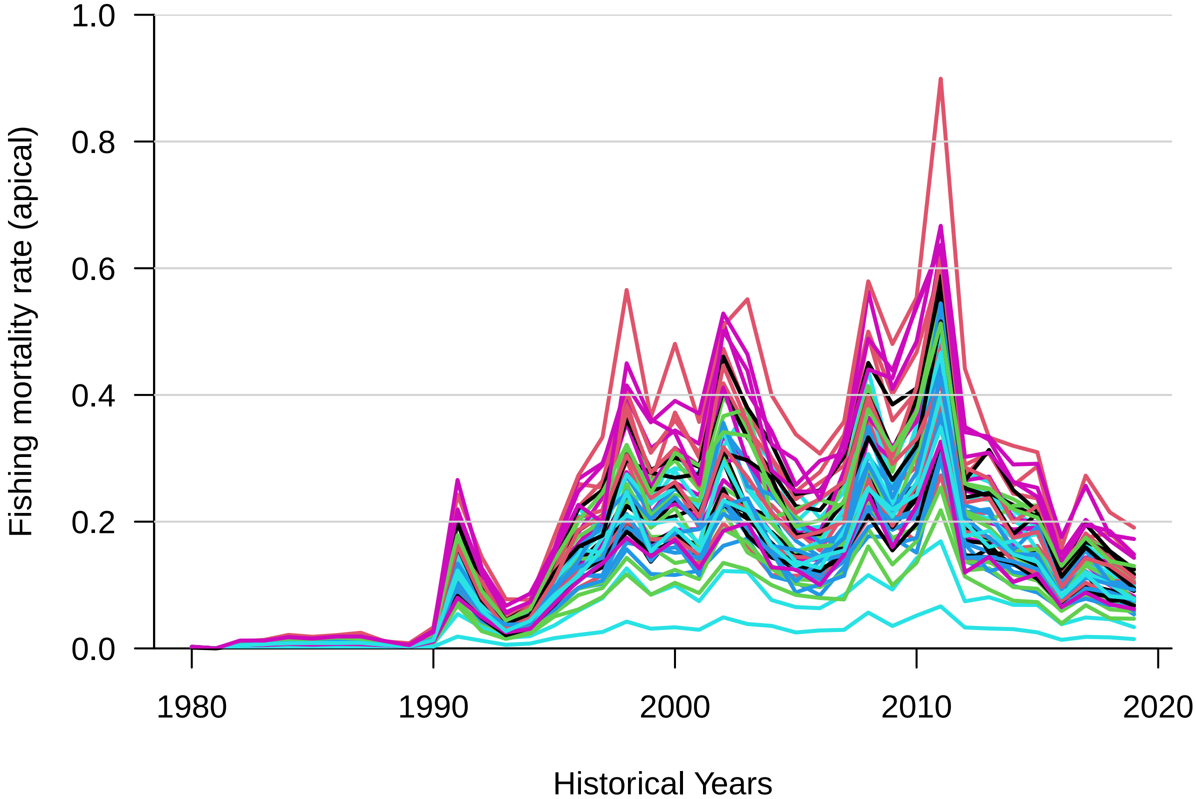


Absolute Time-series of absolute catch:



Historical Fishing Mortality

Historical Time-Series Time-series of historical fishing mortality:



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