Southern California Red Sea Urchin

Operating Model Report

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Introduction

This report describes the parameters used in the base operating model for an MSE of the commercial Red Sea Urchin (Strongylocentrotus franciscanus) fishery in Southern California. Red Sea Urchin are common in nearshore kelp forests and rocky reefs off the coast of California.The sea urchin fisheries in northern and southern California are two distinct regions, separated by a large distance and experiencing different exploitation histories and environmental and ecological conditions. Commercial fishing began in southern California in 1972, and landings in this region have typically been higher than those from the north, with the majority of the southern catch coming from the Channel Islands. For the purposes of this project, we are focusing the MSE on the southern portion of the stock.

No formal stock assessment has been conducted on Red Sea Urchin in California. However, monitoring studies have shown a decrease in density and availability of commercial-sized Red Sea Urchin at the Channel Islands, and catches have reached an all-time low in recent years, likely due to poor environmental conditions

(CDFW 2019). Parameter estimates were based on published estimates or California Department of Fish and Wildlife (CDFW) data whenever possible, and expert judgement when no estimates were available. The number of simulations for a final model run (nsim) was set at 250 and fishing was projected 50 years to the future (proyears). The management interval tested was 1 year. 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 each stochastic MP was set at 0.5.

Operating Model

The OM rdata file can be downloaded from here

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

Species Information

Species: *Mesocentrotus franciscanus*

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: RSU_CA

nsim: The number of simulations: 250

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): 50

Red Sea Urchin can live to be more than 50 years old in California and over 100 years old in the northern regions along the west coast. Maximum age was set at 50 years, which is high enough that only a small proportion of the original cohort remains alive at maximum age for the full range of M values examined in the MSE.

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): 9e+05

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.

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): 0.09, 0.4

In the early days of the fishery, the life span of red sea urchin was suggested to be 7 – 10 years. However, more recent work using tetracycline and calcein tagging has demonstrated that the longevity of the species is much greater, exceeding 100 years in British Columbia and Washington (Ebert and Southon 2003, Ebert 2008). The lifespan of red sea urchin in southern California appears to be much shorter, with few individuals reaching ages of 50 years (Ebert and Southon 2003).

Both growth and natural mortality have been found to vary spatially in northern California (Morgan et al. 2000). Natural mortality (M) has been estimated from 0.05 – 0.204 in northern California, and 0.088 – 0.4 in southern California (Ebert and Russell 1992, Ebert et al. 1999, Morgan et al. 2000). These fine-scale variations in M are thought to be related to greater abundance of sea urchin predators in southern California (Morgan et al. 2000). Sea urchin are believed to be slow-growing, and reach large sizes. This implies that maximum age must be quite high.

Ebert et al. (1999) estimated a mean annual survival probability of 0.77 yr-1 in southern California, which corresponds to a value of M of 0.26. This value was selected as the best estimate of M for red sea urchin in southern California, and given the high uncertainty in this parameter, a CV of 25% was assumed and the range for M defined as 0.195 – 0.32.

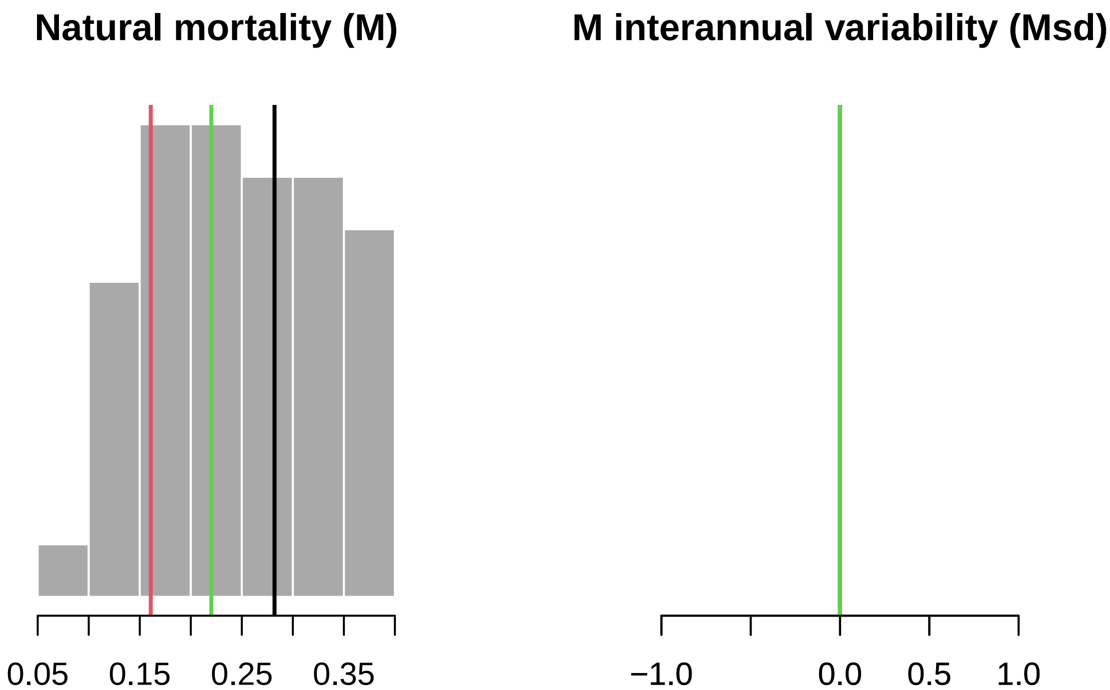
Msd: Inter-annual variation in M expressed as a coefficient of variation of a log-normal distribution. For each simulation a single value is drawn from a uniform distribution specified by the upper and lower bounds provided. If this parameter is positive, yearly M is drawn from a log-normal distribution 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

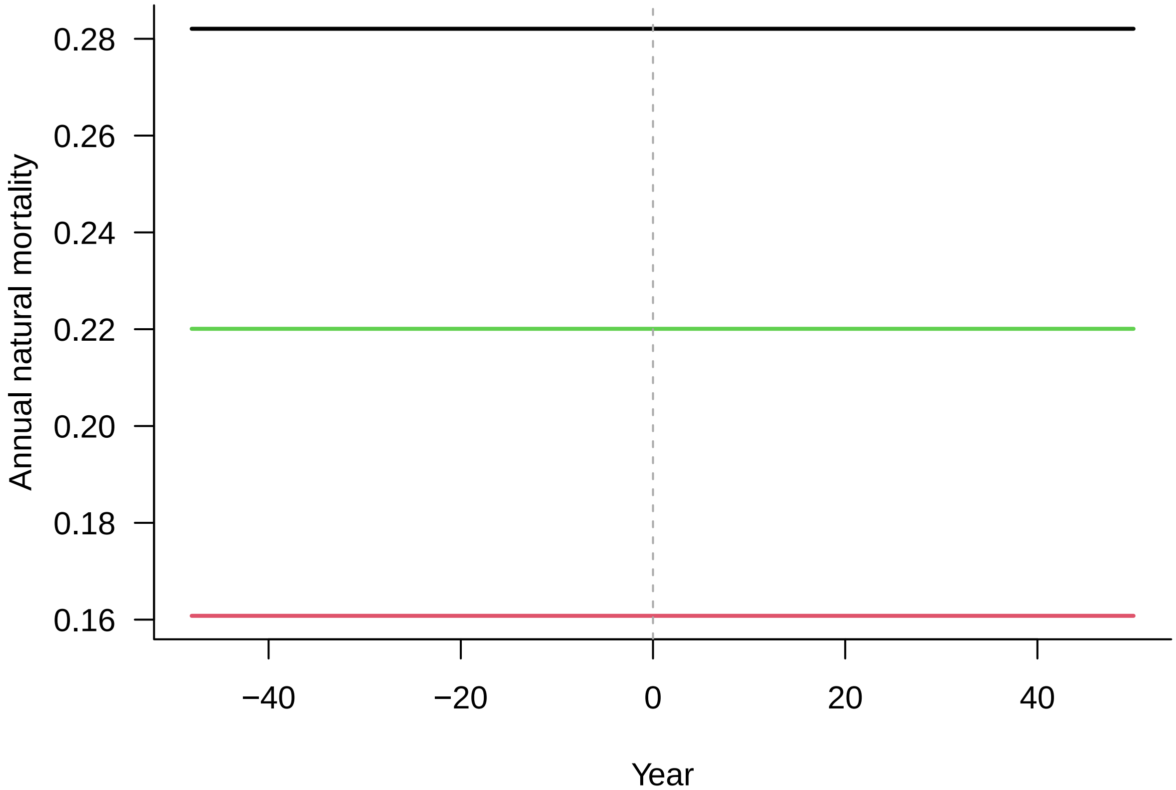
Not Used.

Natural Mortality Parameters

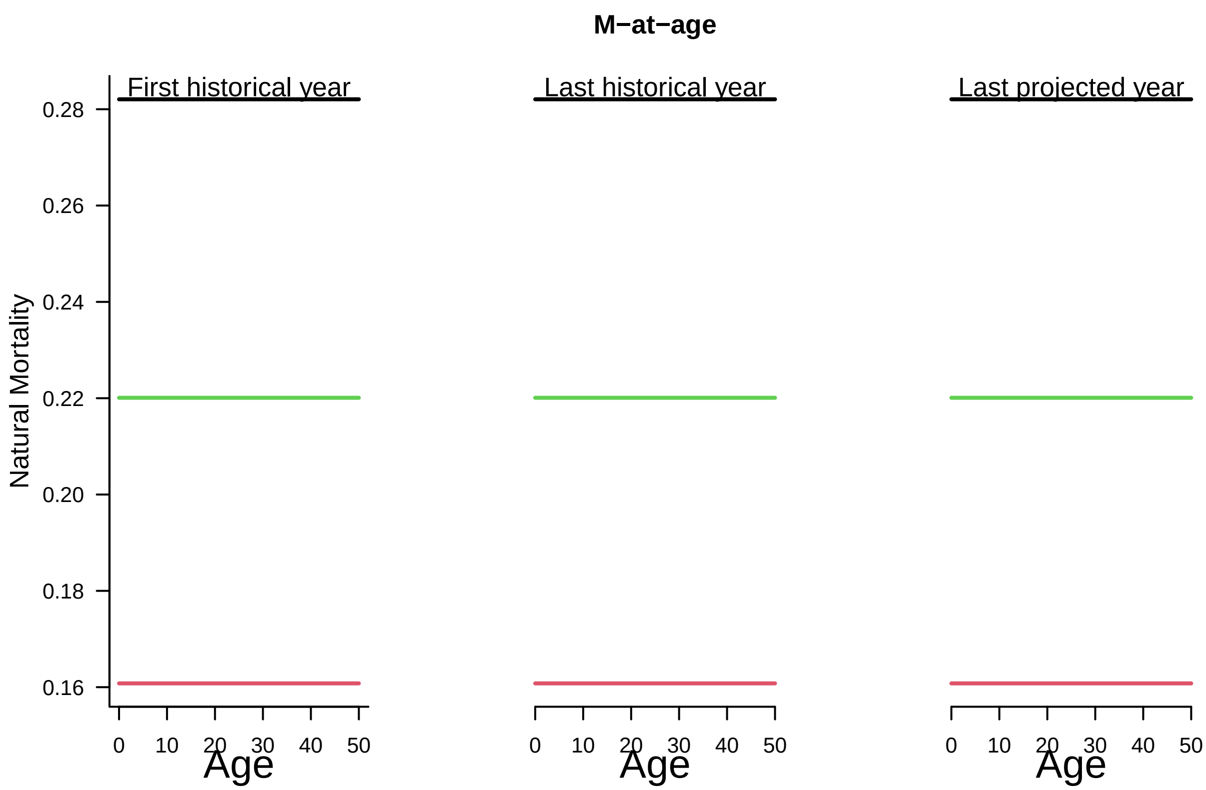
Sampled Parameters Histograms of simulations of `M`, and `Msd` parameters, with vertical colored lines indicating 3 randomly drawn values used in other plots:



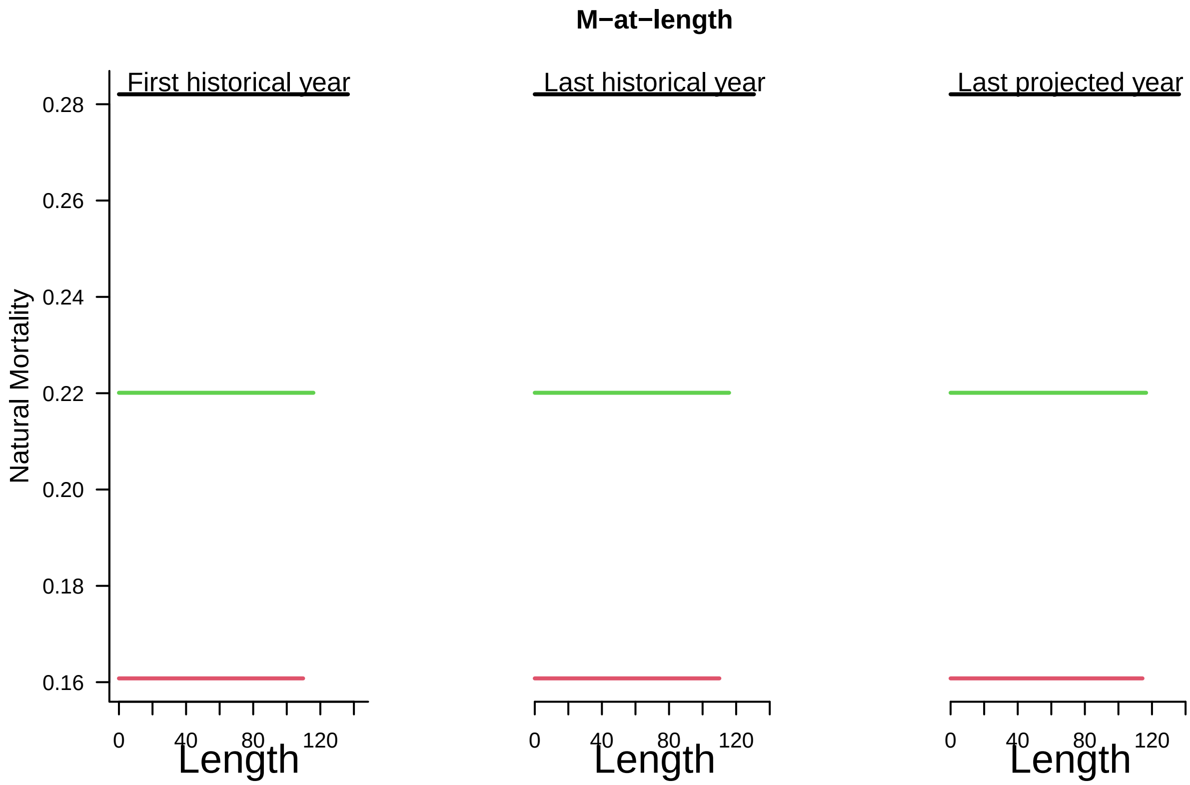
Time-Series The average natural mortality rate by year for adult fish for 3 simulations. The vertical dashed line indicates the end of the historical period:



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): 0.5, 0.8

Recruitment appears to be episodic in northern California, Oregon, Washington, and British Columbia, but more stable in southern California (Kalvass and Hendrix 1997). Many researchers suggest that red sea urchin are particularly vulnerable to recruitment overfishing which this suggests that the steepness of the stock recruitment relationship is low. However, little data exists to estimate this parameter. The range for steepness (h) was set to 0.4 – 0.6.

Recruitment variability is believed to be moderately high, and driven by environmental conditions. The ranges for annual recruitment variability (Perr) and autocorrelation in recruitment (AC) were set to 0.3 – 0.6 and 0.5 – 0.9 respectively.

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

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.

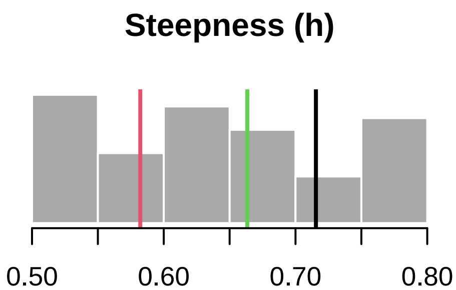
Specified Value(s): 0.2, 0.5

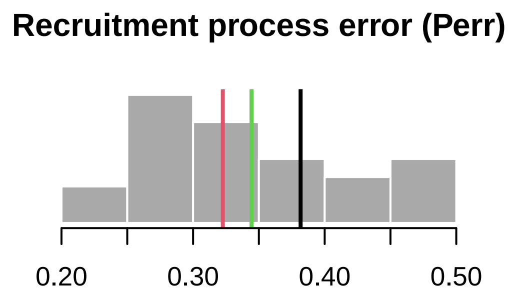
AC: Autocorrelation in the recruitment deviations in log space. For each simulation a single value is drawn from a uniform distribution specified by the upper and lower bounds provided, and used to add lag-1 autocorrelation to the log recruitment deviations. Uniform distribution lower and upper bounds.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

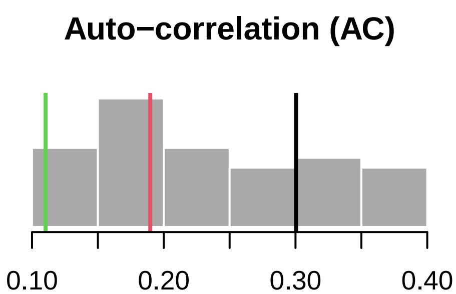
Specified Value(s): 0.1, 0.4

Recruitment Parameters

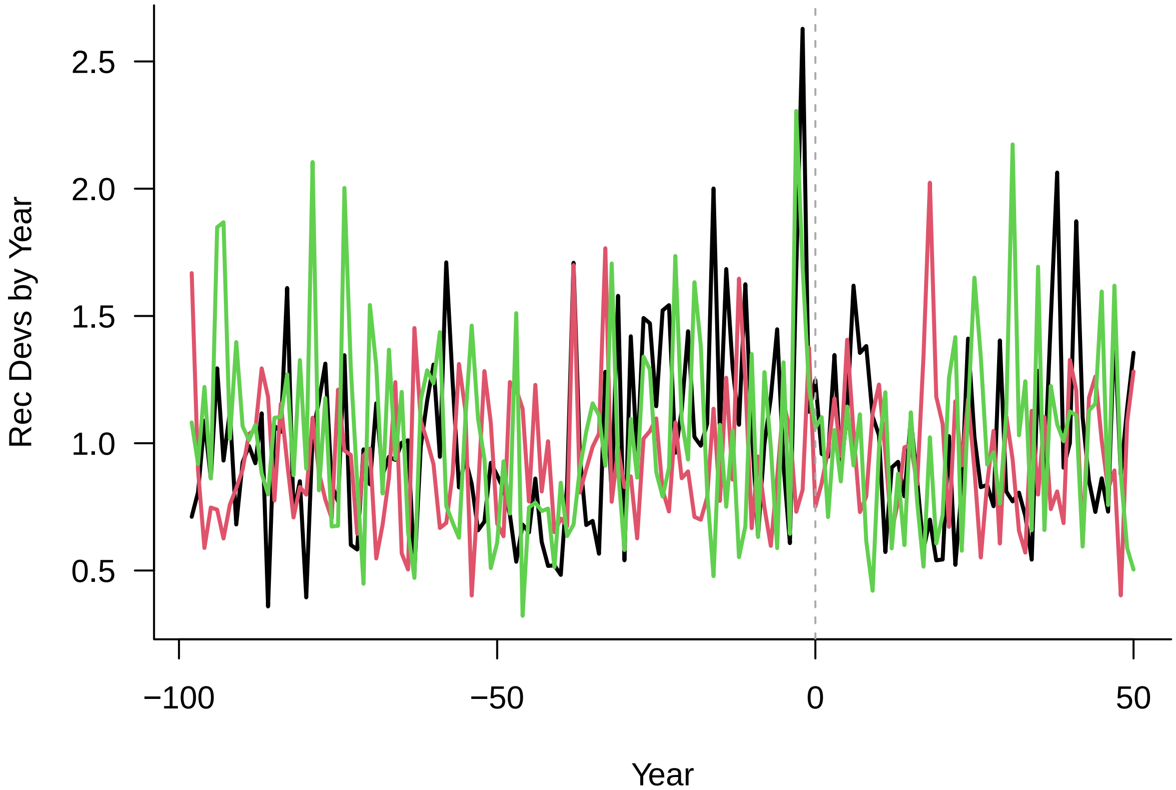
Sampled Parameters Histograms of 48 simulations of steepness (`h`), recruitment process error (`Perr`) and auto-correlation (`AC`) for the Beverton-Holt stock-recruitment relationship, with vertical colored lines indicating 3 randomly drawn values used in other plots:







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): 109, 145

The von Bertalanffy equation may not the best model for describing growth (Ebert et al. 1999, Rogers-Bennett et al. 2003), and in particular does not describe the growth of the small individuals very well. However, given the existing size limit, the focus of the MSE model is on the larger size classes, which are usually better described by the von Bertalanffy model. The growth of red sea urchin is highly variable, and the estimates of the von Bertalanffy parameters from Roger-Bennett et al. (2003) and Ebert et al. (1999) were used to determine the range used in this study. No information exists on appropriate values for t0, and this was set to 0 for the study.

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): 0.13, 0.3

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

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.

Specified Value(s): 0.1, 0.2

Given the variability in growth we assumed the variability in length at age was large, ranging from 10-20% of the mean.

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.

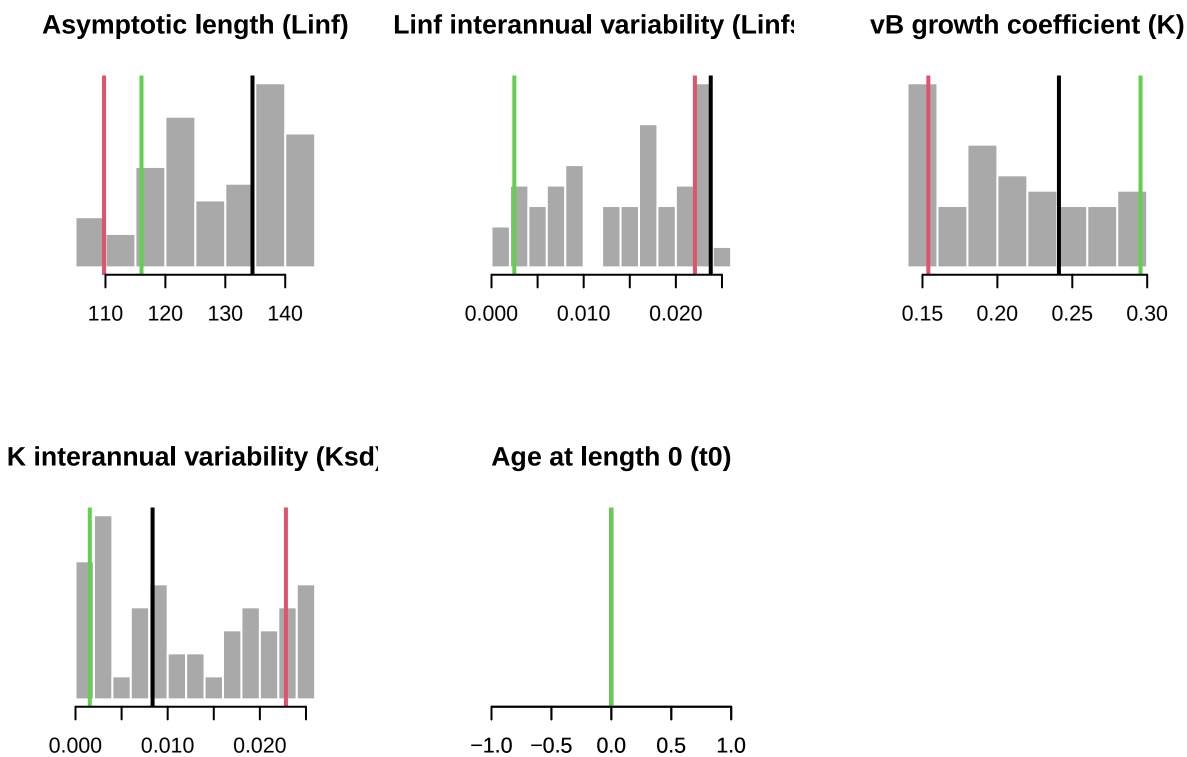
Linfsd: Inter-annual variation in Linf. For each simulation a single value is drawn from a uniform distribution specified by the upper and lower bounds provided. If this parameter has a positive value, yearly Linf is drawn from a log-normal distribution with a mean specified by the value of Linf drawn 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

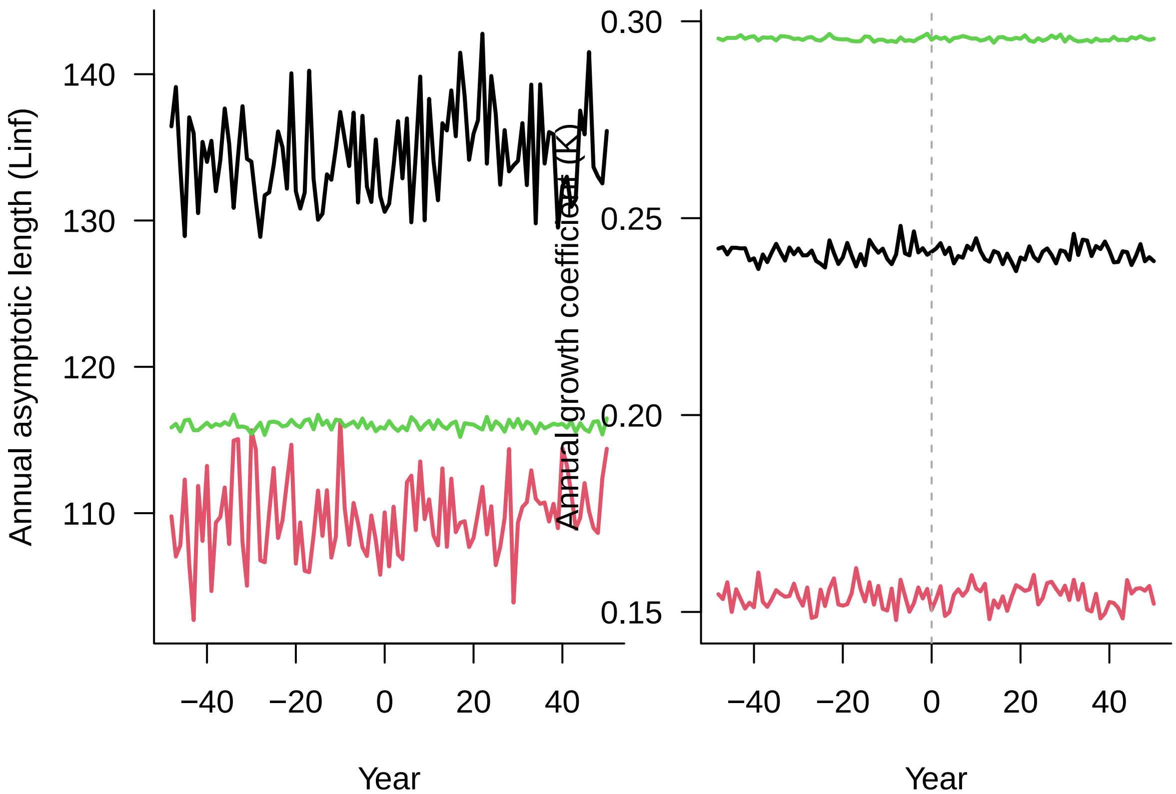
We modeled a small amount of year to year variation in the maximum average size to account for changing environmental conditions from year to year.

Growth Parameters

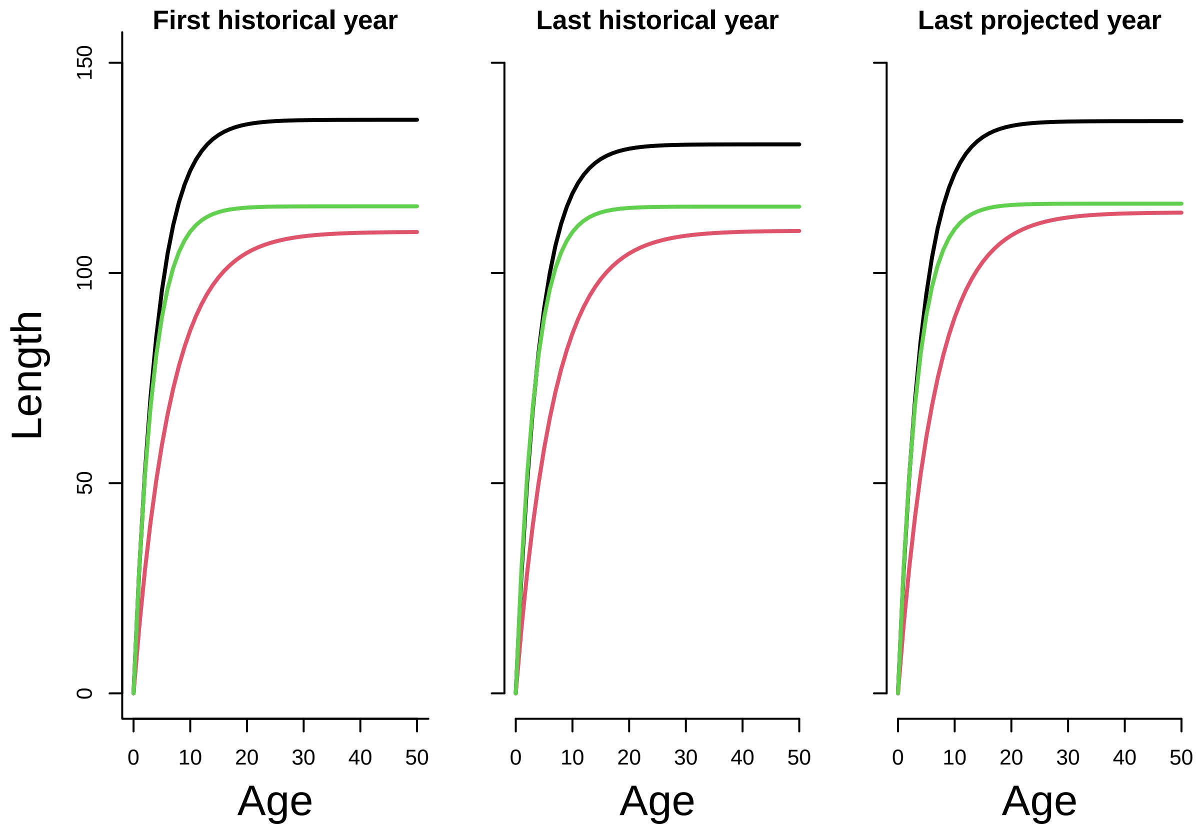
Sampled Parameters Histograms of simulations of von Bertalanffy growth parameters `Linf`, `K`, and `t0`, and inter-annual variability in Linf and K (`Linfsd` and `Ksd`), with vertical colored lines indicating 3 randomly drawn values used in other plots:



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): 40, 50

Most studies cite Bernard and Miller (1973) for information on the size-at-maturity (sexually mature at 40 – 50 mm test diameter, or about 2 years of age). In addition, Tegner (1989) plotted gonad weight against test diameter and found that individuals begin to mature between 40 and 50 mm, and that gonad weight (and likely egg production) increase exponentially with test diameter. Based on this information, CDFW set a size limit of 83 mm (3.25 in) in southern California, which is intended to allow individuals to spawn more than once before entering the fishery (CDFW 2019). We modeled the length at 50% maturity to range between 40 and 50mm, and the difference between the length at 95% maturity and 50% maturity (L50_95) was assumed to be 10 to 30 mm.

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.

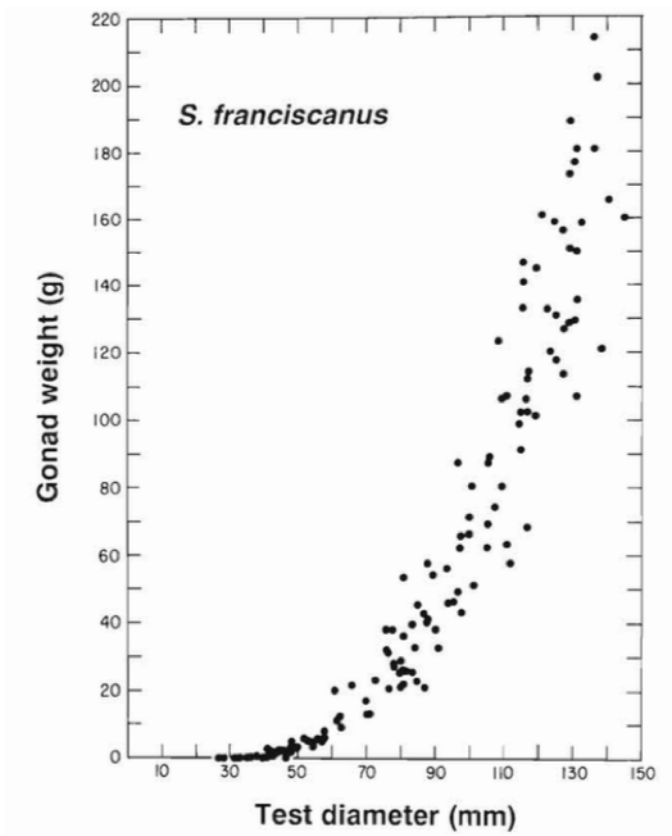
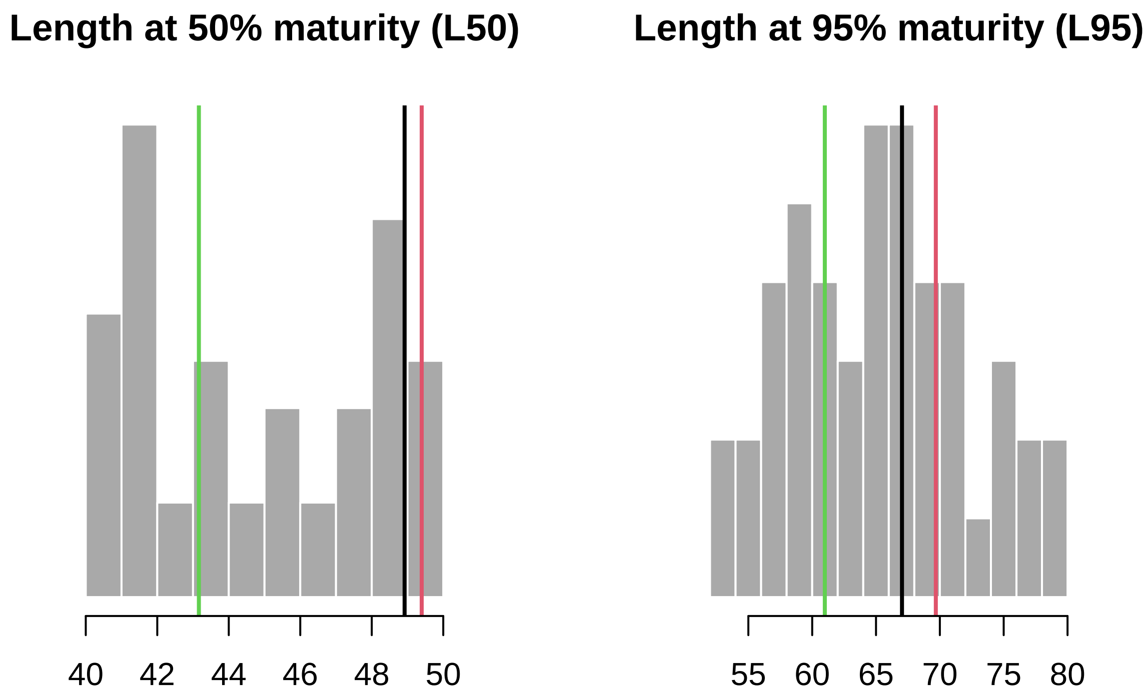


Figure 1: Gonad weight (g) vs. test diameter (mm) for Red Sea Urchin collected in 1975 from Point Loma, California (Reproduced from Tegner 1989).

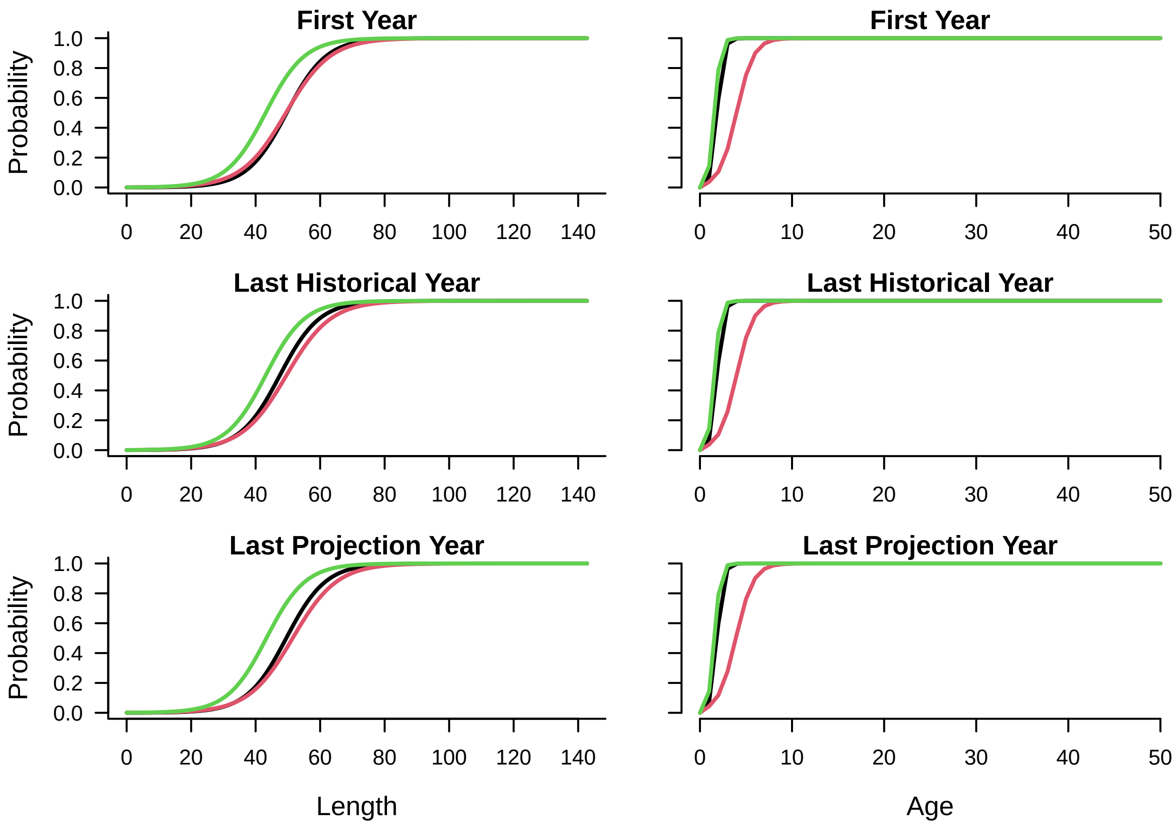
Specified Value(s): 10, 30

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:



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): 0.2, 0.5

Depletion is defined as the current spawning stock biomass relative to unfished levels. No information exists on the current level of depletion for the stock in southern California. A minimum legal length above the size of maturity has been in place since 1988, and it is thought that 100% of the catch is mature. There does not appear to be any evidence of a decline in recruitment attributable to the fishery. Furthermore, it is estimated that 15-25% of the red sea urchin stock in California is in marine protected areas (MPAs) that are closed to all fishing activities. Therefore, it is believed that fishing has not heavily depleted the Red Sea Urchin stock in southern California. However, there is concern that recent environmental conditions, which have led to a decline in gonad quality and thus landings, may also have increased mortality rates due to disease or starvation. As a result, the bounds for the depletion level were set at 0.2 - 0.5, which was lower than in the initial phase of this project.

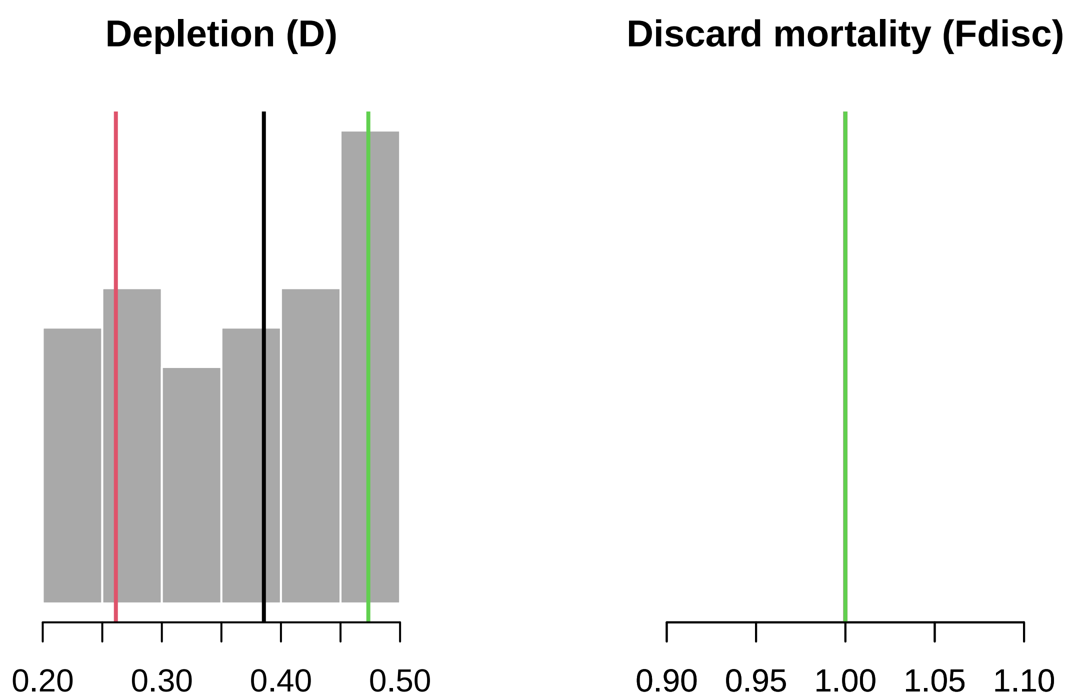
Fdisc: The instantaneous discard mortality rate the stock experiences when fished using the gear type specified in the corresponding fleet object and discarded. For each simulation a single value is drawn from a uniform distribution specified by the upper and lower bounds provided. Uniform distribution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

Specified Value(s): 1, 1

Because this is a dive fishery, in which Red Sea Urchin are harvested by hand, the fishery is very selective. However, fishermen will crack open urchins to determine whether they are "pickable", i.e., whether they have a gonad content that is of a high enough quality to sell. This means that there is some level of mortality associated with harvest as fishermen search. Therefore, we assume a low discard rate of 1-2%, with 100% discard mortality.

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

No estimates for the length-weight parameters exist for California. The MSE model is not sensitive to these parameters, and values from a Canadian study were used (Campbell 1998).

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): 2.71

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

Red Sea Urchin are found in shallow rocky reef and sandy kelp forest habitats in Southern California. Because of this they 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 Red Sea Urchin 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 Red Sea Urchin is distributed proportionally to the available habitat, and so 15.7% of the initial population is in Area 1.

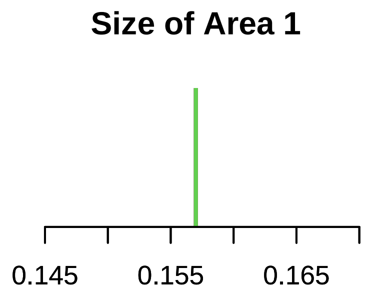
Prob_staying: The probability of individuals in area 1 remaining in area 1 over the course of one year. Please specify numbers between 0 and 1. For each simulation a single value is drawn from a uniform distribution specified by the upper and lower bounds provided. For example, in an area with a Prob_staying 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.

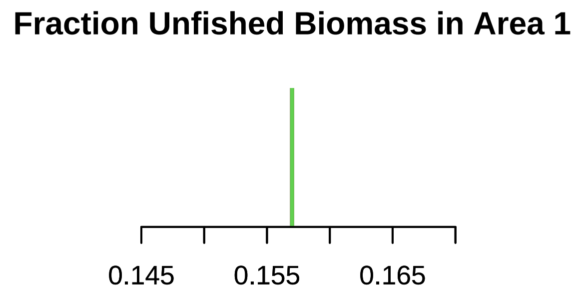
Specified Value(s): 0.95, 0.99

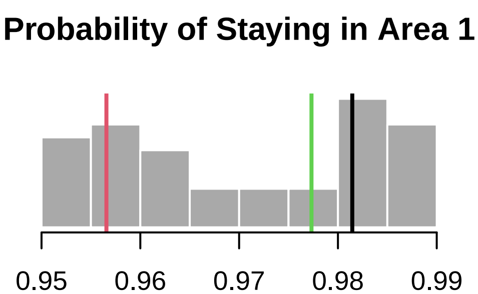
Sea urchin are relatively sedentary, and so the probability of staying in each area was set to a high value of 0.95 - 0.99.

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): 49

The fishery for Red Sea Urchin in southern California began in the early 1970s, and a 49-year (1971 – 2019) fishing history was assumed (nyears).

Spat_targ: Distribution of fishing in relation to vulnerable biomass (VB) across areas. The distribution of fishing effort is proportional to VB^Spat_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

Spatial targeting was set to 1 to represent a stock that is actively targeted by the fishers.

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).

Because the only metric of fishing effort available was the number of active permit holders, we based estimates of historical fishing mortality on yearly catches by the commercial fleet. Catches generally increased from 1971 to 1990, then gradually decreased until 2000. After that they were very stable until 2015, when catches declined precipitously due to a sharp decrease in gonad quality in response to poor environmental conditions. EffLower and EffUpper were parameterized by scaling catches to the maximum, +/- 20%.

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).

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
1971	6.70e-06	8.20e-06
1972	1.36e-04	1.67e-04
1973	8.25e-02	1.01e-01
1974	7.82e-02	9.56e-02
1975	1.45e-01	1.78e-01
1976	2.30e-01	2.81e-01
1977	5.02e-01	6.14e-01
1978	4.40e-01	5.38e-01
1979	6.24e-01	7.63e-01
1980	5.92e-01	7.23e-01
1981	8.03e-01	9.81e-01
1982	6.05e-01	7.39e-01
1983	5.71e-01	6.97e-01
1984	4.63e-01	5.66e-01
1985	5.41e-01	6.61e-01
1986	6.91e-01	8.45e-01
1987	6.77e-01	8.27e-01
1988	7.13e-01	8.72e-01
1989	8.10e-01	9.89e-01
1990	9.00e-01	1.10e+00
1991	8.37e-01	1.02e+00
1992	6.61e-01	8.08e-01
1993	6.42e-01	7.85e-01
1994	5.97e-01	7.29e-01
1995	5.81e-01	7.11e-01
1996	5.40e-01	6.60e-01

EffYears	EffLower	EffUpper
1997	4.48e-01	5.47e-01
1998	2.38e-01	2.91e-01
1999	3.66e-01	4.47e-01
2000	3.45e-01	4.22e-01
2001	2.98e-01	3.64e-01
2002	2.88e-01	3.52e-01
2003	2.94e-01	3.60e-01
2004	3.63e-01	4.43e-01
2005	3.35e-01	4.10e-01
2006	3.20e-01	3.91e-01
2007	3.19e-01	3.90e-01
2008	2.54e-01	3.11e-01
2009	2.74e-01	3.35e-01
2010	2.63e-01	3.22e-01
2011	2.71e-01	3.31e-01
2012	2.73e-01	3.33e-01
2013	2.92e-01	3.57e-01
2014	2.84e-01	3.47e-01
2015	2.40e-01	2.94e-01
2016	1.80e-01	2.20e-01
2017	1.27e-01	1.55e-01
2018	1.08e-01	1.32e-01
2019	7.92e-02	9.68e-02

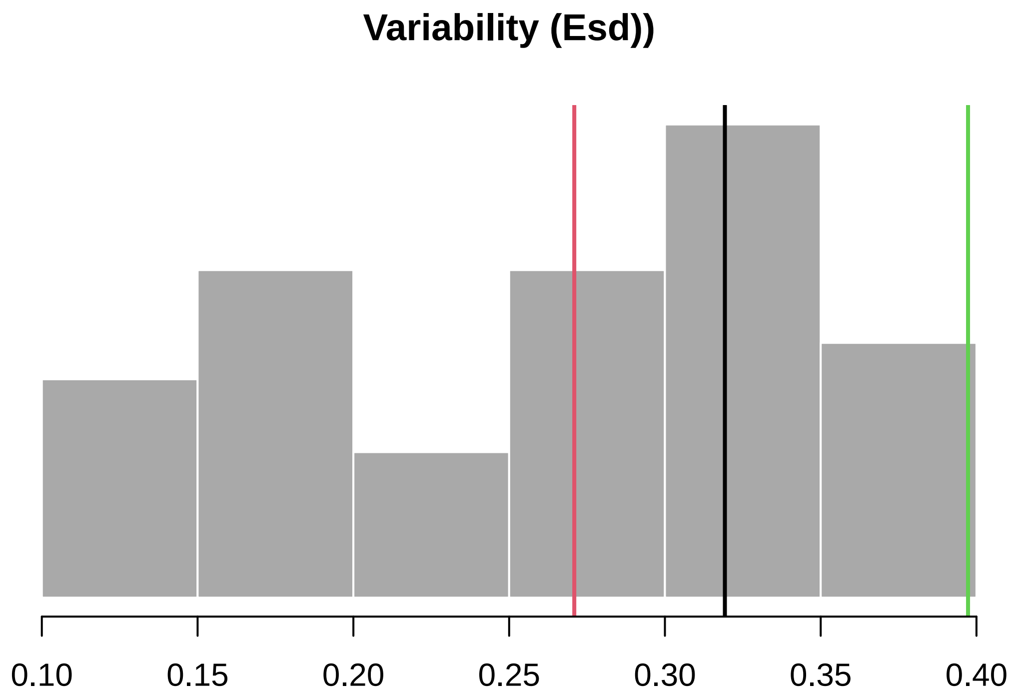
Esd: Additional inter-annual variability in fishing mortality rate. For each historical simulation a single value is drawn from a uniform distribution specified by the upper and lower bounds provided. If this parameter has a positive (non-zero) value, the yearly fishing mortality rate is drawn from a 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): 0.1, 0.4

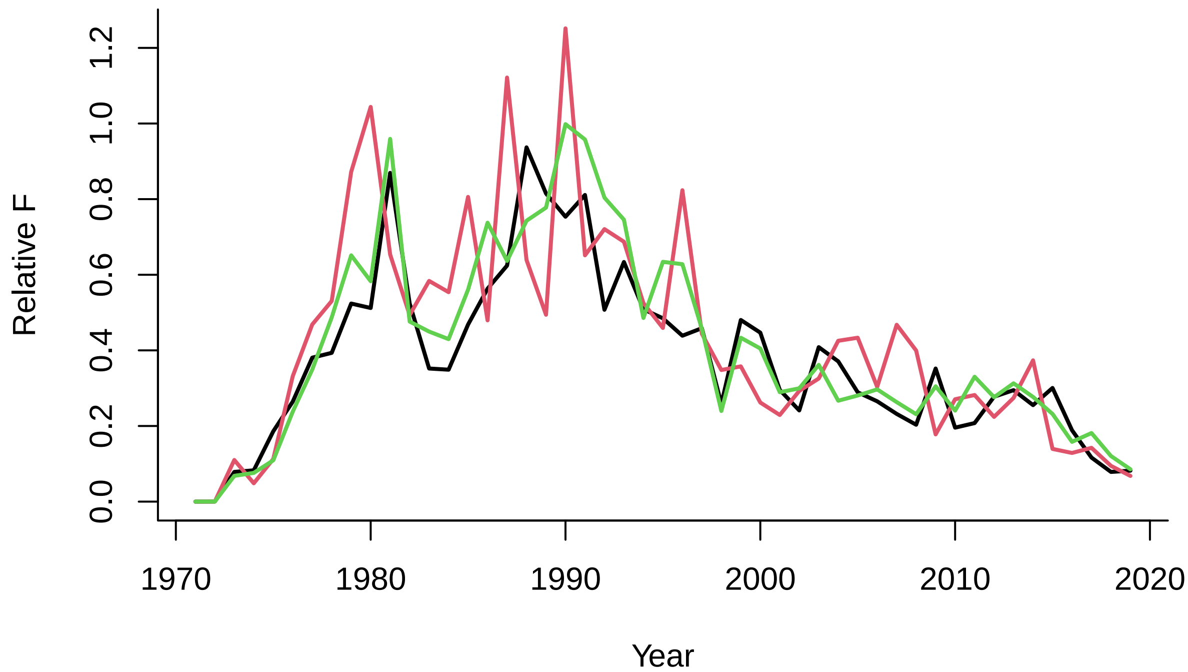
Esd was assumed to range between 0 and 0.4.

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, 2

It was assumed that future catchability increases may range from 0 to 2% due to potential advances in the ability of divers to cover more ground via the use of underwater scooters.

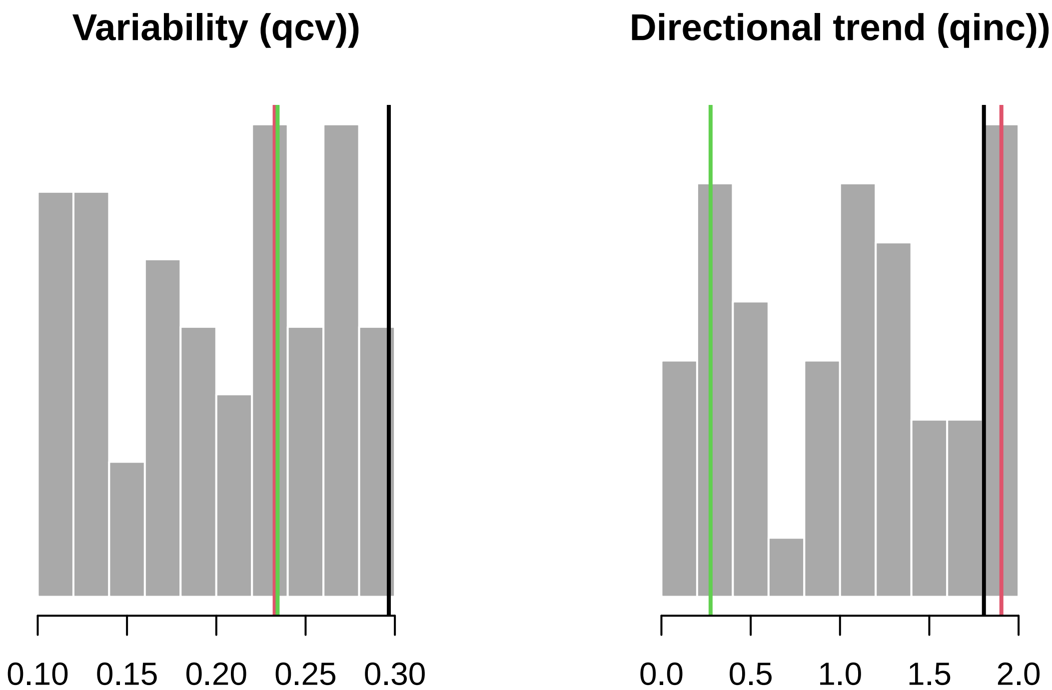
qcv: Inter-annual variability in catchability expressed as a coefficient of variation. For each simulation a single value is drawn from a uniform distribution specified by the upper and lower bounds provided. This parameter applies only to forward projections.

Specified Value(s): 0.1, 0.3

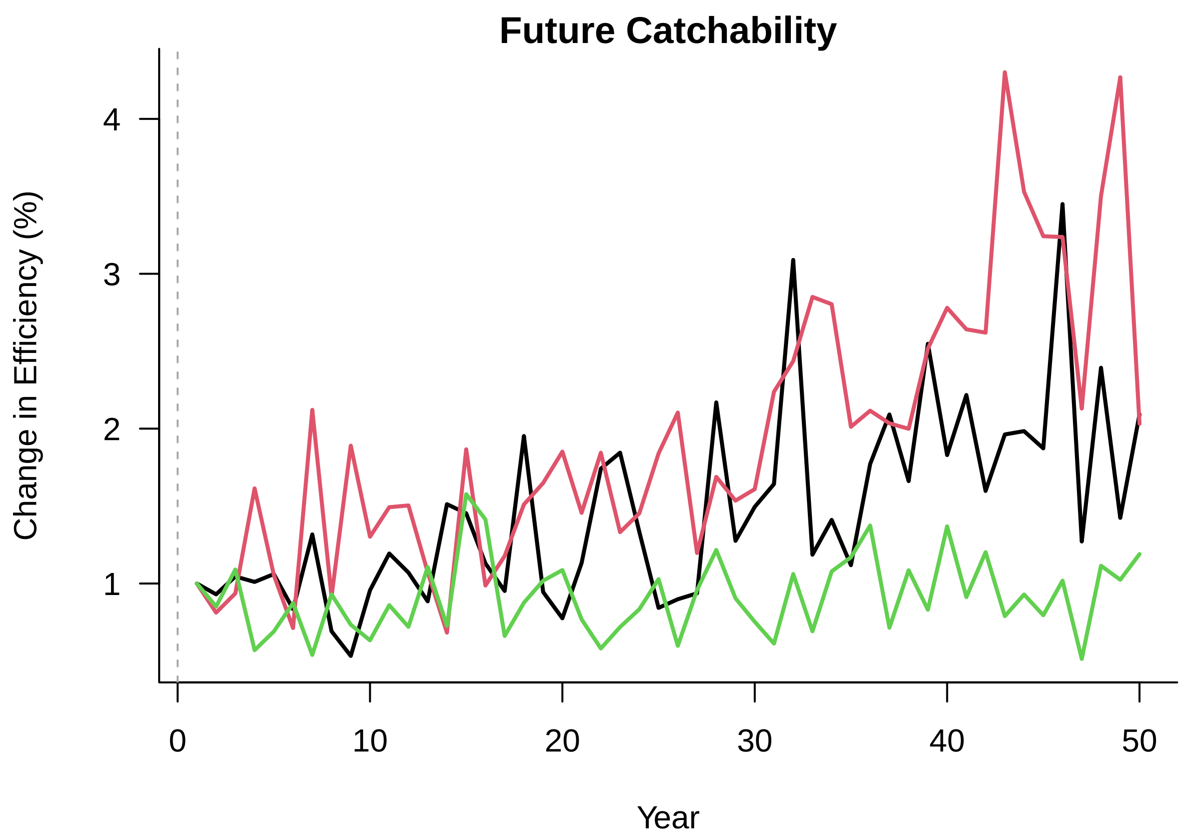
There is no information available on catchability. qcv was assumed to range between 0.1 and 0.3.

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): 40, 42

Because this is a dive fishery, in which Red Sea Urchin are harvested by hand, we assumed that the size at first and full selectivity closely mirrored the size limit of 83 mm (3.25 in). It was also assumed that selectivity is logistic (Vmaxlen = 1). Divers are allowed to retain up to 30 undersized individuals, but there is no data on how often that is utilized, or what sizes are retained.

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): 50, 60

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

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): 74, 76

Retention was modeled as a knife-edged curve following the size limit of 83 mm (3.25 in).

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): 82, 83

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

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): 0.01, 0.02

We assumed a very small discard rate associated with the practice of cracking a few urchin in each area to determine whether the gonad quality is marketable.

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

Because Red Sea Urchin inhabit shallow rocky reef habitat in depths of less than 100 ft (30.5 m), the current network of MPAs in California likely play an important role in providing refuge to spawning populations. The Department estimates that 15.7% of Red Sea Urchin habitat (both reef and soft sediments) occurs inside the boundaries of MPAs in southern California. 65% 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

This section describes the parameters that are used to generate the simulated fishery data within the MSE model. The primary data available for this fishery are from routine recording of commercial landings, as well as fishery-independent sampling by the Channel Islands National Park Service (CINPS) Kelp Forest Monitoring program, which has been monitoring sites in southern California since 1982. This survey has collected length measurements and transect densities of red sea urchin in southern California from 37 sites, mainly around the Channel Islands. The parameters used for the observation model were based on the values presented in Carruthers et al. (2014) and are found in the 'Generic_obs' observation object in the DLMtool except where information was found to suggest alternative values (see below for more information).

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

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

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 age 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 age 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): 3000, 3500

While length samples are not recorded, there is a considerable amount of length data taken from fishery-independent surveys. The numbers used here reflect the numbers of samples from the CINP KFM surveys.

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): 3000, 3500

We assume that the effective sample size is less than the true number of length samples taken because multiple samples are generally taken from a single site on a single day.

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): 0.2, 0.5

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): 0.6, 0.8

The CINP KFM survey has followed the same protocol since the early 1980s, in which SCUBA divers count the number of Red Sea Urchin encountered at randomly selected points along 100-meter transect lines at 37 fixed locations throughout the northern Channel Islands. We calculated the coefficient of variation for the survey index of abundance across all years. 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. However, on average this survey has had a stable CV ranging between 0.6 and 0.8, and these values were assumed for future surveys.

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 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): 0.5, 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

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

The CV for natural mortality was increased to 30% to reflect the uncertainty in this parameter.

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

The CV for the estimated K parameter was increased to 20% to reflect high uncertainty in this parameter.

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

The CV for the estimated Linf parameter was increased to 10% to reflect high uncertainty in this parameter.

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): 0.5

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): 0.2

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

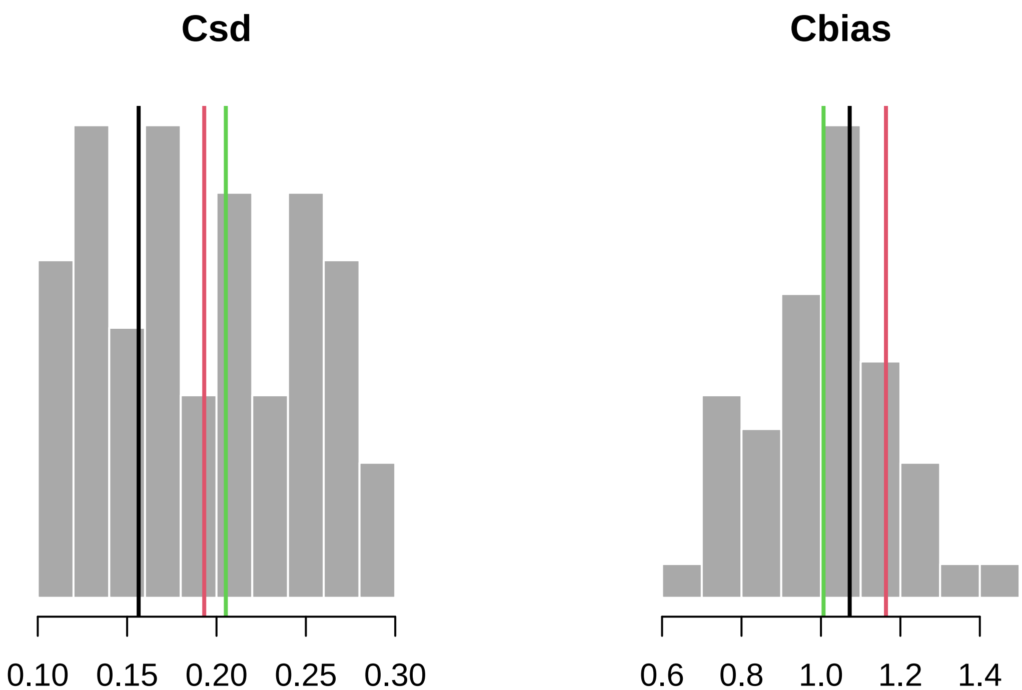
No justification provided.

Obs Plots

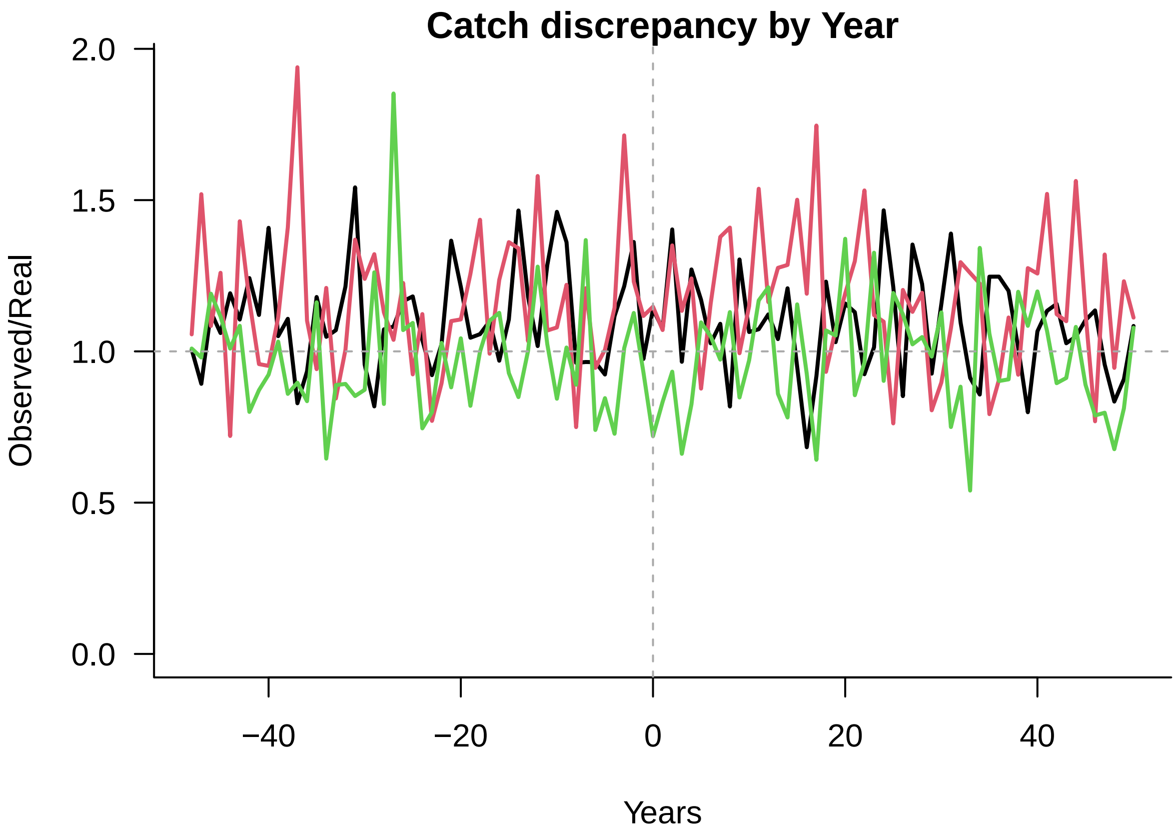
Observation Parameters

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:

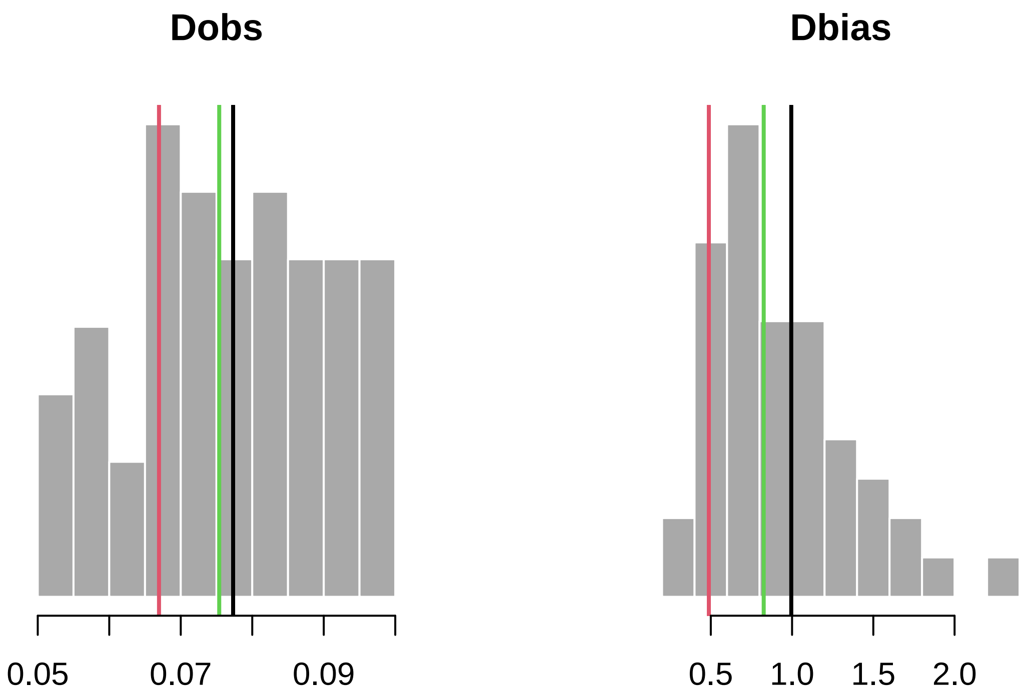


Time-Series Time-series plots of catch observation error for historical and projection years:

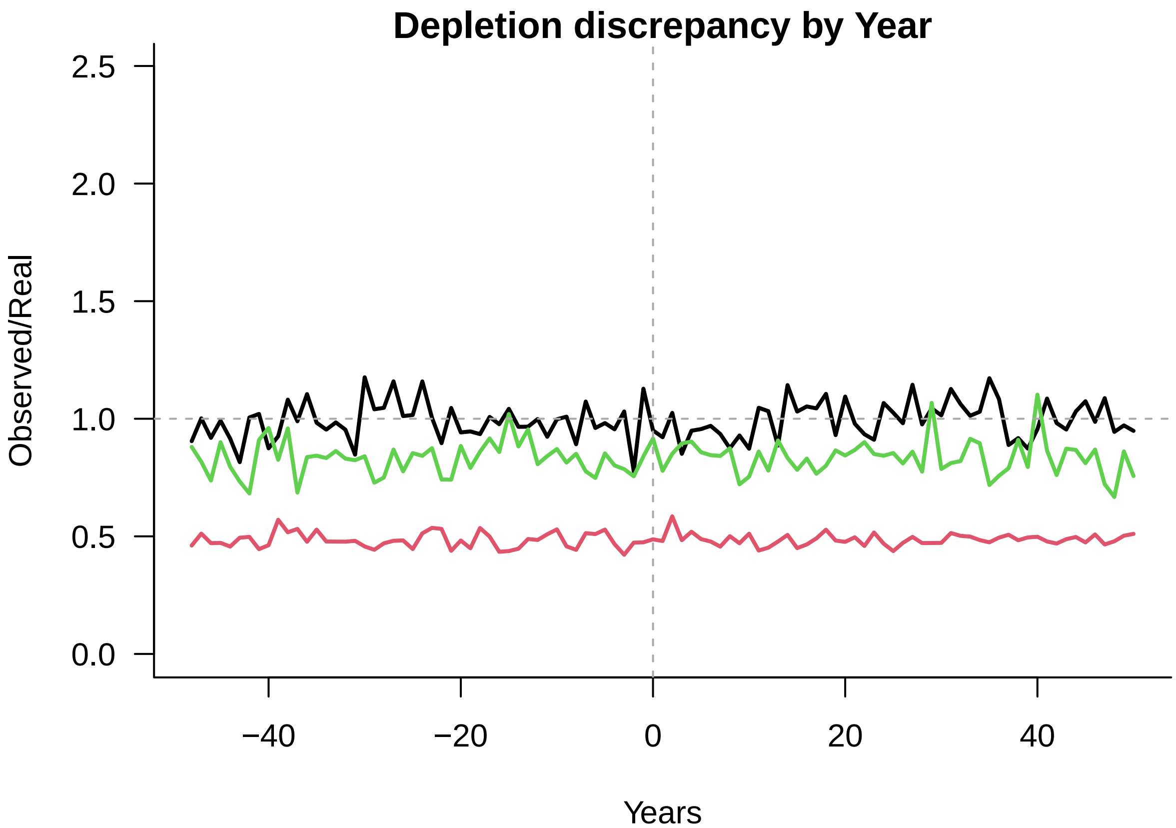


Depletion Observations

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:

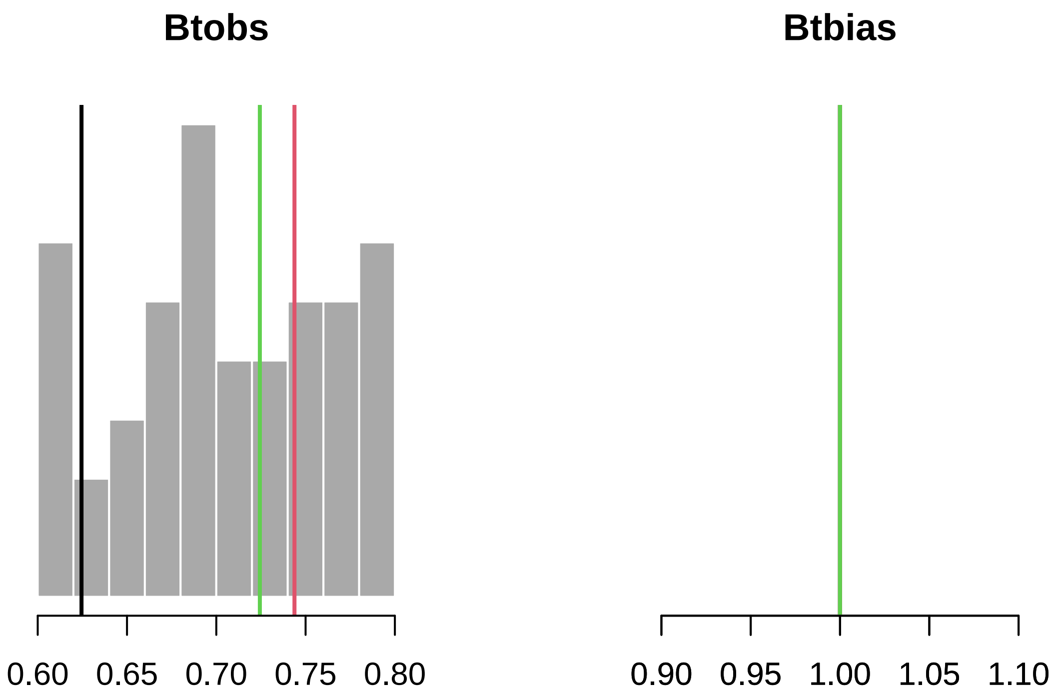


Time-Series Time-series plots of depletion observation error for historical and projection years:

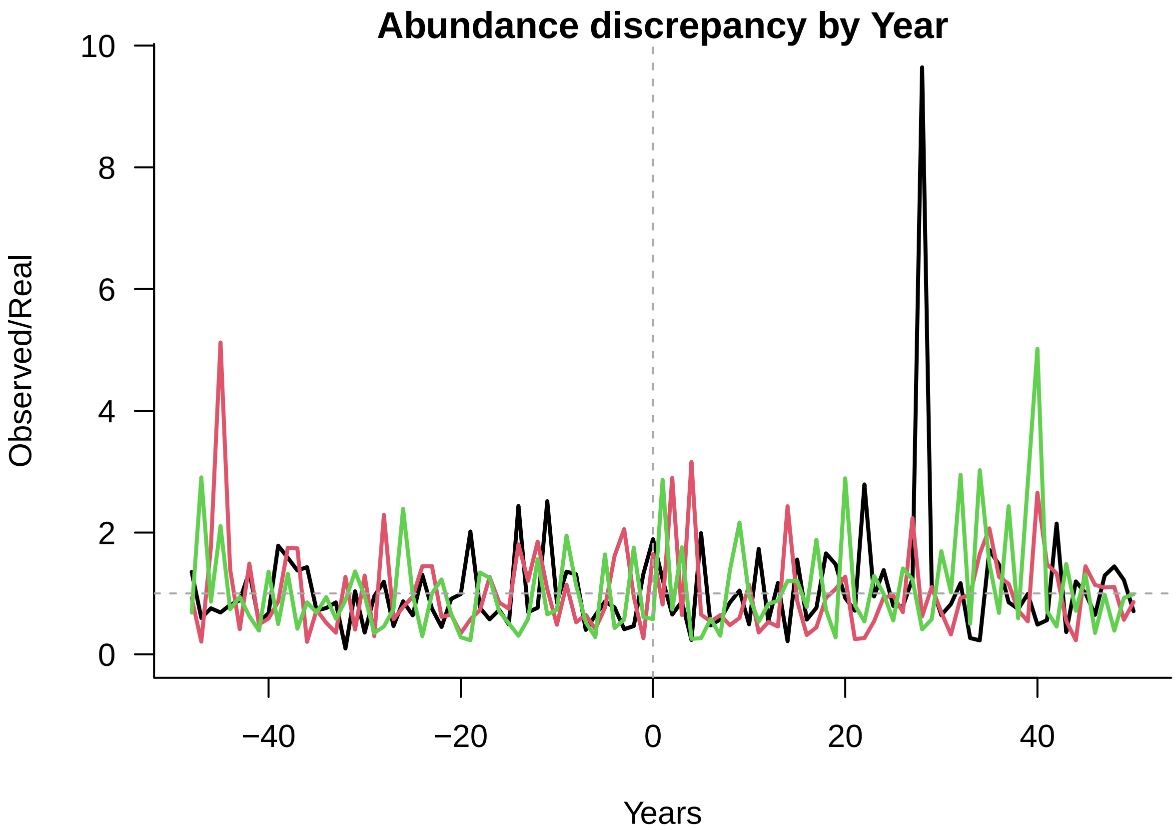


Abundance Observations

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:

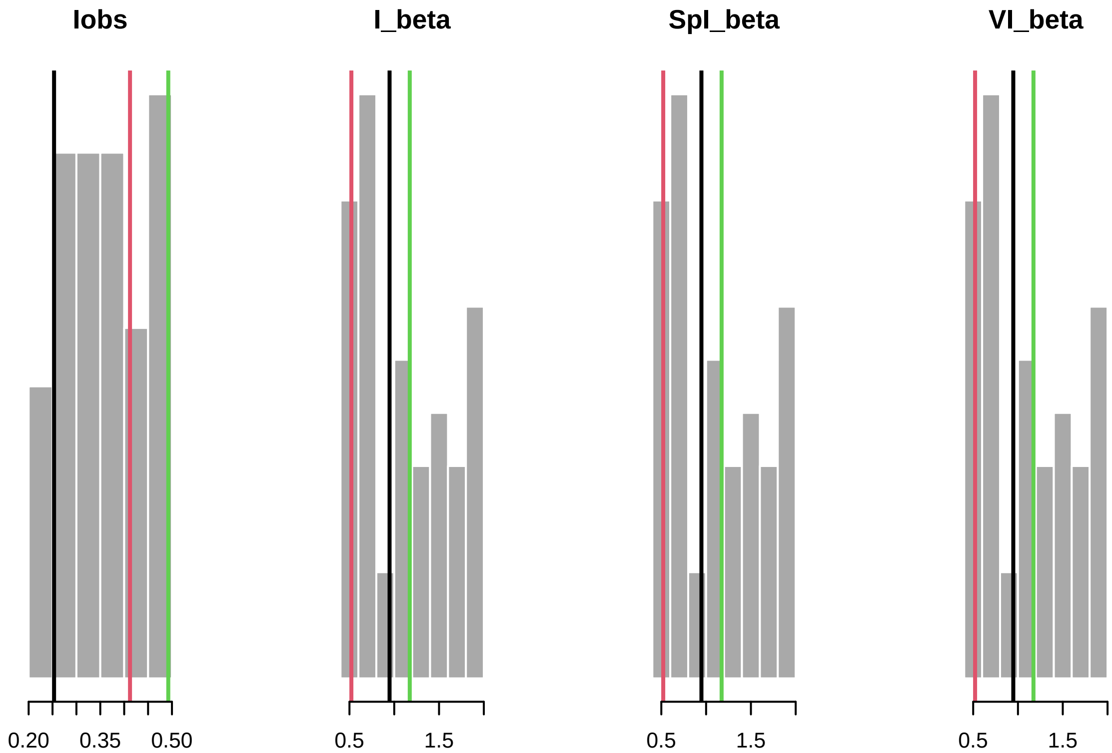


Time-Series Time-series plots of abundance observation error for historical and projection years:

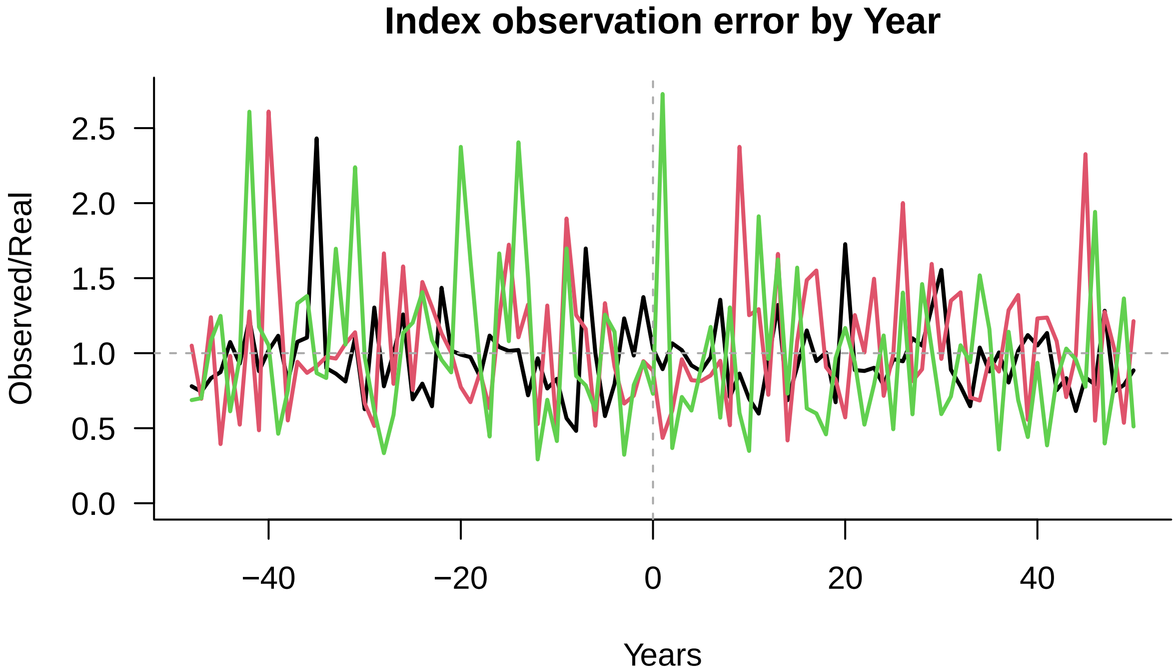


Index Observations

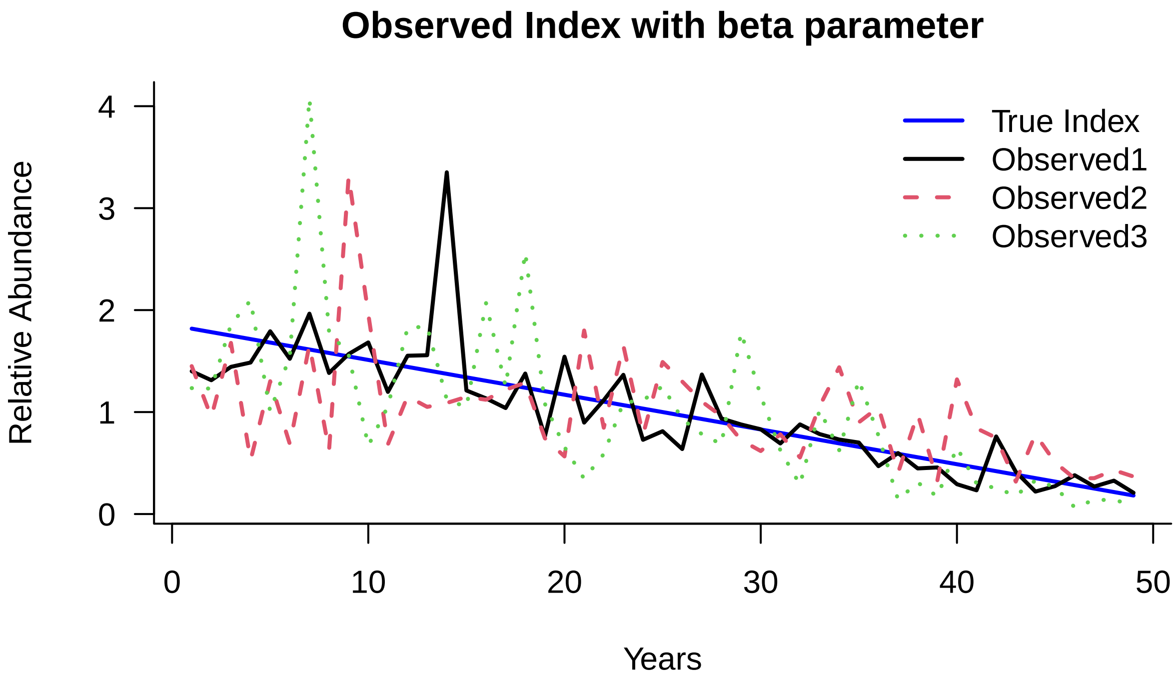
Sampled Parameters Histograms of 48 simulations of inter-annual variability in index observations (`Iobs`) and hyper-stability/depletion in observed index (`beta`), with vertical colored lines indicating 3 randomly drawn values used in other plots:



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

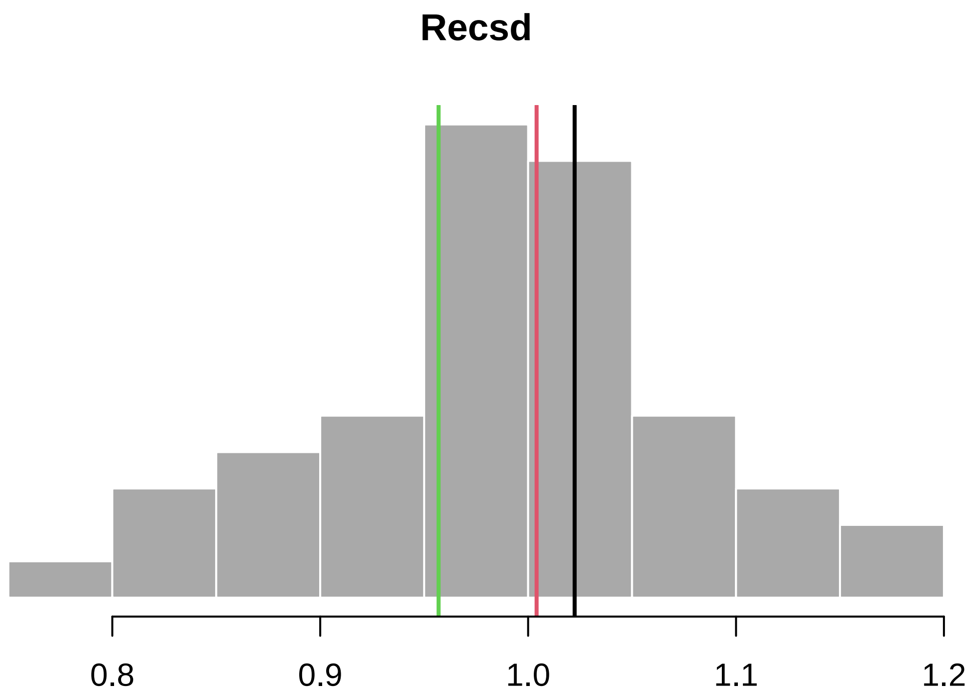


Plot showing an example true abundance index (blue) with 3 samples of index observation error and the hyper-stability/depletion parameter (`beta`):

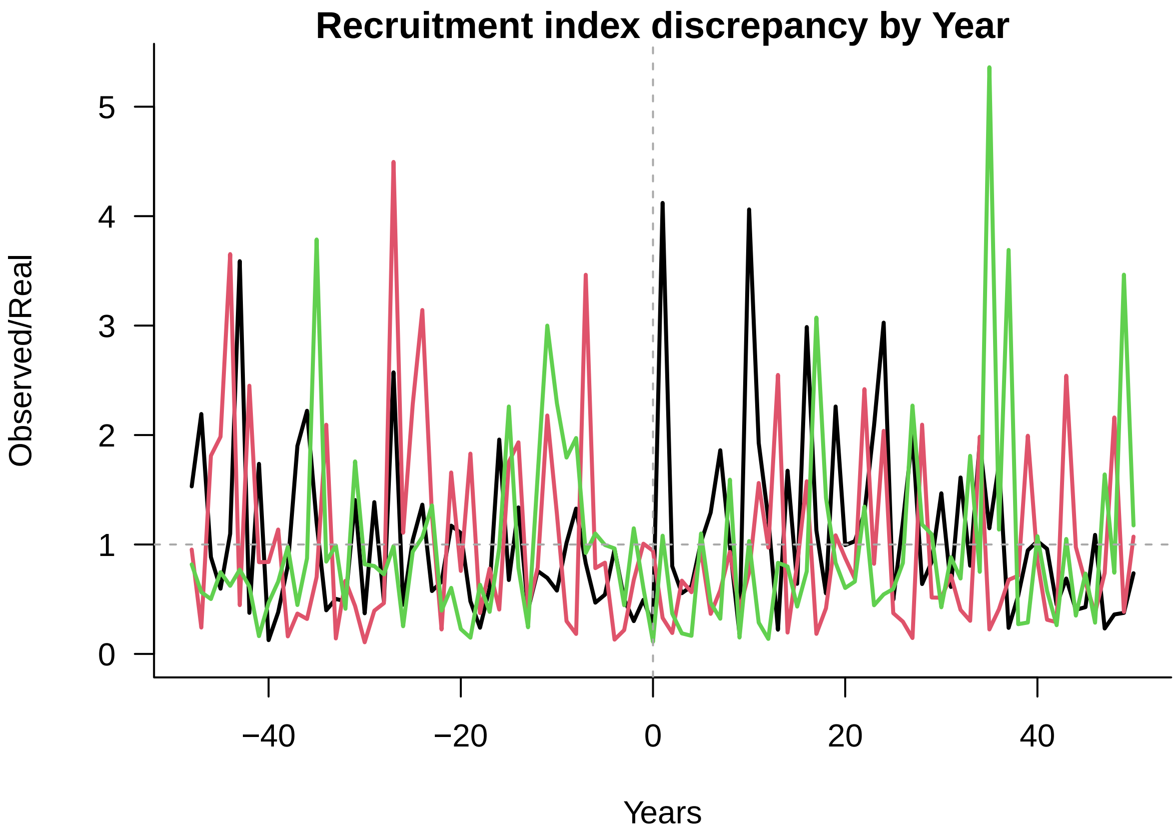


Recruitment Observations

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:

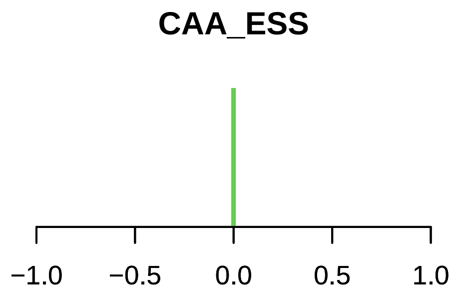


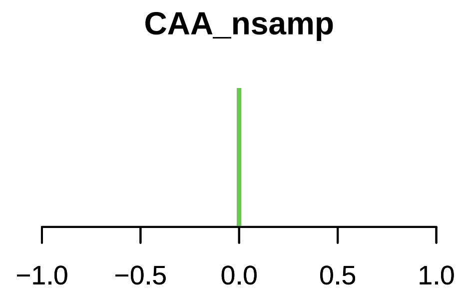
Time-Series Timeseries plots of observeration error for recruitment:

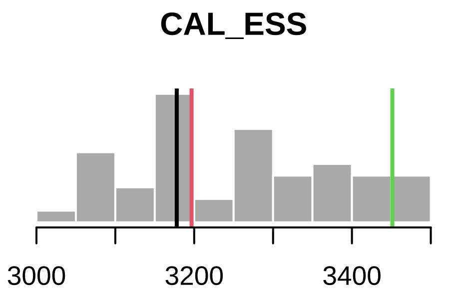


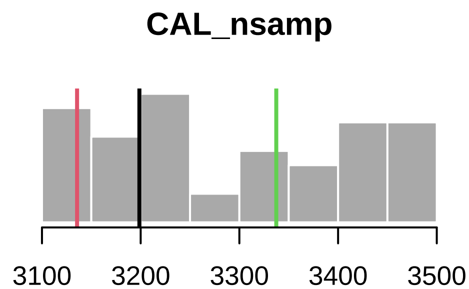
Composition Observations

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:



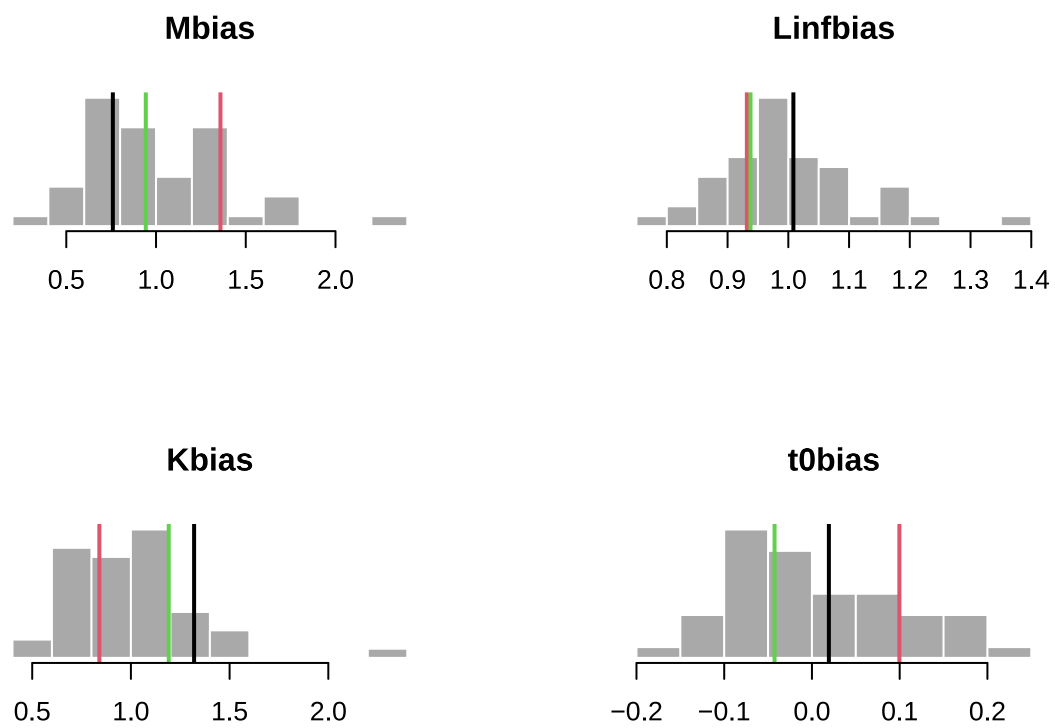


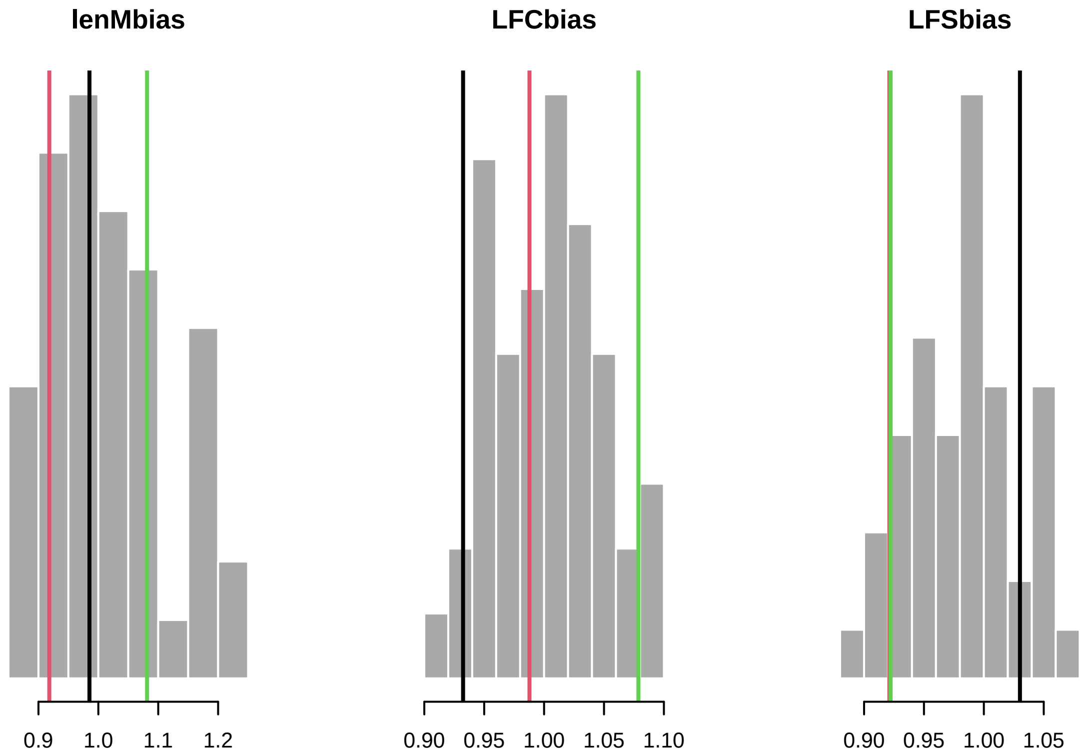




Parameter Observations

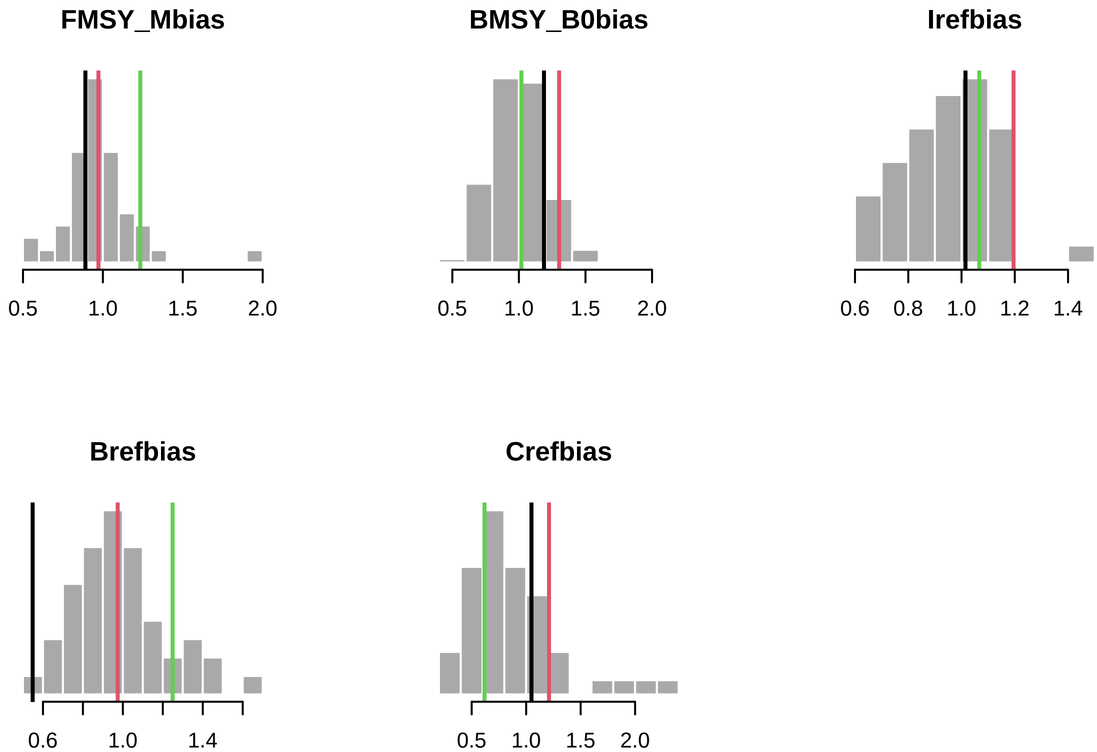
Sampled Parameters Histograms of 48 simulations of bias in observed natural mortality (`Mbias`), von Bertalanffy growth function parameters (`Linfbias`, `Kbias`, and `t0bias`), length-at-maturity (`lenMbias`), and bias in observed length at first capture (`LFCbias`) and first length at full capture (`LFSbias`) 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
1.3
1.4
Kbias
0.5
1.0
1.5
2.0
t0bias
−0.2
−0.1
0.0
0.1
0.2



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

The sea urchin fishery has never been managed with a TAC, and so we assumed that a TAC would be applied with some implementation error, but did not have information on what the direction or maginitude of this error would be. We assumed that the TAC would result in mean catch levels between 90 and 110% of the desired catch, with a standard deviation between 0 and 5%. We assumed the same values for a TAE. While the fishery has effort limits currently in the form of days of the week and numbers of permits, there is no evidence that either of these regulations really restrict the amount of fishing effort currently applied, or allows CDFW to target a specific level of effort in terms of numbers of trips or days fished, number of dive hours, etc, so it is unknown how well a specific limit could be implemented. We assumed that the size limit is well enforced, with retained sizes being between 98 and 100% of the size limit, with no variation from year to year.

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): 0.9, 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, 0.05

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): 0.9, 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, 0.05

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): 0.98, 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.

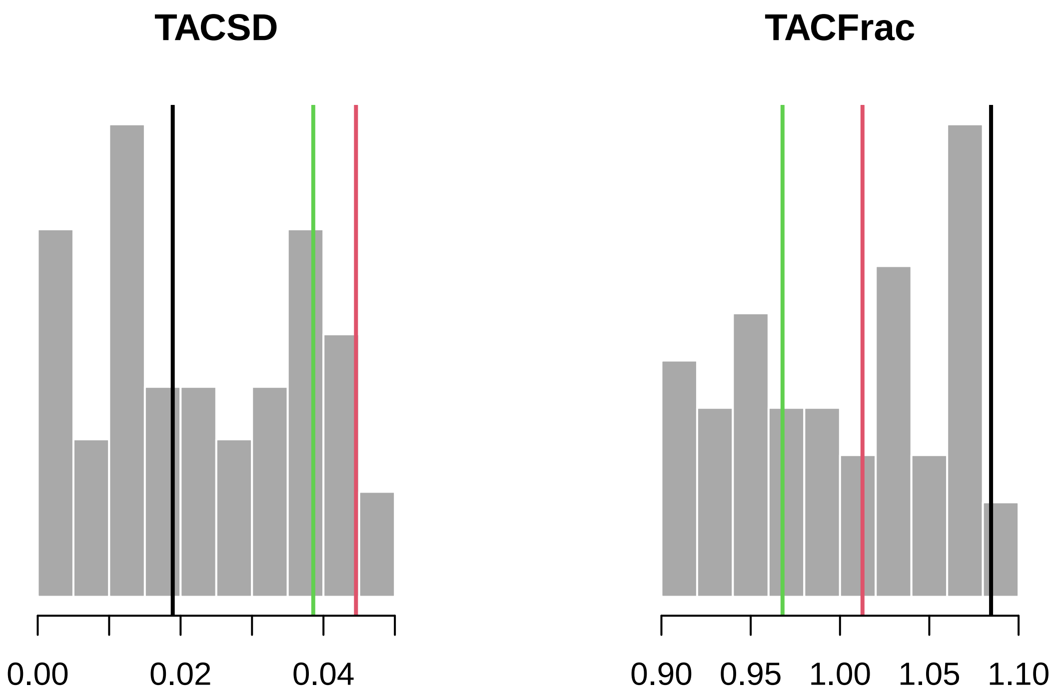
Specified Value(s): 0, 0

Imp Plots

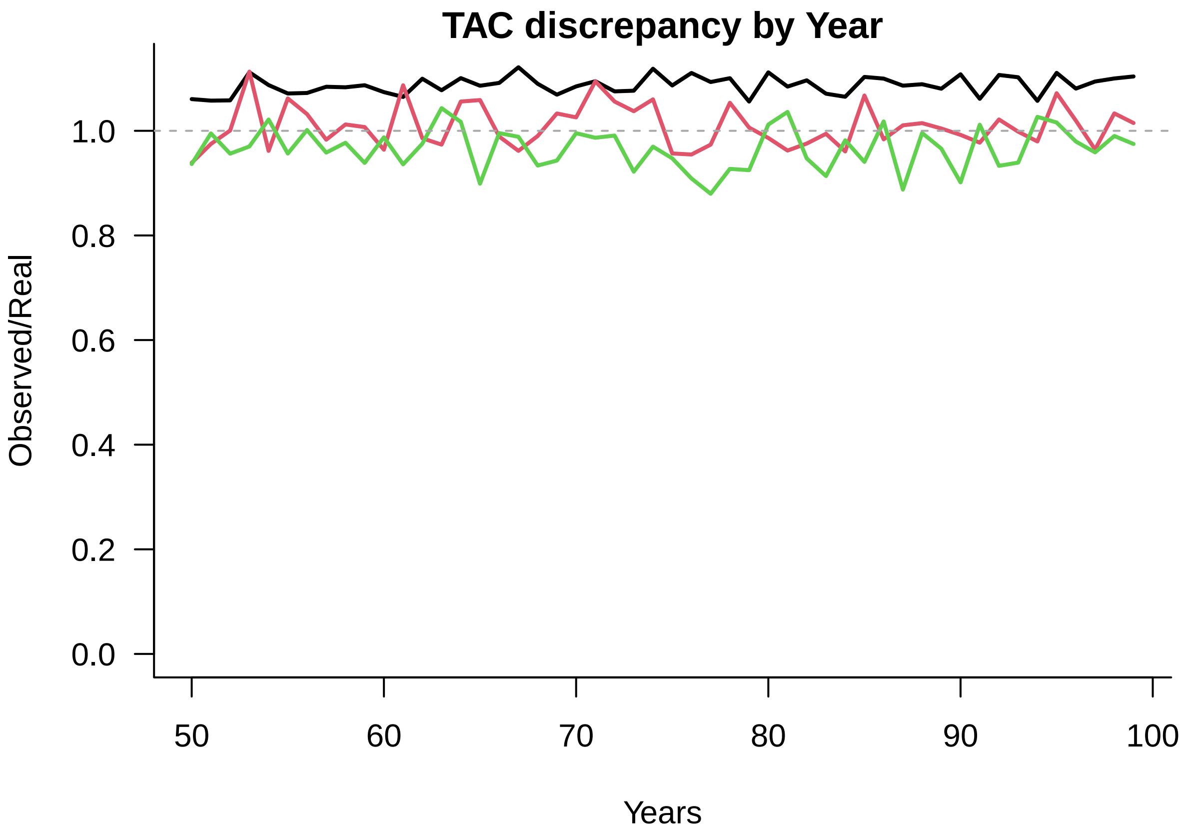
Implementation Parameters

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:

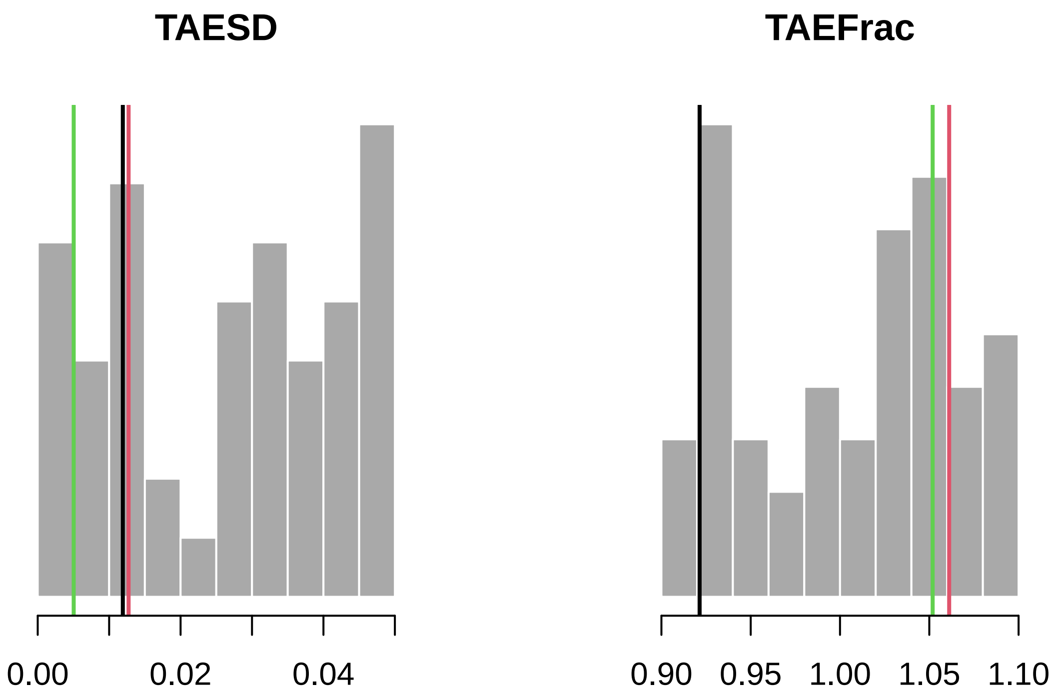


Time-Series Time-series plots of 0 samples of TAC implementation error by year:

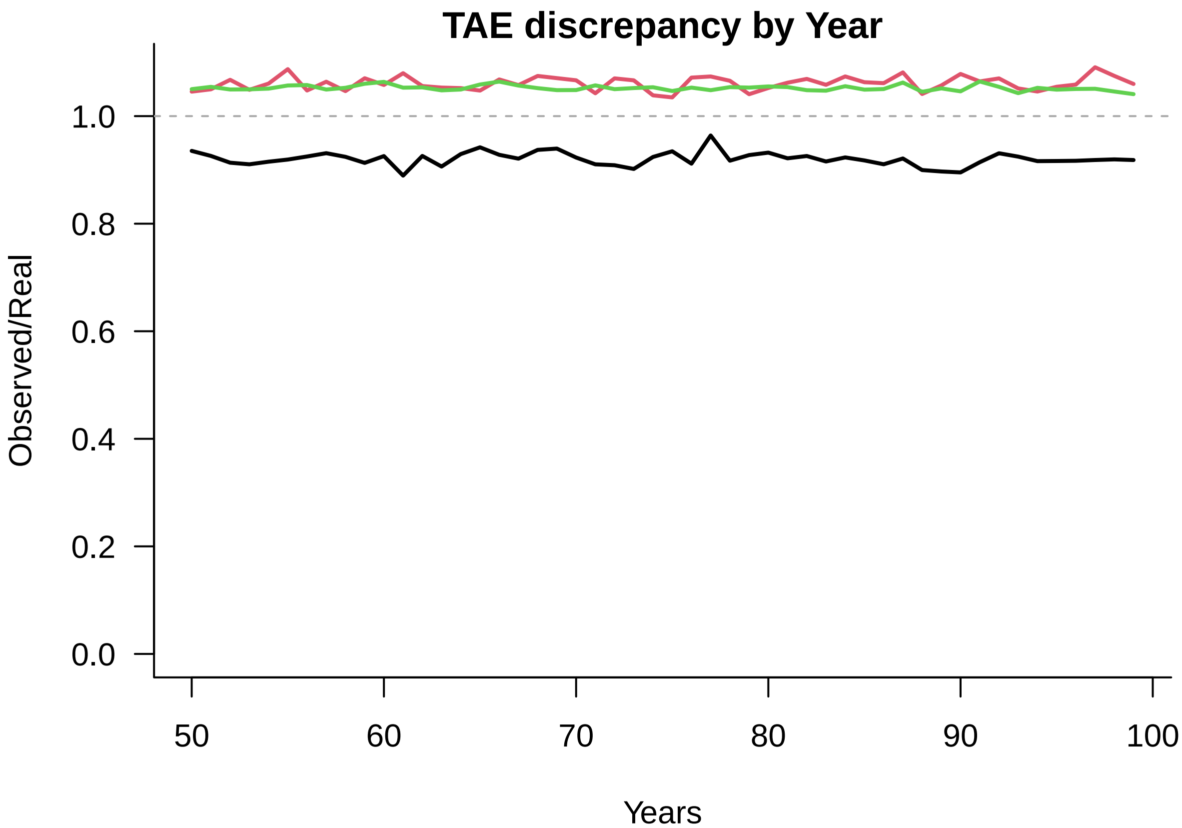


TAE Implementation

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:

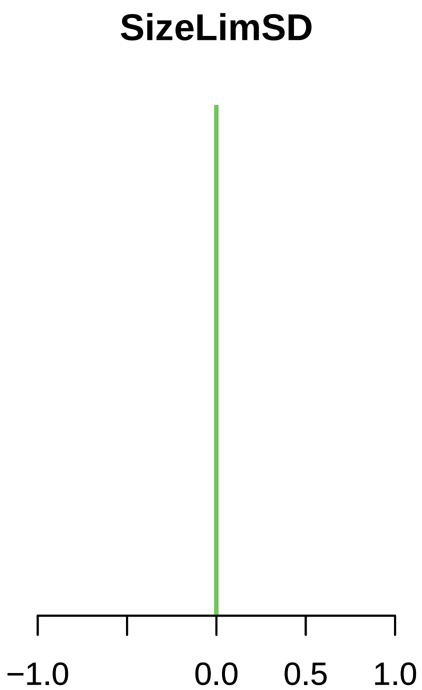


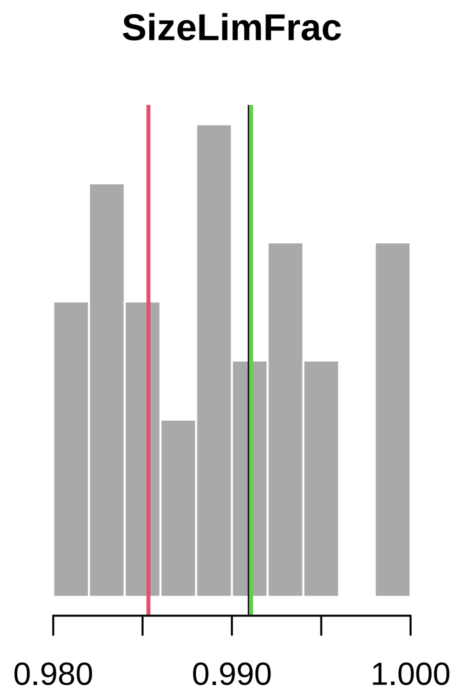
Time-Series Time-series plots of 0 samples of TAE implementation error by year:



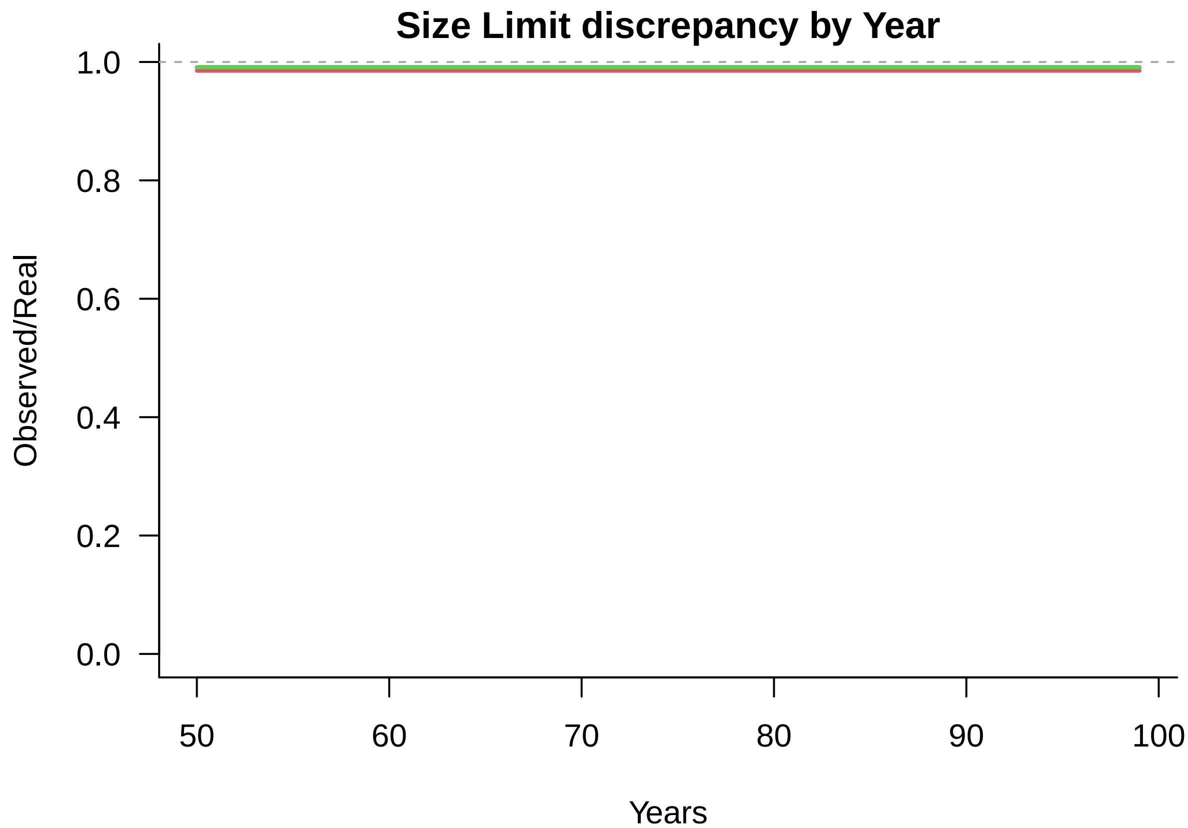
Size Limit Implementation

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:

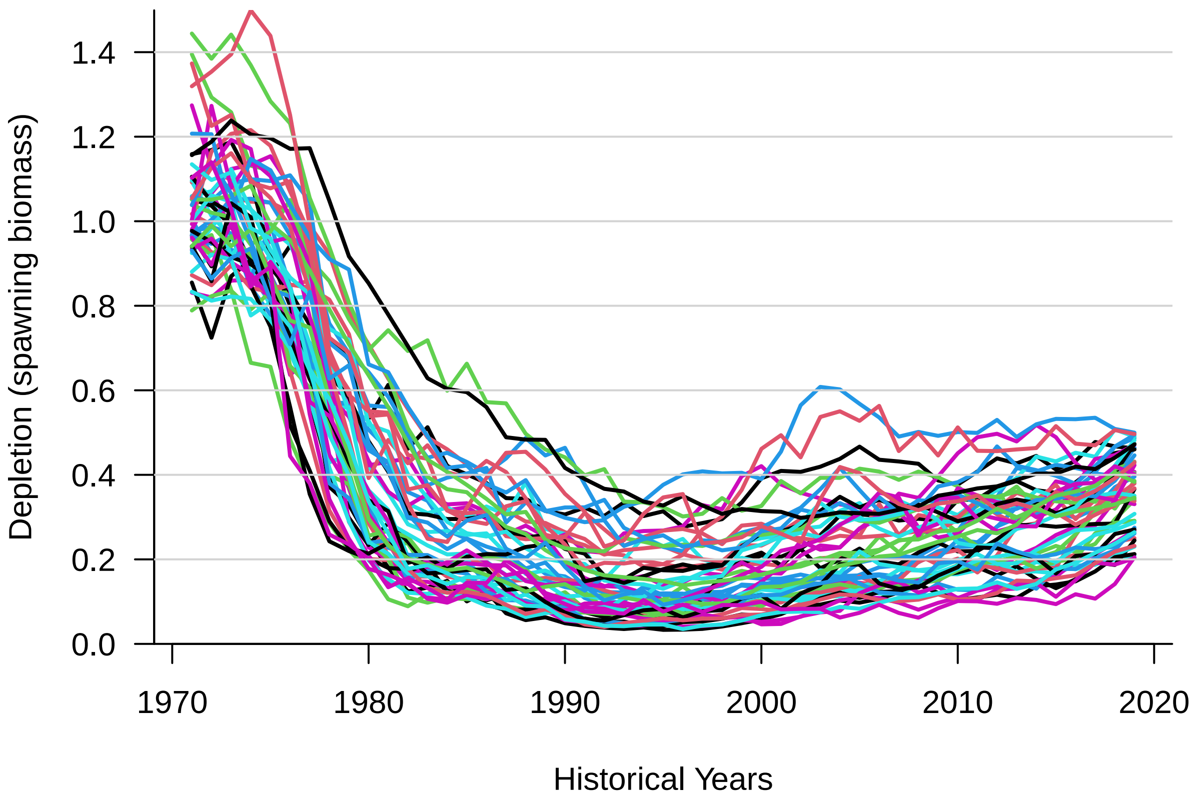


Historical Simulation Plots

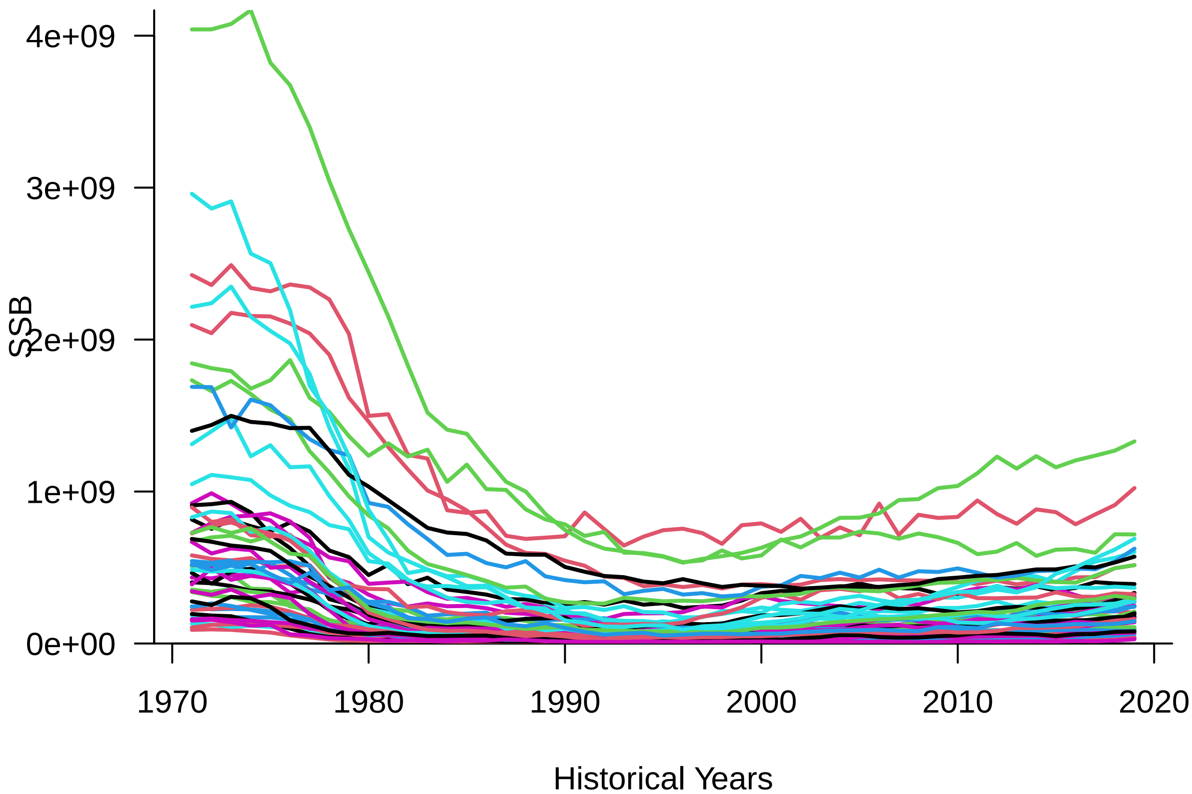
Historical Time-Series

Spawning Biomass

Depletion Time-series plots of SB/SB0:

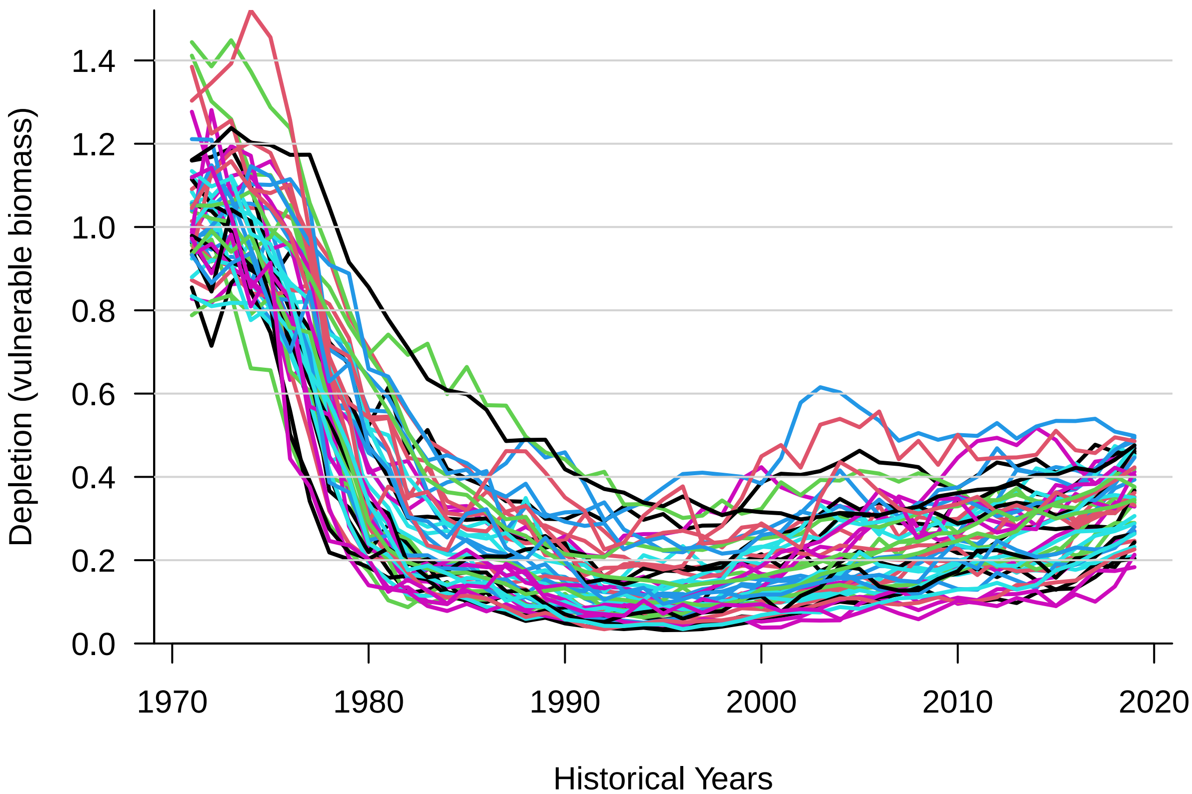


Absolute Time-series plots of absolute SB:

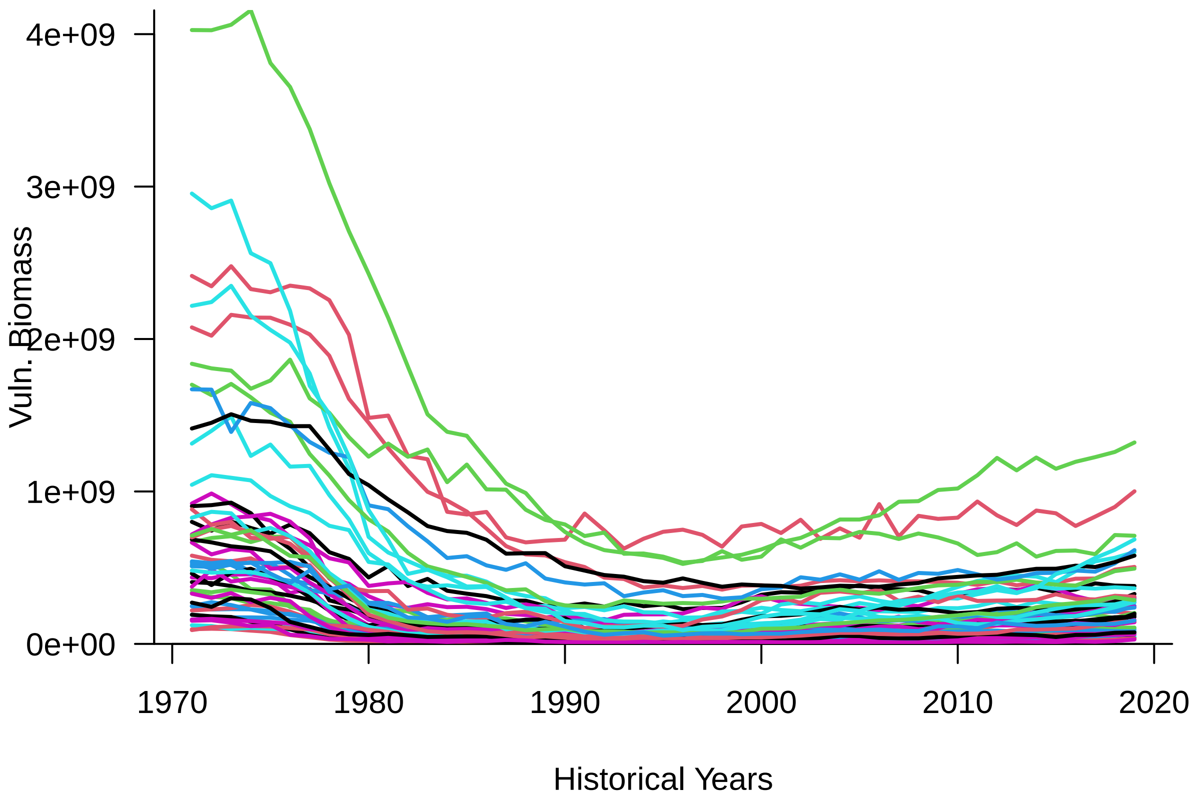


Vulnerable Biomass

Depletion Time-series plots of VB/VB0:

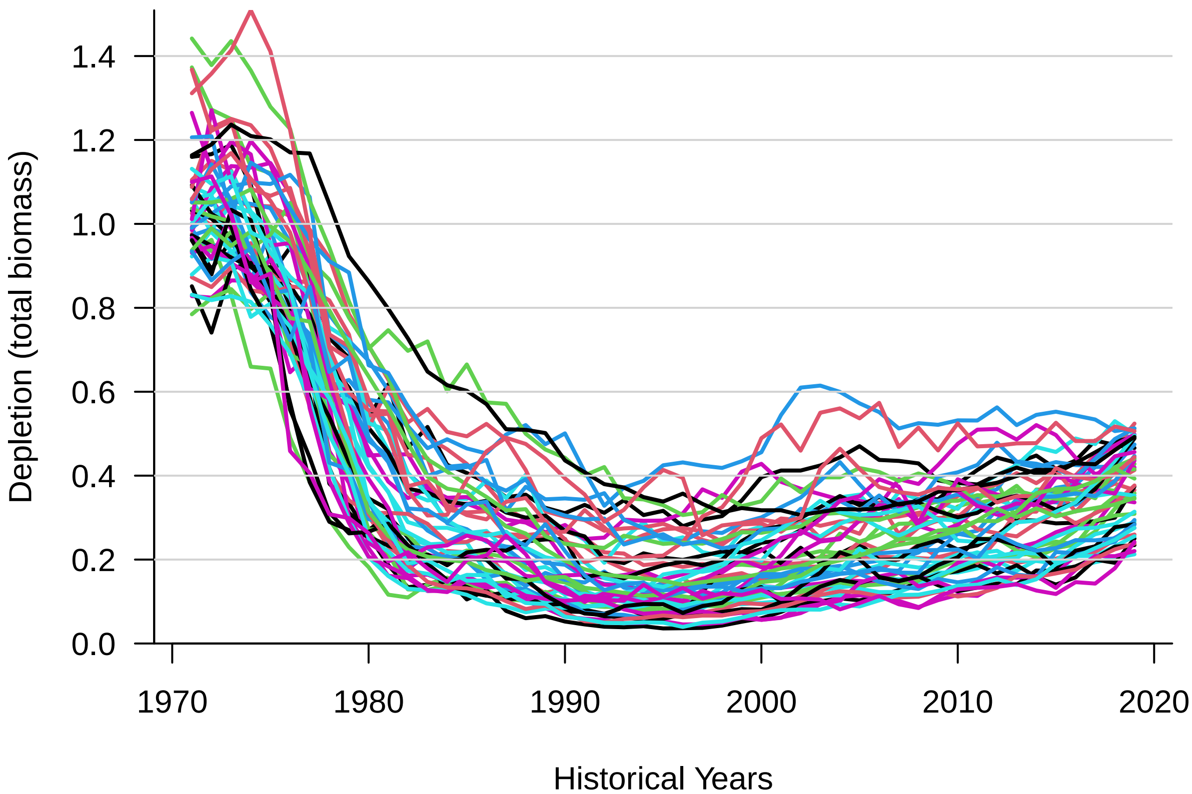


Absolute Time-series plots of absolute VB:

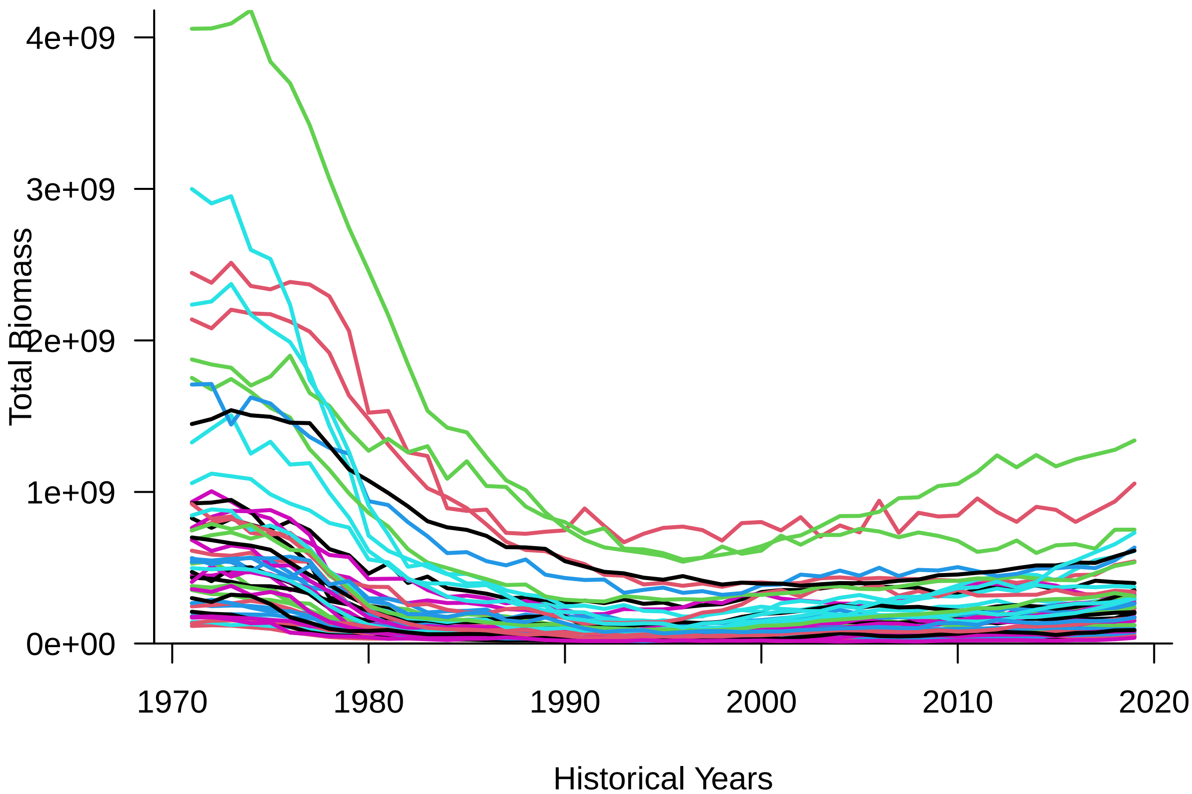


Total Biomass

Depletion Time-series plots of B/B0:

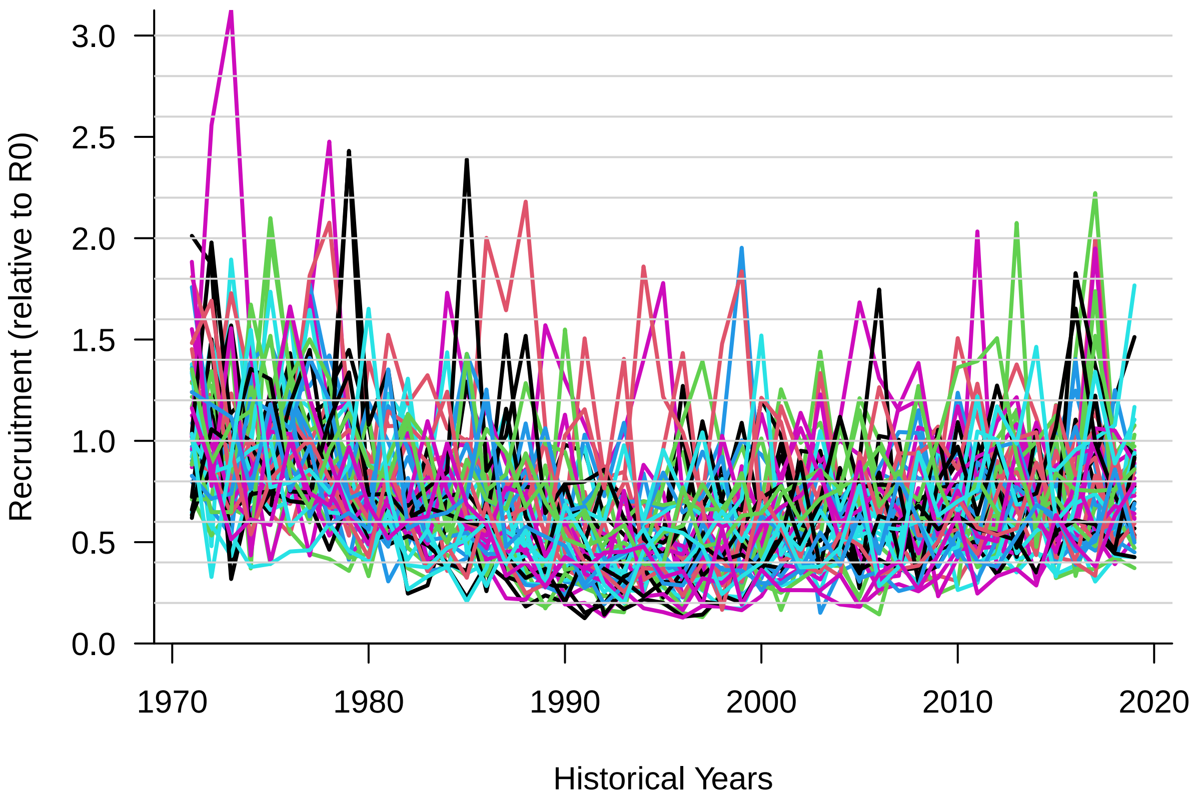


Absolute Time-series plots of absolute B:

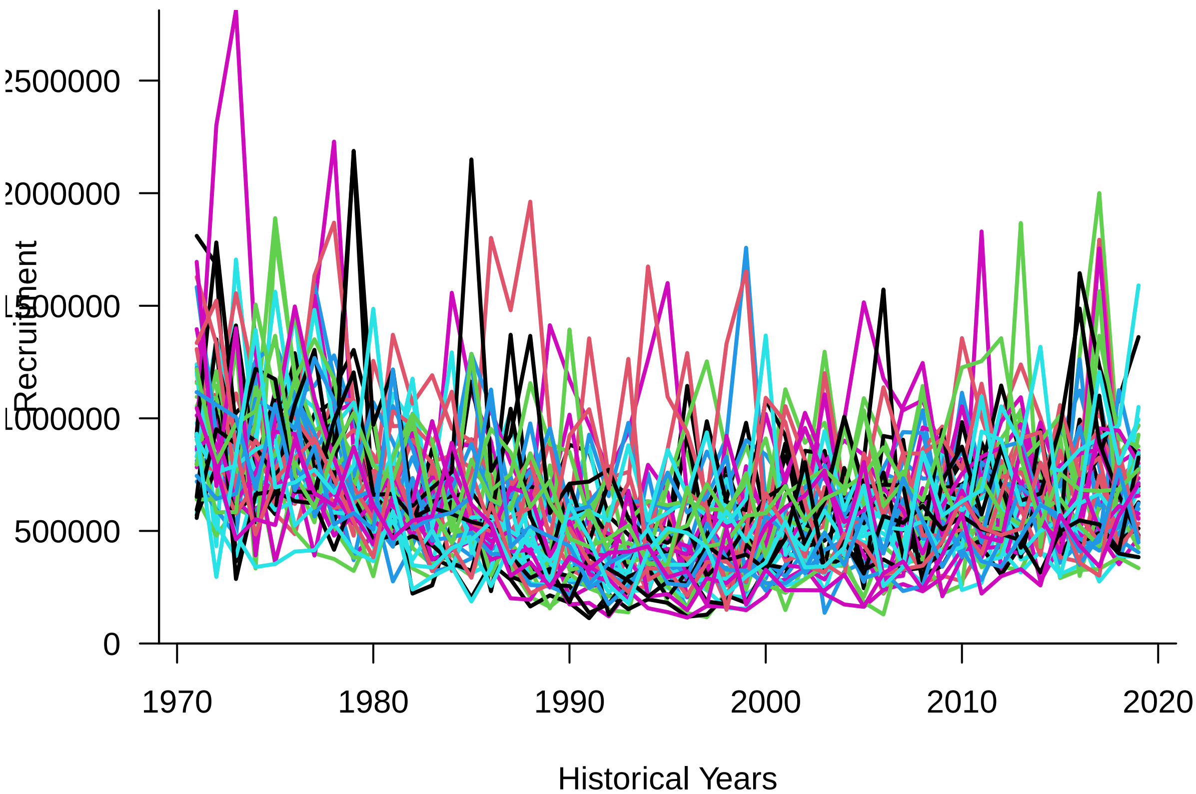


Recruitment

Relative Time-series plot of recruitment relative to R0:

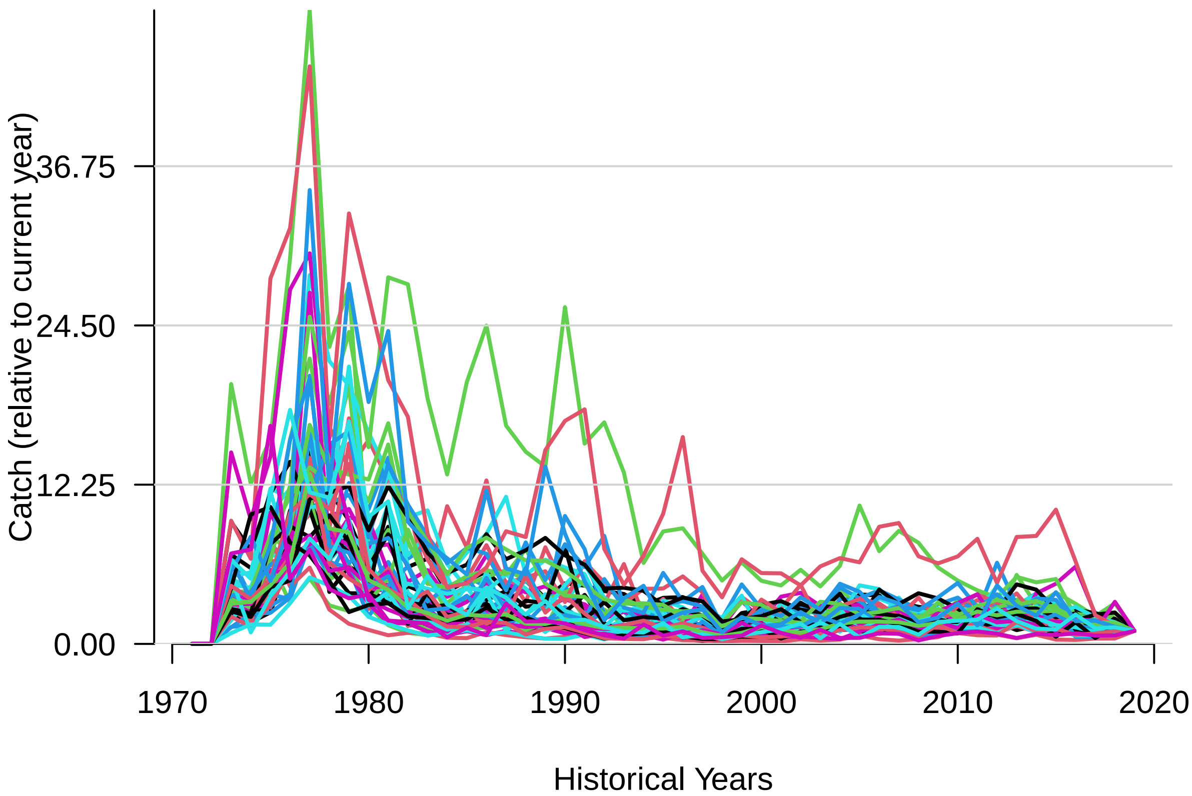


Absolute Time-series plot of absolute recruitment:

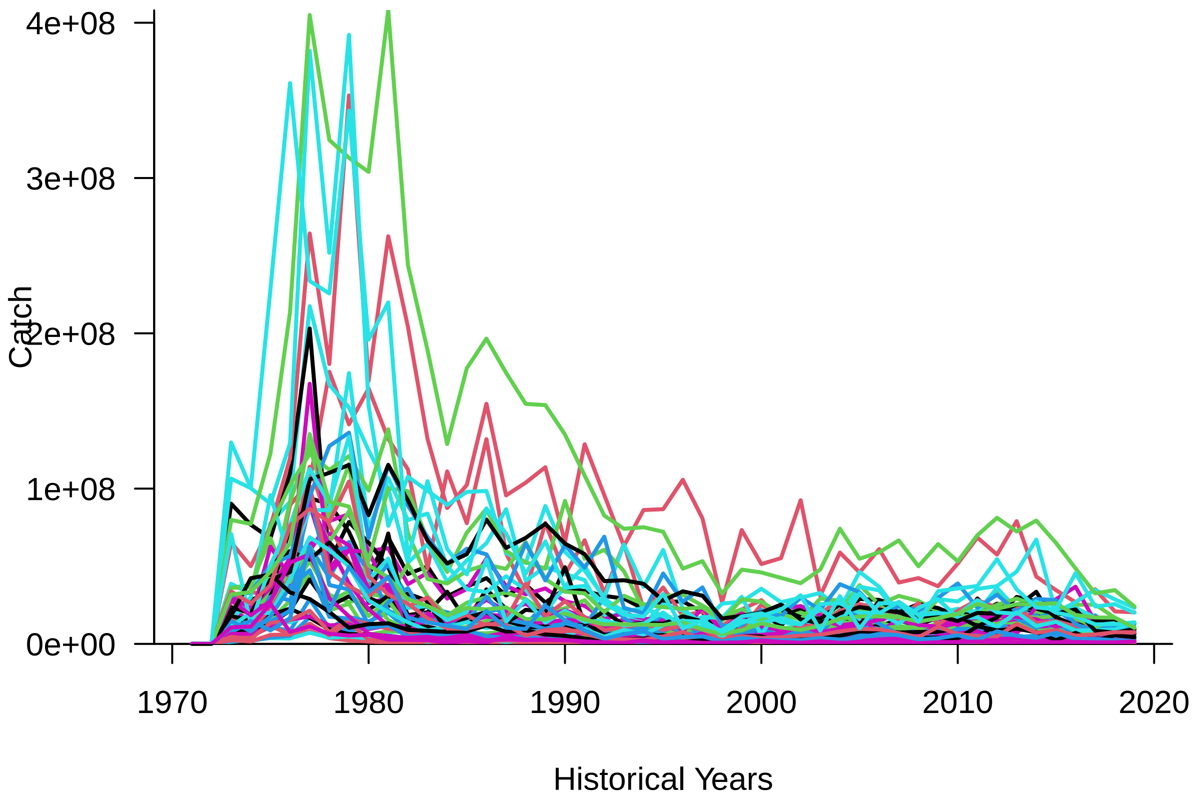


Catch

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

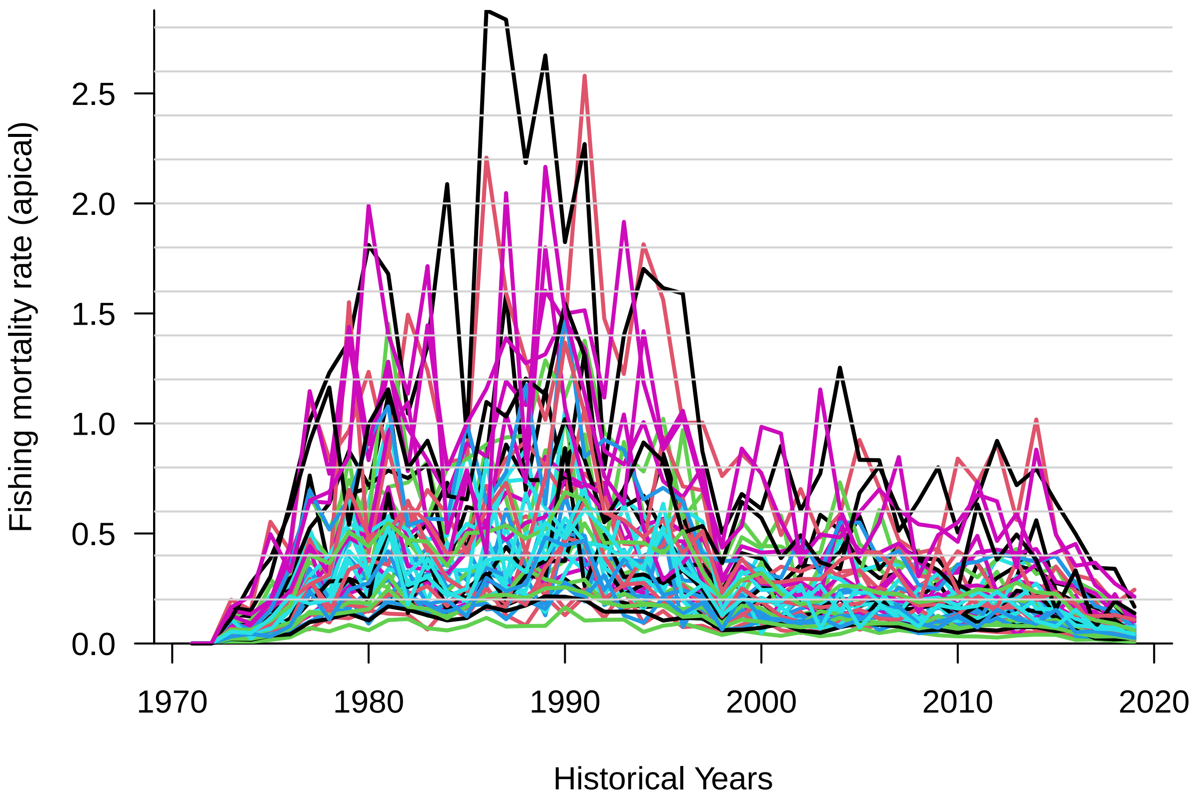


Absolute Time-series of absolute catch:



Historical Fishing Mortality

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



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