Determining Yields and Reference Points for Data-Poor Stocks: Combining DCAC and SRA

E.J. Dick and Alec MacCall
NOAA Fisheries
Southwest Fisheries Science Center
Fisheries Ecology Division

DRAFT provided for SSC Groundfish Subcommittee review– January 22, 2010

This information is distributed solely for the purpose of pre-dissemination peer review under applicable information quality guidelines. It has not been formally disseminated by NOAA Fisheries. It does not represent and should not be construed to represent any agency determination or policy.

Abstract

We describe a method for determining reasonable yield and management reference points for data-poor species. Data requirements include estimates of annual catch, approximate natural mortality rate and age at maturity. The method produces management reference points concerning yield (OFL and MSY) and biomass ($B_{unfished}$, B_{MSY} , and $B_{current}$). The approach merges stochastic stock-reduction analysis (Walters et al., 2009) with depletion-corrected average catch (DCAC; MacCall, 2009) and is useful when only catch and basic life history data are available. Uncertainties in natural mortality, stock dynamics, optimal harvest rates, and stock status are incorporated using Monte Carlo simulation. Comparison of model outputs to data-rich stock assessments suggest that our method is effective, along with DCAC, for estimating sustainable yields for data-poor stocks with variable, but not highly episodic, recruitment.

Introduction

Estimation of stock status and sustainable yield is a primary focus of traditional stock assessment. Management of data-rich stocks is often based on assessment models that incorporate a variety of data sources and that provide estimates of stock status, management targets, and sustainable yield. The focus of management for data-poor stocks is more often on estimates of sustainable yield because insufficient data are available to adequately assess stock status. Common approaches for data-poor stocks include defining a proxy value for sustainable catch, e.g. average catch, possibly reduced to account for uncertainty in stock status. Advice regarding the extent of these reductions has been based on qualitative descriptions of stock status, such as “above B_{MSY},” or “overfished.” (Restrepo et al., 1998).

Recent legislation (NMFS, 2009) requires the regional fishery management councils in the United States to adopt annual catch limits (ACLs) for all stocks or stock complexes in their fishery management plans (FMP). This requirement provides an incentive to evaluate the basis for existing catch-based estimates of sustainable yield, and to consider ways to improve upon the existing framework. Here we evaluate two alternative methods for determining yield and management reference points for data-poor stocks, with applications to groundfish species in the northeast Pacific. Both methods use quantitative and explicit assumptions about the status of data-poor stocks to provide estimates of sustainable yield.

Depletion-corrected average catch (DCAC; MacCall, 2009) is an estimate of sustainable yield for data-poor stocks of uncertain status. DCAC adjusts historical average catch to account for one-time “windfall” catches that are the result of stock depletion, producing an estimate of yield that was likely to be sustainable over the same time period. Advantages of the DCAC approach to determining sustainable yield for data-poor stocks include: 1) minimal data requirements, 2) biologically-based adjustment to catch-based yield proxies with transparent assumptions about relative changes in abundance, and 3) simple to compute.

In this paper we also describe an alternative approach that combines concepts from DCAC with the modeling framework commonly referred to as stock reduction analysis (SRA) (Kimura and Tagart, 1982; Kimura et al., 1984). We also incorporate the stochastic approach for SRA introduced by Walters et al. (2006) and use Monte Carlo simulation to derive probability distributions of stock size and management reference points (MRPs). Walters et al. showed that they could reduce their uncertainty in past abundances by evaluating biomass trajectories that were consistent with historical catches, model assumptions, and an estimate of current absolute abundance. They also described likelihood and fully Bayesian approaches to SRA that are useful when time series of relative abundance are available.

We extend the stochastic SRA approach to estimate yield for data-poor stocks with uncertain status. Walters et al. (2006) used stochastic SRA to identify population trajectories that were consistent with an estimate of current absolute abundance for white sturgeon. Since abundance estimates are lacking for many data-poor stocks we borrow a key component of DCAC, assumed distributions of relative abundance in a given year, and evaluate the (conditional) sustainable yields. As with stochastic SRA, Monte Carlo simulations provide estimates of plausible trajectories, resulting in distributions of biomass (current and unfished) and other MRPs such as B_{MSY}, MSY, and the current OFL.

To evaluate model performance, we use data from 28 assessed stocks (northeast Pacific groundfish) and compare results from the traditional age-structured assessment models with the two data-poor methods described above.

Data and Methods

We compiled estimates of annual catch (metric tons, landed and discarded dead), natural mortality, and female age at 50% maturity from the most recent stock assessments for 28 species (Tables 1 and 2). When an assessment reported length-based maturity schedules, we used the length-at-age relationship from the assessment to approximate age at 50% maturity. We also constructed time series of catch through 2008 for all assessments by appending recent catch data, when necessary, from total mortality reports (e.g. Bellman et al., 2009) or using data from commercial and recreational landings databases (Table 3).

DCAC incorporates uncertainty in natural mortality (M), the ratio of F_{MSY} to M, and relative change in abundance (Δ) using Monte Carlo simulation. We extend this to account for uncertainty in the ratio of B_{MSY} to unfished biomass (henceforth referred to as K), setting the expected value of this ratio's distribution to 0.4 for rockfishes (genera *Sebastes* and *Sebastolobus*) and other roundfishes, and to 0.25 for flatfishes following the current target biomass proxies adopted by the Pacific Fishery Management Council (PFMC, citation). To facilitate comparison with stock assessment results, we set the expected value of the relative change in abundance (Δ) in the assessment year to the reported value ($1 - B_{asmt.\_yr} / K$). The only input distribution that does not vary among stocks in our analysis is the ratio of F_{MSY} to M for which we assume an expected value of 0.8, as suggested for demersal species in the northeastern Pacific by Walters and Martell (2007) (Table 4). Final runs were based on 10,000 independent draws from each distribution.

Estimation of sustainable yield using DCAC requires the sum of catches over many years. For each species we define this time period as the first year in which catches increased dramatically through 1999, the year when significant management actions were implemented in U.S. waters off the west coast (Table 4). Excluding early years with minimal catch and recent years when catches were largely constrained by regulations prevents estimates of DCAC (and average catch) from averaging over years with little fishing effort. In contrast, dynamic DCAC calculations are based on the entire time series of catch (described below).

For each set of draws from the input distributions, DCAC is

$$DCAC = \frac{\sum C_t}{n + \frac{\Delta}{\left(\frac{B_{MSY}}{K}\right)\left(\frac{F_{MSY}}{M}\right)(M)}} \tag{1}$$

where C_t is catch in year t, and n is the length of the catch time series in years. The uncertainty in the input distributions is propagated in the distribution of DCAC values, which we summarize for each species using quantiles and the mean. Importantly, this implementation of DCAC specifically assumes that biomass is approximately equal to K at the beginning of the time period.

Depletion-based stock reduction analysis

MacCall (2009) describes DCAC as a "one-parameter production model." It is likely to be sustainable if current abundance is not dramatically different from the period over which catches were summed. We now describe an approach (depletion-based SRA) that extends DCAC by 1) restoring the link between production and biomass, and 2) considering alternative hypotheses regarding changes in abundance during the historical catch period. This method combines DCAC's distributional assumptions regarding stock status with the dynamic models and simulation approach of stochastic stock reduction analysis (Walters et al., 2007).

Algorithm for specifying a hybrid Schaefer/Pella-Tomlinson-Fletcher model that is similar to a Beverton-Holt SRR driven production model

It has been conventional to assume a Beverton-Holt stock-recruitment relationship (BHSRR) for west coast groundfish stocks. Although it is possible to develop an explicit production model that is driven by BHSRR dynamics (e.g., Mangel et al., 2009), the required demographic data (e.g., growth, maturity, selectivity) are lacking or unreliable in most cases. In order to maintain consistency with data-rich assessments, we develop a generic delay-difference production model that closely mimics the properties of a BHSRR-driven demographic model while not requiring the detailed supporting data.

The following models are based on a delay-difference model of the form

$$B_t = B_{t-1} + P(B_{t-a}) - C_{t-1} \tag{2}$$

where B_t is biomass at time t, P is latent production based on a preceding biomass, C is catch, and a is age at reproductive maturity.

The BHSRR model

Mangel et al. (2009) explored the following model, which has the important shape properties of a BHSRR-driven production model (but is somewhat limited in generality, which is not a problem in the present application). Here the latent annual production (P) is expressed as an annual difference model rather than by a differential equation model as appears in Mangel et al. Because the BFSRR model is only used in equilibrium calculations, the delay terms are not needed.

$$P = \frac{\alpha B}{1+\beta B} - MB \quad (3)$$

where B is biomass, α and β are model parameters, and M is the natural mortality rate on an annual basis. Mangel et al. show that unfished biomass (K) is

$$K = \left(\frac{1}{\beta}\right)\left(\frac{\alpha}{M} - 1\right) \quad (4)$$

this has the solution

$$\beta = \frac{\alpha}{M} - 1 \quad (5)$$

if we want to scale the model to a value of K = 1.

We also want to specify a specific value $B_{peak} = B_{MSY}/K$, which in the special case of unit unfished biomass (K = 1) is given by

$$B_{peak} = \frac{\sqrt{\frac{\alpha}{M}-1}}{\frac{\alpha}{M}-1} \quad (6)$$

so that a value of α/M can be obtained for a given value of B_{peak}. An arbitrary value of M (such as 0.2) can be used, which establishes the value of α. The value of β is obtained from the solution of equation (5), so the production model (3) is fully specified, and the production to biomass ratio is

$$\frac{P}{B} = \frac{\alpha}{1+\beta B} - M. \quad (7)$$

The Pella-Tomlinson-Fletcher (PTF) model

Following the Fletcher (1978) reparameterization of the Pella-Tomlinson model (Pella and Tomlinson, 1969), again cast as an annual difference model, latent annual production is given by

$$P = gm\left(\frac{B_{t-a}}{K}\right) - gm\left(\frac{B_{t-a}}{K}\right)^n \quad (8)$$

where the exponent n (n>0) determines the skewness of the production curve and

$$g = \frac{n^{n/(n-1)}}{n-1} \quad (9)$$

is positive for n>1 and negative for n<1. The parameter m is the maximum sustainable yield (*MSY*), and as before, K is the unfished biomass. The equilibrium latent production to biomass ratio is

$$\frac{P}{B} = gmK^{-1} - gmB^{n-1}K^{-n}. \quad (10)$$

The hybrid model

As noted by McAllister et al. (2000), a major drawback of the generalized production model is that modeled productivity near the origin can be unrealistically high, especially when n<1 (i.e., B_{peak}<K/e). McAllister et al. recommended that the PTF model be used at values $B > B_{MSY}$, and that a Schaefer model be used for $0 < B < B_{MSY}$, with a "join-point" at B_{MSY}. We propose a join-point (B_{join}) that better approximates a BHSRR-driven model, based on a goodness of fit criterion.

Reversion to the Schaefer model for $B < B_{join}$ is based on the slope of production to biomass ratio (s) at the join point, which for the PTF model is

$$s = (1-n)gmB_{join}^{n-2}K^{-n} \tag{11}$$

and for $B_{t\text{-}a} < B_{join}$, the Schaefer model is

$$P = B_{t-a}\left(P\left(B_{join}\right)/B_{t-a} + s\left(B_{t-a} - B_{join}\right)\right) \tag{12}$$

The optimal value of B_{join} was chosen by means of a least-squares solution of the difference between the P/B values of BHSRR model and those of the Schaefer model evaluated at ten evenly-spaced locations on the interval [0.05K, B_{join}].

Algorithm for application of the depletion-based stock reduction analysis to catch and life history data

Application of depletion-based stock reduction analysis begins with the same set of input distributions as DCAC (M, F_{MSY}/M, B_{MSY}/K, and Δ). A single set of draws from each of these distributions are sufficient to fully specify the generalized production model given a catch history and an estimate of current relative abundance. The skewness parameter, n, is obtained numerically using the relationship in Fletcher (1978)

$$\frac{B_{MSY}}{K} = n^{1/1-n} \tag{13}$$

which also determines the value of g (equation 9). A "trial" estimate of F_{MSY} is obtained from the product of the current draws for M and the ratio of F_{MSY}/M. Given the current draw for Δ, a numerical search routine is employed to identify the value of K that is consistent with the time series of catch, production latency (time to maturity), and current assumptions about stock productivity (M, F_{MSY}/M, *and* B_{MSY}/K). This value of unfished biomass is found by minimizing the difference between (1-Δ) and the ratio of biomass in the target year to unfished biomass (assuming $K = B_1$). This process is repeated for several thousand draws from the input distributions.

As Walters et al. (2006) indicate, not all combinations of the input parameters will permit the model to match the assumed relative stock depletion in the target year. Trajectories that predict negative biomass in any year (stock extinction) are removed from the set of plausible runs, since abundance in the target year is assumed to be positive (but may be highly uncertain). From the trajectories that succeed in "threading the needle," as Walters et al. put it, we can obtain a distribution of B_{MSY} from the product of K and B_{MSY}/K, a distribution of MSY from the product of B_{MSY} and F_{MSY}, and a distribution of the current OFL from the product of F_{MSY} and current biomass.

We compiled estimates of MRPs and other output from the most recent stock assessment reports for each species (Table 5). Unfortunately, assessments conducted for the PFMC rarely document the model-estimated OFL in the assessment year (reporting the adopted OFL instead) because of a two-year lag between assessments and management. We plan to collect model output files and obtain current estimates of the OFL, which will allow for a more direct comparison with distributions of OFL obtained using depletion-based stock reduction analysis (DB-SRA).

MSY (SPR proxy) is consistently reported in west-coast assessments, allowing for comparison with both the DCAC and the DB-SRA approaches. We divided the distributions of DCAC and MSY (from DB-SRA) by the assessment's point estimate of MSY (SPR) for all species. We plot the re-scaled distributions against a reference line (unity) for comparison (Figures 1 and 2).

Other MRPs such as K ($B_{unfished}$), OFL in the assessment year, and BMSY are similarly comparable. Since MRPs such as MSY and BMSY may depend on the choice of proxy, or be model-estimated, we present results for each of these quantities for three species (canary rockfish, petrale sole, and northern vermillion rockfish). Comparison of OFLs, BMSY, and unfished biomass, all on a relative scale, are forthcoming.

Because not all combinations of input parameters provide plausible trajectories when conditioned on the model, landings, and relative abundance, it is informative to compare the values that did not generate negative biomass estimates versus those that did (Table 6).

[results are currently presented as tables and figures]

Tables and figures:

Table 1: Stock assessments for 28 species of Pacific groundfish compared with DCAC and Dynamic DCAC. Assessment documents are available from the Pacific Fishery Management Council's website (www.pcouncil.org).

Table 2 Catch (mt) from recent stock assessments (landings plus estimates of dead discard) by species and year. See Table 1 for species code definitions.

Table 3: Estimates of recent years' catch (mt) appended to time series of catch from stock assessments conducted in either 2005 or 2007.

Table 4: Parameters of input distributions and range of years for summed catches used in DCAC calculations. Standard deviations of the bounded (transformed) beta distributions are on the scale of the untransformed distribution.

Table 5: Management reference points and other quantities from stock assessments. Female spawning biomass, when available, was doubled to approximate output of DB-SRA model (total mature biomass, males + females). Summary biomass was used for general comparisons when spawning output was in units of eggs or larvae.

Table 6: Percentage of runs that resulted in an estimate of negative biomass for at least one year (based on 5000 iterations).

Table 7: Summary statistics for DCAC distributions, by species, based on 5000 simulations.

Figures 1-3: Comparison of DCAC to MSY (SPR proxy), average catch, and time series of catch, for canary rockfish, petrale sole, and northern vermilion rockfish

Figure 4: DCAC distributions for 28 assessed groundfish stocks, scaled relative to the assessment estimate for MSY (SPR proxy). Box-and-whisker plots characterize the median, inter-quartile range (IQR), and 95% intervals of the distributions

Figure 5: Distribution of DCAC simulations, integrated across 28 stocks, scaled relative to the assessment estimates for MSY (SPR proxy). The reference line at unity represents

agreement with the assessment's point estimate. Uncertainty in the assessment estimate of MSY is not considered.

Figure 6: Distribution of annual biomass estimates for canary rockfish from 5000 simulations of depletion-based stock reduction analysis (DB-SRA). Uncertainty in the assessment estimate of MSY is not considered.

Figure 7: DB-SRA estimates of MSY, OFL, unfished mature biomass (male & female), and BMSY for **canary rockfish**. Box and whisker plots characterize the median (thick vertical line), inter-quartile range (box), and 95% intervals ('whiskers'). Letters represent point estimates from the stock assessment, where S=SPR proxy, B=biomass target proxy, E=model-estimated, and integers represent summary biomass (integer=summary age)

Figure 8. DB-SRA estimates of MSY, OFL, unfished mature biomass (male & female), and BMSY for **petrale sole**. Box and whisker plots characterize the median (thick vertical line), inter-quartile range (box), and 95% intervals ('whiskers'). Letters represent point estimates from the stock assessment, where S=SPR proxy, B=biomass target proxy, E=model-estimated, and integers represent summary biomass (integer=summary age).

Figure 9. DB-SRA estimates of MSY, OFL, unfished mature biomass (male & female), and BMSY for **vermilion rockfish** (north). Box and whisker plots characterize the median (thick vertical line), inter-quartile range (box), and 95% intervals ('whiskers'). Letters represent point estimates from the stock assessment, where S=SPR proxy, B=biomass target proxy, E=model-estimated, and integers represent summary biomass (integer=summary age).

Figure 10. DB-SRA estimates of MSY for 26 species, scaled relative to MSY(SPR proxy) estimates from the most recent assessment. Box-and-whisker plots characterize the median, IQR, and 95% intervals of the distributions. The reference line at unity represents agreement with the assessment's point estimate. Uncertainty in the assessment estimate of MSY is not considered.

Figure 11: Distribution of MSY from DB-SRA, integrated across 28 stocks, scaled relative to the assessment estimates for MSY (SPR proxy). Uncertainty in the assessment estimate of MSY is not considered.

Figure 12: Frequency histograms of input distributions for canary rockfish; combined bar heights represent frequencies used in DCAC; shaded areas represent frequencies of runs retained (those with positive biomass trajectories) following DB-SRA.

Figure 13: Frequency histograms of input distributions for petrale sole; combined bar heights represent frequencies used in DCAC; shaded areas represent frequencies of runs retained (those with positive biomass trajectories) following DB-SRA.

Figure 14: Frequency histograms of input distributions for vermilion rockfish (north); combined bar heights represent frequencies used in DCAC; shaded areas represent frequencies of runs retained (those with positive biomass trajectories) following DB-SRA.

Table 1. Stock assessments for 28 species of Pacific groundfish compared with DCAC and Dynamic DCAC. Assessment documents are available from the Pacific Fishery Management Council's website (www.pcouncil.org).

Group	Common Name, Region	Scientific Name	Species Code	M [1/yr]	Age at Maturity	Assessment Year
Elasmobranch	Longnose skate	*Raja rhina*	LSKT	0.2	16	2007
Flatfish	Arrowtooth flounder	*Atheresthes stomias*	ARTH	0.166	8	2007
Flatfish	Dover sole	*Microstomus pacificus*	DOVR	0.09	7	2005
Flatfish	English sole	*Parophrys vetulus*	EGLS	0.26	4	2007
Flatfish	Petrale sole	*Eopsetta jordani*	PTRL	0.2	7	2009
Flatfish	Starry flounder, North	*Platichthys stellatus*	STRY_N	0.3	3	2005
Flatfish	Starry flounder, South	*Platichthys stellatus*	STRY_S	0.3	3	2005
Rockfish	Black Rockfish, North	*Sebastes melanops*	BLCK_N	0.24	10	2007
Rockfish	Black Rockfish, South	*Sebastes melanops*	BLCK_S	0.24	7	2007
Rockfish	Blackgill Rockfish	*Sebastes melanostomus*	BLGL	0.04	20	2005
Rockfish	Blue Rockfish	*Sebastes mystinus*	BLUR	0.1	6	2007
Rockfish	Bocaccio	*Sebastes paucispinis*	BCAC	0.15	3	2009
Rockfish	Canary Rockfish	*Sebastes pinniger*	CNRY	0.08	8	2009
Rockfish	Chilipepper	*Sebastes goodei*	CLPR	0.16	3	2007
Rockfish	Cowcod	*Sebastes levis*	CWCD	0.055	11	2009
Rockfish	Darkblotched Rockfish	*Sebastes crameri*	DBRK	0.07	7	2009
Rockfish	Gopher Rockfish	*Sebastes carnatus*	GPHR	0.2	4	2005
Rockfish	Longspine Thornyhead	*Sebastolobus altivelis*	LSPN	0.06	13	2005
Rockfish	Pacific Ocean Perch	*Sebastes alutus*	POP	0.05	8	2009
Rockfish	Shortspine Thornyhead	*Sebastolobus alascanus*	SSPN	0.05	10	2005
Rockfish	Splitnose Rockfish	*Sebastes diploproa*	SNOS	0.048	8	2009
Rockfish	Vermillion Rockfish, North	*Sebastes miniatus*	VRML_N	0.1	6	2005
Rockfish	Vermillion Rockfish, South	*Sebastes miniatus*	VRML_S	0.1	6	2005
Rockfish	Widow Rockfish	*Sebastes entomelas*	WDOW	0.125	12	2009
Rockfish	Yelloweye Rockfish	*Sebastes ruberrimus*	YEYE	0.047	15	2009
Roundfish	Lingcod, North	*Ophiodon elongatus*	LCOD_N	0.18	4	2009
Roundfish	Lingcod, South	*Ophiodon elongatus*	LCOD_S	0.18	4	2009
Roundfish	Sablefish	*Anoplopoma fimbria*	SABL	0.07	6	2007

Table 2. Catch (mt) from recent stock assessments (landings plus estimates of dead discard) by species and year. See Table 1 for species code definitions.

YEAR	ARTH	BCAC	BLCK_N	BLCK_S	BLGL	BLUR	CLPR	CNRY	CWCD	DBRK	DOVR	EGLS	GPHR	LCOD_N
1876												1.1		
1877												1.1		
1878												1.1		
1879												2.3		
1880												2.3		
1881												2.3		
1882												3.4		
1883												4.6		
1884												4.6		
1885												5.7		
1886												6.9		
1887												8.0		
1888												10.3		
1889												12.6		
1890												14.9		
1891												17.1		
1892		166.8					217.0					20.6		
1893		157.4					205.0					25.1		
1894		148.0					193.0					30.8		
1895		138.7					180.0					36.6		
1896		130.9					171.0					43.4		
1897		123.2					160.0					52.6		
1898		115.5					151.0					62.8		
1899		107.7					140.0					75.4		
1900		119.2					155.0		0.0			90.3		
1901		130.7					169.0		5.3			108.6		
1902		142.1					185.0		10.7			130.3		
1903		153.6					200.0		16.0			156.6		
1904		165.1					215.0		21.4			188.7		
1905		176.4					229.0		26.7			226.4		
1906		187.7					244.0		32.0			271.1		
1907		199.0					259.0		37.4			326.1		
1908		210.3					274.0		42.7			391.4		
1909		236.6					307.0		48.0			469.4		
1910		263.0					342.0		53.4			563.5		
1911		289.3					377.0		58.7		11.3	677.3		
1912		315.7					411.0		64.0		22.6	813.1		
1913		342.0					445.0		69.4		33.9	976.7		
1914		368.3					479.0		74.7		45.2	1172.9		
1915		394.7		0.0			514.0		80.0		56.5	1408.7		
1916	0.0	473.9		2.9		0.4	666.0	36.9	85.4		63.1	2825.9		
1917	0.0	747.3		5.9		2.9	819.0	58.9	137.7		172.0	3864.8		
1918	0.0	798.5		8.8		5.3	973.0	61.3	125.6		207.7	3131.8		
1919	0.0	529.3		11.7		6.6	637.0	38.6	75.1		217.9	2475.2		
1920	0.0	550.3		14.7		8.8	664.0	40.8	81.6		188.3	1714.6		
1921	0.0	462.7		17.6		10.4	562.0	35.1	71.3		287.9	2184.2		
1922	0.0	416.7		20.5		12.1	508.0	32.2	70.1		485.8	3158.5		
1923	0.0	489.3		23.5		14.6	601.0	38.6	93.9		558.5	3185.8		
1924	0.0	442.4		26.4		16.3	560.0	40.4	125.9		783.5	4110.3		
1925	0.0	505.4		29.3		18.9	647.0	46.8	138.2		863.5	4017.6		
1926	0.0	711.1		32.3		22.0	889.0	62.5	171.5		852.5	3865.3		
1927	0.0	610.1		35.2		23.4	754.0	56.1	142.3		1032.8	4690.4		
1928	0.0	639.1		34.4		26.7	738.5	62.3	111.4	18.1	1013.5	4143.5		46.1
1929	5.6	597.4		63.1		27.9	659.4	74.0	102.6	20.3	1158.2	4811.1		142.3
1930	1.8	714.8		62.5		32.7	822.3	79.2	126.9	22.1	1078.3	3732.4		113.2
1931	1.8	688.6		55.5		34.0	830.3	87.8	161.0	26.1	929.4	1927.5		61.1
1932	12.4	555.9		41.7		34.5	655.9	63.7	109.5	16.4	886.3	3540.5		68.1
1933	7.8	429.1		35.4		35.6	568.5	60.0	82.0	16.0	825.6	3346.4		104.2
1934	5.2	493.7		45.5		37.6	530.7	60.7	70.7	16.3	872.8	2844.9		76.1
1935	10.4	533.5		53.3		42.0	571.1	71.9	53.0	17.4	896.6	3226.5		72.1
1936	33.7	631.6		60.5		46.3	583.2	65.9	20.6	11.4	840.1	3403.6		104.2
1937	147.8	588.7		53.7		50.6	537.4	73.7	24.9	13.9	942.7	3159.0		75.1
1938	7.5	460.9		55.0		48.6	394.3	74.2	18.7	16.5	782.4	2543.2		158.3
1939	453.2	372.7		67.9		42.3	318.2	78.7	22.0	23.2	1330.3	2991.3		163.3
1940	640.5	382.1	6.0	64.0		59.2	386.1	133.3	23.7	23.2	1263.5	3038.0		232.4
1941	846.3	308.3	13.8	61.1		11.6	359.8	197.9	29.5	27.4	1215.6	2202.4		629.1

Table 2 (Continued). Catch (mt) from recent stock assessments.

YEAR	ARTH	BCAC	BLCK_N	BLCK_S	BLGL	BLUR	CLPR	CNRY	CWCD	DBRK	DOVR	EGLS	GPHR	LCOD_N
1942	411.9	124.4	21.5	58.6		5.1	107.3	303.8	10.6	19.8	1574.4	2064.4		518.0
1943	1716.9	292.1	29.3	157.7		6.6	155.1	1032.0	12.4	84.4	3944.4	3638.5		677.3
1944	407.3	736.6	37.0	249.2		15.6	219.4	1523.4	2.0	221.6	1578.9	2140.6		1298.5
1945	113.4	1413.0	44.8	458.7		49.1	434.2	3253.2	4.6	472.4	2250.3	1886.6		802.6
1946	166.9	879.7	52.5	396.9		55.9	380.0	2046.4	11.7	274.8	2962.5	4998.2		890.8
1947	425.4	889.7	67.1	277.3		67.8	346.6	1135.3	18.8	253.3	2377.3	3333.6		348.7
1948	936.2	765.6	68.0	204.0		82.9	347.3	1080.8	29.9	138.0	5257.7	6029.6		547.1
1949	1165.5	827.8	75.8	187.8		97.5	368.5	1142.9	38.7	144.3	5563.4	3546.0		1253.5
1950	202.0	1216.4	85.0	220.5	162.0	122.2	576.0	1228.3	44.0	156.6	8133.9	5673.2		957.0
1951	345.0	1758.7	93.8	257.2	220.0	137.4	869.5	1044.2	49.2	211.0	8648.1	4188.7		1102.3
1952	390.0	1966.4	102.5	201.6	214.0	116.5	1054.7	963.4	36.7	188.7	9737.0	3824.5		861.8
1953	1322.0	2271.0	111.3	205.8	244.0	101.2	1207.2	661.2	31.2	176.4	5994.7	2910.8		479.0
1954	80.0	2401.8	120.0	241.6	253.0	112.2	1215.0	792.5	46.8	182.5	6873.5	2623.3		804.7
1955	339.0	3052.8	128.8	246.3	253.0	132.2	1380.7	807.7	52.1	234.6	6356.6	2828.8		1400.0
1956	5123.0	3650.3	137.5	183.7	285.0	149.6	1643.3	633.9	65.2	293.1	6530.7	3786.8		995.2
1957	3715.0	3566.3	146.3	210.7	318.0	148.4	1686.7	1115.2	55.7	331.5	6216.1	4436.0		1180.6
1958	3193.0	3580.0	155.0	286.8	356.0	246.4	1888.6	1039.4	56.4	302.3	5854.5	5520.2		1134.5
1959	3489.0	2847.1	163.8	272.5	305.0	205.1	1593.2	1068.6	52.3	276.3	6570.7	5427.1		1747.8
1960	2998.0	2435.8	172.5	264.6	274.0	154.2	1443.5	1188.1	57.1	311.5	8145.3	4337.6		2175.8
1961	3558.0	1924.3	181.3	191.0	216.0	123.1	1145.7	1124.6	60.0	271.7	6640.5	4187.8		1967.0
1962	3235.0	1730.5	190.0	204.6	196.0	134.5	1118.1	1270.5	48.0	330.4	7619.3	4496.1		1280.8
1963	3029.0	2008.5	198.8	258.1	235.0	135.7	1077.3	975.6	57.3	354.8	8440.1	4489.3		949.9
1964	3318.0	1522.8	168.3	202.7	162.0	105.7	883.5	810.0	51.9	245.1	7905.3	4742.0		1216.0
1965	2762.0	1745.7	249.1	285.7	188.0	162.0	993.3	1111.0	70.1	448.5	7628.2	5042.7	19.2	1552.6
1966	2848.0	3418.3	299.8	265.5	272.0	175.1	2182.3	2988.6	76.6	4193.8	7457.4	5522.5	19.2	1495.9
1967	2600.0	5330.5	190.6	296.7	395.0	171.7	2796.0	1428.3	102.4	3087.0	5683.4	5191.7	19.2	2119.3
1968	2282.0	3405.2	332.3	305.3	212.0	303.9	1775.0	1619.0	105.0	2437.8	7032.6	5468.3	19.2	2164.6
1969	2359.0	2346.6	377.1	399.5	155.0	291.3	1090.4	1535.1	125.1	258.9	10178.6	3788.1	31.0	1518.2
1970	2169.0	2846.0	206.9	470.6	181.0	391.0	1272.6	1486.5	95.8	268.0	11375.5	3102.4	17.4	1056.5
1971	2177.0	2496.8	202.4	369.7	231.0	347.6	1253.0	1602.0	106.1	445.9	11095.9	2851.0	8.7	1196.9
1972	2604.0	3653.0	133.6	470.9	280.0	475.6	1899.3	1676.3	152.6	601.5	15299.5	3300.5	19.3	1170.9
1973	3060.0	7201.0	186.8	480.4	331.0	726.6	3644.4	2316.7	171.8	845.1	14721.8	3772.8	19.8	1631.4
1974	2910.0	9001.1	255.2	589.6	380.0	838.9	3960.4	1841.6	183.6	741.0	13508.1	3858.0	28.1	1805.2
1975	2758.0	6403.6	442.2	479.6	431.0	830.8	3227.8	1835.3	182.5	573.2	15016.2	4578.9	59.2	1811.0
1976	3065.0	6176.9	104.0	642.6	480.0	698.7	3091.9	1476.6	189.3	580.3	16406.9	5754.8	62.9	1738.3
1977	2585.0	4860.5	261.8	637.8	531.0	640.3	2091.2	2167.0	191.2	265.9	15380.0	3735.2	39.3	1573.4
1978	3250.0	4366.7	519.5	659.0	571.0	545.1	1933.5	3073.5	203.2	414.5	16411.2	4510.9	77.8	1423.4
1979	4107.0	6116.1	285.8	967.0	884.0	706.2	2724.9	3483.9	262.1	1002.2	20900.7	4710.4	60.9	2216.1
1980	3199.0	5384.3	439.6	898.7	822.0	538.9	3255.0	3995.9	223.6	562.7	17861.4	4142.8	114.2	2246.7
1981	3351.0	5752.3	527.8	1344.9	1061.0	865.6	2776.4	3532.4	224.1	966.9	20180.3	3780.0	94.4	2307.3
1982	5074.0	6598.6	597.3	1455.3	1341.0	768.8	2491.9	5543.6	325.5	1130.0	25019.3	3833.3	69.8	3159.4
1983	4608.0	5597.8	609.0	1303.5	1035.0	717.2	2464.7	4918.5	141.7	953.1	23306.4	3090.9	38.0	3453.1
1984	4751.0	4676.2	701.5	1206.9	623.0	481.8	2922.5	2405.2	242.4	1292.0	21790.5	2457.5	51.3	3216.8
1985	5228.0	2863.6	566.9	1134.8	758.0	432.7	3182.4	2729.7	240.7	1810.2	22710.7	2955.2	47.7	3403.1
1986	4337.0	3120.6	693.2	767.4	977.0	140.3	3147.5	2303.0	193.0	1278.8	18787.5	3152.5	52.8	1586.5
1987	5192.0	2648.6	647.6	591.4	885.0	267.1	2059.3	3180.6	105.8	2441.2	19935.3	3978.7	51.0	2053.2
1988	4024.0	2304.3	703.9	616.8	1042.0	314.9	2690.8	3073.8	100.5	1669.0	19665.0	3421.7	83.1	2023.5
1989	5834.0	2756.2	532.3	798.8	547.0	276.3	3395.4	3335.3	38.0	1287.1	20372.9	3780.3	68.9	2521.0
1990	7802.0	2624.4	516.8	882.1	694.0	252.7	3110.2	2803.6	32.0	1669.5	17041.0	2906.6	159.4	1989.1
1991	7033.0	1713.8	536.0	962.5	484.0	223.7	3310.5	3207.1	28.0	1224.1	19835.5	3339.1	184.2	2525.6
1992	5380.0	1832.0	478.1	1269.3	789.0	675.0	2753.2	2866.5	37.9	697.0	17454.7	2555.8	206.5	1528.2
1993	4346.0	1593.0	424.2	868.9	407.0	509.0	2392.9	2235.4	24.5	1208.4	15711.1	2534.1	208.6	1739.4
1994	4482.0	1294.2	427.7	842.9	382.0	374.6	1877.0	1217.9	39.6	873.7	10331.8	1817.5	158.6	1586.2
1995	3594.0	818.0	273.4	847.3	357.0	244.8	2020.7	1196.4	25.1	791.0	11744.1	1761.7	114.5	1068.7
1996	3570.0	547.4	288.2	850.5	376.0	208.1	1870.3	1558.8	29.9	738.6	13043.2	1539.8	89.2	1222.5
1997	3569.0	498.4	312.0	814.3	277.0	359.8	2109.7	1480.1	9.2	837.2	10861.1	1911.0	80.0	1223.8
1998	4084.0	211.1	263.7	754.7	236.0	297.1	1429.8	1495.0	4.0	964.4	8574.6	1441.0	75.6	460.2
1999	6578.0	213.1	222.8	703.2	49.0	234.4	976.8	898.7	7.2	371.7	9737.7	1245.1	83.5	509.0
2000	4523.0	160.5	225.9	655.4	89.0	166.3	499.0	199.8	4.9	413.5	9294.7	1060.7	91.3	238.9
2001	3619.0	138.9	190.4	876.0	134.0	135.3	517.4	133.0	0.5	274.4	7291.6	1362.8	144.3	262.2
2002	3318.0	89.7	239.2	689.1	143.0	167.3	328.9	98.1	0.5	178.9	6675.1	1682.6	108.2	408.5
2003	3412.0	12.8	238.4	1060.9	189.0	229.1	20.6	59.9	0.5	127.3	7815.4	1124.8	147.1	397.7
2004	3317.0	85.1	268.9	686.5	168.0	164.7	235.8	50.3	0.5	252.0	7145.3	1218.0	50.3	385.4
2005	3015.0	107.3	334.3	717.7		184.6	192.1	60.4	0.5	129.2		1114.7		438.7
2006	2407.0	59.7	323.3	627.2		341.5	126.7	62.0	0.5	200.4		1078.1		512.4
2007		62.5						44.7	0.5	264.3				494.2
2008		78.1						40.5	0.5	213.4				506.2

Table 2 (Continued). Catch (mt) from recent stock assessments.

YEAR	LCOD_S	LSKT	LSPN	POP	PTRL	SABL	SNOS	SSPN	STRY_N	STRY_S	VRML_N	VRML_S	WDOW	YEYE
1876					1.0									
1877					1.0									
1878					1.0									
1879					1.0									
1880					11.6									
1881					22.2									
1882					32.7									
1883					43.3									
1884					53.9									
1885					64.5									
1886					75.0									
1887					85.6									
1888					96.2									
1889					106.8									
1890					117.4									
1891					127.9									
1892					138.5									
1893					149.1									
1894					159.7									
1895					170.3									
1896					180.8									
1897					191.4									
1898					202.0									
1899					212.6									
1900					223.2									
1901					233.7	54.4	5.0	2.6						
1902					244.3	108.8	12.0	2.6						
1903					254.9	163.2	17.0	5.2						
1904					265.5	217.5	22.0	6.5						
1905					276.1	271.9	28.0	7.8						
1906					286.6	326.3	33.0	10.4						
1907					297.2	380.7	38.0	11.7						
1908					307.8	435.1	44.0	13.0						
1909					318.4	489.5	49.0	14.3						
1910					330.0	543.9	54.0	16.9						
1911					340.5	598.3	59.0	18.1						
1912					351.1	652.7	66.0	19.4						
1913					361.7	707.1	70.0	22.0						
1914					372.3	761.5	75.0	22.0						
1915					382.9	815.9	82.0	24.6			74.0	121.0		
1916		19.6			388.5	870.3	87.0	25.9			74.0	121.0	82.7	2.2
1917		39.2			528.9	924.6	137.0	27.2			74.0	121.0	128.8	3.6
1918		58.9			426.0	979.0	139.0	29.8			74.0	121.0	148.1	4.3
1919		78.5			335.4	1033.4	88.0	31.1			74.0	121.0	102.1	2.2
1920		98.1			232.1	1087.8	93.0	32.4			74.0	121.0	104.5	2.4
1921		117.7			295.6	1142.2	79.0	33.7			74.0	121.0	86.6	2.3
1922		137.3			427.0	1196.6	73.0	36.3			74.0	121.0	75.1	2.1
1923		157.0			429.6	1251.0	91.0	37.6			74.0	121.0	82.5	2.2
1924		176.6			535.4	1305.4	99.0	38.9			74.0	121.0	52.8	2.8
1925		196.2			531.0	1359.9	111.0	41.5			74.0	121.0	65.5	4.9
1926		215.8			524.1	1414.3	149.0	41.5			74.0	121.0	99.9	5.9
1927		235.5			634.8	1468.7	128.0	44.1			74.0	121.0	82.8	6.9
1928	389.6	255.1			621.9	1523.1	124.0	45.4			74.0	121.0	95.0	6.6
1929	535.5	274.7			711.2	1577.5	120.0	46.7			74.0	121.0	92.6	7.6
1930	593.8	294.3			661.7	1631.9	134.0	49.3			74.0	121.0	120.2	9.1
1931	570.6	313.9			678.2	1686.3	151.0	50.6			74.0	121.0	108.1	8.5
1932	414.6	333.6			810.9	1740.7	88.0	51.9			74.0	121.0	109.3	11.5
1933	654.2	353.2			849.2	2122.5	81.0	63.5			74.0	121.0	95.0	8.5
1934	408.6	372.8			1621.3	2473.2	78.0	63.6			74.0	121.0	101.3	10.4
1935	484.1	392.4			1606.1	2809.8	87.0	63.6			74.0	121.0	108.9	13.2
1936	368.3	412.0			1323.2	1846.5	67.0	66.1			74.0	121.0	121.2	14.0
1937	478.9	431.7			1897.2	1933.6	60.0	61.0			74.0	121.0	114.3	13.0
1938	396.3	451.3			2167.8	1698.1	62.0	68.7			74.0	121.0	96.7	13.1
1939	323.7	470.9			2405.4	1971.5	69.0	81.7			74.0	121.0	86.3	12.4
1940	378.1	490.5			2449.5	1603.2	60.0	98.6			74.0	121.0	98.1	13.5
1941	300.6	510.1			2226.2	1470.4	60.0	141.4			74.0	121.0	88.2	14.8

Table 2 (Continued). Catch (mt) from recent stock assessments.

YEAR	LCOD_S	LSKT	LSPN	POP	PTRL	SABL	SNOS	SSPN	STRY_N	STRY_S	VRML_N	VRML_S	WDOW	YEYE
1942	174.9	529.8			3419.7	2275.6	27.0	158.3			74.0	121.0	51.1	14.3
1943	358.1	549.4			3613.5	2988.7	80.0	349.0			74.0	121.0	153.4	25.8
1944	365.2	569.0			2821.7	3527.2	128.0	493.1			74.0	121.0	372.1	52.8
1945	351.1	588.6			2592.7	3758.0	236.0	587.8			74.0	121.0	721.4	97.2
1946	584.4	608.3			3933.8	3159.1	174.0	280.3			74.0	121.0	609.4	85.8
1947	1086.8	627.9			3203.8	1405.3	114.0	62.3			74.0	121.0	294.2	33.7
1948	1129.0	647.5			4371.4	2072.5	126.0	197.3			74.0	121.0	266.8	42.2
1949	951.8	667.1			4067.9	2178.8	103.0	218.1			74.0	121.0	203.2	31.9
1950	1053.8	367.6			4551.8	1835.4	181.0	198.7			70.0	121.0	236.7	34.6
1951	1015.5	264.3			3015.6	2910.0	245.0	396.1			75.0	121.0	391.5	42.1
1952	775.3	298.9			2807.1	1665.3	254.0	228.6			65.0	121.0	370.6	37.4
1953	534.9	913.7			2224.4	1036.8	546.0	88.4			59.0	121.0	332.7	31.8
1954	596.9	333.5			2846.5	1845.4	798.0	166.3			61.0	121.0	263.4	37.9
1955	628.0	948.8			2805.8	1845.4	587.0	166.4			66.0	121.0	280.4	46.9
1956	690.9	422.0		2231.0	2201.1	3718.4	891.0	1008.8			62.0	121.0	430.8	51.2
1957	1066.1	365.2		2442.0	2783.9	3012.3	765.0	371.9			64.0	121.0	454.1	59.5
1958	1046.8	379.9		1587.0	2348.3	1846.2	612.0	385.0			74.0	121.0	529.4	69.4
1959	895.3	517.3		1958.0	2526.5	2731.1	901.0	517.8			67.0	121.0	423.6	61.8
1960	791.9	315.9		2364.0	2562.0	3561.8	1224.0	614.2			67.0	121.0	387.3	55.1
1961	849.3	1568.4		4149.0	3087.7	2601.3	1003.0	568.8			54.0	121.0	323.2	46.2
1962	700.3	878.7		5793.0	2615.8	3143.1	755.0	299.5			56.0	121.0	366.8	52.9
1963	700.3	994.7		6788.0	2649.1	2195.4	638.0	371.2			54.0	121.0	438.1	57.8
1964	585.6	972.5	15.0	5807.0	2246.6	2615.0	409.0	240.3			58.0	121.0	510.0	52.5
1965	672.5	553.3	34.5	8063.0	2365.1	2597.6	559.0	548.3			65.0	121.0	266.1	63.9
1966	799.6	681.6	24.2	18761.0	2137.2	1723.5	5243.0	1534.5			78.0	121.0	4379.0	70.5
1967	884.1	677.4	11.5	13289.0	2153.2	4563.0	5527.0	1625.3			89.0	121.0	5099.9	69.4
1968	933.8	1191.8	11.5	7262.0	1944.6	3018.8	3121.0	2621.1			85.0	121.0	2447.0	74.1
1969	896.6	771.6	33.4	1197.0	1907.0	5788.3	319.0	731.8			90.0	121.0	550.1	99.6
1970	1288.0	428.2	48.3	2177.0	2654.6	4049.3	278.0	929.1	599.0	241.0	99.0	121.0	628.8	109.1
1971	1602.5	186.6	50.6	1951.0	2590.9	4351.1	227.0	1112.6	585.0	219.0	95.0	112.0	785.1	120.8
1972	2314.0	288.0	94.4	1558.0	2932.1	7484.5	298.0	2223.2	1301.0	458.0	109.0	137.0	524.0	159.4
1973	2495.8	294.2	107.0	2145.0	2457.5	5956.3	677.0	4076.4	1424.0	507.0	132.0	154.0	949.4	155.7
1974	2622.6	287.5	88.6	1800.0	3073.3	8963.8	421.0	1921.6	1149.0	366.0	122.0	176.0	693.4	170.9
1975	2422.5	325.4	113.9	1152.0	3190.0	11055.8	486.0	2999.0	1577.0	484.0	115.0	128.0	957.7	166.8
1976	2417.8	891.9	62.1	1677.0	2595.4	24833.9	471.0	1373.6	2514.0	763.0	110.0	105.0	1590.7	195.7
1977	1536.6	898.1	117.4	1242.0	2048.7	9474.3	462.0	1911.1	2171.0	644.0	94.0	199.0	2811.0	200.1
1978	1838.9	1453.7	216.4	2120.0	2573.3	13957.6	573.0	1599.8	1715.0	546.0	66.0	180.0	1931.2	310.1
1979	2483.4	1542.8	302.7	1952.0	2813.1	24791.0	503.0	2417.5	1770.0	656.0	80.0	211.0	3607.6	317.8
1980	2769.9	998.5	411.0	1965.0	2161.0	9373.0	669.0	1693.9	1424.0	560.0	139.0	250.0	23167.4	259.6
1981	2454.7	3212.7	128.9	1720.0	2201.9	11793.6	899.0	2290.0	1592.0	435.0	46.0	245.0	28678.4	364.3
1982	2269.8	2165.5	474.3	1242.0	2363.8	18998.2	669.0	2546.8	1255.0	324.0	110.0	368.0	27798.7	421.3
1983	1514.8	1676.6	339.7	2215.0	2728.9	14849.8	1149.0	3078.9	976.0	364.0	99.0	172.0	12296.2	366.0
1984	1461.1	862.6	426.0	1959.0	2021.3	14007.5	1477.0	3773.7	575.0	379.0	103.0	343.0	11821.3	251.3
1985	1685.6	1242.9	839.4	1792.0	1717.1	14271.7	1683.0	4557.1	985.0	356.0	99.0	295.0	10762.6	288.0
1986	1468.4	1026.1	845.3	1653.0	1786.8	13479.8	1134.0	3919.6	513.0	275.0	120.0	421.0	11159.0	227.8
1987	1817.6	1177.5	1379.9	1305.0	2457.9	12987.0	676.0	3454.9	574.0	240.0	166.0	287.0	15055.5	251.3
1988	2079.6	759.7	3180.3	1645.0	2318.4	11025.1	876.0	3127.6	742.0	216.0	198.0	222.0	12210.7	279.5
1989	2252.0	838.3	3671.3	1706.0	2244.9	10532.2	741.0	5274.5	1038.0	153.0	131.0	313.0	14550.2	346.9
1990	1862.0	661.0	6856.8	1230.0	1893.1	9303.7	886.0	4476.0	719.0	94.0	236.0	296.0	11940.1	237.4
1991	1610.8	563.9	3449.2	1659.0	2054.2	9674.6	1135.0	3825.8	1141.0	89.0	287.0	328.0	7657.0	368.0
1992	1416.5	334.1	6375.6	1306.0	1719.2	9511.1	688.0	3653.0	439.0	78.0	326.0	291.0	7368.3	372.8
1993	1172.1	523.1	6250.3	1500.0	1687.4	8237.0	970.0	4173.6	466.0	49.0	392.0	253.0	9706.3	318.7
1994	836.2	735.5	5380.7	1176.0	1542.0	7631.4	862.0	3726.2	250.0	28.0	248.0	383.0	7701.4	223.4
1995	836.5	367.4	6540.7	965.0	1666.7	7952.6	772.0	2336.3	280.0	25.0	153.0	278.0	7976.5	254.6
1996	851.3	1474.0	5752.4	938.0	1905.2	8426.3	866.0	1943.5	227.0	41.0	135.0	239.0	7304.7	217.7
1997	787.1	2685.5	4719.7	751.0	2055.5	8033.8	1047.0	1783.4	203.0	65.0	131.0	93.0	7756.8	244.1
1998	509.3	1220.2	2670.7	739.0	1763.6	4404.4	2780.0	1498.2	292.0	90.0	155.0	143.0	4865.5	107.0
1999	589.1	1835.4	2136.4	593.0	1623.2	6651.6	500.0	1001.5	145.0	69.0	124.0	169.0	4768.4	155.8
2000	300.1	2108.3	1797.2	171.0	1894.7	6294.9	245.0	1036.8	145.0	45.0	91.0	99.0	4663.6	40.9
2001	286.6	1342.3	1438.0	307.0	1986.6	5884.6	211.0	676.1	68.0	78.0	89.0	51.0	2279.0	56.1
2002	688.1	487.6	2287.5	177.8	2088.2	3926.8	125.0	960.2	60.0	47.0	88.0	66.0	431.6	15.8
2003	1115.1	1323.0	1869.1	145.2	1792.9	5450.6	320.0	1014.1	64.0	48.0	210.0	119.0	43.0	12.4
2004	241.3	581.5	911.6	149.8	2275.5	5798.0	383.0	866.7	121.0	48.0	82.0	172.0	100.7	12.3
2005	401.8	959.1		80.6	2951.4	5757.9	210.0						199.4	15.1
2006	449.5	1157.1		82.1	2176.4	5524.3	610.0						215.1	12.4
2007	300.3			155.7	2373.0		154.0						258.5	19.6
2008	212.3			106.0	2115.0		149.0						242.8	16.7

Table 3. Estimates of recent years' catch (mt) appended to time series of catch from stock assessments conducted in either 2005 or 2007.

		Year			
Source	Species Code	2005	2006	2007	2008
Total Mortality Reports	ARTH			3099.0	3409.0
	BLCK_N			260.0	156.0
	BLCK_S			577.0	593.0
	BLGL	90.0	123.0	51.0	72.0
	CLPR			128.0	151.0
	DOVR	7507.0	7730.0	10227.0	11820.0
	EGLS			914.0	436.0
	GPHR			55.0	67.0
	LSPN	750.0	854.0	928.0	1463.0
	SABL			5545.0	6078.0
	SSPN	796.0	853.0	1194.0	1485.0
CALCOM and	BLUR			153.7	110.4
RecFIN (A+B1)	GPHR	62.6	61.6		
	STRY_S	38.6	20.1	13.4	10.6
	VRML_N	174.2	168.4	135.9	70.6
	VRML_S	158.6	55.6	81.8	47.0
PacFIN and RecFIN	STRY_N	21.0	50.8	8.1	3.2
Avg. of 2005-2006 catch	LSKT			1058.0	1058.0

Table 4. Parameters of input distributions and range of years for summed catches used in DCAC calculations. Standard deviations of the bounded (transformed) beta distributions are on the scale of the untransformed distribution.

	Natural Mortality (M, 1/yr)		F_{MSY} / M		Relative Abundance Change (Δ)			B_{MSY} / B_0				
	Lognormal Distribution		Lognormal Distribution		Beta Distribution (bounded)			Beta Distribution (bounded)			DCAC time period	
Species Code	Mean, E{M}	SD{ln(M)}	Mean, E{F_{MSY}/M}	SD{ln(FMSY/M)}	Mean, E{Δ}	SD{Δ}	Bounds (upper, lower)	Mean, E{B_{MSY}/B_0}	SD{B_{MSY}/B_0}	Bounds (upper, lower)	Start Year	End Year
ARTH	0.166	0.4	0.8	0.1	0.21	0.1	(0.01, 0.99)	0.25	0.05	(0.05, 0.95)	1956	1999
BCAC	0.15	0.4	0.8	0.1	0.72	0.1	(0.01, 0.99)	0.4	0.05	(0.05, 0.95)	1943	1999
BLCK_N	0.24	0.4	0.8	0.1	0.47	0.1	(0.01, 0.99)	0.4	0.05	(0.05, 0.95)	1940	1999
BLCK_S	0.24	0.4	0.8	0.1	0.3	0.1	(0.01, 0.99)	0.4	0.05	(0.05, 0.95)	1942	1999
CLPR	0.16	0.4	0.8	0.1	0.29	0.1	(0.01, 0.99)	0.4	0.05	(0.05, 0.95)	1942	1999
CNRY	0.08	0.4	0.8	0.1	0.76	0.1	(0.01, 0.99)	0.4	0.05	(0.05, 0.95)	1943	1999
DBRK	0.07	0.4	0.8	0.1	0.73	0.1	(0.01, 0.99)	0.4	0.05	(0.05, 0.95)	1943	1999
EGLS	0.26	0.4	0.8	0.1	0.05	0.1	(0.01, 0.99)	0.25	0.05	(0.05, 0.95)	1910	1999
POP	0.05	0.4	0.8	0.1	0.71	0.1	(0.01, 0.99)	0.4	0.05	(0.05, 0.95)	1956	1999
PTRL	0.2	0.4	0.8	0.1	0.88	0.1	(0.01, 0.99)	0.25	0.05	(0.05, 0.95)	1920	1999
WDOW	0.125	0.4	0.8	0.1	0.62	0.1	(0.01, 0.99)	0.4	0.05	(0.05, 0.95)	1979	1999
YEYE	0.047	0.4	0.8	0.1	0.6	0.1	(0.01, 0.99)	0.4	0.05	(0.05, 0.95)	1943	1999
CWCD	0.055	0.4	0.8	0.1	0.95	0.1	(0.01, 0.99)	0.4	0.05	(0.05, 0.95)	1901	1999
BLGL	0.04	0.4	0.8	0.1	0.48	0.1	(0.01, 0.99)	0.4	0.05	(0.05, 0.95)	1950	1999
BLUR	0.1	0.4	0.8	0.1	0.7	0.1	(0.01, 0.99)	0.4	0.05	(0.05, 0.95)	1945	1999
DOVR	0.09	0.4	0.8	0.1	0.37	0.1	(0.01, 0.99)	0.25	0.05	(0.05, 0.95)	1940	1999
GPHR	0.2	0.4	0.8	0.1	0.03	0.1	(0.01, 0.99)	0.4	0.05	(0.05, 0.95)	1965	1999
LSKT	0.2	0.4	0.8	0.1	0.34	0.1	(0.01, 0.99)	0.4	0.05	(0.05, 0.95)	1916	1999
LSPN	0.06	0.4	0.8	0.1	0.29	0.1	(0.01, 0.99)	0.4	0.05	(0.05, 0.95)	1982	1999
LCOD_N	0.18	0.4	0.8	0.1	0.38	0.1	(0.01, 0.99)	0.4	0.05	(0.05, 0.95)	1941	1999
LCOD_S	0.18	0.4	0.8	0.1	0.26	0.1	(0.01, 0.99)	0.4	0.05	(0.05, 0.95)	1928	1999
SABL	0.07	0.4	0.8	0.1	0.64	0.1	(0.01, 0.99)	0.4	0.05	(0.05, 0.95)	1967	1999
SSPN	0.05	0.4	0.8	0.1	0.34	0.1	(0.01, 0.99)	0.4	0.05	(0.05, 0.95)	1956	1999
SNOS	0.048	0.4	0.8	0.1	0.34	0.1	(0.01, 0.99)	0.4	0.05	(0.05, 0.95)	1949	1999
STRY_N	0.3	0.4	0.8	0.1	0.56	0.1	(0.01, 0.99)	0.25	0.05	(0.05, 0.95)	1970	1999
STRY_S	0.3	0.4	0.8	0.1	0.38	0.1	(0.01, 0.99)	0.25	0.05	(0.05, 0.95)	1970	1999
VRML_N	0.1	0.4	0.8	0.1	0.35	0.1	(0.01, 0.99)	0.4	0.05	(0.05, 0.95)	1962	1999
VRML_S	0.1	0.4	0.8	0.1	0.41	0.1	(0.01, 0.99)	0.4	0.05	(0.05, 0.95)	1970	1999

Table 5. Management reference points and other quantities from stock assessments. Female spawning biomass, when available, was doubled to approximate output of DB-SRA model (total mature biomass, males + females). Summary biomass was used for general comparisons when spawning output was in units of eggs or larvae.

group	species.code	MSY_SPR_proxy	MSY_Btarget_proxy	MSY_estimated	SSBatMSY_SPR	SSBatMSY_Btarget	SSBatMSY_estimated	SSB_assmt_yr	SSB_2009	SSBunfished	SummaryAge	SummaryBioUnfished	OFL_assmt_yr	OFL_2009	Depl_assmt_yr
Flatfish	ARTH	5245	5148	5844	30780	32125	16593	63302	65625	80313	3	98022	NA	11267	0.79
Rockfish	BCAC	1258	1250	1270	NA	NA	NA	NA	NA	NA	1	44070	831	831	0.28
Rockfish	BLCK_N	408	408	423	NA	NA	NA	NA	NA	NA	3	11390	535	505	0.53
Rockfish	BLCK_S	1035	1035	1065	NA	NA	NA	NA	NA	NA	2	29100	NA	1454	0.7
Rockfish	BLGL	223	NA	NA	NA	7598	NA	9954	NA	19006	NA	21558	NA	NA	0.52
Rockfish	BLUR	275	NA	NA	NA	NA	NA	NA	NA	NA	1	13223	NA	NA	0.3
Rockfish	CLPR	2099	2155	2164	15482	21034	12126	23827	22379	33390	1	45057	2700	3037	0.71
Rockfish	CNRY	954	959	960	17818	20794	19898	12340	12340	51986	5	68539	NA	NA	0.24
Rockfish	CWCD	53.6	53.6	54.3	1746	1746	1485	196	196	4366	1	4643	6.5	6.5	0.05
Rockfish	DBRK	575	575	597	NA	NA	NA	NA	NA	NA	1	32303	483	483	0.27
Flatfish	DOVR	16505	NA	NA	234562	NA	NA	377974	191926	598108	5	596145	26931	27161	0.63
Flatfish	EGLS	3877	3452	4252	22822	28810	13052	83814	77422	72024	3	59944	NA	14326	0.95
Rockfish	GPHR	126	NA	NA	842	NA	NA	1931	1096	1995	1	2440	404	174	0.97
Roundfish	LCOD_N	1710	1734	1909	13671	13230	7781	20484	20484	33075	2	44057	2846	2846	0.62
Roundfish	LCOD_S	1492	1514	1678	10462	10124	5856	18656	18656	25311	2	35041	2705	2705	0.74
Elasmobranch	LSKT	787	1264	1268	1688	5628	5252	9268	9346	14068	2	90955	NA	3428	0.66
Rockfish	LSPN	3687	NA	NA	NA	56610	NA	150098	138298	210314	2	227972	2838	3766	0.71
Rockfish	POP	1124	NA	NA	30224	NA	NA	21588	21588	75560	3	NA	811	811	0.29
Flatfish	PTRL	2080	2060	2376	19856	20268	9592	5875.2	5875.2	50668	3	39211	NA	NA	0.12
Roundfish	SABL	4871	6328	6303	83088	195838	183118	187790	189386	489594	2	464394	NA	9914	0.38
Rockfish	SNOS	1244	1236	1268	NA	NA	NA	NA	NA	NA	4	87588	NA	NA	0.66
Rockfish	SSPN	2009	NA	NA	61929	NA	NA	92578	90202	140750	2	248325	NA	NA	0.66
Flatfish	STRY_N	818	NA	NA	NA	3860	NA	4242	NA	9648	2	12102	NA	NA	0.44
Flatfish	STRY_S	396	NA	NA	NA	1868	NA	1445	NA	4668	2	5854	NA	NA	0.62
Rockfish	VRML_N	131	NA	NA	NA	2251	NA	3632	NA	5627	1	6583	245	NA	0.65
Rockfish	VRML_S	171	NA	NA	NA	3871	NA	6551	NA	9677	1	11192	359	NA	0.59
Rockfish	WDOW	3031	3518	3526	NA	NA	NA	NA	NA	NA	1	220930	NA	NA	0.39
Rockfish	YEYE	49	56	56	NA	NA	NA	NA	NA	NA	8	8492	NA	NA	0.2

Table 6. Proportion of simulations for each species that were not consistent with the catch history (i.e. biomass went negative) given the model assumptions.

Species Code	Proportion Negative
CWCD	91.4%
BCAC	84.6%
STRY_N	59.1%
STRY_S	46.9%
CNRY	40.9%
WDOW	36.2%
PTRL	26.7%
BLCK_N	25.3%
POP	18.6%
LSKT	17.2%
LCOD_N	15.6%
DBRK	10.7%
BLUR	10.0%
BLCK_S	6.6%
LCOD_S	6.2%
CLPR	3.8%
EGLS	1.6%
YEYE	1.6%
SABL	0.3%
VRML_S	0.2%
SNOS	0.2%
VRML_N	0.2%
ARTH	0.2%
GPHR	0.1%
BLGL	0.0%
DOVR	0.0%
LSPN	0.0%
SSPN	0.0%

Table 7. Summary statistics for DCAC distributions.

			quantiles				
species code	**common name**	**mean**	**5%**	**25%**	**50%**	**75%**	**95%**
ARTH	Arrowtooth flounder	3356.7	2678.4	3169.7	3427.0	3614.2	3778.1
BCAC	Bocaccio	2230.7	1705.1	2066.3	2268.0	2437.7	2617.9
BLCK_N	Black Rockfish North	246.9	218.3	238.8	249.8	257.7	265.6
BLCK_S	Black Rockfish South	513.5	466.6	502.3	518.7	530.5	541.6
BLGL	Blackgill Rockfish	249.9	150.2	207.5	250.7	292.8	345.6
BLUR	Blue Rockfish	227.8	160.4	204.1	231.6	255.2	282.3
CLPR	Chilipepper	1650.9	1439.2	1592.7	1674.3	1731.2	1784.4
CNRY	Canary Rockfish	1233.8	834.6	1085.1	1249.3	1402.3	1578.5
CWCD	Cowcod	51.2	34.4	44.6	51.6	58.1	66.2
DBRK	Darkblotched Rockfish	481.9	312.6	419.7	488.1	551.8	628.7
DOVR	Dover sole	8094.8	5661.4	7250.6	8264.5	9110.1	9957.2
EGLS	English sole	3348.0	3189.8	3361.2	3377.7	3382.5	3385.7
GPHR	Gopher Rockfish	73.4	71.1	73.9	74.1	74.2	74.3
LCOD_N	Lingcod North	1358.5	1179.9	1310.4	1377.2	1427.2	1474.2
LCOD_S	Lingcod South	1029.4	940.0	1006.2	1039.6	1063.5	1084.8
LSKT	Longnose skate	627.2	577.6	614.5	632.4	646.1	658.8
LSPN	Longspine Thornyhead	1885.3	1031.9	1510.8	1892.3	2262.2	2715.3
POP	Pacific Ocean Perch	1402.0	800.7	1142.8	1393.1	1661.0	2029.5
PTRL	Petrale sole	1620.8	1230.8	1493.8	1646.8	1776.4	1914.7
SABL	Sablefish	5379.2	3121.8	4425.3	5376.5	6317.2	7623.0
SNOS	Splitnose Rockfish	665.5	451.2	589.5	676.4	752.9	840.2
SSPN	Shortspine Thornyhead	1420.9	925.4	1235.8	1449.3	1630.2	1829.7
STRY_N	Starry Flounder North	714.5	519.5	649.0	726.9	790.9	868.0
STRY_S	Starry Flounder South	241.5	188.5	224.8	246.2	262.5	279.5
VRML_N	Vermillion Rockfish North	100.9	74.3	92.6	102.8	111.3	120.6
VRML_S	Vermillion Rockfish South	159.4	108.0	140.9	162.4	180.5	201.8
WDOW	Widow Rockfish	6742.4	4136.8	5644.7	6768.1	7873.3	9277.7
YEYE	Yelloweye Rockfish	89.8	55.3	76.2	90.0	104.8	122.0

Figure 1: DCAC for canary rockfish. Black solid line with circles is the time series of catch from the assessment. Blue lines bracket years over which catch is summed. Red horizontal line is MSY(SPR) from assessment. Black horizontal line is average catch over the time period. Green lines are the DCAC median (solid) and 2.5% and 97.5% quantiles (dashed).

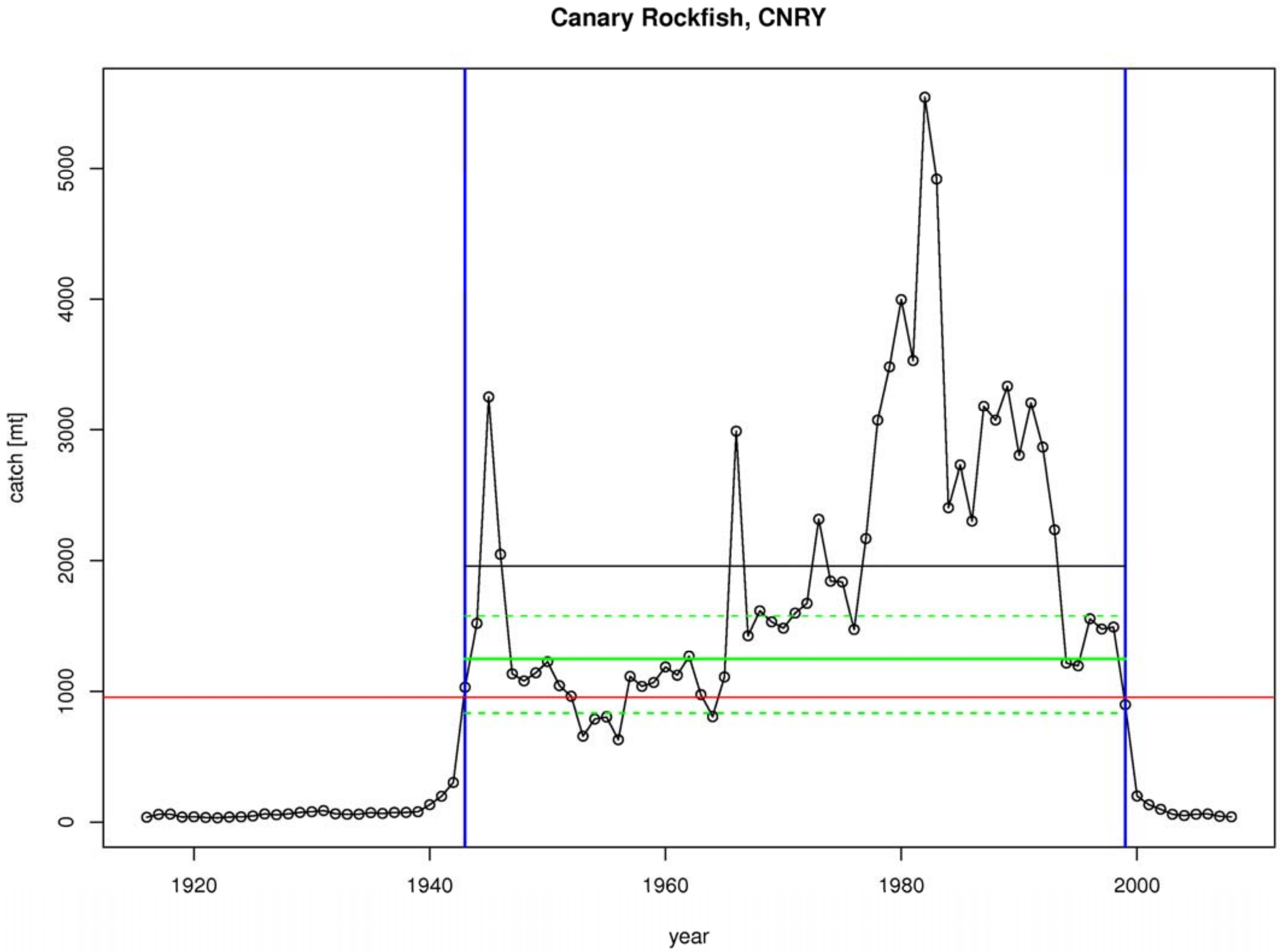


Figure 2: DCAC for petrale sole. Black solid line with circles is the time series of catch from the assessment. Blue lines bracket years over which catch is summed. Red horizontal line is MSY(SPR) from assessment. Black horizontal line is average catch over the time period. Green lines are the DCAC median (solid) and 2.5% and 97.5% quantiles (dashed).

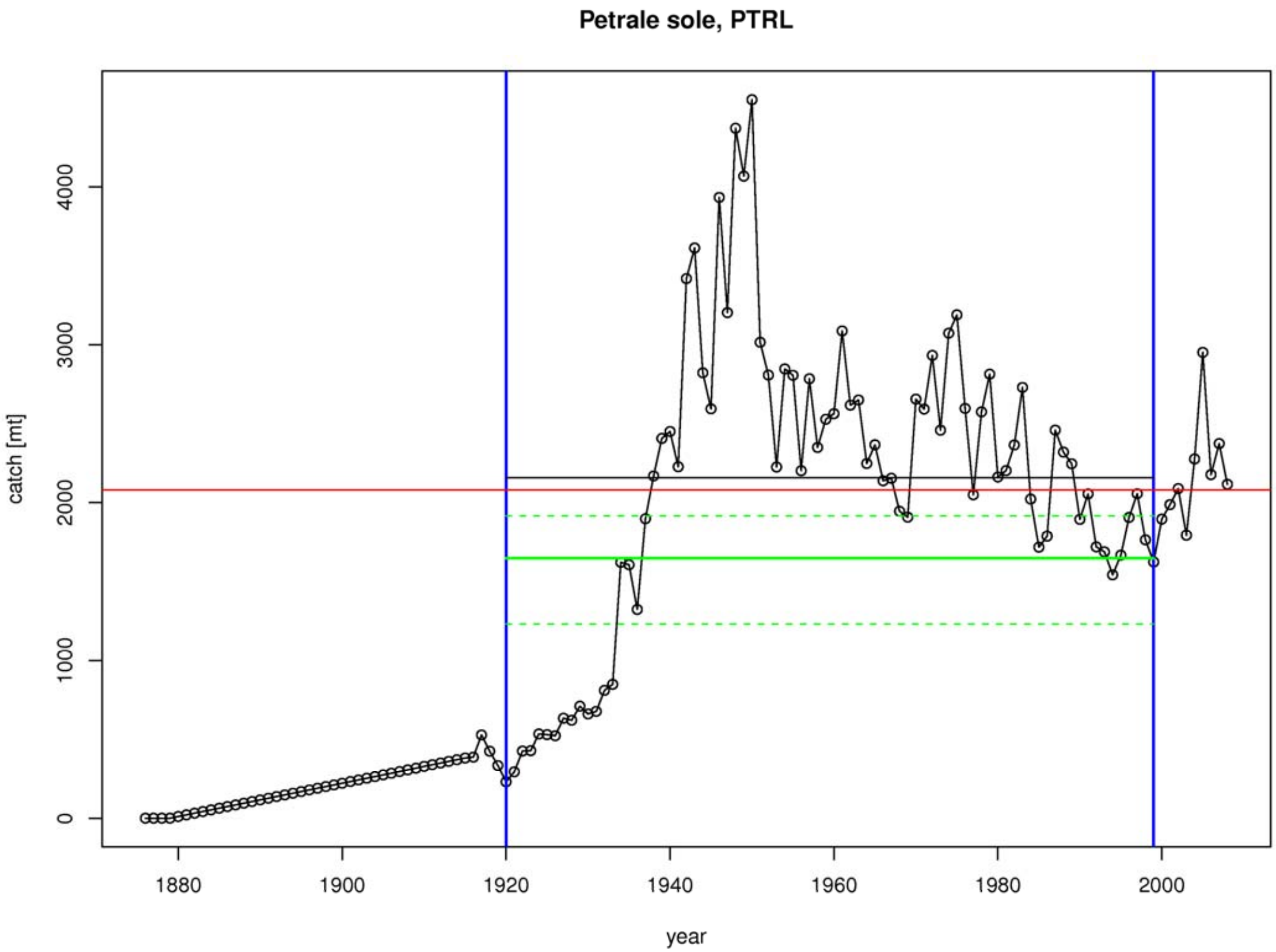


Figure 3: DCAC for vermilion rockfish (north). Black solid line with circles is the time series of catch from the assessment. Blue lines bracket years over which catch is summed. Red horizontal line is MSY(SPR) from assessment. Black horizontal line is average catch over the time period. Green lines are the DCAC median (solid) and 2.5% and 97.5% quantiles (dashed).

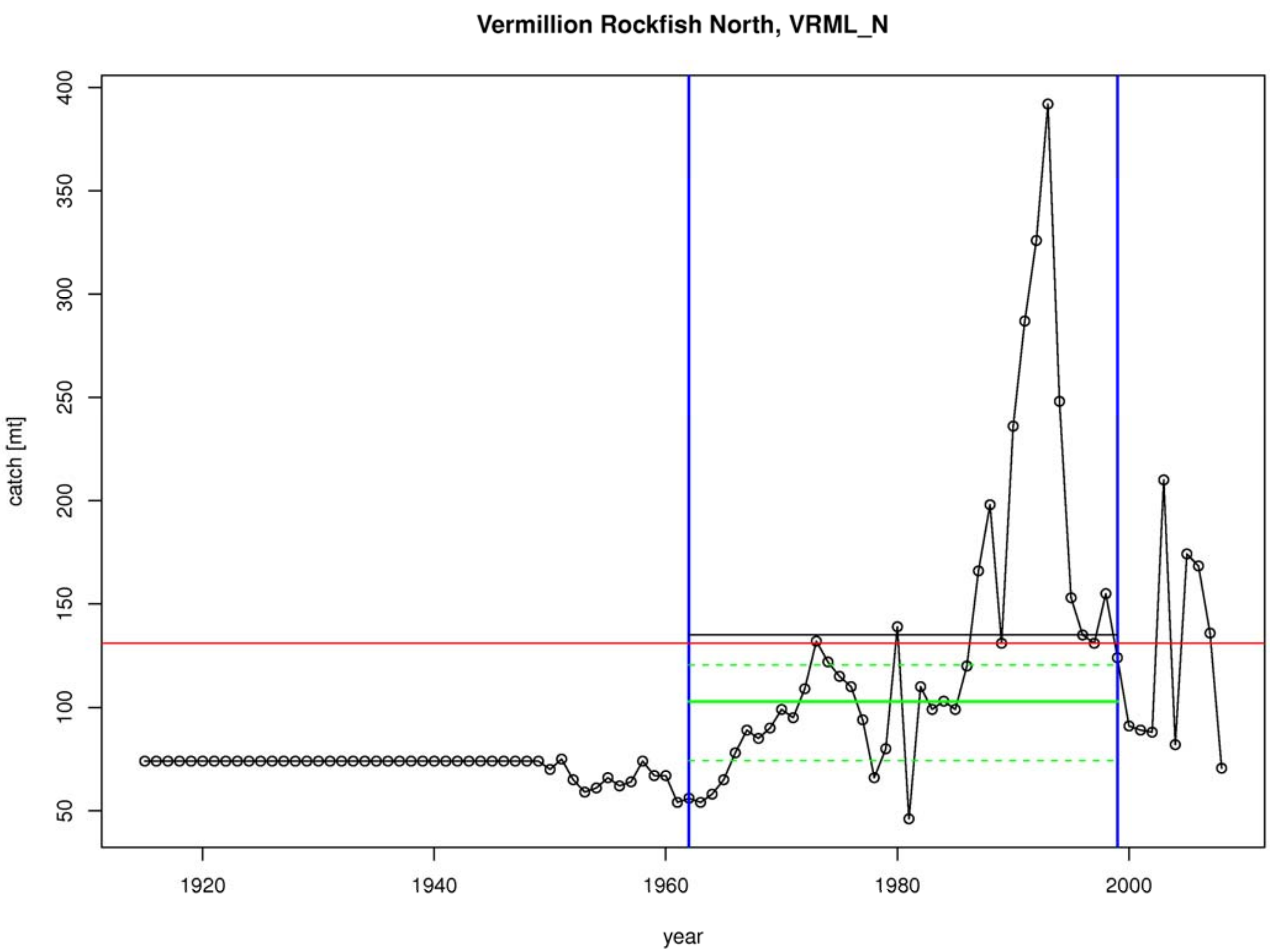


Figure 4. DCAC distributions for 28 assessed groundfish stocks, scaled relative to the assessment estimate for MSY (SPR proxy).

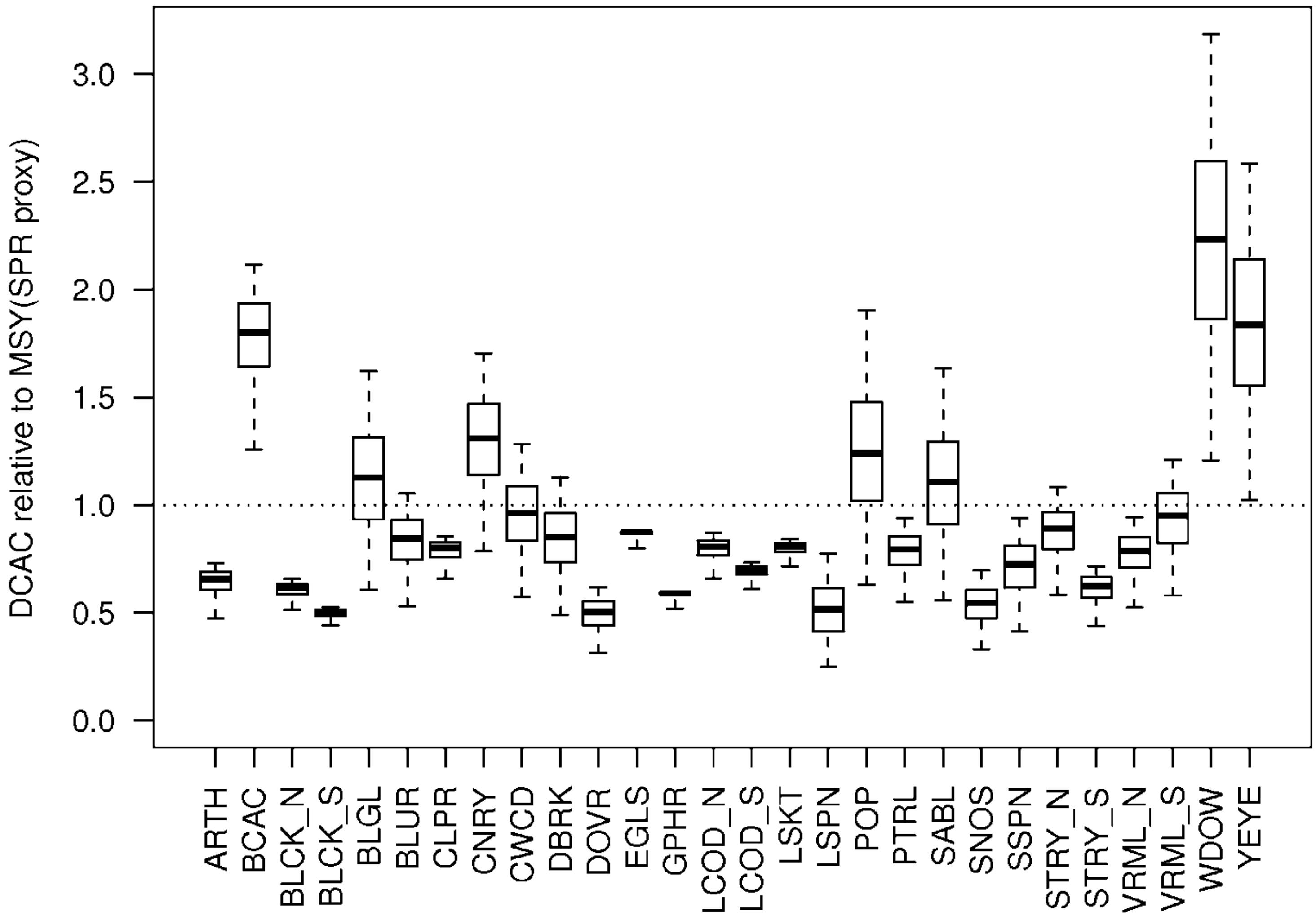


Figure 5. Distribution of DCAC simulations, integrated across 28 stocks, scaled relative to the assessment estimates for MSY (SPR proxy).

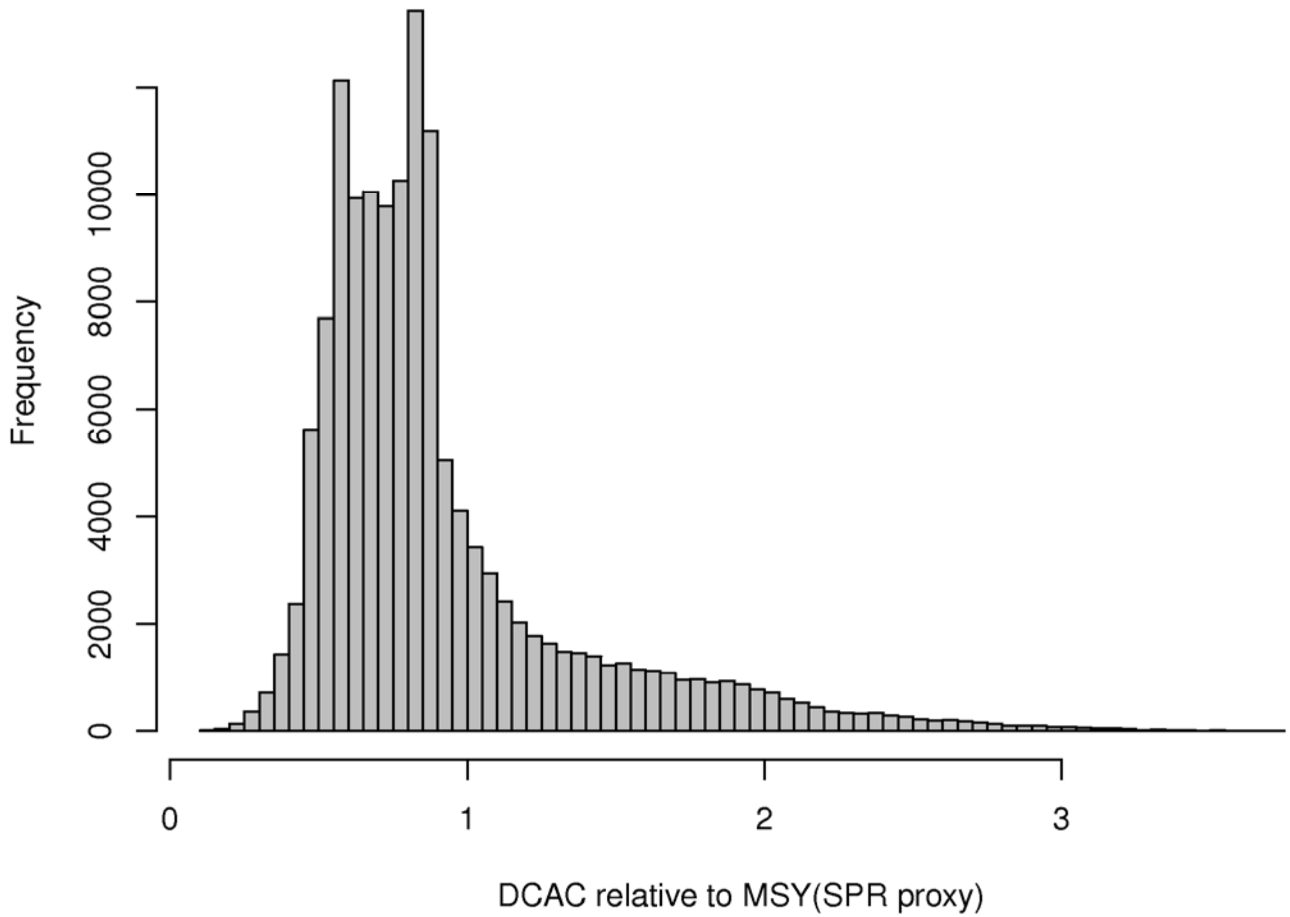


Figure 6. Annual biomass distributions (mature male and female biomass) for canary rockfish based on depletion-based stock reduction analysis (DB-SRA). Results are based on 2955 non-negative runs (out of 5000 simulations). Solid line = median, dashed lines = 0.25 and 0.75 quantiles (IQR), dotted lines = 0.025 and 97.5 quantiles.

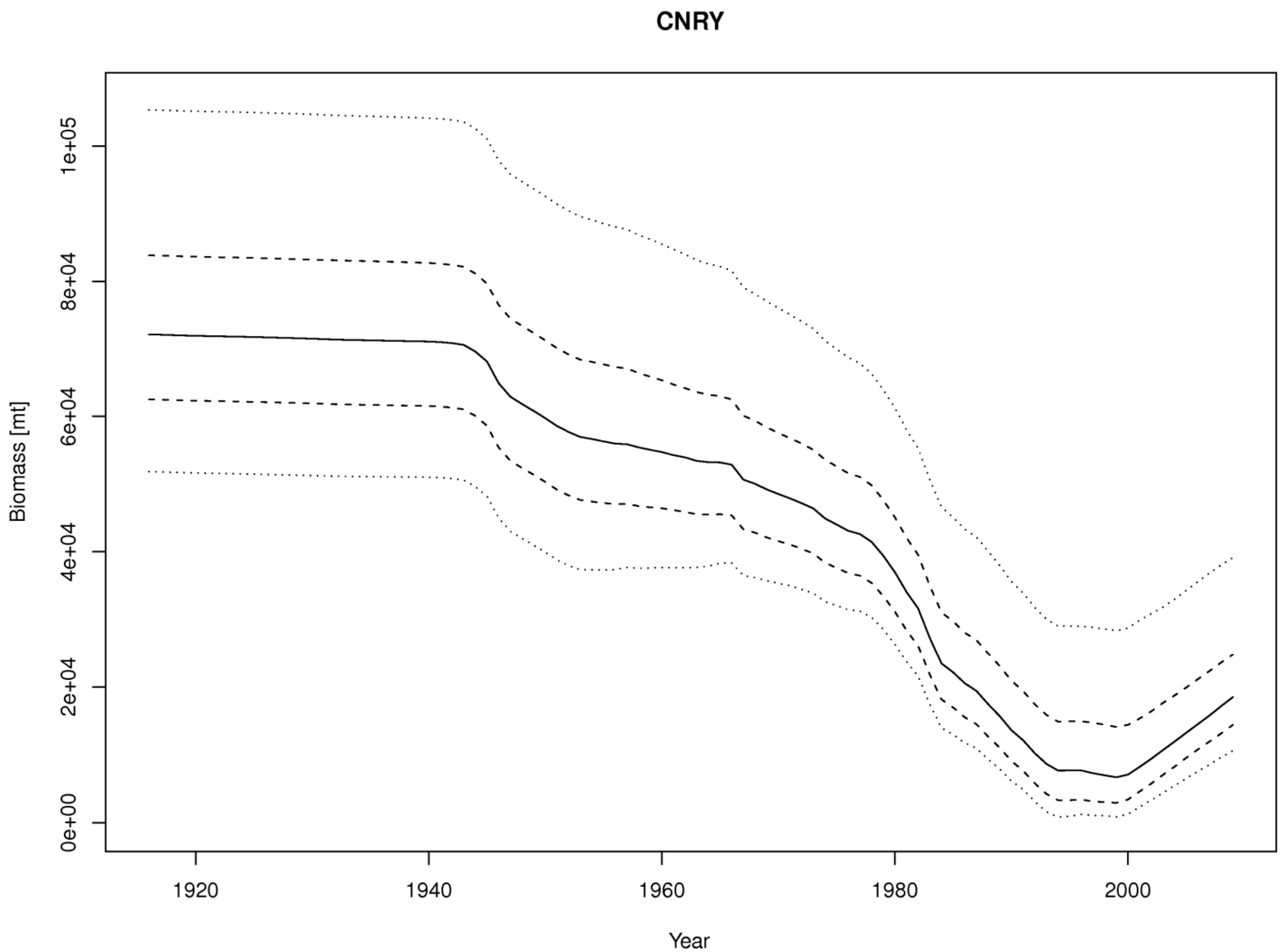


Figure 7. DB-SRA estimates of MSY, OFL, mature biomass (male & female), and BMSY for canary rockfish. Box and whisker plots characterize the median (thick vertical line), inter-quartile range (box), and 95% intervals ('whiskers'). Letters represent point estimates from the stock assessment, where S=SPR proxy, B=biomass target proxy, E=model-estimated, and integers represent summary biomass (integer=summary age).

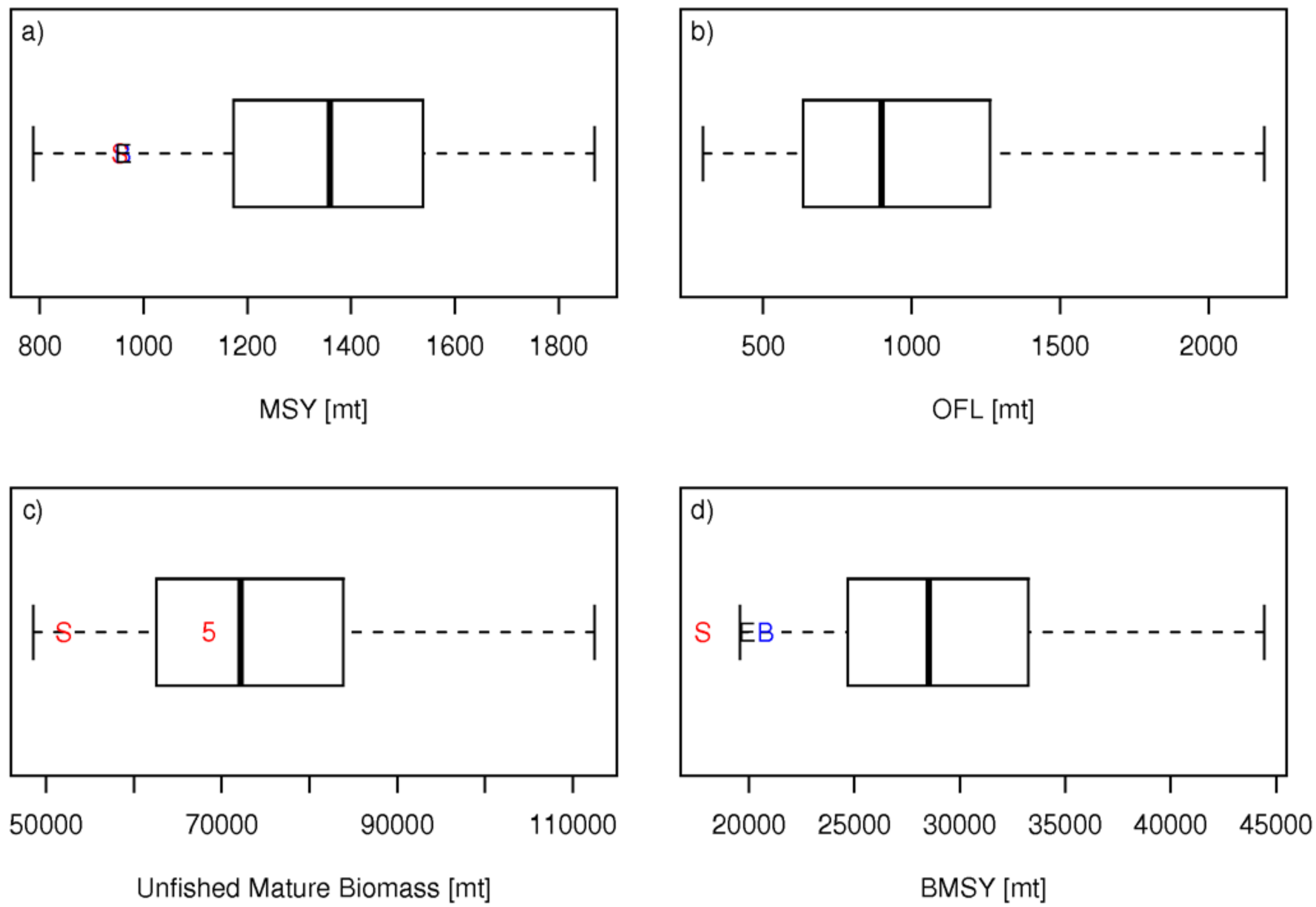


Figure 8. DB-SRA estimates of MSY, OFL, mature biomass (male & female), and BMSY for petrale sole. Box and whisker plots characterize the median (thick vertical line), inter-quartile range (box), and 95% intervals (‘whiskers’). Letters represent point estimates from the stock assessment, where S=SPR proxy, B=biomass target proxy, E=model-estimated, and integers represent summary biomass (integer=summary age).

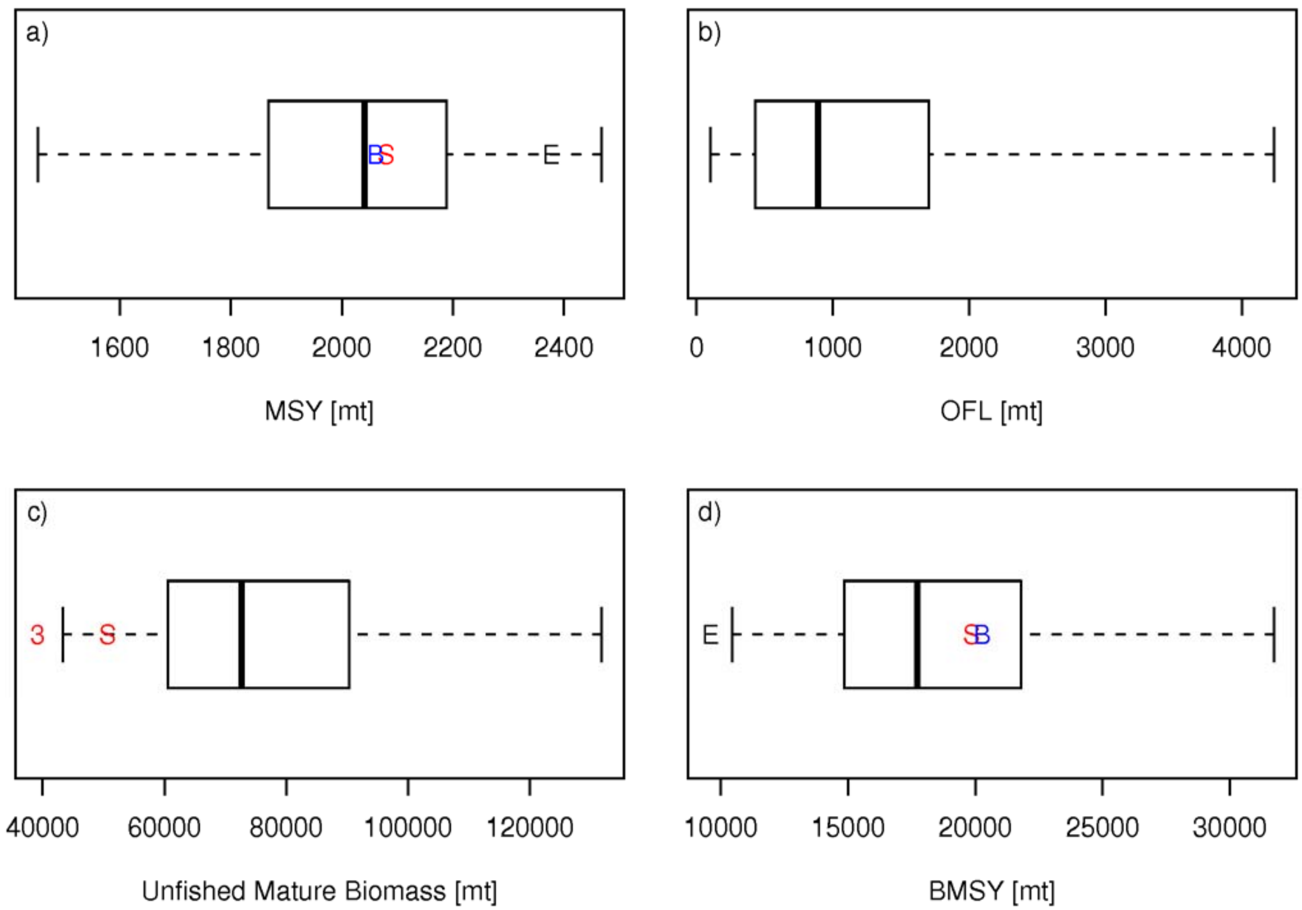


Figure 9. DB-SRA estimates of MSY, OFL, mature biomass (male & female), and BMSY for vermilion rockfish (northern stock). Box and whisker plots characterize the median (thick vertical line), inter-quartile range (box), and 95% intervals ('whiskers'). Letters represent point estimates from the stock assessment, where S=SPR proxy, B=biomass target proxy, E=model-estimated, and integers represent summary biomass (integer=summary age).

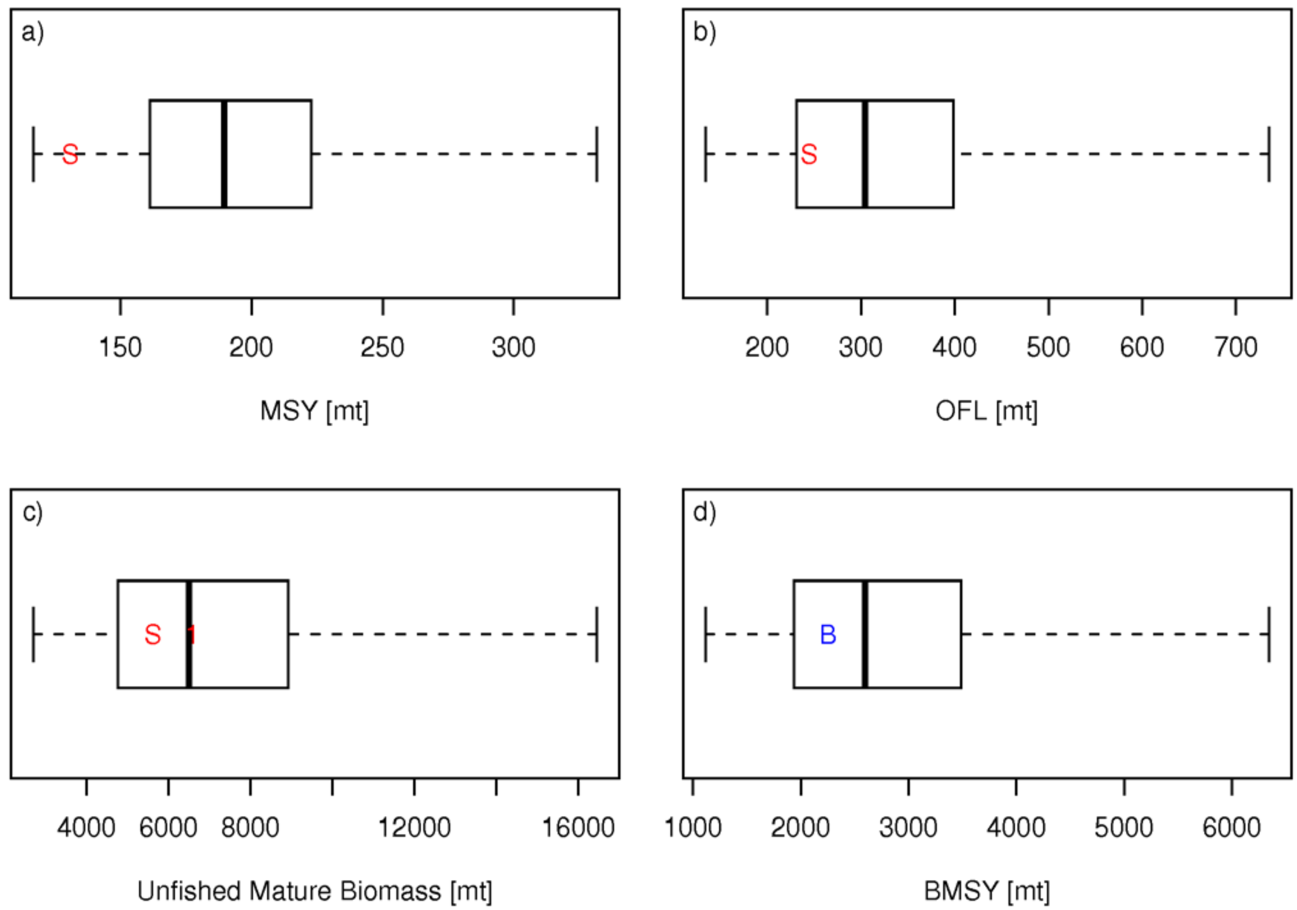


Figure 10. DB-SRA estimates of MSY for 26 species, scaled relative to MSY(SPR proxy) estimates from the most recent assessment. Box-and-whisker plots characterize the median, IQR, and 95% intervals of the distributions. The reference line at unity represents agreement with the assessment's point estimate. Uncertainty in the assessment estimate of MSY is not considered.

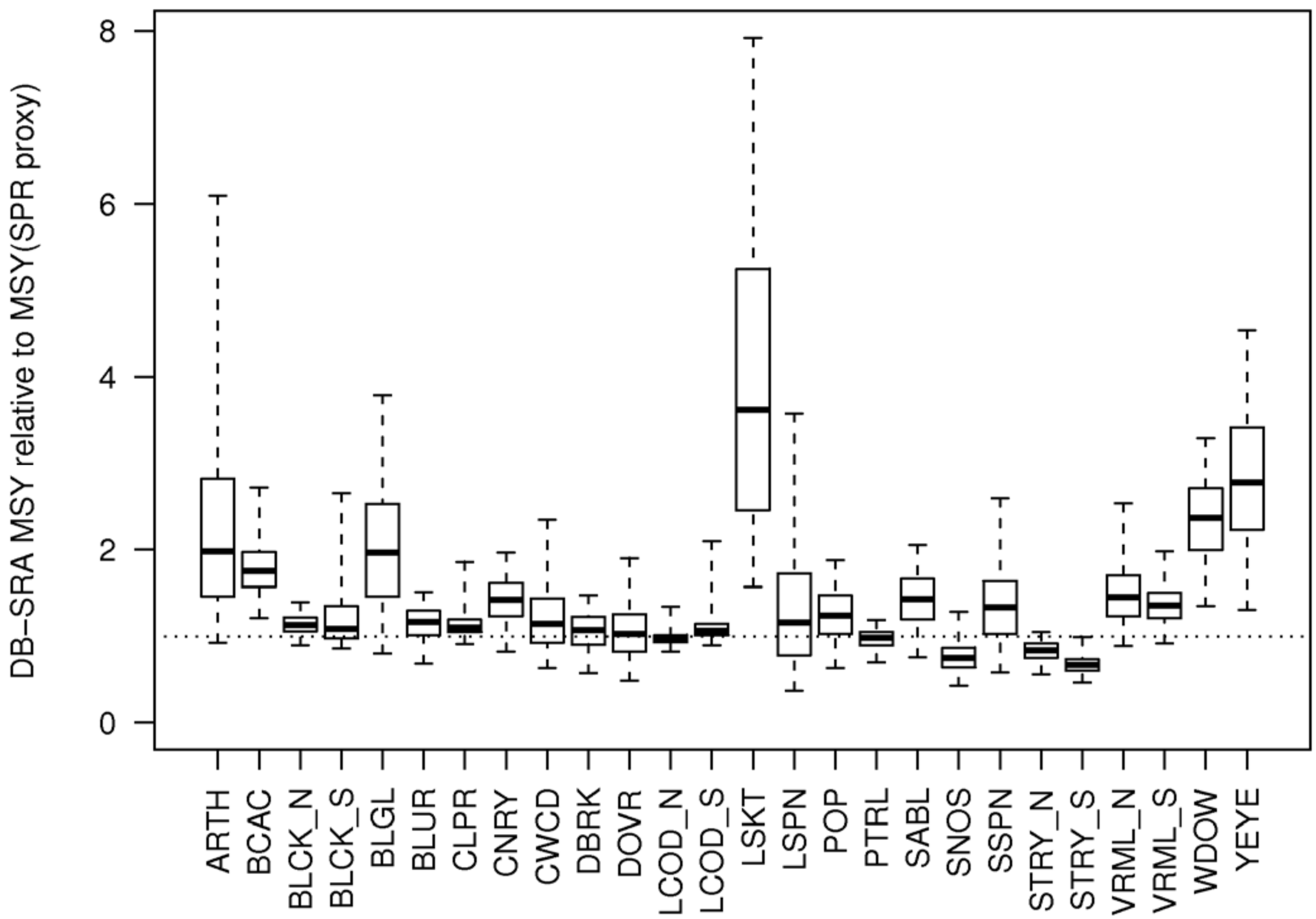


Figure 11: Distribution of MSY from DB-SRA, integrated across 28 stocks and scaled relative to the assessment estimates for MSY (SPR proxy). Uncertainty in the assessment estimate of MSY is not considered.

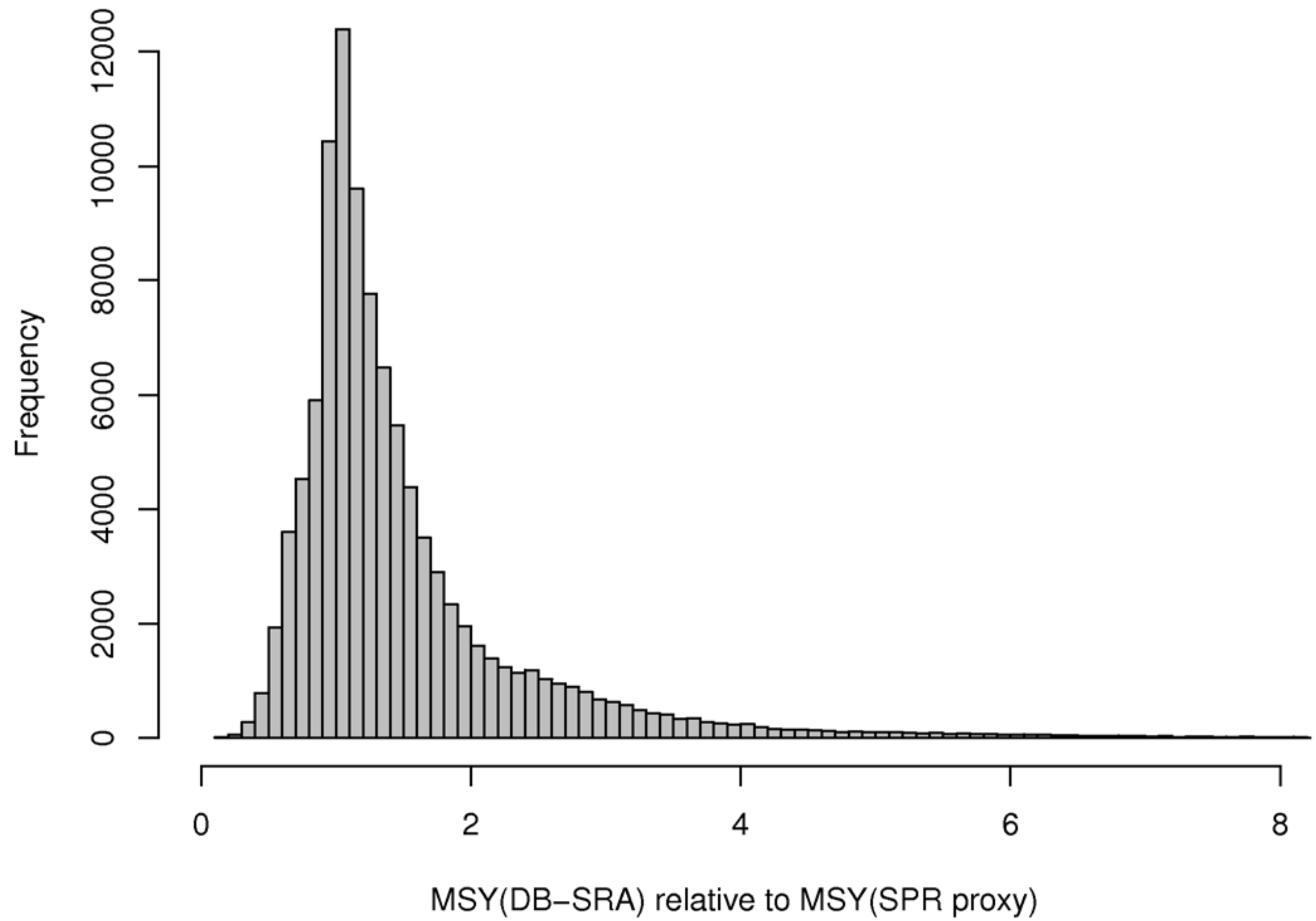


Figure 12: Frequency histograms of input distributions for canary rockfish; combined bar heights represent frequencies used in DCAC; shaded areas represent frequencies of retained runs (those with positive biomass trajectories) based on DB-SRA.

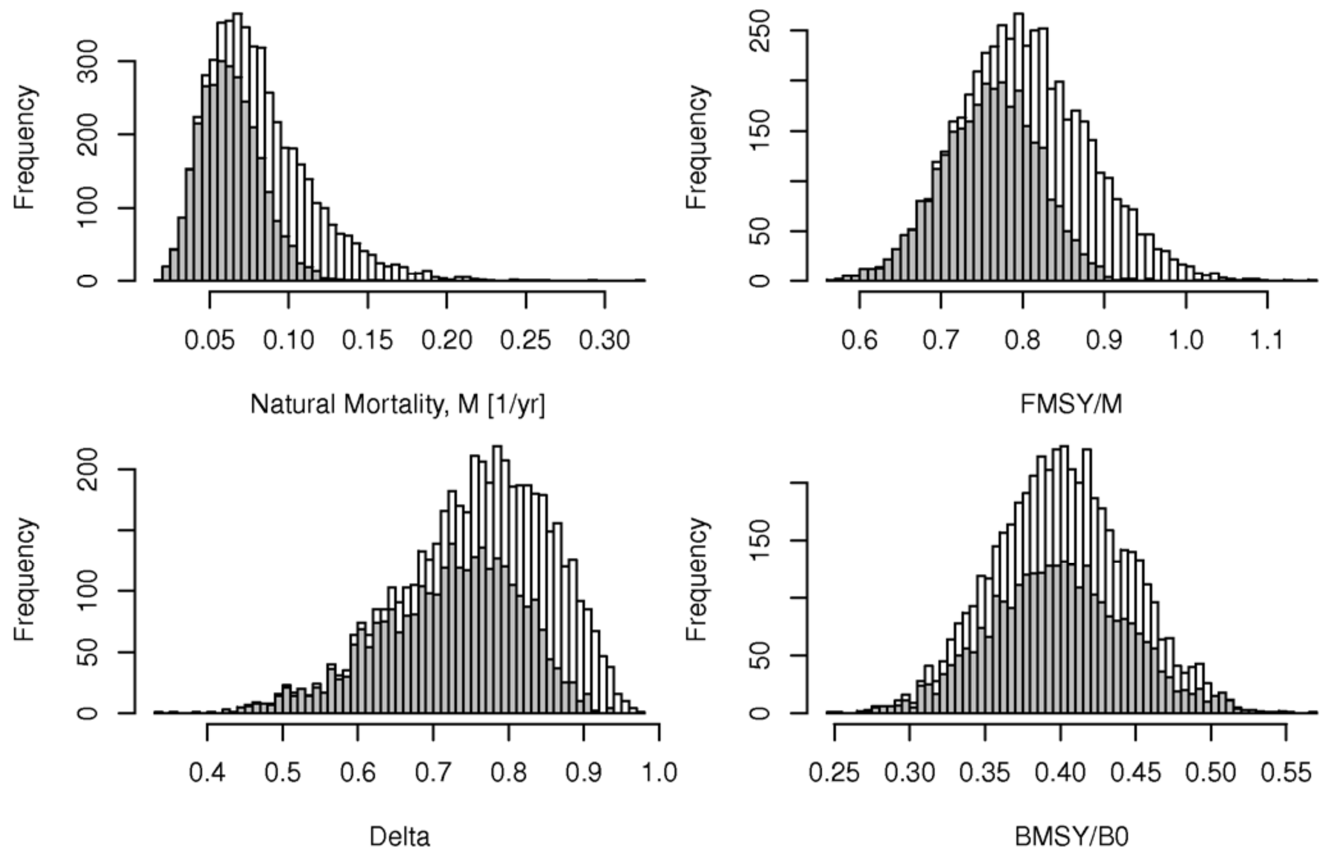


Figure 13: Frequency histograms of input distributions for petrale sole; combined bar heights represent frequencies used in DCAC; shaded areas represent frequencies of retained runs (those with positive biomass trajectories) based on DB-SRA.

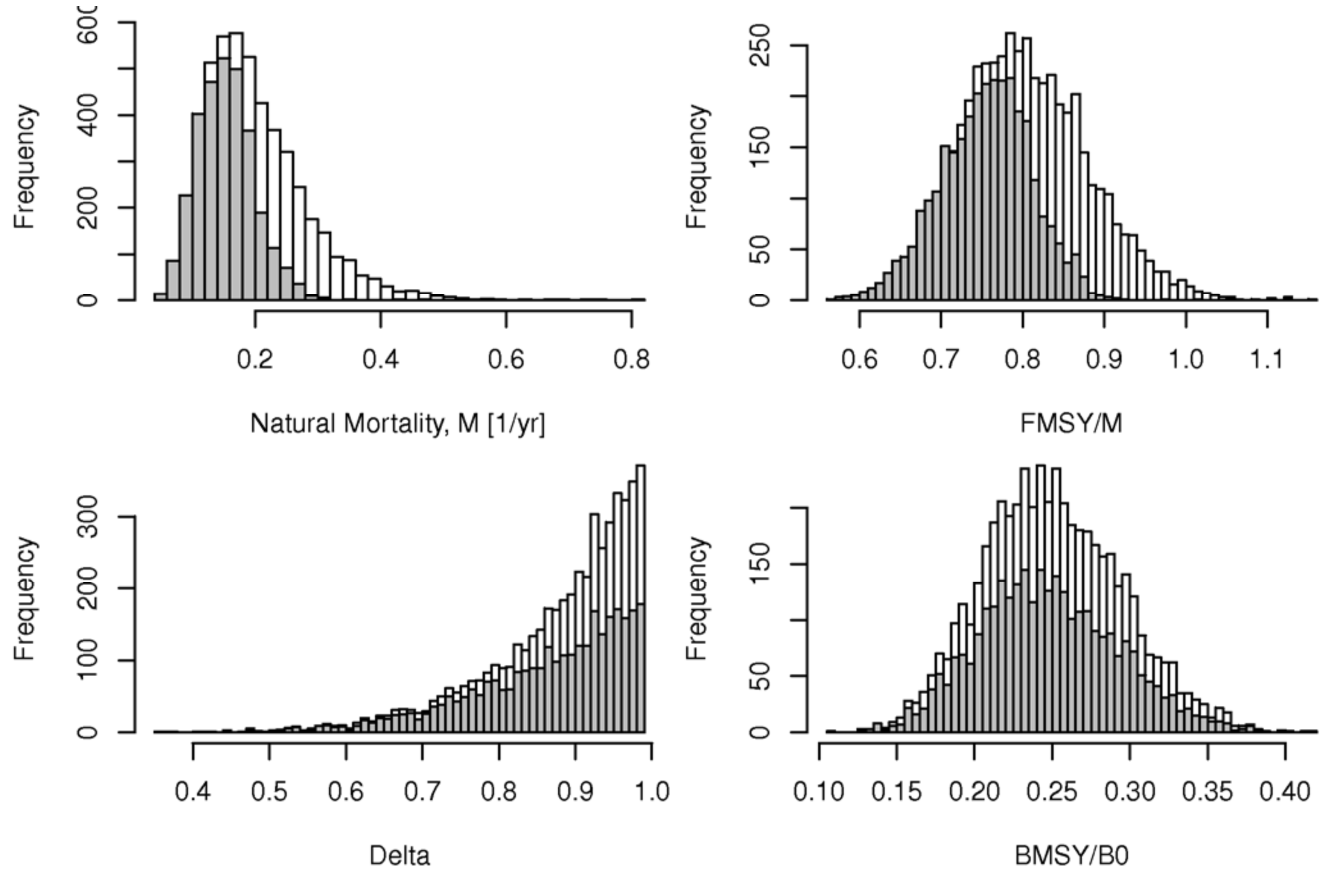
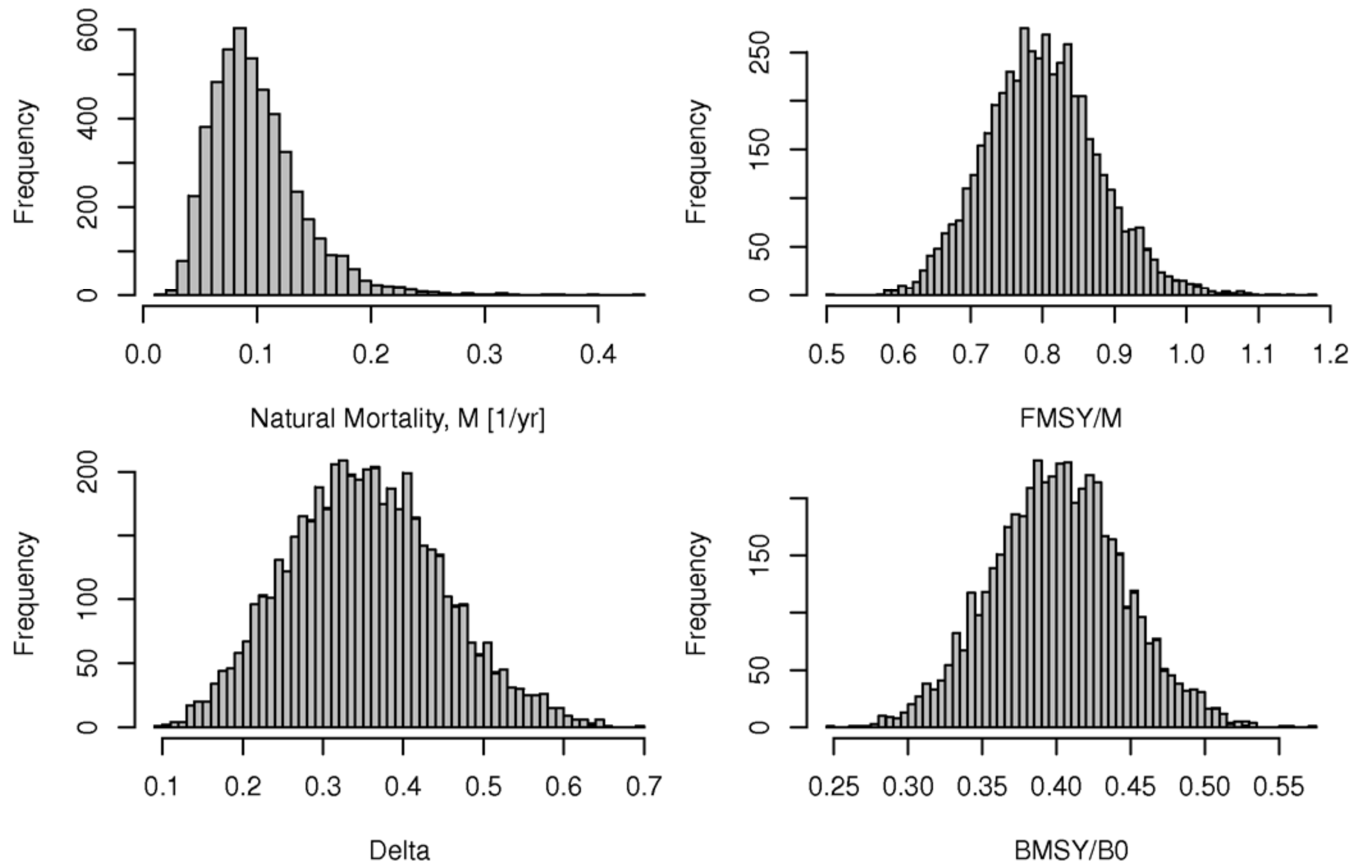


Figure 14: Frequency histograms of input distributions for vermilion rockfish (north); combined bar heights represent frequencies used in DCAC; shaded areas represent frequencies of retained runs (those with positive biomass trajectories) based on DB-SRA.



References

Bellman, M.A., Heery, E., and J. Majewski. 2009. Estimated discard and total catch of selected groundfish species in the 2008 U.S. west coast fisheries. West Coast Groundfish Observer Program. NWFSC, 2725 Montlake Blvd E., Seattle, WA 98112.

Dorn, M. W. 2002. Advice on West Coast rockfish harvest rates from Bayesian meta-analysis of stock–recruit relationships. North American Journal of Fisheries Management 22:280–300.

Fletcher, R. I. 1978. On the restructuring of the Pella-Tomlinson system. Fishery Bulletin 76(3): 515-521.

Kimura, D. K. and J. V. Tagart. 1982. Stock reduction analysis, another solution to the catch equations. Canadian Journal of Fisheries and Aquatic Sciences 39:1467-1472.

Kimura, D. K., J. W. Balsinger, and D. H. Ito. 1984. Generalized stock reduction analysis. Canadian Journal of Fisheries and Aquatic Sciences 41:1325-1333.

MacCall, A. D. 2009. Depletion-corrected average catch: a simple formula for estimating sustainable yields in data-poor situations. ICES J. Mar. Sci. 66:000-000.

Mangel, M., J. Brodziak, and G. Dinardo. 2009. Reproductive ecology and scientific inference of steepness: a fundamental metric of population dynamics and strategic fisheries management. Fish and Fisheries. Published online October 12, 2009.

Maunder, M. N. 2003. Is it time to discard the Schaefer model from the stock assessment scientist's toolbox? Fish. Res. 61:145-149.

McAllister, M. K., E. A. Babcock, E. K. Pikitch, and M. H. Prager. 2000. Application of a non-equilibrium generalized production model to South and North Atlantic swordfish: combining Bayesian and demographic methods for parameter estimation. Col. Vol. Sci. Pap. ICCAT, 51(5):1523-1550.

NMFS. 2009. Magnuson–Stevens Act Provisions; Annual Catch Limits; National Standard Guidelines. Federal Register, 74: 3178–3213.

Pella, J. J. and P. K. Tomlinson. 1969. A generalized production model. IATTC Bulletin 13: 421-458.

Punt. A. E., M. W. Dorn, and M. A. Haltuch. 2008. Evaluation of threshold management strategies for groundfish off the U. S. west coast. Fish. Res. 94:251-266.

Restrepo, V. R. et al. 1998. Technical Guidance On the Use of Precautionary Approaches to Implementing National Standard 1 of the Magnuson-Stevens Fishery Conservation and Management Act. NOAA Technical Memorandum NMFS-F/SPO-40.

Walters, C. J., S. J. D. Martell, and J. Korman. 2006. A stochastic approach to stock reduction analysis. Canadian Journal of Fisheries and Aquatic Sciences 63:212-223.

Walters, C. J. and S. J. D. Martell. 2007. Fisheries Ecology and Management. Princeton University Press, Princeton, New Jersey. 399 p.